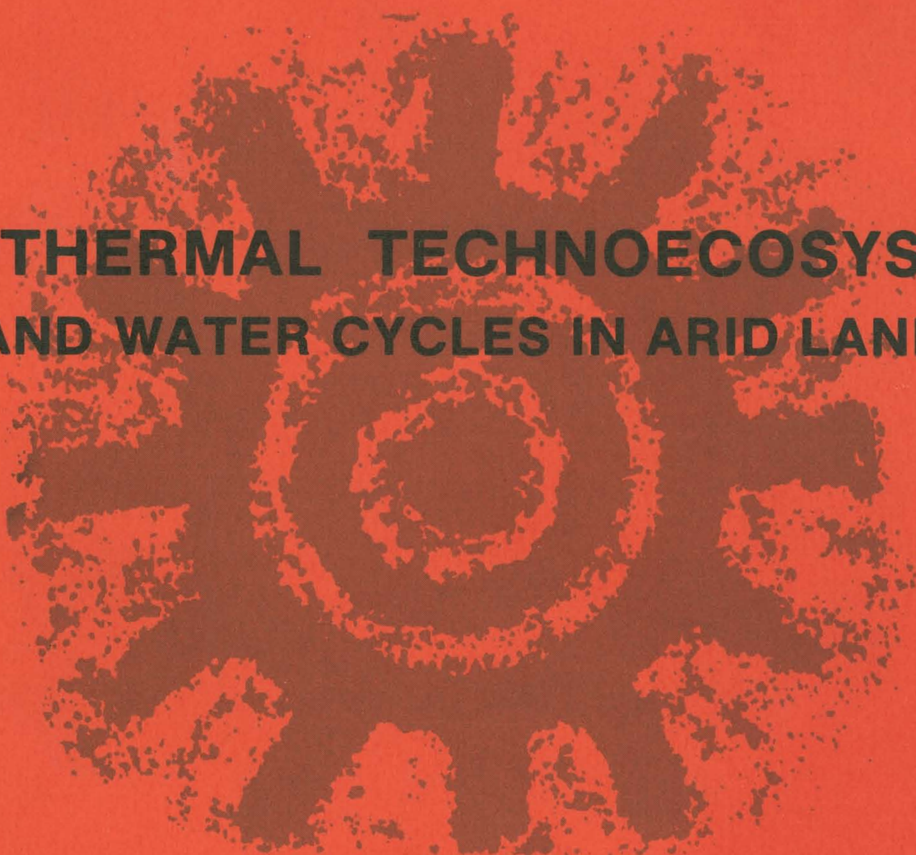
Arid Lands Resource Information Paper No. 8

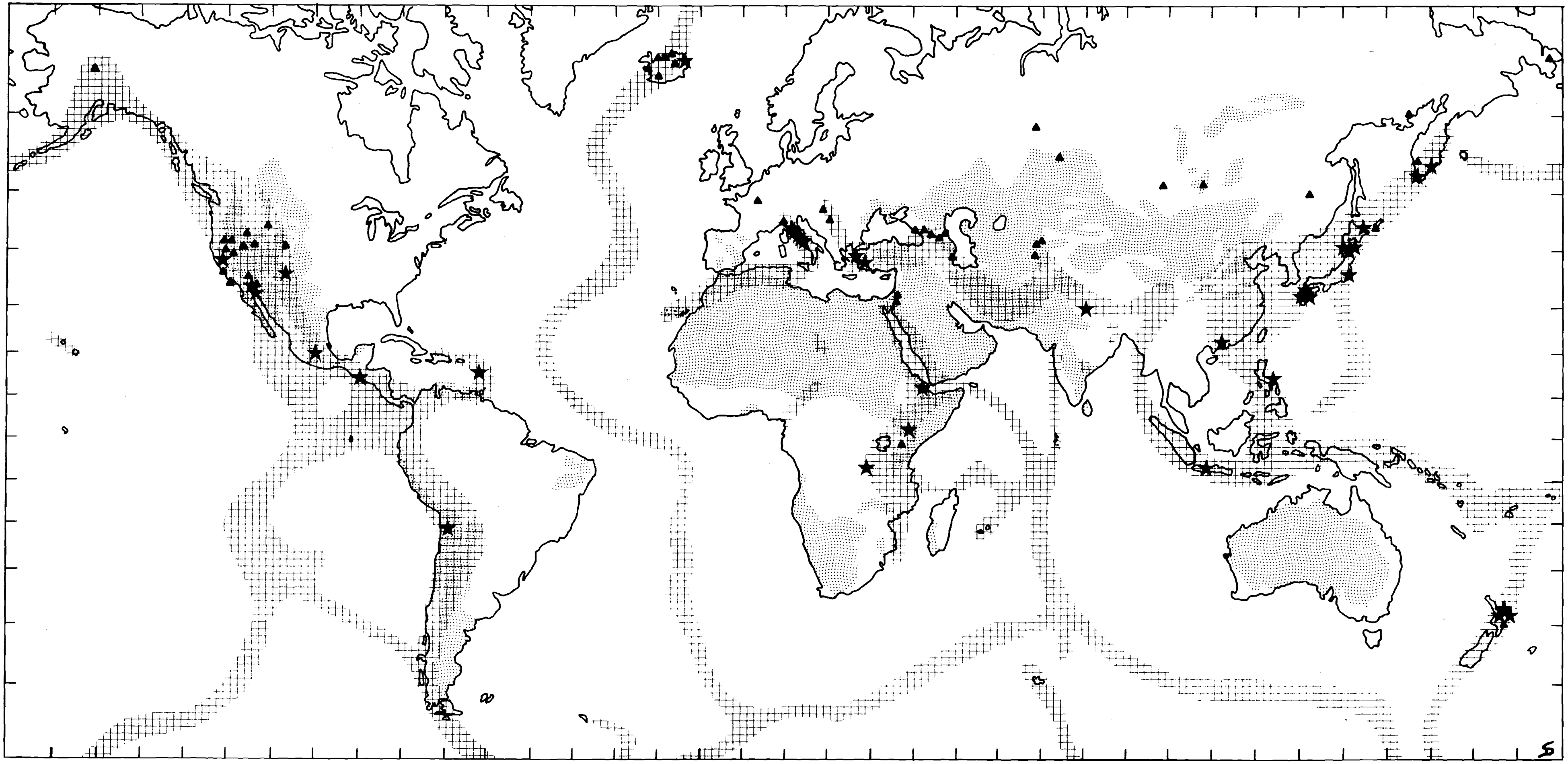
GEOTHERMAL TECHNOECOSYSTEMS AND WATER CYCLES IN ARID LANDS



by Christopher Duffield

University of Arizona
OFFICE OF ARID LANDS STUDIES
Tucson, Arizona
1976

DUFFIELD GEOTHERMAL TECHNOECOSYSTEMS OALS



GEOTHERMAL REGIONS AND ARID LANDS OF THE WORLD

Symbols

Geothermal Regions (except geopressured systems) (after Geonomics, 1975*)

Arid and Semiarid Lands (after Meigs in McGinnies, Goldman, and Paylore, 1968*)

★ Geothermal Powerplant (existing or being developed) (after Mehta, 1976*)

▲ Major Non-Electric Use of Geothermal Resources (compiled from Mehta, 1976*; Peterson and El-Ramley, 1975*; and Geonomics, 1975*)

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CONTENTS

ILLUSTRATIONS

FOREWORD

The Arid Lands Resource Information Paper presented here, the sixth prepared for the Water Resources Scientific Information Center (WRSIC), was supported in part by U. S. Department of the Interior, Office of Water Research and Technology Grant No. 14-31-0001-5254, to the University of Arizona, Office of Arid Lands Studies, Patricia Paylore, Principal Investigator. [Two other Papers, Nos. 5 and 7 in the series, were funded by another Federal agency.]

Arid Lands Resource Information Paper No. 2, "Exploration and Exploitation of Geothermal Resources in Arid and Semiarid Lands," first issued in 1973, is now out-of-print. The intent of the present Paper was to revise that earlier literature review with its annotated bibliography, by recognizing the unusual developments in this field in the interim, with new geothermal fields discovered, new demands for geothermal energy as an alternative source to more conventional sources, and an astonishing number of new publications reflecting accelerated research.

As the knowledgeable reader of this new Paper will sense, however, the author has gone far beyond a simple update by offering us an innovative and we believe a completely new position from which to view this exotic energy source and contemporary efforts to develop it. To many of us, the young are ordinarily looked upon as reckless and extremist, but this is not the first time I have found the young looking beyond today, or even tomorrow, to think critically and soberly about long-term effects instead of short-term benefits. Duffield, native Tucsonan, with a Master's degree in geology and now pursuing the Ph.D. degree in Arid Lands Resource Sciences, is such a person. Like his predecessors in this series: Casey (No. 1, 1972), Sherbrooke (No. 3, 1973), Chalmers (No. 4, 1974), and Bowden (No. 6, 1975), Duffield has been bold to challenge conventional technical wisdom, but I do not think I have been foolhardy to support him and those others. I believe this is the purpose of education — to experiment, create, disagree, learn, and provoke, within a framework of severe discipline. This Paper satisfies me that it too is a worthy example of such attitudes.

I wish once more to thank the National Science Foundation for its early funding of the development of the computer program which now handles so successfully the Arid Lands Information System (ALIS). The extensive bibliography accompanying this Paper was produced by ALIS, and includes over one hundred references prepared by the Office of Arid Lands Studies originally under previous OWRT/WRSIC grants. These, and others where users are referred to SWRA [Selected Water Resources Abstracts] in lieu of abstracts, are taken from RECON, ERDA's Oak Ridge-based information system.

While Duffield and I are grateful to OWRT/WRSIC for their support of the Office of Arid Lands Studies, University of Arizona, in helping maintain this Office as a U.S. Center of Competence in water-related problems of arid lands, neither the U. S. Department of the Interior nor the University of Arizona is responsible for the views expressed herein.

Patricia Paylore
Assistant Director
Office of Arid Lands Studies
The University of Arizona

November 22, 1976

PREFACE

Why have you opened this book?

If you are attracted by one of the key concepts in the title (geothermal, technoecosystems, water cycles, arid lands) then there is something here for you. This is an ambitious and multifaceted work designed for a very diverse audience, yet in its structure it is a unified whole. Naturally, I hope that you will have time and broad enough interest to read the entire text and appreciate its overall scheme. But I realize that for some readers only one or two sections will be especially pertinent and useful. Therefore, to help guide you to the most relevant sections, I will briefly outline the book's goals and underlying organization.

My aim has been to comprehensively review the literature on geothermal resources and the technology for exploiting them, with particular attention to arid lands and the various roles of water. But more than that, I have tried to develop a single holistic intellectual framework within which all this diverse detailed technical information can be rationally and intuitively and esthetically synthesized, and within which any future geothermal discoveries and activities can be easily comprehended. The new framework I have come up with, what I call "technoecology", is based on the close analogy between biological ecosystems and large complex industrial systems ("technoecosystems"), and may actually transcend in importance and universal applicability the geothermal review which it structures.

The book has three major divisions: the first chapter, the rest of the text, and the bibliography. Chapter I presents, for the first time in print, the basic structure and major insights of technoecology at its present embryonic stage of development. Subsequent chapters apply technoecological methods and language in an extensive overview of geothermal topics. Those who are interested only in technoecology need read just the first chapter; however, they will miss a concrete application and extension of its principles. Geothermal purists can start reading at Chapter II, but they may find themselves bewildered by unfamiliar terminology and concepts. Clearly, these two parts of the book complement and enhance each other. The 300-item annotated bibliography not only supports the text and its literature citations, but should also be useful in itself -- its computerized indexes offer rapid access to the geothermal literature.

Here are a few highlights of the geothermal review:

- Chapter II traces geothermal heat back to its astrophysical origins billions of years ago. And geological details of natural geothermal reservoirs are organized by a new unifying concept of hierarchically cascaded convection systems -- from continental drift to geysers and hot springs.

- In Chapter III, diverse geothermal technologies are reviewed in a way never before attempted, from the technoecological viewpoint of biological-industrial analogy. Biological concepts like evolution, niches, and succession are used throughout in the industrial context. Adaptations of geothermal technoecosystems to the various geothermal resource types of the preceding chapter are described.

- Chapter IV seeks to demonstrate that geothermal resources, although large, are indeed quite limited when compared with possible exploitation rates. Large-scale geothermal exploitation, it is suggested, could eventually have severe and irreversible impacts on natural geological systems, perhaps even at global scale.

- In Chapter V, the facts and principles of all preceding chapters are applied in a detailed, extensive case study of extremely arid Imperial Valley, California, its geothermal resources, and its existing and planned geothermal technoecosystems. A major conclusion is that here, too, the resources are quite small compared with the giant exploitation systems which are on the drawing board.

- Chapter VI briefly surveys the roles of geothermal technoecosystems in arid developing regions of the world, and summarizes geothermal resource development schemes which are being planned or implemented in them. Finally, Chapter VII brings us home again.

Water, with its innumerable roles in geological systems and geothermal technoecosystems, is a silvery thread which is woven into the entire text. Its antithesis, aridity, forms a starkly contrasting, pervasive background for discussions of water patterns. Inventions and conceptual innovations are scattered throughout this manuscript; they should be readily apparent to those who are familiar with the material.

I wish to conclude the preface with some remarks about technoecology. For more than six years I have been fascinated by the resemblance of industrial systems, observed from a jet airliner window, to biological systems at various scales. Reviewing for this paper the full range of literature on geothermal resources and technology finally gave me the opportunity to bring my early intuitive perceptions to fruition in a more solidified intellectual framework.

I have found that not only can this technoecological framework be an effective means for comprehensively organizing countless facets and details of geothermal technology into a single coherent structure, but that it can also be applied just as easily and effectively to other technologies. In fact, it is now my belief that technoecology can enhance observation, comprehension, and appreciation of any industrial system anywhere in time and space.

Technoecology offers us innumerable unexpected insights. For instance, just one major surprise of the technoecological viewpoint is that industrial systems are not as unnatural as some of us have thought. Perhaps we can now feel at home with them in a way never before possible. Our libraries are exploding with diverse information and theories gathered and propounded by technical workers in multitudinous specialized fields. Technoecology may be one broad framework within which this diversity of thought and data fragments can be synthesized.

I hope that this book conveys some small part of my wonder and excitement in such a discovery. Needless to say, I think I am onto something important. Almost daily I discover new applications and possibilities of technoecological overview. And during trips to the library I find many near misses -- books and articles, in numerous fields, which could benefit from technoecological vocabulary and techniques, and whose authors verge closely on technoecology's explicit and elaborate statement of macroscale biological-industrial analogy. Now seems to be the right time to bring this framework to the attention of the global scientific and intellectual community. Technoecology is presently in a very fluid state; written comments and suggestions from readers will be eagerly read and carefully considered.

The philosophy of this work is that, beyond our fragmented words and artificially-structured specializations, knowledge and nature are boundless and unified. At this level of abstract perception it is no accident that science merges into poetry and cosmic adventure. As you prepare to start the first chapter, I suggest that you sit back and mentally fasten your seat belt.

Christopher Duffield

Tucson, Arizona
November 22, 1976

ACKNOWLEDGMENTS

Many people helped bring this work to fruition, and I am deeply grateful to them.

I owe special thanks to my editor, Miss Patricia Paylore, who set me free, provided generous support, and awaited this manuscript with extreme patience. She shows considerable courage by publishing such a large paper with such a novel approach.

Dr. George Gaylord Simpson read a short precursor of Chapter I in 1973 and steered me away from several pitfalls of the biological-industrial analogy; any others into which I may have fallen since then are my own fault. Dr. Laurence M. Gould gave encouragement along the way and has read the manuscript. Portions of the book have been reviewed by Dr. Denis L. Norton, Dr. William B. Bull, and John S. Duffield.

Numerous individuals at the Office of Arid Lands Studies helped at various stages of this project. Charles C. Bowden asked me if geothermal heat is of value left in the ground; I have sought to answer his question. Nancy Ferguson introduced me to Dr. Howard T. Odum and his work in 1975. Helen A. Kassander and Mary Ann Stone helped with physical steps in bibliography compilation. Mercy A. Valencia searched the remote-access computerized files of RECON, ERDA's energy information system. Some bibliography abstracts were modified from previous OALS publications. Julie V. Garrettson entered the bibliography into computer storage, and Mr. Lynn V. Lybeck designed and operated the program which organized and printed it. Portions of the manuscript were typed by Ruth E. Cross and Merle Theis. And Betty Prewitt, Anna Elias-Cesnik, and Lorayne Freidinger typed the final copy.

Ingeniero Samuel Paredes and his staff of the Comisión Federal de Electricidad offered warm hospitality and much information at the Cerro Prieto geothermal powerplant, Baja California, Mexico. Tucson attorneys-at-law Fish, Briney, Duffield, and Miller contributed ample office facilities on weekends and late at night. My family, and especially my grandmother Gladys F. Carroll, provided physical and moral sustenance. Further assistance and a wealth of information were given by many other individuals and agencies, too numerous to mention here. In addition, I am indebted intellectually to a great number of scientists, philosophers, and teachers, only a few of whom are listed in the Bibliography and Supplementary References.

Finally, I would like to express profound appreciation of the technoecosystem and the cycles of stars and earth which have made all this possible.

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IV, 202 p, 8 fig, 7 tab, 400 ref.

16. Abstract Large, complex industrial systems are closely analogous to biological ecosystems and can be called "technoecosystems". This analogy has many profound implications for design, management, and comprehension of industrial civilizations and their components. Rapidly evolving technology for exploitation of geothermal resources (heat, fluids, and chemicals) is reviewed within the framework of technoecology. Water is vital to geothermal technoecosystems as heat storage and transfer medium, as coolant for thermodynamic cycles of power production and distillation, and as chemical reactant and solvent. In arid lands, fresh water can be an especially valuable output for agricultural, industrial, and municipal use; geothermal technoecosystems are carefully adapted to water availability and needs. Systems planned or established in arid developing regions and Imperial Valley, California, are presented as detailed case studies. Where resource conditions are favorable, geothermal technoecosystems can produce large amounts of power, water, space and process heat, and industrial chemicals in a short time. However, geothermal reserves are finite and nonrenewable at projected exploitation rates. For billions of years geothermal heat has driven dynamic geological ordering processes through a cascaded hierarchy of convection systems. Geothermal technoecosystems outcompete geological systems in heat extraction. Hence ever-deeper geothermal resource exploitation threatens geological systems of ever-larger scale with irreversible modification and possible extinction. Annotated bibliography. (Duffield-Arizona)

17a. Descriptors *Geothermal studies, *Arid lands, *Bibliographies, *Geology, *Technology, *Reviews, Engineering structures, Multiple purpose projects, Ecosystems, Industries, Exploration, Exploitation, Resources development, Comprehensive planning, Desalination, Electric power production, Environmental effects, Research and development, Water resources development, Thermodynamics, Energy conversion, Convection, Economics, Ecology, Limiting factors, Adaptation, Evolution, Succession, Niches, Competition, Distribution patterns, Heat transfer.

17b. Identifiers

*Technoecology, *Imperial Valley, Technoecosystems, Technoorganisms, Salton Trough, Developing countries.

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WRSIC 102 (REV. JUNE 1971)

GEOTHERMAL TECHNOECOSYSTEMS
AND WATER CYCLES IN ARID LANDS

I. INTRODUCTION TO TECHNOECOLOGY

1. Macrovision

Drop what you're doing and let's go flying in a small private jet over the arid southwestern United States. A roar, the crush of acceleration, and we gently part from the surface and slide up into the clear, blue-vaulted atmosphere. Airport vehicles and buildings fall behind, looking like miniature toys. And as we climb, mesquite trees and creosote bushes in the desert below us change from discrete plants to dots in geometric patterns and finally to a delicate texture subtly varying with soil gradations, topography, and dry drainage system traceries, and sliced by a sparse network of tiny powerlines, dirt roads, and highways. In smooth, swift transition our senses have left the human world and entered the macroscale.

As we gain speed and altitude, two geometric transformations alter our spatial perception of environment. The first I call the "zoom effect" because it is roughly equivalent to the action of a zoom lens. Increasing distance from earth's surface makes objects appear smaller by subtending smaller visual angles. Small objects disappear below the resolution limit; large objects, previously not visually comprehensible, come into view as synoptic wholes. If thinking, as R. Buckminster Fuller (1963*, p. 141) asserts, is frequency modulation by tuning out finite microcosmic and macrocosmic irrelevancies, then the zoom effect automatically expands the scale of our thinking by moving our sensory resolution limits up the size hierarchy of earth systems.

As the zoom effect takes us to the macroscale, the "parallax effect" gives this world three-dimensional depth and the intuitive sense of reality. Nearer objects move by at angular velocity greater than farther objects, and highly evolved neural pathways integrate these parallax clues with perspective clues to give us the vivid perception of motion through three-dimensional space (Johansson, 1975*). This effect is independent of the binocular depth perception mechanism, as can be verified by covering one eye while moving about on foot or in vehicle. Even with two eyes, objects far beyond range of binocular depth perception can be seen in three dimensions if relative motion is fast enough.

Parallax effect can be roughly simulated by substituting synchronous binocular parallax through time. If two photographs are taken approximately perpendicular to flight path (at 900 kilometers per hour), one four seconds after the other, and are viewed stereoscopically, objects many kilometers away are seen in three dimensions. The appearance is that the eyes are one kilometer apart, or alternatively that the landscape and cloudscape are miniaturized before us by a factor of 15,000.

Our flight speed increases, and what once was distant background scenery begins to move by in perceived three dimensions against a still more distant, imperceptibly moving background. A second's glance out the window and our eyes see enough parallax to capture macroscale geometry as a three-dimensional mental model. We intuitively perceive a large valley much as we would a small room, with cumulus clouds as three-dimensional sculptures and mountains as furniture. Still faster, and the valley seems to shrink, as we begin to sense depth and shape at still greater distances.

For a moment we might imagine the zoom and parallax effects of continued acceleration and climb. Earth curvature becomes perceptible as we rise through the stratosphere, and soon the planet is seen as a solid sphere drifting by in black space. Then the solar system becomes a perceptibly three-dimensional cluster of pinpoints, and ultimately even the near stars are seen to move in three

*References marked with asterisk are listed in the Supplementary References section. All others are listed in the Bibliography.

dimensions against the still more distant stellar background. Of course at the higher speeds there is relativistic distortion of both space and time, probably with colorful omnidoppler effects (Fuller, 1963*). But even these effects, with experience, might become intuitively familiar.

Zoom effect (based on distance) and parallax effect (based on speed) work together. For best direct human perception of systems at a particular scale, there is an optimum combination of distance and speed. Too much zoom is like looking at a flat photograph or peering through a telescope -- much detail of proper scale, but no intuitive three-dimensional feel. With too much parallax, objects flash by as streaks, like walls of a subway.

By choice of observation vehicle, zoom and parallax effects can be rationally combined to lever our perception through a wide range of scales. The unaided human body is suitable for observing systems scaled from 0.1 millimeter to a hundred meters (six orders of magnitude). Automobiles, except where roads are elevated, are not well suited for observation of systems over a few hundreds of meters in size; with too little zoom effect, rapid parallax of nearby objects confuses the eyes. Jet aircraft are ideal for viewing systems sized from meters to tens of kilometers (4 orders of magnitude), the general size range of most industrial systems. And for systems ranging from kilometers to thousands of kilometers (3 orders of magnitude), orbital spacecraft are probably best.

Small jet airplane is the best observation vehicle for our present study of industrial systems. It has optimum speed and altitude ranges to ratio our senses up to the scale of concern, plus the advantages of rapid three-dimensional maneuverability and global range extended by worldwide refueling support network. Furthermore, speed and acceleration capabilities are such that apparent gravitational force can be generated in any direction or even diminished to zero, which adds still another sensory dimension to our novel experience of environment.

When we fly, we bring with us all our intellectual knowledge of macro-phenomena, gained at human scale on the surface. As zoom and parallax effects bring direct spatial perception up to the macroscale of these phenomena, the result can be ecstasy. The atmospheric scientist in us sees clouds and whole weather systems; the geologist in us sees landforms and lithologic contacts; the geographer in us sees settlement patterns and urban networks; and the ecologist in us sees vegetation distribution and altitude zoning. And all these phenomena are seen as they really are at this instant, as three-dimensional realities in their natural setting, in full color, and viewable from any angle and altitude we choose.

This special mode of direct three-dimensional visual perception at the macroscale (result of zoom and parallax effects together) can be called "macrovision".

H.T. Odum (1971*) writes of a "macroscope of systems science" whereby large systems of which men are a part can be studied by abstract model making after conceptual elimination of small-scale details. Macrovision from fast aerial vehicles makes such detail elimination automatic, and makes intuitive perception of large systems effortless for almost anyone.

The inventions of microscope and telescope opened up vast new fields of exploration and knowledge. We might guess that the possibilities of macrovision (direct visual perception, not study of photographs) are just starting to be realized. Only a few humans, as yet, habitually think in spatial terms at this scale. Macrovision experience can increase the number of members in this special group.

Another effect of fast jet flying is that humans rapidly become subvisible; we leave the human world. We escape (temporarily) from the press of bodies, from the fascinating trivia of daily life. We are free for a while from the influence of human personalities which dominate the popular media, free from the countless political, economic, social, and academic territories and hierarchies (although we must still keep track of air-patrolled international borders). The ivory tower was never so high. And when the blinders which all of these human-scale complexities impose on us are suddenly removed, we can comprehensively overview the planetary patterns with new objectivity, with broadened awareness and deeper understanding. This is a world which public consciousness seldom enters.

Airline passengers fly many millions of kilometers in jets each year. But macrovision opportunities are mostly wasted on them. Some travelers prefer continuous immersion in the human world, with an aisle seat, movies, and a cocktail. Others briefly glance out windows at the unfamiliar geometries and then return to the human-scale world of a book, the stewardess, or dinner. A few people do enjoy watching the scenery for longer periods of time. However, most of them seem to miss the potential impact of macrovision, and instead fit the sights into microscale concepts and the language and labels of daily life at the surface.

But suppose we dismiss our microscale habits and accept this directly-perceived macroscale world as reality. Let's look beyond our old words and doctrines to see what is really going on at the macroscale. What new insights will come to us? What new language can we create to describe these macro-phenomena? What new macroscale strategies can we discover? What new things can we learn for the benefit of our fellow humans down there, few of whom ever have the privilege to perceive at this level?

2. Technoecosystem, Technospecies, and Technoecology

Sunlight glints off the wings as we sweep over desertscapes of varicolored alluvium and pass waves of mountain ranges which atmospheric milkiness turns light blue with distance. We focus on the complex man-controlled system which has flowered in this arid physical setting.

Behold the macro-system of cities, mines, powerplants, military bases, industrial complexes, and irrigated agricultural grids, all meaningfully distributed and intricately interconnected by such channels as highways, railroads, pipelines, power transmission lines, canals, and chains of microwave repeaters. Notice the geometric patterns, square tesselations, circles, and symmetries which order these systems in various spatial contexts.

And behold the countless thousands of discrete industrial modules of diverse distinctive types. Some modules are stationary (houses, office buildings) while others are mobile (automobiles, tractors, airplanes, and trains). Each type has characteristic morphology, behavior, and distribution pattern. And each mobile type has a distinctive support system of navigation aids, terminals, and manufacturing and maintenance facilities.

Where we have seen this complexity, diversity, and integration of matter, energy, and information flows and storages before? Certainly nowhere else at the macroscale, but everywhere in the microscale biological world, from cellular to ecosystem level. Industrial systems and biological systems are analogous. And this macroscale aggregate of human-controlled systems is so closely analogous to a biological ecosystem that I suggest we call it a "technoecosystem". In this view, the distinct groups of discrete industrial modules are analogous to biological species and can be called "technospecies".

We can tentatively define "technoecosystem" as a large, complex, spatially or functionally distinguishable non-human physical system under conscious human control. Any sufficiently large and complex subset of a technoecosystem is also a technoecosystem. And the aggregate of all technoecosystems is simply the technoecosystem (just as the aggregate of all men is man). Since the bulk of the technoecosystem is presently confined to this planet's surface, it can also be called the "technoecosphere". But spacecraft demonstrate that a spherical shell is not the ultimate confining geometry for the technoecosystem.

"Technospecies" is tentatively defined as a type or group of spatially discrete, morphologically and functionally similar, complex industrial modules ("technoorganisms" or "technobes"). This definition is analogous to the definition of species in paleontology; in both cases morphology and function which evolve through time are the only clues to speciation. "Technospecies" is intended to be a rather loose term to be applied to groups of industrial modules which are similar at whatever level of generalization is useful at the time. Hence, for example, "technospecies" can refer to road vehicles in general, or trucks in general, or a type of truck, depending on the level of detail needed. It seems unlikely that technospecies will ever be formally grouped in a hierarchical classification system as biological species are (species, genus, family, order, etc.), although the analogy is apparent.

"Technoecology" can probably be defined in as many ways as "ecology" is. Perhaps it is least limiting to define "technoecology" as the study of large, complex industrial systems by analogy to biological systems, particularly at the ecosystem level. Technoecology, though, is not solely a passive study, for the technoecosystem is under collective human control, and our changing perception of it will alter our management of it. Thus technoecology also involves active evolution of macroscale technoecosystem strategies.

The prefix "techno-" (from Greek "techne" meaning art, skill, or craft) is used as synonym for the word "industrial" in the sense of skillful, intelligent, conscious manipulation of non-human objects and systems by a man or men. "Technoecosystem" is a more concise, more cohesive, more efficient expression than "industrial ecosystem", although I regard the two as equivalent. For the same reason, "technospecies", "technoorganism", and "technoecology" are used in lieu of "industrial species", "industrial organism", and "industrial ecology".

The prefix "eco-" is from Greek "oikos" meaning house, and may actually be used for industrial systems more appropriately than for biological systems, since technoecosystem is house for man. However, "eco-" brings with it a wealth of connotations from its long association with the biological world and more recently with the sociological world. It implies diversity and complexity of discrete parts in a dynamic, integrated whole system.

3. Technoecosystem Territory

First step in studying a system is to define it, to choose a boundary which is logical, useful, easy to perceive, and (at best) interesting. The technoecosystem is (to restate the definition just given) that extra-corporal part of human life support system which is under human control. Its boundary thus has a plural concave inside-ness (the convex skins of humans) and a convex outside-ness (the outer limit of human control and the inner boundary of the natural environment). This zone of human-controlled environment is clearly an important subset of universe, and deserves a specific name of its own -- "technoecosystem". Since the boundaries we define determine what we see, this definition of technoecosystem has numerous implications for our perception of the world.

Inner boundary of technoecosystem is fairly distinct. It brings food, comfort, and information to humans, removes wastes, and responds to human actions and commands. Outer boundary is more nebulous and indeterminate, since conscious control is difficult to define at its outer limits. This boundary accumulates raw materials, information, and energy, and discharges waste.

No boundary in nature (which includes technoecosystem and man) is absolutely sharp, and the technoecosystem boundary is no exception. When, for instance, does food leave technoecosystem and enter man? And does the technoecosystem include a flashlight beam wave front pulsed at the stars? Such questions are academic; in practical life we draw the boundary where it is expedient. From our airplane, the outer technoecosystem boundary looks quite distinct (surfaces of vehicles, edges of settled areas), and the inner boundary is irrelevant because men cannot be seen.

The technoecosystem includes all machines, tools, biological systems, and all flows, storages, and channels of materials, energy, and information under conscious human influence. Perhaps we can say it includes not only all these parts but also their relationships to each other, to man, and to the natural environment. Technoecosystem parts range from instruments of pleasure (stereos and violins) to sophisticated tools of destruction (ICBM missile networks). Scientific instruments, which extend human senses into new dimensions of physical reality, are included in the technoecosystem. This book is part of technoecosystem, and was probably delivered to you via technoecosystem transport channels.

The technoecosystem is a cybernetic system of tools which create, mesh with, and destroy each other, which support, mesh with, and destroy men, which survive by taking energy and material resources from the natural environment and transforming them to structure and waste. This system is all under human guidance (although often indirectly through time and space, since technoecosystem is nonsimultaneous and only partly overlapping). And it is designed (ostensibly) for the support and benefit of the humans who own, operate, and inhabit it. The technoecosystem is like an exoskeleton, with its own self-regulatory, self-maintaining, self-augmenting metabolism, and quite a few internal and external feedback mechanisms not directly known, predicted, or understood by humans. Technoecosystem and man are interdependent (by definition), and have evolved together.

An interesting implication of the technoecosystem definition is that natural phenomena become part of technoecosystem to the extent that they are consciously controlled or influenced by men. Thus, managed bioecosystems such as forests and fisheries are no longer "natural ecosystems" (as they are frequently called), but are technoecosystem subsets. By this definition, domesticated plants and animals, tilled soils, dammed rivers, discovered ore reserves, tapped geothermal reservoirs, and seeded clouds are also parts of the technoecosystem, at least to the extent they are controlled.

Clearly, the global technoecosystem is much larger than most of us realize. And present human policy is apparently to seek to extend its boundaries ever farther into the realm of natural environmental cycles. It is conceivable that the technoecosystem could very soon extend fingers of human control into essentially all systems on the planet, but whether such a technoecosystem would survive or even benefit man is questionable.

Another interesting aspect of the technoecosystem definition is that it rationally and specifically defines the outer physical boundary of man: it is the surface of the decentralized, discontinuous skin of worldwide humanity. In this manner we skirt around the complexities of the social, psychological, and cultural worlds (linguistics, politics, thought, knowledge, creativity), although the technoecosystem supports them all and includes many of their manifestations.

Much is written about the impact of man on the environment. But it is the technoecosystem, not man, by our definition, which has most of this impact. It is not man that consumes vast quantities of coal, oil, steel, and concrete. The technoecosystem does this (under human supervision) as part of its self-maintenance and growth processes.

An important corollary of the technoecosystem definition is that we (man) are not our life support systems (although we often confuse ourselves with them). We are not our machines. Clothing does not make the man. Perceiving this distinction can give us a sense of distance and detachment from the systems we control and inhabit. Technoecosystems operate in a world of their own, not our world. A technoecosystem maladapted to ambient energy and matter conditions can disintegrate, but we do not have to die with it if an alternative technoecosystem capable of supporting the same human population can be developed in time (perhaps cannibalizing highly concentrated parts and materials of the old system). Realization of this crucial distinction between man and technoecosystem may help us approach technoecosystem management and design more flexibly. And it may augment our empathy for our fellow naked men embedded (often unknowingly) in a technoecosystem which they and their ancestors have built and modified by tiny increments, and to which their reflexes, viewpoints, and even self-images are closely tuned.

There are few manifestations of human form at the macroscale. Mt. Rushmore is one of them. As we fly over the technoecosystem, experiencing macrovision, we have essentially no clues to the shape of the men at its controls. Other intelligent beings with radically different body shape, color, and communication techniques could conceivably develop similar macroscale technoecosystem patterns in a similar environment.

Archaeologists face an analogous situation. Due to passage of time (instead of geometric zoom effect), they cannot know with exactness the physical appearance, lifestyle, or language of an ancient people. Instead, they find the resistant hard parts of an abandoned, disintegrated technoecosystem. Soft parts, relationships, and flow dynamics of the system are gone, the natural environment has changed, the people are dead from time flow. The past must be inferred from what remains. Archaeology (without study of human bones) is paleotechnoecology.

4. Technoecosystem Sectors

The technoecosystem can be conceptually divided into sectors many different ways. Especially useful subdivisions are: outward-inward, biological-mechanical-inorganic, and high-energy-low-energy.

Outward sector of technoecosystem is the outwardly oriented part (toward natural environment), and inward sector is the inwardly oriented part (toward man). Outward sector consists of basic large-scale production systems for materials gathering and bulk processing, heavy manufacturing, energy collection and transmission, agricultural production, and waste disposal. These systems tend to have low component diversity and few frills, and they are adapted to natural environmental conditions and to inward sector demands. Inward sector consists of more delicate consumption systems for micro-processing of materials and energy (light manufacturing), and for support of human lives, activities, and social-political systems. Inward sector systems tend to have very high component diversity and many frills, and they are adapted to human physiology and culture and to support constraints (supply) of the outward sector. Outward sector is analogous to the engine, drive train, and frame of an automobile, while inward sector is analogous to the styled exterior and the plush interior with comfortable seats, radio, and control levers.

An alternative breakdown of technoecosystem is into biological, mechanical, and inorganic sectors. Biological sector consists of all biological materials and living animals, plants, and bioecosystems under conscious human control. Mechanical sector is composed of all "man-made" machines, systems, materials, and structures (non-biological) whose geometry or chemistry is unique to technoecosystem. And inorganic sector consists of all non-biological, non-mechanical materials and systems which are under conscious human control (including soils, ore reserves, controlled water, tapped geothermal reservoirs, and wastes in storage or transit).

High-energy (developed, rich) parts of technoecosystem and low-energy (underdeveloped, developing, poor) technoecosystem parts grade into each other and are non-uniformly distributed at various scales in both space and time.

In high-energy technoecosystems, mechanical and inorganic sectors dominate and biological sector plays a relatively minor role. Large mechanical components are integrated into macroscale ecosystem patterns. Long-distance transport and macroscale regional specialization and interdependence are common. Technomass (analogous to biomass) and energy flow per person are high, human labor is a small fraction of total energy flow, and large, comfortable cabins and cybernetic control rooms are provided. Outward and inward sectors are usually separated spatially and socially. Most people inhabit the large inward sector, and are generally ignorant of still larger outward sector functions. Social awareness and culture have few ties (except aesthetic) to the natural environment. Technology is highly developed and rapidly evolving, and people play highly specialized roles in high-energy technoecosystems.

In low-energy technoecosystems, biological sector dominates; mechanical and inorganic sectors are of relatively little importance. Mechanical components are usually few, small, and discrete, and do not form macroscale ecosystems. Transport and specialized interdependence networks are spatially small; local independence is common. Technomass and energy flow per person are low, human labor is a large fraction of total energy flow, and no plush cybernetic control rooms are provided. Outward and inward sectors are usually very close and often combined spatially and temporally; their social systems overlap and are usually indistinguishable, since the same people are involved in the functions of both. Inward sector is small, and most people are aware of and participate in the functions of outward sector. Social awareness and culture are very closely tied to the natural environment. Technology is at low level and changes very slowly. People who live in low-energy technoecosystems tend to be generalists.

5. Technoecosystem Leverage

Human physical configuration has changed little in the past few centuries; but technoecosystem life support systems have evolved extremely rapidly and have grown in size (at least in industrialized regions) much faster than human population. The result has been dramatic increase in standard of living for most humans, with concomitant amplification of social and scientific innovation. Growth and evolution of per capita technoecosystem has increased many-fold the leverage of individual humans over flows of matter, energy, and information.

Technoecosystem is a neutral system of levers which reflects at macroscale the creativity, thought, strategy, and engineering expertise of tiny human individuals. Due to hierarchical social-economic-political systems, macroscale technoecosystem patternings frequently reveal the strategies and inventions of only a few powerful men. Technoecosystems amplify whoever is at the controls. Tiny individual humans (e.g., corporation presidents, political leaders) play major roles as spokesmen and decision makers for large technoecosystem subsets.

The present potential magnitude of technoecosystem leverage becomes apparent when we compare per capita mass and energy flows for the biosphere and for the mechanical sector of U.S. technoecosystem. Leverage of powerful men can be orders of magnitude greater than these per capita figures.

Total living biomass in the biosphere is probably only slightly more than total plant biomass, which Wittaker and Likens (1975*) estimate as 1841×10^9 metric tons (t), or 1.841×10^{15} kilograms (kg). Assuming world human population of 4×10^9, world per capita share of world plant biomass is 460,000 kg. By comparison, U.S. Department of the Interior (1975*) estimates 1974 U.S. per capita annual [technoecosystem] consumption of new mineral materials (excluding mineral fuels and organic chemicals) to be 22,205 pounds/year (lb/yr), or 10,000 kg/yr. This is only 2 percent of world per capita biomass. But if we include lumber, organic chemicals, and earthworks in the mechanical sector, and assume that annual bulk solid waste is a small fraction of annual bulk solid consumption, then we can guess that U.S. per capita mechanical sector technomass has over several decades grown to about equal world per capita plant biomass. If this is true then the ratio of U.S. mechanical technomass to U.S. citizen mass (50 kg) is roughly 10,000:1. Adding biological and inorganic technoecosystem sectors probably multiplies this ratio several-fold.

Still more striking is the comparison between world per capita biosphere net primary (plant) production and U.S. per capita technoecosystem primary fuel consumption. Total biosphere net primary production, energy base for all bioecosystem trophic pyramids, is quoted by Wittaker and Likens (1975*) as 6.9×10^{17} kilocalories (kcal)/yr, or a world per capita value of 1.7×10^8 kcal/yr. In contrast, U.S. per capita [technoecosystem] consumption of primary fuels is estimated by Steinhart and Steinhart (1974*) to be 116 kilowatts (kw) which equals 8.7×10^8 kcal/yr (compared with approximate human metabolic rate of 0.11 kw = 8.4×10^5 kcal/yr). Thus U.S. per capita fuel consumption is more than 5 times the magnitude of world per capita net primary production, and ratio of U.S. per capita fuel consumption to U.S. citizen metabolic rate is roughly 1000:1. If high energy quality of technoecosystem fuels were taken into account, these ratios would be even greater.

Our jet plane (typical executive jet) is an excellent example of substantial technoecosystem leverage. Its mass is roughly 5000 kg, 100 times human body mass. And its useful power at cruise is 1500 kcal/sec (6 megawatts), or 60,000 times human metabolic rate (0.027 kcal/sec). These figures do not include the massive, high-energy engineering, manufacturing, and support facilities on the ground which make our flight possible. Not only is substantial leverage demonstrated, but the typical outward-inward sector duality of technoecosystem and its complex subsets is also manifest: the cabin, instruments, and controls are carefully designed around human morphology, psychology, and biochemistry; and the airframe is precisely engineered for rapid, maneuverable flight through its element.

In low-energy, less-developed technoecosystems, evolution of human-scale tools and technospecies is slow. Local systems are designed from standard components by generalists, but macroscale patterns tend to develop more by natural selection of successful configurations than by conscious design.

In high-energy, industrialized technoecosystems, design at most scales is institutionalized and allocated chiefly to specialists. Architects design houses, engineers of all types design systems within their specialties. Human engineers fit machines to men, and systems and industrial engineers design complex mesoscale technoecosystems. In most cases, though, these professional specialists concern themselves with micro- to mesoscale parts and technospecies. Assembly of these parts into macroscale technoecosystem patterns is either left to decentralized spontaneous organization or turned over to a few powerful military or industrial macroscale generalists for whom technospecies are as toys to manipulate within global technoecosystem strategies.

Potential for rapid technoecosystem evolution and improvement in high-energy technoecosystems is very great, but may be generally slowed by conservatism of established technoecosystem managers. The role of natural selection of technoecosystem patterns is much smaller in high-energy than in low-energy technoecosystems due to powerful observational and analytical tools and techniques as well as to rapid transmission of and access to information storages. Awareness of failures guides future conscious engineering practice.

Technoecosystem design and management is a natural, intuitive human function. It can be observed in the spontaneous play of children with dolls, toy technoecosystem parts, and toy technoorganisms. And it is manifest in people's spontaneous ability to organize and manage complex households.

The technoecosystem is our accumulated aggregate of levers, invented and cybernetically networked and multiplied to support us and extend our control over flows in nature. High-energy technoecosystem inward sector (inner end of levers) is like a cow with countless specialized udders. It feeds, clothes, houses, and showers us, flushes our wastes away, and gives us a workplace and a role in its complex production system. High-energy inward sector configurations vary greatly according to human behavioral and cultural differences, but can be relatively homogeneous despite physical environmental differences.

In contrast, outward sector (outer end of levers) patterns are, as already mentioned, carefully adapted (consciously or unconsciously) to environmental conditions and resources distribution. We find different technospecies, channels, and technoecosystem configurations in different environments (atmospheric, subterranean, submarine, arid terrestrial, etc.). High energy outward sector macrotechnology tends to be independent of cultural background. People of many cultures drive cars, fly airplanes, and manage electric powerplants.

At the same time that technoecosystems are adjusted to environmental conditions, the physical environment reacts to technoecosystem configurations and actions. Even low-energy technoecosystems, based chiefly on biological energy flows, have major macroscale effects on natural phenomena (e.g., extinction of game animals, desertification, rapid denudation of hillslopes). But high-energy technoecosystems have diversified from original biological basis to tap the highest-concentrated potential energy storages of many terrestrial energy cycles (oil, coal, geothermal heat, water power), and much more extensive environmental effects are to be expected.

Preston Cloud (1974*) traced the early evolution of bioecosystems, their progressive revolutionary transformation of surface and atmospheric geochemistry, and in turn the role of these environmental changes in determining subsequent survivable ecosystem configurations. It is apparent that technoecosystem evolution is subject to similar environmental feedback, and that global-scale environment-technoecosystem interaction may be just beginning. It is important to note, however, that bioecosystem revolutions took tens to hundreds of millions of years, while major technoecosystem revolutions are now occurring on a scale of decades.

6. Technoecosystem as Macro-Medium

Marshall McLuhan (1964*) wrote that such media ("the extensions of man") as speech, clothing, radio, typewriters, automobiles, and weapons have profound consequences on our lives which nevertheless are quite invisible. We are quite conscious of the detailed, surficial message, content, or programming of a medium, but we are usually completely unconscious of the pervasive, subliminal, sense-stretching, perception-altering, life-changing effects of the medium itself. We see the figure, but not the ground within which it is immersed. The medium, according to McLuhan, is the real message, but it exists before we think of it, and we do not usually perceive it until it changes or no longer surrounds us.

Technoecosystem is a medium. In fact it is the ultimate medium, the macroscale physical medium within which all other extensions of man are embedded. It has been the ultimate, omni-flexible medium of human expression through the ages, supporting human lives and expressing human lifestyles, manifesting ideas and inventions, weaving men into invisible perceptual networks. Civilizations, wars, technospecies, history, science are all just messages carried by this most fluid of media.

Like water to fish, technoecosystem is invisible to most of us who inhabit it. We live our daily lives at the microscale, the level of technoecosystem components. We are all intensely aware of the specialized properties and behavior of these parts and how they affect us. But it is only at the macroscale, beyond common daily experience, that all these discrete and diverse components are elegantly integrated into a single ecosystem. Macrovision is one powerful tool to help us look beyond microscale messages to see the macroscale medium. The technoecosystem concept itself is another.

Still less visible than technoecosystem is the medium of media, within which not only technoecosystem but also man and all other systems are embedded: the universe with all its physical and mathematical laws.

Biologists and environmentalists have noticed, looking outward, that bioecosystems are perturbed and destroyed by "man" or "man's machines". But even these observers, who are highly sensitive to ecosystem patterns, seem (as a group) to have missed the explosive realization that industrial systems (of which domesticated bioecosystems are only a part) have become ecosystems themselves, through direct, unconscious, spontaneous convergence. Even these highly trained observers have not been able to perceive clearly the true nature of the medium within which they are immersed.

It is hard for humans to escape from the technoecosystem for very long and still stay alive. Usually, in trying to get away, we use and take with us a minimum set of technoecosystem life support parts. And if we do not, we soon design and build our own technoecosystem parts and systems on the spot. Even to rise above the technoecosystem and see it as an ecosystem through macrovision requires a fast aircraft technoorganism.

We experience technoecosystems other than our own when we travel in person or through books. The change of man-made and natural environment brings both our own technoecosystem and the new one from invisibility to visibility. Good science fiction provides particularly rich technoecosystem imaginings, with diverse planetary technoecospheres, embedded in nonsimultaneous interstellar technoecospace, molding and responding to the lives of the characters.

In using radiotelescopes to search for extraterrestrial intelligent life we assume that organisms may vary but that radio technology must be quite similar since the same laws of physics will apply (Sagan and Drake, 1975*). If the technology is detected, then the intelligence can be inferred. In other words, we will not contact intelligent beings on other planets directly; instead our huge radiotelescope technoecosystem modules seek electromagnetic emissions from similar technoecosystem modules which are light years away. The implication here is that intelligent life develops technoecosystems. If man is defined as conscious designer, operator, and enjoyer of technoecosystem, then we might say that the weak intelligent signals we seek across interstellar spaces can only be from man, amplified by technoecosystem leverage. UFO's may be technoorganisms!

7. Popular Technoecology

The concept of technoecosystem may seem foreign and unfamiliar at first. Actually, it is not an entirely new idea. The analogy between industrial and biological systems is deeply rooted in our culture, instinct, and language, and it has countless local manifestations.

The first machines known to early men were biological machines. As mechanical devices were invented and evolved, first as discrete artifacts and later as complex modular systems, it was probably only natural for men to give them names derived from analogous experiences in the biological world. We see evidences of this today in such metaphorical terms as "iron horse", and in the use of "nose", "skin", "wings", and "tail" for parts of an airplane "bird". The deeply intuitive human sense of biological analogy is manifested in primitive societies by totemism and many rituals, and by decoration of weapons, boats, and other artifacts to look like animals or plants.

Children in hunter-gatherer societies learn about biospecies at an early age; such knowledge is vital for their survival in the ambient bioecosystem. In contrast, children in a modern industrial metropolis learn names of technospecies first -- car, airplane, truck, train -- for these are the important modules in their technoecosystem surroundings. As they grow up, industrialized children do not pretend to become bioorganisms in ritual as hunter-gatherer children do. Instead, they actually learn to sit at the controls of diverse macroscale technoorganisms. The elaborate vocabulary which technoecosystem inhabitants have evolved for discussing varieties, behaviors, and distinguishing features of technoecosystem components is directly comparable to detailed biological vocabulary of bioecosystem dwellers.

Biological analogies and metaphors are pervasive in our popular industrial culture. Streets are called arteries, factories are called plants, cars have animal names. Jokes and humorous or metaphorical references to biological-industrial analogy crop up frequently in mass communication media. Cars are used in paleontology texts as analogy for biospecies diversity and taxonomic hierarchy. In popular art, political cartoons, and advertisements, machines and factories are personified as monsters or politicians, and cars and buildings have smiling faces. World War II Flying Tiger airplanes were painted to look like ferocious predators. And it is perhaps a cliche now that car and driver, ship and crew, airplane and pilot can behave as single integrated organisms; cybernetics has become popular art form.

Who could miss the striking resemblance of helicopters and tractors to insects, of airplanes to birds? None of us seems to have any difficulty seeing machines as organisms. And all it takes for us to see whole industrial systems as ecosystems is to extend this same organismic perceptual filter to the macroscale.

Apparently we all sense to some degree that bioecosystems and technoecosystems are closely analogous. However, this analogy seems to have been overlooked in serious thought, and remains on a subconscious level of popular consciousness in humor and metaphor. The macroscale biological-industrial analogy is a simple idea, even an obvious one, and its implications are great and many. Now may be the time for us to bring this analogy into the open and put it to good use.

The technoecosystem concept will survive if it is a natural idea, if it does indeed lie just below the surface of popular awareness, just waiting for a name to bring it to life. The term "technoecosystem" may be all that is needed to solidify the bio-techno analogy on the conscious level of popular thought, to make fundamental macroscale industrial strategy not only comprehensible but also <u>interesting</u> to the general public.

If the technoecosystem concept should at the same time happen to strike the global sense of humor, all the better! It might be good for us to take ourselves, our social systems, and our machines a little less seriously, to see ourselves from outside our technoecosystem.

8. Intellectual Technoecology

> It [civilization] ended when the man-made environment began to take on the characteristics of a natural ecology, that is, when it became interlocking, responsive and self-regenerating. All this has happened, if only in its crude beginnings, within the last few decades.
>
> -- George B. Leonard (1968*, p. 83)

> It is usual to talk about "industries," and even individual firms, as if they were autonomous entities, yet this is somewhat artificial. Although language and habits of thought make it easier to talk about autos or General Motors than about the industrial enterprise as a whole, for which we do not even have a convenient term, every industrial company depends so intimately on its fellows that it would be convenient to have a word similar to the biologists' term "ecosystem" to describe a community of interdependent enterprises.
>
> -- Sheldon Novick (1975*, p. 37)

These two quotations are the closest approaches to the technoecosystem concept that I have yet found in the literature. They seem to indicate that the intellectual climate may now be right for introduction of this technoecosystem idea. Many writers in numerous fields have used words and concepts quite close to "technoecosystem", as defined in this paper, but none that I know of has presented a term with the same meaning and nuances.

Biologists, and particularly bioecologists, have sensed that human and human-controlled systems are similar to biological ecosystems. For example, E. P. Odum (1971*) wrote of "an applied human ecology", but it is a nebulously defined expression, within which he includes items like human population control, land-use planning, economic policy, and natural resource conservation and recycling. Similarly, Foin (1972*) used the term "human ecosystem" (which he did not define) to include the domain of public health, air pollution, social and population problems, agriculture, urban systems, and fuel resources. It might facilitate clearer thinking to use "human ecology" and "human ecosystems" for human social, behavioral, and biological patterns, and reserve technological life support system patterns for "technoecology" and "technoecosystems".

Caswell et al (1972*) used "industrialized ecosystem" to include earth cycles, biosphere, humans, agricultural systems, and industrial systems. Clearly this concept is much more general (and perhaps less useful) than "technoecosystem"; its boundaries encompass not only technoecosystem but also man and part of natural environment.

Loucks and D'Alessio (1975*) used "man-occupied ecosystems" for biological ecosystems modified by man. This concept does not include non-biological artifacts and industrial systems (as technoecosystem does) and its fuzzy boundary includes bioecosystem parts not under conscious human control.

Nicholson (1972*) described "technosphere" as

> ...the whole system which man has evolved for cropping, for extracting minerals, really for parasitising the biosphere, the lithosphere and the hydrosphere, and for processing what he takes out of it in ways which yield some economic production, some marketable products, but also yield by-products or waste products which go back into the biosphere....

"Technosphere" (technological equivalent of "biosphere") seems to have the same boundaries as "technoecosphere" or "global technoecosystem", but it misses the biological analogy, the crucial connotation of "technoecosystem" that industrial systems are complex hierarchical ecosystem networks.

A basic assumption that underlies H.T. Odum's (1971*) work is that biological and industrial systems (and many other types of system as well) have similar patterns and behaviors because they obey the same thermodynamic and physical laws. He writes of "systems of man and nature" and of "man's systems", but he apparently does not yet have a term (like "technoecosystem") for systems controlled by but not including man.

Anthropologists and sociologists are mainly interested in humans and their behavioral systems. To them, it seems, physical life support systems are mere props which are extensions of people, which affect people, and from which people and their behaviors and world views can be inferred (as in archaeology). Traditional terms "civilization" and "culture" refer to combined humans and technoecosystem-- there is no boundary at the skin. "Artifacts" and "tools" are seen as physical objects separate from humans, but these terms suggest isolated objects, not complex, integrated, evolving systems.

Ecological anthropologists study food and energy systems of primitive, low-energy societies in relationship to beliefs and behavior (their main concerns) and natural environment. For such a low-energy society, life support system is primarily an obvious bioecosystem. But ecological anthropologists, not having the technoecosystem concept, seem to have difficulty extending their observations and methods to complex macroscale industrialized societies. Perhaps closest to technoecosystem concept is their term "material culture" (Steward, 1955*), but it implies physical life support system as an expression of human behavior rather than as a separate unified physical system under human control. Another related term is "the superorganic" which means "symbols, and the cultures synthesized from symbols and symbol use" (Rappaport, 1971*), or historically developed specialized adaptations of behavior patterns found among at least one but not all human groups (Steward, 1955*). Still more oriented toward social and behavioral patterns are "cultural ecology" and "social ecology" (ibid.).

The dangers of using biological analogies for social systems are suggested by the acts committed by World War II Nazis in the name of the evolution of the social organism. There may be similar dangers of abuse of biological analogies in industrial system design and management. But ecosystem scale analogy may be safer than analogy at organismic scale because ecosystems are more complex, diverse, and fluidly adaptive over long and short runs than are organisms. Furthermore, ecosystems have decentralized controls and complex networks of independence and interdependence. However, it is clear that we must be careful with our analogies, and remember that they are not identities.

Economists deal with the human life support system, at least that part of it which experiences money flows. But they tend to see the system from within, to model in terms of money alone, to ignore thermodynamics and physical and environmental constraints. Economists tend to concentrate on distribution of wealth (through money switching and distortion mechanisms) rather than on the macroscale physical life support system, which is the actual source of all wealth. Money can blind us to the physical reality of this macroscale technoecosystem which surrounds us. The term "economy" is often used for large technoecosystem subsets, but it focuses our attention on money flows between human technoecosystem operators and inhabitants, rather than on actual technoecosystem physical support functioning.

Georgescu-Roegen (1975*), one economist who does look at physical and thermodynamic constraints, uses biologist A. Lotka's expression "exosomatic instruments" for physical extensions of man. This term specifies the same boundary at human skin that "technoecosystem" does, but it does not suggest the biological analogy or the ecological integration of all exosomatic instruments at the macroscale.

Historians have tended to glorify human personalities and political events. However, a new wave of historians, exemplified by F. Braudel (1972*, 1974*), has begun to examine and display history within its true constraints of technology and physical-biological nature. Technoecosystem, within its natural setting, seems to have guided human affairs more than most of us have realized.

The organismic analogy of human history (as propounded by Spengler) is apparently strongly condemned by most historians as unscientific. But Von Bertalanffy (1968*) suggested that the analogy simply manifests the operation of general systems principles, and can be useful if it is not mistaken for a statement of identity. Ecosystem analogy of history might be even more useful than organismic analogy.

Geographers study people in their technoecosystem surroundings, and technoecosystem in its physical environmental context. And they use numerous methods and theories which have their analogous counterparts in the biological world. The technoecosystem concept may significantly enliven geography and open the way for substantial bioecology-geography interface and quantitative theory transfer.

General systems theory seems to support and encourage the technoecological viewpoint. Systems of all types and at all scales exhibit similar behavior (e.g., hierarchical organization), and appear to be governed by the same unifying physical and mathematical laws. General systems theoretists (e.g., Von Bertalanffy, 1968*) have seen social systems as a higher-than-organism level of the biological organizational hierarchy. However, until now they seem to have missed the insight that industrial systems have similar feedback mechanisms and hierarchical matter-energy organization networks. Systems philosopher Laszlo (1972*) discussed physical, biological, and social systems. But there is no place in his scheme for technoecosystems -- physical-biological systems controlled by social systems! Media tend to be invisible to those who dwell within them.

Systems and industrial engineers use the term "industrial system" (which misses out on macroscale ecological analogy and home-for-man connotation of "technoecosystem"), and the term "man-machine system" (which describes their field of concern but neglects the human-skin inner boundary of technoecosystem). Mathematical systems theory has branched into biological and technological specialties (among others); the technoecosystem viewpoint suggests a synthesis of these sub-fields.

Cybernetics and bionics are both sciences which interface biology and engineering, and as such they are both closely related to technoecology.

Cybernetics (defined as study of "control and communications in the animal and the machine" by its originator, Norbert Weiner [Trask, 1971*]) deals chiefly with the man-machine interface, and with control mechanisms, information processing, and information flows in machines. It has been applied mainly to engineering of computers, communications networks, and servomechanisms, although some work has been done seeking analogous control circuitry and control mechanisms in organisms. Cybernetic insights and methods will be of great use in technoecology.

Bionics is a less specialized field than cybernetics. It was originally defined (by J.E. Steele in 1958) as "the science of systems whose function is based on living systems, or which have characteristics of living systems, or which resemble these", and it was later redefined more practically by Gerardin (1968*) as "the art of applying the knowledge of living systems to solving technical problems". Whereas cybernetics concentrates on engineering and only occasionally looks for biological analogs, bionics searches the biological world for structures and innovations which can be adapted to serve analogous functions in the technoecosystem.

Clearly, technoecology (in its pure and applied aspects) can fit into the bionics definitions just given. But bionics as defined and bionics as it has actually been applied are two different worlds. Although bionics is defined in terms of "living systems" in general, it has in practice dealt with biological systems only at subcellular to organismic level, and has found engineering applications only on the micro-component to technoorganism scale. Technoecology, in contrast, is a macroscale science, which compares macroscale technoecosystems to macroscale bioecosystems, and searches biological world for new macroscale industrial designs and strategies. Applied technoecology is macroscale bionics.

9. Bio-Techno Comparison

Technoecosystems and bioecosystems have many common characteristics. They look alike, with complex but orderly spatial patterns of diverse, discrete, mobile and stationary modules. They are both self-organizing, self-regulating open systems, with hierarchical cybernetic control networks employing positive and negative feedback loops for homeostatic maintenance of internal order. They both accumulate information and project it into the future via preferred hierarchical energy, matter, and information flow and storage patterns. Both have multilevel energy quality trophic structure, and are limited in physical structure alternatives by availability of essential materials (e.g., metals, minerals, water, organic chemicals). Spatial territory hierarchies occur in both technoecosystems (e.g., hierarchical hexagonal market territories [Plattner, 1975*][1]) and bioecosystems (e.g., approximately hexagonal desert shrub distribution patterns within approximately hexagonal rodent territories within approximately hexagonal predator territories). And both technoecosystems and bioecosystems and their components evolve through time, although at greatly different time scales.

These similarities between bioecosystems and technoecosystems are not accidental. Both types of system are governed by the same thermodynamic and physical laws, the same universal geometric, topological, and mathematical laws, the same relativistic framework, and the same constraints of matter, energy, and information. In addition, bioecosystems and technoecosystems that we are familiar with have evolved on the same planet with its a priori gravitational field, thermal regime, and element abundances.

Furthermore, technoecosystems have come to resemble living systems because they are organized around and by living organisms (men), because some technoecosystem subsets are modified bioecosystems and some technospecies are biospecies, and because some mechanical technoecosystem parts are conscious imitations of bioecosystem parts. In the future, through technoecology, whole technoecosystems may become conscious partial imitations of bioecosystems.

Finally, it simply makes good economic and energetic sense to design technoecosystems with macroscale low-entropy channel networks, with energy-matter storages, with optimal energy systems location, and with compact, efficient, well-adapted modules in rational, orderly, integrated patterns. Such systems compete well and survive; others do not. Whether consciously or not, technoecosystems must evolve to be similar to bioecosystems -- because they work.

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[1] Market territories in three-dimensional technoecospace might be expected to be dodecahedronal volumes (see Fuller, 1975*), representing closest packing of spheres. This geometry is found in closely packed cells and bubbles.

Although the results are similar, the means of technoecosystem and bioecosystem evolution are different. Biospecies and bioecosystems evolve solely by long-term, decentralized, unconscious natural selection of successful, competitive features generated by random variations. In contrast, natural selection plays only a minor role in evolution of technospecies and technoecosystems. They evolve mainly through short-term conscious human design and decisions based on accumulated information and highly adapted, rapidly evolving mental and physical design strategies. Natural biological management strategy is long-term stability, whereas technological strategy is short-term growth and maximum control.

In technoecosystem, information flow and storage is freed from biochemical constraints, resulting in rapid information accumulation and transfer (at speed of light) capability. Human social networks and centralized power hierarchies facilitate direct, conscious, highly organized macroscale and microscale design and production projects.

Technoecosystem is the extension of life into new worlds of inorganic and electromagnetic interactions. New properties of matter and energy are utilized, and new geometries (e.g., wheels and axles) can be exploited. Technoecosystems, unlike bioecosystems, can use the mechanical world: complex levering and rotation, crystal structures, orbital trajectories, and macrostructures. Technoecosystem energy flow is often in discrete packages which create structures and materials that will withstand decay for a long time. In contrast, biological systems must maintain tissue complexity at all scales with nearly constant energy flow.

Technoecosystem modules are not limited in size (as biological organisms are) by genetic functions and nerve tissue performance. They can be large, dispersed, but centrally-controlled networks, organized by high-speed electromagnetic communications channels. Technoorganisms (except biological ones) are not self-regenerative; but the whole technoecosystem is -- new parts are made by centralized manufacturing rather than decentralized biological reproduction.

Biological ecosystems within technoecosystems seem to have standard trophic pyramid structure, with energy concentration progressively increasing, species diversity and population decreasing, and large energy losses between levels (although high quality fossil fuel energy is fed in for some maintenance functions, rather than internal energy loopbacks). Mechanical fossil fuel technoecosystem subset trophic structure (e.g., oil wells, tankers, refineries, pipelines, service stations, cars) is somewhat different, however. Fuels are already concentrated, so low (producing) trophic level is characterized by simple, non-diverse systems with low population and high energy flow, and high (consuming) trophic level exhibits very large population and high diversity. Energy quality increase and energy loss appear to be less between trophic levels for fossil fuel technoecosystems than for biological technoecosystems.

Technoecosystems exhibit behaviors and properties analogous to biological systems at several (cellular to ecosystem) levels. But ecosystem level was chosen as the best analogy for several reasons. Both bioecosystems and technoecosystems consist of numerous interspersed and interacting populations of distinct types of spatially discrete and separated complex modules. Both have mobile and stationary modules. Both have relatively simple bulk energy and materials flows. Both exist at terrestrial macroscale where gravity flattens them, often at horizontal planar interfaces between phases (liquid-gas, solid-liquid, solid-gas), so vertical dimension is generally less than horizontal. And in both bioecosystems and technoecosystems the highly organized modules are embedded in much matrix of unorganized solids and fluids.

Furthermore, since machines are so easily and popularly seen as organisms in organismic roles (see, for instance, Rowland, 1968*), it seems natural to liken larger systems to ecosystems. Technoecosystem is like an ecosystem to the extent that its control is decentralized, and like an organism to the extent control is centralized. Whether we see a technoecosystem as organism or as ecosystem depends on the phenomenon and the spatial scale with which we are concerned.

Is technoecosystem a form of life? It certainly is the manifestation of life at the macroscale, freed from biochemical limitations and extending complex hierarchical organization into new realms of geometry, speed, and matter-energy properties. Its evolutionary patterns certainly mirror aspects of biological evolution, only on a much larger and faster scale, and semi-consciously guided by intelligent creatures. Finally, technoecosystems are probably the only detectable manifestations of life in other stellar systems. But we could not call technoecosystems "macroscale life" or "macrolife" unless we were willing to expand our concept of life beyond the biochemical-biological world. Perhaps we can call them "industrial life" or "technolife", instead, but we must remember that this is not identity but very good analogy. We now recognize that in viruses life grades indistinguishably into the non-living world at the microscale. We may someday dare to state that in technoecosystem life grades indistinguishably into the non-living world at the macroscale.

As soon as we realize that in observing industrial civilization we are just seeing an ecosystem, then we can perceive all the diverse technological "problems", revolutions, successes and failures, and complex evolving structures in a unifying framework. Economic development, energy crises, water and food shortages, inventions, territory expansions and losses, and hierarchical control networks are all as old as life, and recur in many frameworks at many levels and on many time and space scales in the biological world.

The technoecosystem concept brings a whole rich galaxy of biological ideas and experiences to the technological world. There are many lessons for us to learn from present ecosystems (products of millions of years of survival and design perfection by natural elimination of maladapted configurations) and from records of past ecosystems. We might try projecting our observations and knowledge from biological microscale to industrial macroscale in order to obtain new insights and perhaps evolve more rational and successful global industrial strategies.

10. Thermodynamics, Energy, and Money (Once in Forever)

Energy flow makes things happen. And this flow is governed by the second law of thermodynamics, also known as "time's arrow" and "the entropy law" (Georgescu-Roegen, 1975*). This law can be stated in several ways: heat flows only from higher temperature object to lower temperature; potential (free, available) energy flows only toward lower potential; order trends irreversibly toward disorder; closed systems run down; potential energy progressively and irreversibly becomes unavailable energy; concentrated energy becomes progressively more diffuse; entropy increases. Layzer (1975*) suggests that this entropy law may be a result of expansion of the universe faster than processes for attaining thermodynamic equilibrium.

But in apparent contradiction to this law, we see order in the world. We see order maintained and even increased in stellar, earth, and atmospheric cycles, and especially in biological and industrial systems. The contradiction is resolved when we note that these are all open systems, that order is increased and maintained in them only by energy flow through them, at the expense of increased disorder outside.

Open systems are what I call "entropy jets". They maintain structure and information, grow, and evolve by consuming high-energy orderly fuels and materials, and ejecting low-energy disorderly wastes and low-grade heat. Or, as Georgescu-Roegen (1975*, p. 353) puts it, they maintain themselves "by sucking low entropy (negentropy) and expelling high entropy." Systems which evolve mechanisms for most effectively maintaining this flow survive; other systems do not. Low entropy occurs in many forms, including thermal energy, kinetic energy, nuclear energy, gravitational potential energy, chemical bond energy, pressure differential, geometric order, information, and purity and concentration of substances.

Entropy jet operation is irreversible; once potential energy is degraded it cannot be returned to its original form without expending still more potential energy. Operation of technoecosystem, what Georgescu-Roegen (1975*) calls "the economic process", is an example of this. The economic process is irreversible; each of its events happens once in forever. Decisions are irreversible. Potential energy resources which run technoecosystem do not care how they are used (for peace or war) or how fast. They just follow a relentless trend--toward less. On earth we steer through time only once. It may seem that we are doing the same thing again, cyclically. But we are not. We are always downstream from before, potential energy has declined, the environment is different, the position of the stars has changed.

The technoecosystem we are flying over manifests the entropy law. Energy distribution networks demonstrate that energy flow is one-way. Technoorganisms powered by heat engines take on concentrated fuels and expel hot gases. Huge machines in well-organized technoecosystems strip mine high-potential-energy coal reserves to be burned. Others strip mine copper ore and expend fuels to concentrate the metal into a pure form which has high survival value in enhancing potential energy pumping performance of the technoecosystem. Energy in diverse forms is transported at low energy cost in specially adapted low-noise entropy-shielded channels.

Even our jet flight is irreversible. The plane (representing a very high concentration of energy flow investment) slowly wears out, concentrated fuel burns, hot gases are exhausted, and energy disperses as turbulence and as sound waves breaking across the desert. But we are gaining information, experience, and insight, which through future weightless thoughts and decisions will (we hope) guide future irreversible energy flows in such a way that our present energy expenditure will be repaid over and over.

Most people, if asked, say that they are making money, that many of their activities are related to money. But as we take off in our jet, money disappears just as humans do. At the technoecosystem macroscale, instead of money we see large technoecosystem structures and channels for flow of energy (including materials and information). These forms and flows all manifest microscale decisions and strategies based in major part on money considerations; but they are not money itself.

Money is apparently a decentralized mechanism for switching and steering energy flows in technoecosystem. It is weightless, invisible, purely abstract and mathematical, and can now be transferred and manipulated at the speed of light. Money can be viewed as perfectly distilled quanta of evolutionary advantage. Money flow controls energy flow. But this control is very site- and time-specific; it depends on instantaneous local energy-dollar equivalence ratio and on local peculiarities of technoecosystem configuration, energy and materials inventory, and flow capabilities, among other factors.

H. T. Odum (1971*) showed that money flows in the direction opposite to the energy flow it controls, and that distortion and manipulation of the money system alters configuration and flows of the technoecosystem energy system. Money cycles are entirely within technoecosystem, yet technoecosystem survival is based on flow of energy from environment. Hence Odum (1975) suggests either measuring these external flows in terms of money equivalents or stating all flows in units of energy of reference quality.

Money can be inflated or deflated simultaneously in different parts of the technoecosystem, so it does not always represent the same quantity of high-quality energy. Money flow is especially useful for microscale allocation of technoecosystem flows and structures. But at the macroscale it has often been badly distorted, either consciously, or through automatic functioning of maladaptive financial institutions. Our fixation on money often blinds us to what really matters: macroscale efficiency and survivability of the technoecosystem, based solely on energy and matter flows and structure geometries.

Energy and materials are real physical entities; their existence is independent of human whim. But money is abstract information, and men can manipulate and warp it. Money is recycled again and again. But the energy flow which it controls is irreversible, occurs once in forever.

Many people think that it is money flow in the global economy which supports them, though actually it is not money but the physical functioning of the global technoecosystem (and many natural environmental systems) which provides our physical sustenance.

Energy flow modeling techniques used by bioecologists have been adapted by H.T. Odum (1971*) for study of industrial systems, economic systems, socio-political systems, and diverse biological and inorganic systems. Central to Odum's work is a special energy circuit language for modeling these systems. Some of the symbols which Odum has devised are presented in Fig. 1 and appear in diagrams scattered through this paper. These symbols and others like them can be combined in diagrams to show conceptual energy flow relationships between system components. And they can be replaced by differential equations for digital modeling, or by appropriate electrical or hydraulic modules for analog modeling. Second law of thermodynamics is included in energy circuit models by the use of the heat sink module where irreversible energy transformations take place.

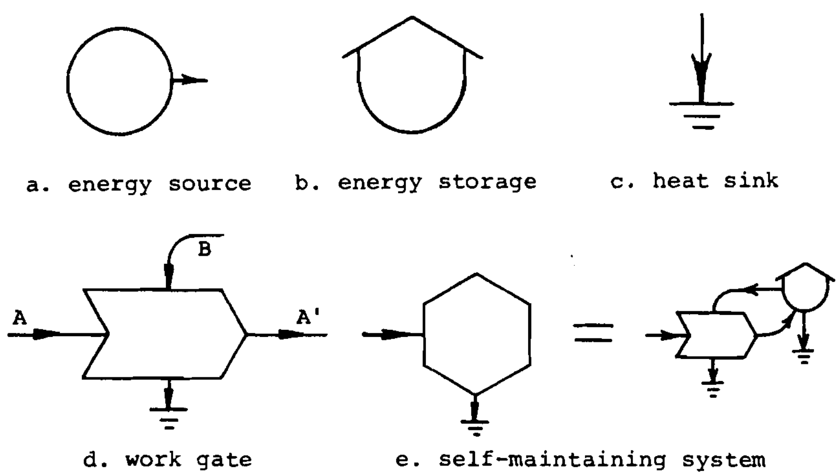


Figure 1. Some energy circuit language modules

Slightly modified from H.T. Odum (1971*, p. 38-39). In work gate module, energy flow B makes energy flow A-A' possible, as in turning a valve.

Besides a general introduction to energy circuit diagrams (1971*), Odum has provided a more detailed, quantitative analysis of the various modules (1972*), and has applied them to natural geological cycles (1972) and to arid lands technoecosystems (1975). Gilliland (1975) used Odum's techniques in a preliminary analysis of geothermal power production.

In their 1975 papers Odum and Gilliland summarized several energy system concepts which are helpful for comprehension of technoecosystem functioning. Energy quality represents actual ability to do useful work: one kilocalorie of gasoline can do more work than one kilocalorie of heat in warm water. Those systems which maximize power flow compete best and survive; and power flow is maximized by developing multi-step energy transformation chains (like biological food chains) which progressively concentrate some low-quality energy to higher quality (at the price of degradation of most of the low quality energy to still lower quality) and use this higher-quality energy for amplification, pumping, and control of the low-quality energy transformation (see Fig. 2).

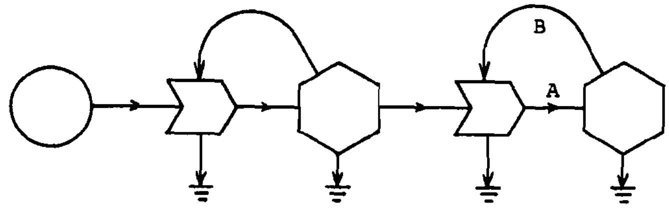


Figure 2. Two-stage energy transformation chain with energy quality increasing downstream

Net Energy = A - B

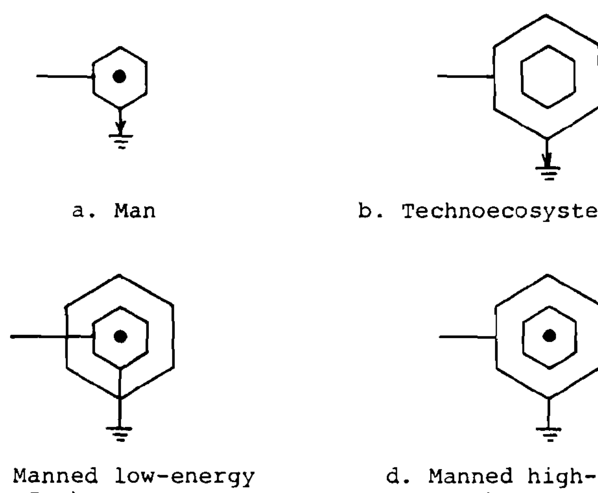
Net Energy Ratio = A/B

<u>Net energy</u> is the difference between high-quality energy produced and high-quality energy invested in some energy transformation process at lower energy quality level (A minus B in Fig. 2). Net energy must be positive for a system to survive alone. And for a system to compete, its <u>net energy ratio</u> (ratio of energy output to energy cost, or A/B in Fig. 2) must at least equal the ratios of its competitors. However, non-competitive systems can be maintained by high quality energy subsidy provided from outside sources, perhaps obtained through manipulation of money flows and energy-dollar exchange rates.

One monetary unit ideally represents a constant amount of energy at a particular quality level (constant energy-dollar ratio), but this rarely happens either spatially or temporally in real technoecosystems. As a result, economic analysis and net energy analysis can differ in their assessment of the favorability of a particular energy transformation process. In such a case, businessmen tend to count their fortunes according to economic analysis, but real wealth (technoecosystem performance) accrues only as net energy.

11. <u>New Modules</u>

Two important types of systems -- men and technoecosystems -- are included in so many energy circuit models that they deserve symbols of their own. I propose that we use the module designs shown in Fig. 3.



a. Man

b. Technoecosystem (empty)

c. Manned low-energy Technoecosystem

d. Manned high-energy Technoecosystem

Figure 3. Energy circuit modules for man and technoecosystem

The "man module" (Fig. 3-a) can be used for one, several, or many humans, gathered together, or dispersed. It is identical to the self-maintaining system module (Fig. 1-e) except for the dot in the middle.

This dot -- we might call it the "self module" -- is important because it points out the crucial difference between men and all other self-maintaining systems in nature. The human body is incontestibly a physical machine, subject to thermodynamic principles, like other systems. But it seems to carry within it something unique and special in the known universe, what we might call intelligence, consciousness, intellect, or the sense of self.

In. H. T. Odum's (1971*) scheme, the aim of all systems evolution is to maximize energy flow. But there seems to be more to the human world than just metabolism. As Georgescu-Roegen (1975*, p. 353) puts it, the real purpose, "the real output of the economic process [technoecosystem functioning] is not the material flow of waste, but the still mysterious immaterial flux of the enjoyment of life." The self, this unique property of humans, may be the enjoyer of this flux of enjoyment.

J. Bronowski in The Identity of Man (1971*) argued that it is "knowledge of the self" which makes man not a machine, and different from all other systems. But references to this singular human property are not limited to philosophical discussions. Jagdish Mehra (1973*) wrote about the special role that consciousness plays in the equations and theory of quantum mechanics. Physicist John Wheeler (1974*) attempted to show that consciousness may be an inherent and even necessary component of the universe. And it is possible that humanity's decentralized creative intellect and sense of self represent antientropic metaphysical universe, which geometrically complements entropic physical universe at the quantum level in Buckminster Fuller's (1975*) comprehensive mathematical synthesis. Indeed, it is because the self seems to be antientropic, a creative source of organization, that the dot in the man module is not connected to energy flow lines.

Without the dot in the man module, without the sense of self in system, our human world is reduced to beautiful but mindless evolution, the clashing and meshing of automatons in the blind rush to evolve maximum power flow configurations. I suggest that we keep the dot in the man module at least as long as pure consciousness, whatever it is, has not been reduced to biochemical formulas or mechanistic stimulus-response models. Behavior of systems composed of or controlled by humans seems to be fundamentally different from behavior of other systems. The self module dot, representing this difference, should serve to humanize energy circuit modeling.

Technoecosystem, like man, is a very special kind of self-maintaining system. It is the physical matrix which humans control and within which their multiple, decentralized sense of self is embedded and amplified. Just as self animates man, man animates technoecosystem.

The shape of the proposed "technoecosystem module" (Fig. 3-b, c, and d) shows this relationship. This module can represent a local, regional, or global technoecosystem, just as the man module can represent one human or many. By our definition of technoecosystem, an unmanned technoecosystem (Fig. 3-b), a technoecosystem not under conscious human control, is no longer a technoecosystem and will cease to behave as one. In low-energy technoecosystems (Fig. 3-c), where human metabolism is a large fraction of technoecosystem power, energy flow lines are connected to the man module. These lines are not drawn, though, for high-energy technoecosystems (Fig. 3-d), where human metabolism magnitude is relatively insignificant. For simplicity, complex energy transformations and cybernetic control pathways are not shown in the technoecosystem module. However, specific technoecosystem functions (work gates, energy storages) can be extracted from the module for purposes of analysis, as in Fig. 4-c.

Tools and their ultimate synthesis, the technoecosystem, are controllers and amplifiers of energy flow, guided by conscious strategy. Fig. 4 illustrates conceptually how technoecosystems may have started and how they expand by extension of control over ever-larger natural systems.

The sense of self may involve the sense of being in a system and somehow separate from it. This perception of separateness paves the way for development of strategies for manipulating external systems, in other words, for creation of technoecosystems. It may be (as Fig. 4 implies) that technoecosystem and sense of self evolved at the same time, and that they can only coexist. Thus we might consider defining man on the basis of this two-fold characteristic: man as biological system with 1) a sense of self and 2) a technoecosystem.

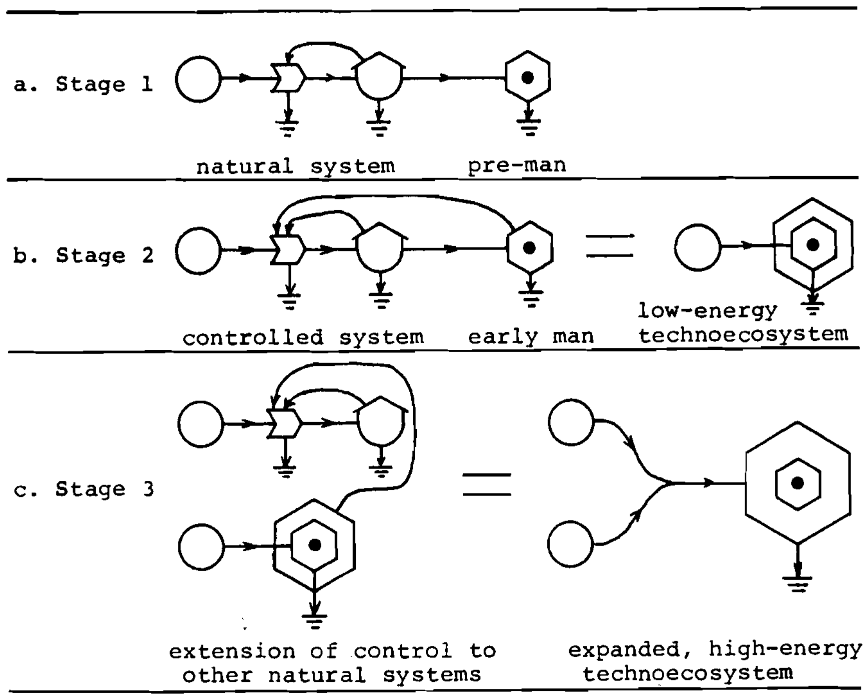


Figure 4. Creation and growth of technoecosystem

12. Technoecosystem Niches, Evolution, and Succession

One remarkable feature seen from our jet is the careful adjustment of many technoecosystem components to environmental conditions. Highway and canal geometries and routes are largely determined by topography and geology, mine sites are determined by mineral deposit locations, crops grow only where soil and irrigation water permit. This molding of technoecosystem to environmental geometries, energy gradients, and materials peculiarities, within the limits of human knowledge and technology, must occur either consciously or unconsciously for the system to operate effectively and survive. A good example of environmental determinism of technoecosystem is the pre-Columbian convergence of irrigated agricultural patterns in both Old and New Worlds.

As environmental conditions change, so must technoecosystem. And since technoecosystem (like living systems) changes many of the environmental variables it is adjusted to, it is always forced by itself (if not by outside forces) to evolve into new configurations. Technoecosystem subsets boom in some areas and are abandoned in others as technology, resource, and environmental conditions change. This happens at many scales of time and space.

Another determining factor for technoecosystem configuration is historic precedent. Small weightless decisions made at one time in history can steer large energy flow patterns later in time. Precedents often have great inertia and may be irreversible because energy cost of change can be much greater than simple maintenance of historic configurations. Examples are city locations and dam sites. There is great potential energy in a natural landscape, and it degrades as technoecosystem design decisions are progressively made. Clearly, making good precedents is of prime importance.

A concept of "technoecosystem niche", analogous to the biological concept of species niche (see Shugart and Patten, 1972* for a brief review) may be useful. A preliminary definition for technoecosystem niche is the hyperspace (for given environment and technology) of all possible technoecosystem configurations which will survive, at least for a reasonable time. Niches exist apart from technoecosystem; technoecosystems fit into them.

Energy source is a prime determinant of technoecosystem configuration, so we can divide a technoecosystem niche into a number of "energy niches". An energy niche can be defined as the hyperspace of all possible technoecosystem configurations, based on a specific energy source, which will survive for a reasonable time. In present technological discussions, a reasonable time seems to mean only 30 years minimum. An energy niche determines the morphology and function of a technoecosystem or technoecosystem subset which exploits it, just as an organism's niche and food type determines its morphology, metabolism, and behavior. One technoecosystem can exploit more than one energy niche at a time.

Both energy niches and technoecosystem niches are determined by such factors as technological knowledge, natural environment patterns, pre-existing technoecosystem configurations, and thermodynamic-physical laws.

A simplified view of a technoecosystem niche is to consider it a production possibilities surface with three dimensions: human population supported, quality of life, and duration of technoecosystem survival. Obviously, larger population leaves fewer options for technoecosystem configuration, duration, and quality of life. Technoecosystem niches, however, are actually somewhat indeterminate. The many bounding variables are non-linearly interconnected, and they react to irreversible technology changes and real-time decision pathway precedents.

All this complex high-energy technoecosystem we are flying over is only a few decades old. A time-lapse conceptual movie squeezing the last 100 years into a minute would show explosive growth and incredibly fast evolution of technoecosystem components.

What we see here in southwestern U.S. is symptomatic of a synchronous explosion all around the world, an explosion of both the technoecosystem and the human population which it supports. A century ago the largely agrarian global technoecosystem ran mostly on human and animal labor, with a few higher energy steam locomotives and steamships providing distribution services. Who then could have predicted the massive, very high-energy, intricately integrated global technoecosystem of today, with cars, airplanes, tankers, superhighways, diesel ships and trains, pipelines, and space vehicles? Today's world atlas shows that almost every major city, ancient or modern, now has its jetport, attesting to world wide participation in life at the new macroscale.

Only very recently has technoecosystem manifested itself at the multikilometer scale. This extremely rapid evolution and diversification of technospecies and technoecosystem, and this accelerating growth of technomass are seen in the biological world only if we run the tape of geological history at 1 to 10 million times its actual speed. As in the biological world, all stages of technoecosystem and technospecies evolution coexist on this planet, although often only in local vestigial form.

As technoecosystem evolves, independent (uncontrolled) variables progressively become dependent (controlled) variables, in a form of technological zoom effect. Most environmental adjustments used to be worked out by nature's balancing. But now, as technoecosystem suddenly reaches global scale, ever larger-scale physical processes are appearing in our economic accounting system.

This recent dramatic exponential explosion of technoecosystem and human population seems to result directly from the discovery and opening up of what can be called the "fossil fuel energy niche". The fantastically rapid evolution of high power flow technoecosystem networks tapping newly exploitable concentrated potential energy reservoirs is closely analogous to the rapid population growth, evolution, and expansion of diversity which biological groups exhibit (over longer time periods) when new ecological niches open up to them through their own adaptations or through environmental change.

A great technological fossil fuel energy chain has grown from nothing in only two centuries: extraction, processing, and distribution systems for petroleum, coal, and natural gas; geological exploration systems; specially adapted technospecies; and vast urban and industrial consumption centers. The fossil fuel niche has brought to many millions of people the experience (previously limited to kings) of control over ever-larger energy flows, with the illusion it brings of eternal improvement, relative omnipotence, and near immortality. The secret is out, and now many more millions of people who still live in low-energy technoecosystems seek the same thrill, the same experience of physical well-being which high-energy technoecosystems seem to promise. As world per capita technoecosystem energy flow continues to grow, the global technoecosystem becomes increasingly dependent on the fossil fuel energy niche.

But there is a catch. The fossil fuel energy niche is limited, and it is closing almost as soon as it has opened (Hubbert, 1971). By now the details are familiar to most of us: oil and gas running out in a few decades, projected conversion to coal technology for only a century or two more, and continuously increasing energy costs and consequent decreasing net energy yield. Furthermore, these fossil materials are likely to have much greater value in future technoecosystems as chemical feedstocks than as fuel for irreversible, one-time-only burning.

We can define two kinds of energy niches. "Stock niches" are based on finite stores of energy, and provide the opportunity for a pulse of technoecosystem expansion and subsequent decay. The fossil fuel energy niche is a stock niche. In contrast, "flow niches" are based on relatively constant energy flows (which are, however, of limited size). Flow niches can support long-term relatively stable state after initial growth episodes.

On earth, the relatively constant energy flows are solar radiation, winds, tides, water power, and geothermal heat flow. Before humans began technoecosystem evolution, the biological world as a whole was exploiting a solar energy flow niche. However, with possibly a few local and temporary exceptions, technoecosystems seem to have never reached a steady state, even when they were based on solar energy flow through biological systems. Available flow niches have been progressively overexploited and then technologically transcended through new technoecosystem adaptations. It is uncertain how much longer this can continue. The pulse of fossil fuel energy niche technoecosystem growth may result in a larger human population and technoecosystem than can be supported in any terrestrial flow niche. Actually, such overgrowth may already have happened.

A great global research and development scramble is on to explore and open new energy niches, by inventorying environmental energy resources and developing new technoecosystem modules to exploit them. Any source which provides adequate net energy at competitive net energy ratio can contribute to global technoecosystem primary sector energy flow. An energy concentration and transport chain can be based on any suitable primary energy source (for instance by electrolytic hydrogen production for pipeline and cryogenic tanker distribution) and used to power any type of technoorganism anywhere. However, the efficiency of doing this varies between energy sources, so only one or two will probably predominate at any one time. While developing alternatives we must still maintain (at least for the present) the technoecosystem configurations which fossil fuel energy niche precedents have brought us.

Technoecosystem energy niches currently being explored range from the nuclear energy niche (with its configuration of fuel mining, processing, and transportation networks, powerplants, waste disposal facilities, and associated nuclear weapons plants) to the solar energy niche (with such proposed configurations as biomass harvesting for fuel synthesis, and solar power satellites [maybe manufactured from moon-mined metals] for broadcasting electricity to the planet's surface). Later chapters of this paper discuss present and proposed technoecosystem configurations for exploiting the geothermal energy niche.

Each alternative energy niche is currently being explored as a possible technoecosystem option to augment the present dominant and pervasive fossil fuel technoecosystem energy flow after an initial period of being subsidized by it. However, in not many decades it will be necessary to switch the global technoecosystem almost completely over to other energy niches. Each alternative energy niche entails its own unique mix of resource geometry, energy quality, and supply limits, its own environmental effects, and a unique technoecosystem configuration (which will affect what people do and how they live). There is as yet no integrated plan for global technoecosystem energy niche transfer; it is likely that such a change, if it takes place, will happen spontaneously and in unexpected ways, as in previous energy niche transfers, unless some planning is done in advance.

All energy niches being explored now, with the possible exception of the multi-faceted solar energy niche, are finite, stock niches. Even the geothermal energy niche, based on relatively constant heat flux from deep in the earth, is a stock niche at projected exploitation rates. The solar energy niche looks to many people (e.g.,Georgescu-Roegen, 1975*) like the ultimate energy niche for long-term survival and possible steady-state. It seems to promise a revolutionary transition from the current animal-like boom-and-bust fuel-seeking state of technoecosystem to an idealized large-scale plant-like autotrophic steady-state for the long run. But it remains to be shown that a large high-energy technoecosystem with projected billions of human operators can be based entirely on an energy chain which concentrates incoming solar radiation.[2]

Energy niche transition is never instantaneous. To technoecosystem dwellers it may be almost imperceptibly slow. As net energy ratio decreases and relative price increases for energy from fossil fuel technoecosystems, alternative energy niches with lower net energy ratios and higher prices become progressively more attractive and eventually competitive for some uses. If decisions were made solely on the basis of energy units, the energy niche transfer would take place when net energy ratios were equal. However, manipulation of the economic system through grants, tax advantages, and tariffs can subsidize development of a new niche which is not yet (and may never be) competitive in terms of net energy. Such subsidy can be useful for preparing a new technology in advance of the real need for it. But unfortunately such subsidies can become institutionalized through massive public relations investments and political maneuvering by the industrialists who control the energetically suboptimal technoecosystem, resulting in large, inefficient, but self-perpetuating energy systems which survive on liberal fossil fuel subsidy. The nuclear power industry may be an example of this.[3]

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[2]Gabel (1975*) attempted to show that a global technoecosystem flow niche exists which involves channeling many energy flow resources (solar, geothermal, winds, tides, etc.) through a "global energy utility". He concluded that it is possible now to build a global technoecosystem which will support all the world's humans at a high-energy high-quality standard of living. Unfortunately, he inventoried only gross energy stocks and flows, and did not include net energy, net energy ratios, or energy quality in his analysis.

[3]It appears that due to high costs of construction and industrial and regulatory infrastructure and tremendous initial research and development costs, the nuclear power technoecosystem has not yet yielded net energy, but has consumed (and continues to consume) vast amounts of fossil-fuel technoecosystem net energy resources. Whether the nuclear technoecosystem will ever manage to repay this subsidy during its extremely limited stock niche duration constraints is open to debate. In the meantime, high level radioactive wastes continue to pile up within the technoecosystem, with no long-term technoecosystem strategy or configuration for permanent storage.

Conversion of nuclear technoecosystem to breeder-reactor mode is now planned in order to greatly extend the time-size limits of the nuclear energy niche. Regrettably, the breeder reactor technoecosystem configuration is based on transformation of technoecosystem stocks of non-fissionable uranium 238 into thousands of tons of fissionable plutonium -- a substance noted for its incredible toxicity and the ease with which it can be used to fabricate nuclear explosives. Transportation, storage, and

There is a close parallel between the evolution of the technoecosystem (from its biological origins, as chronicled by archaeology) and the evolution of bioecosystems and their biospecies components (as revealed by paleontology and evolutionary paleoecology). In both, new niches are progressively opened by evolution of new configurations and by environmental change, and expansions of populations and diversity occur subsequently.

Tracing the history of technoecosystem we see these rough stages: 1) pre-man as bioecosystem component, 2) early man using simple tools within bioecosystem, 3) agriculture and husbandry, making possible relatively rapid technological and social evolution, 4) industrialization based largely on fossil fuel niche, resulting in great acceleration of evolution of mechanical and inorganic technoecosystem sectors, and 5) a possible new age of creative global technoecosystem design. In each past case, certain core innovations opened a major new niche, making possible a new growth of technoecosystem size and diversity and a new burst of human population growth. This pattern is reminiscent of the progressive, irreversible evolution of life (at a rate millions of times slower) through a succession of global bioecosystem revolutions (Cloud, 1974*). And it is also similar to ecosystem succession on a much shorter time scale when a new habitat is opened, or to population growth of a species when a successful genetic innovation occurs.

Succession of technoecosystem configuration is seen not only on the global macroevolution scale but also on spatially and temporally smaller scales. For instance, in copper mining the old underground tunneling technoecosystem for mining high-grade veins has given way to massive open pit mining of low-grade ore by giant machinery. In some open pit mines, in fact, the relatively minuscule tunnel timbers, relics of an obsolete technoecosystem, are exposed on the pit walls. Fossil fuel extraction, too, has progressed from high-grade near-surface easy-to-find deposits to ever deeper, better hidden, and often lower-grade reserves. By analogy, geothermal resources exploitation will probably progress from shallow to deep, from hot to cooler, from chemically pure to impure fluids, with concomitant succession of technoecosystem configurations.

The clear trend in technoecosystem succession is for the highest-grade lowest-entropy resources to be used up first. Any excess energy feeds inefficiency or waste, system maintenance at high-energy level, or subsidy of system evolution for future lower grade exploitation. Once a stock niche has been exploited for a while it cannot be exploited at the same energy return again, using the same technology. Either technology must evolve or net energy ratio must decrease. The fossil fuel niche, for instance, would be difficult or impossible to open up a second time if present technoecosystems were destroyed; reserves which remain are deeper and harder to find and extract than were original fuel reserves.

We are all familiar with the symptoms of expansion when a new niche is discovered: diversification of technoorganisms and human roles, expansion of wealth and human populations, rapid self-amplifying technological acceleration, discovery of countless new possibilities and unexpected but profitable subniches. We in the developed nations have experienced these symptoms for several generations.

Numerous mechanisms maintain the momentum of this expansion. People become advocates for their own specialized technoecosystem subset. Technological innovation becomes institutionalized, as in patent systems and research agencies; inventors and applied research scientists consciously seek new ways to expand and improve technoecosystem and its components. And new developments can spread rapidly either through transmission of information or through global transfer of parts, technoorganisms, or even whole technoecosystems (the present wholesale transfer of technoecosystem subsets to the Middle East is an excellent example).

However, it is important to remember that new niches are finite, that initially accelerating growth cannot continue forever. As the limits of a stock energy niche are reached and the niche begins to close, a whole new set of symptoms appears. These can be seen at small scale in the decay of boom towns, and analogous phenomena occur when environmental change closes a biospecies niche. Growth is starved to a stop as net energy ratio declines and further expansion becomes unprofitable. The fluid era of excess wealth, many choices, and easy waste through evolutionary frills comes to an end. The structural whims of opulent expansion freeze to become the rigid framework for a less wealthy future because there is no longer enough excess energy to change them. The structures so joyfully built in

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3, Cont.
multi-step processing of large quantities of plutonium would be an integral part of the proposed "plutonium economy". Therefore extraordinary, nightmarish technoecosystem configurations and repressive social institutions would probably be required for attempted prevention of accidents and nuclear weapons proliferation among nations and terrorist groups.

A single accident or successful sabotage might easily wipe out and befoul the net energy profit of many years of power output. Several mishaps could drastically curtail the global technoecosystem niche. Furthermore, merely a few decades of power production (probably for simple maintenance or growth of present consumer technoecosystems, rather than for transfer to a flow niche) would irreversibly commit the global technoecosystem to keeping all the large quantities of plutonium and high level wastes absolutely separate from the biosphere. They would have to be kept under complete control (i.e. within technoecosystem) for <u>thousands of centuries</u>. Yet high-energy technoecosystems have so far existed on this planet for less than <u>one</u> century. The Committee of Inquiry on The Plutonium Economy (1975*) has carefully reviewed these concerns.

expansion phase become the pathways for entropy increase and decay. Cutbacks, diversity decreases, and abandonment of maladapted, inefficient technospecies occur. Human population carrying capacity and material quality of life decline, with resultant migrations or deaths. Frantic efforts to find a new energy niche may be made. Pollution (which cannot be disposed of because of energy scarcity), social disorders, and activation of military technoecosystems can help bring the niche to a quick closing if a new replacement niche is not found. The fossils left after a niche ends include abandoned technoecosystem parts and low-energy-content remnants of used-up or polluted potential energy reservoirs.

The global fossil fuel technoecosystem is clearly not now in such a state of rapid decline. The petroleum energy sub-niche will probably be closing in a few decades (it already is closing in some areas of the world where reservoirs have been depleted and exploitation has successionally moved to greater depths at other locations), but coal reserves promise a longer (though probably less profitable) era of potential technoecosystem survival. However, in order to avoid eventual technoecosystem catastrophes, fossil fuel technoecosystem should probably be used to subsidize development of new configurations to exploit some new, hopefully longer-lasting high-energy niche.

Some questions to ask about a possible new energy niche are: Will it survive? Will it compete against other niches? How long will it last? What quality of life does it give to humans? How will it affect natural energy flow systems, bioecosystems, and existing technoecosystems? If it is a limited, stock niche, will it permit smooth transition to another energy niche? Will it trigger exponential growth and overshoot its limits? Do we really want it? If not, can we prevent it from starting self-accelerated growth?

Until now, energy niches have been exploited to the hilt without much planning. It appears that from now on, as technoecosystem-grown-huge exploits one planetary energy system or reservoir after another, some long-range macroscale planning will be necessary in order to have any chance of long-term technoecosystem (and human) survivâl. We have demonstrated time and again that any technoecosystem niche's limits can be overstepped in a very short time after first exploitation. Negative feedback mechanisms to rationally limit technoecosystem (and human population) size are badly needed now, while new, unexploited niches are still (we hope) available.

13. Military Technoecosystems

> Very soon, if all goes according to plan, it will be possible to think of the entire world as one big pinball machine. And when that day arrives it will be possible for someone to think about plugging it in.
>
> -- Phil Stanford (1975*, p. 40)

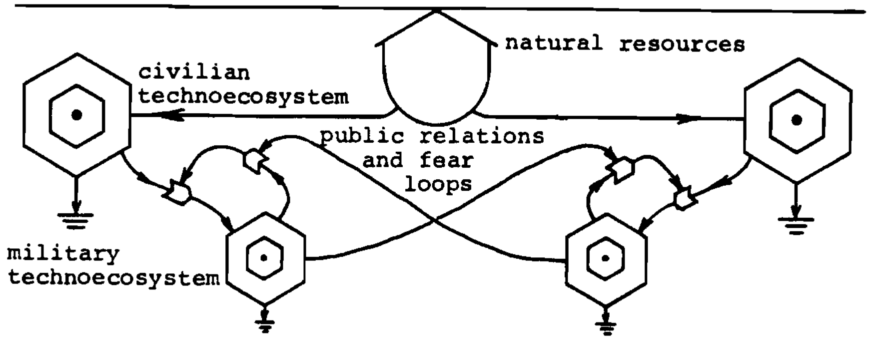
Flying over the vast spaces of the American Southwest, we see components of still another technoecosystem subset, the military sector. We pass over air bases and army bases (each with its specially adapted technoecosystem), a desert warfare proving ground, a storage area for hundreds of obsolete aircraft, huge uninhabited desert areas used for aerial gunnery practice, and (if we know where to look) the inconspicuous tops of silos where intercontinental ballistic missiles tipped with nuclear warheads wait silently. We are reminded that high-ranking military men, too, are conscious macroscale strategists, that they are the pragmatic designers and commanders (through a rigidly hierarchical social system) of a highly specialized and purposeful military technoecosystem of global extent.

Technoecosystem is neutral; it has great potential not only for life support, but also for destruction. Throughout history humans have sporadically steered one part of technoecosystem to combat another part and attempt to destroy its energy flows and storages, its control loops, its structures, and its human operators. Such clashes have arisen between rival technoecosystem managers over technoecosystem territorial disputes, over different philosophies of technoecosystem management, and over limited stocks of high-energy-potential natural resources. Specialized military technoecosystems and technoecosystem components have evolved for purposes of: 1) destroying competing technoecosystems or social hierarchies, or bringing them under control of the attacker (offense), 2) protecting local social-economic hierarchy and its control over local technoecosystem (politics), and 3) protecting a technoecosystem from technoecosystem competitors which threaten military destruction, maintaining control area boundaries, eliminating noise from energy-materials-information transport channels, and protecting high-potential-energy storages (defense).

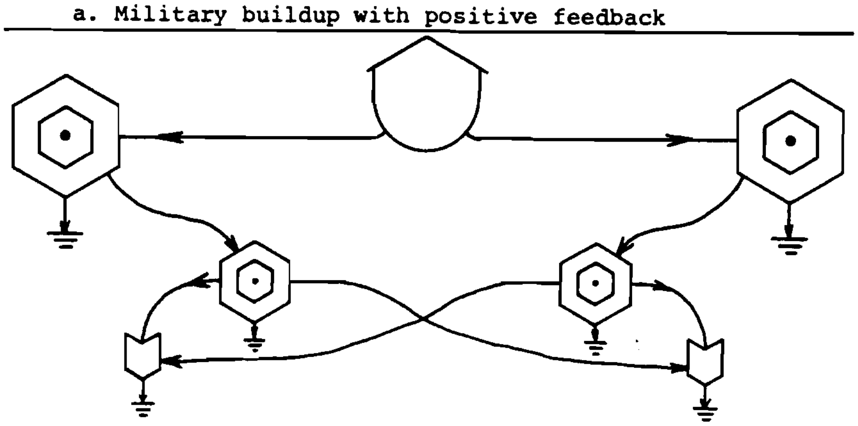
Military technoecosystems are analogous to the top carnivores in bioecological food chains. They utilize the highest-evolved technology and represent the cutting edge of technoecosystem innovation. And they contain the highest energy concentrations to be found anywhere in technoecosystem. Since military technoecosystem role is to rearrange macroscale technoecosystem patterns by disrupting them, and alternatively to protect them from such modification, only the highest technology and energy values will suffice.

The history of accelerating military technoecosystem and technoorganism evolution is familiar to us all. The same evolutionary trends toward higher energy flow, greater speed, increased cybernation and automation, and higher per capita technomass seen in civilian technoecosystems are also manifested by military technoecosystems. But military technoecosystems have always evolved much faster than domestic technoecosystems, and at their expense.

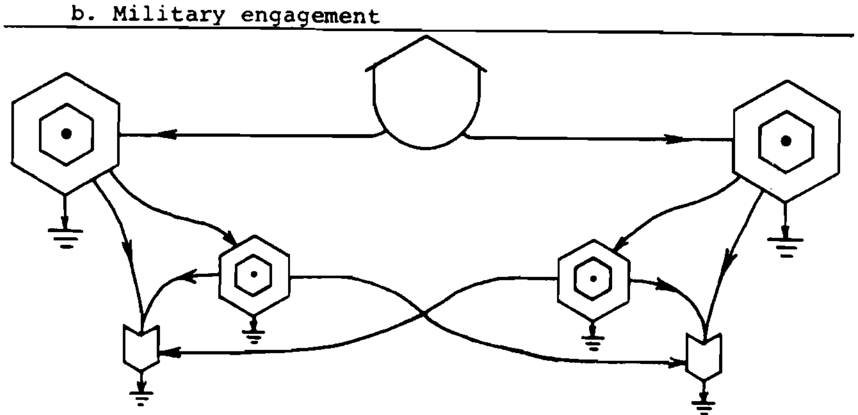
Even in peaceful times, military technoecosystem evolution and growth continue. Boulding (1968*) pointed out that a classical positive (self-enhancing) feedback mechanism operates to preserve this trend. Buildup of one technoecosystem's military sector triggers fear in the competitor and enhances ability of the competitor's military sector to raise funds for a reciprocal military buildup (Fig. 5-a). In similar fashion, costly military technology refinement in one technoecosystem forces equivalent or greater refinement in the other.



a. Military buildup with positive feedback



b. Military engagement



c. Total war

Figure 5. Macroscale roles of military technoecosystems

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Today, around the world, we see the results of centuries of this kind of military technoecosystem growth, competition, and evolution. As great fossil fuel wealth has been spent, military technoecosystems have grown and evolved at a rapidly accelerating rate at the expense of civilian life support system possibilities.

In the last 70 years, and especially the last 30, we have witnessed a spectacular ever-accelerating flux of military technological innovations and a rapid succession of new military technoecosystem configurations. Diversity and numbers of specialized military technospecies for defense and offense in different environments and at different energy levels have skyrocketed: many thousands of specialized aircraft, nuclear submarines, floating fortresses with aircraft technoorganisms aboard, all types of drones and missiles, orbiting scanners. Advanced technology for speed, computing ability and real-time cybernation, communications, remote sensing, technoecosystem destruction, and human death engineering has progressed to an amazing level of sophistication. Still more advanced systems are in the works: laser cannons, killer satellites, unmanned aircraft, cruise missiles (Stanford, 1975*). Destruction investment ratio (destructive effect per dollar spent) has become very large.

There is no end to military evolution and growth in sight. Brushfire wars in Southeast Asia, Africa, and the Middle East give us a glimpse of some of the capabilities of modern military technoecosystems. A booming global weapons industry offers sophisticated technoorganisms and whole technoecosystem complexes to any nation which can afford them on its own or through grants from the high-energy industrial countries. Military technoecosystems have now reached such a state of technological and cybernetic perfection that thousands of discrete missile-technoorganism-delivered positive-feedback (uncontrolled) high-energy nuclear chain reactions can be effortlessly placed in just a few minutes (any few minutes) at any chosen site in much of the world, with great spatial accuracy, and with precisely calibrated destructive effect. Indeed, as Stanford (1975*) described it, the world has become like a pinball machine for the major powers to manipulate (Fig. 5-b, c).

Although military technoecosystems are quite fascinating to observe, they are unfortunately a very large energy drain which keeps the global technoecosystem from realizing its fullest life support capabilities, even in peacetime. A significant fraction of global technoecosystem energy flow pours into the military sector. One official estimate (U.S. Bureau of the Census, 1975*) of military sector cost is roughly six percent of world GNP (and thus of world energy flow, if constant energy-dollar ratio is assumed). And a private group estimates current world military spending as $300 billion per year (New York Times News Service, March 1, 1976).

However, these figures probably understate the magnitude of military effect on the worldwide energy economy because military technoecosystems use the highest technology and thus the highest energy concentrations available (more energy leverage per dollar spent). Also, it is likely that many expenditures closely related to military technoecosystem operation are not included in these numbers. Furthermore, most of global technoecosystem energy flow goes toward maintenance of old structure, and only a small fraction is potentially available for technoecosystem growth and for evolution of new configurations. Global military expenditure cuts deeply into this already small technoecosystem improvement fund. And the military sector monopolizes the lion's share of high-technology research and development.

Paradoxically, developing countries of Africa, Asia, and Latin America, many of which desperately need life-support technoecosystem growth and improvement simply to feed and house their rapidly expanding populations, are now devoting their resources to the greatest relative increase of military spending in the world (ibid.). Even the planet's lowest-energy, low-technology technoecosystems are milked of "excess" kilocalories to exchange for a few imported high-energy high-technology military technoorganisms and their fuel and support systems.

Technoecosystem potential ranges from utopian landscapes to bombed-out radioactive wastelands. It is up to the technoecosystem dwellers, the people of the world, whether their finite technoecosystem energy wealth flows into universities, entertainment, and structures to support new, rich lifestyles, or into bomber exhausts and continued proliferation of nuclear bombs with global destruction capability.

When a technoecosystem niche is a finite stock niche, and its limits are known to be near, then military technoecosystem growth and use may be inevitable, as a competitive advantage amplifier. Perhaps it is only the myth of continued economic growth possibilities which maintains relative peace at present. Perhaps only with current excess availability of rich fossil energies can such tremendous life-supporting and life-destroying facilities coexist. Urgently needed now is something to defuse the global military escalation positive feedback mechanism. Maybe global cooperation to develop a stable high-energy flow niche technoecosystem configuration for everyone (combined with population stabilizing measures) can serve this purpose. The technoecological viewpoint may facilitate such a reorientation.

Macroscale is the level of military strategy, but it is also the level of any potential comprehensive peace strategy which will succeed. High technology and concentrated energy diverted away from military technoecosystems would have a very high amplifier action in bringing the global technoecosystem to a higher level of life support capability and in steering technoecosystem toward a more stable flow-type energy niche. If military systems became obsolete, very high-energy high-technology technoecosystems would still be needed, but their purpose would be different: to maximize technoecosystem productivity and stability for the benefit of world humanity.

Look past the destructive role of military technoecosystems to see the vast capability of producing potentially life-supporting technological innovations which they demonstrate: global cybernation and information processing networks, global application of systems science, rapid comprehensive design and evolution of technoorganisms and technoecosystems for specific purposes and environments. Highest technology could be designed directly for life-support systems, rather than gradually filtering down from secret military uses. And high-speed jets, now allocated chiefly to military patrols, could be more beneficially used as vehicles for advanced macrovision experience by technoecologists and their students.

14. Arid Lands Technoecosystems

> The arid lands have always won. They have become crypts for man's ancient energy systems.
>
> -- Charles Bowden (1975, p. 1)

Everywhere we fly in the arid Southwest we see evidences of the fabulous wealth of its modern technoecosystem. Nowhere else in the arid parts of the world is such a large, highly-evolved, high-energy technoecosystem to be found. Thus, southwestern U.S. is the ideal place to study the ultimate development possibilities (and limits) of arid lands technoecosystems where surplus highly-concentrated energy (e.g., fossil fuels) is available for several decades. It is possible that no other large desert region will ever reach such a high-energy level of cumulative technoecosystem development, if no large energy niche is found to successfully replace the present fossil fuel energy niche.

Scattered profusely across the desert are manifestations of the new high-energy fossil fuel energy niche technoecosystem: cities, railroads, agricultural areas, powerplants. And here and there we see traces of abandoned parts of ancient low-energy technoecosystems: canals, fields, cliff dwellings. Water is scarce in arid lands, by definition, and the remarkable specialized adaptations of both ancient and modern arid lands technoecosystems to this scarcity are strikingly visible from the air. Waterworks of all types (dams, pumps, pipelines, canals, reservoirs, aqueducts, desalting plants) to store and transport this precious fluid are inseparably woven into the fabric of these technoecosystems.

Sharply-bounded green checkerboard patchworks of agricultural land in the middle of barren, brown, extremely arid valleys are clear signs that water in unprecedented vast quantities is being pumped from underground or from a river system and carefully spread over the surface to match evapotranspiration potential made high by low humidity and intense sunlight. And misty plumes rising from powerplant cooling towers, and greenery and swimming pools in desert cities are further evidence of water channeling, visible from the air.

Careful adaptation of desert technoecosystem components and networks to water scarcity is closely analogous to the adaptation of animal and plant physiology and distribution patterns to arid conditions. Water is a prime determinant of technoecosystem and biological system configurations because it has energy value to these systems. And its scarcity in arid lands compounds this energy worth.[4]

Water has many kinds of energy value. H. T. Odum (1970*) listed three forms of potential energy offered by water to an energy system:

1) Gravitational potential energy. It results from solar-powered atmospheric pumping of water to elevations higher than base level (generally the ocean). This form of water energy drives natural fluvial and geomorphic systems, as well as technoecosystem components like canals, siphons, and hydropower stations.

2) Energy value as a chemical fuel for washing, dilution, and chemical solution and reaction. This energy form results from solar-powered atmospheric distillation through the evaporation-precipitation thermodynamic cycle. It drives natural processes like plant root osmotic water intake, and could be used to run an osmosis engine across a boundary between fresh and saline water or between water and dry soil.

3) Energy value as a photosynthesis amplifier, where water is a limiting factor and sunlight is in excess. In this case, the energy value of water is simply equal to the additional net primary plant productivity which it makes possible. Odum does not mention it, but we might also assign energy value to water for animal metabolism which it makes possible.

4Conversely, water also has energy cost to these systems -- for concentration, purification, transport, and storage (Fairchild, 1973). Energy cost of water, like its energy value, is especially high in arid lands. Survival of biological systems and technoecosystems in the desert requires either hydro-energy profit (excess of water's energy value over its energy cost), or outside energy subsidy to overcome hydro-energy loss.

Odum's sample calculations show that each of these three energy components is roughly an order of magnitude larger than the previous one. Thus, Odum concluded, water has by far the greatest value as a concentrated fuel when used for irrigation.

There are, however, other energy values of water:

4) Although I cannot think of an engine that can run on it, water has energy value in arid lands simply because it is unexpected; its mere presence in a specific location in a contrastingly dry region represents information and thus lower entropy.

5) More importantly, water has energy value due to the low humidity of desert air (which results from solar-powered atmospheric circulation patterns and consequent thermodynamic dehumidification). Vapor pressure differential drives water flow and evapotranspiration in plants and soil, cools air in natural and technoecosystem microenvironments, and can run a heat engine simply on the difference between wet bulb and dry bulb temperatures (which is part of the thermodynamic cycle of powerplants with evaporative cooling towers). Water can be considered a fuel for thermal powerplants because its use in cooling towers dramatically increases energy conversion efficiency. Burning at the hot end and evaporation at the cool end of a thermodynamic cycle are both responsible for making a heat engine do work.

6) And finally, water has energy value as an amplifier of industrial processes, especially where water is a limiting factor. Water's many unique properties make it vital for countless industrial processes, including human life support, chemical industries, recreation, and air conditioning. This role of water is directly comparable to its rôle as photosynthesis amplifier. In both cases water input makes energy flow through complex systems possible. For biological systems this means flow of solar power through biochemical and ecological energy chains. And for technoecosystem it means macroscale flow of concentrated fuels, and processing of other materials which have energy flow amplifying ability.

Geothermal fluids contain still another type of potential energy: thermal energy. A geothermal fluid can contain enough heat to pump itself, produce electricity, and distill itself for use as industrial or photosynthesis amplifier. Later chapters discuss this more fully.

Water in arid lands can be considered a concentrated fuel not only because of its energetic usefulness but also because of its energetic origins. It is the relatively small, concentrated, local energetic residual of vast energy flows and thermodynamic cycles in the global atmospheric-hydrospheric system. One calorie of energy value in water represents many calories of sunlight expended to drive this system for water evaporation, transport, condensation, and delivery.

H. T. Odum (1975) presented a brief analysis of water and energy flow in the arid land technoecosystem-environment complex of Arizona. One of his major points is that water, a fuel with high energy value, may be better used for agriculture than for supporting greater urban populations. His explanation is that agricultural products can be exported to pay for concentrated fuel imports, whereas urban centers are non-productive.

Unfortunately, he apparently does not consider the energy value of water as industrial energy flow amplifier, which may actually be greater than the photosynthesis amplifier value of water in arid lands, when energy quality is considered. Even with no agricultural production it is likely that the Southwestern technoecosystem would be supported by fossil fuel energy subsidy from the national and global technoecosystems simply for housing people in the favorable climate and for operating non-agricultural industries.

Some agriculture may be better allocated (in energy terms) to more humid regions, where water is made more freely available by natural energy flows, so energy cost of water delivery and energy opportunity cost of foregone industrial processes are lower. However, as Fischer (1973*) pointed out, water resources are not allocated on the basis of energy value and costs, but on the basis of money value and costs, which can be distorted by political pressures. Artificially low water prices (below energy cost of delivery and industrial energy flow foregone) offered to agricultural users encourage profligate water use for energetically unprofitable crops. This represents an energy and water subsidy from the local and national technoecosystems.

Energy and water subsidies are common in high-energy arid lands technoecosystems (e.g., water-rich gardens and lawns, or lakes for recreation), and there is nothing strictly wrong with them as long as they can be afforded and as long as the technoecosystem niche is not excessively taxed. In fact, an apparent subsidy in one part of technoecosystem may pay for itself by increasing energy flow or enjoyment of life elsewhere in the system.

Specific technological inventions and adaptations of technoecosystems and their components to aridity are a fascinating subject in themselves. A catalog of them would show great diversity of items ranging from microscale to macroscale, from low-energy to high-energy. There are systems and components for diverting natural water flows (in the air and above and below ground), and for water pumping, storage, transportation, and distribution. And there are countless energy conversion systems which use water as a fuel, as a medium, and as an amplifier of energy flows.

Since water is so vital to energy flows in arid lands technoecosystems, we can use the term "water niche" to refer to all the possible survivable technoecosystem configurations based on water as a limiting factor. There are two kinds of water niches in arid lands: flow niches (based on relatively constant water flows like perennial rivers or rainfall over long timespans) and stock niches (based on groundwater). In the Southwest, the flow niches are filled (Colorado River, for instance, is exploited to the hilt), and groundwater stock niches, like fossil fuel stock niches, are being acceleratingly pumped toward rapid closure. As groundwater is depleted and fossil fuel subsidies become more costly in future decades, we may expect these arid lands technoecosystems to continue their successional process, with progressive technoecosystem configuration change, and with evolution of new components and patterns and abandonment of old ones.

In speaking of the succession of arid lands technoecosystems, it is important to note that aridity is not an independent variable. The technoecosystem itself can inadvertently enhance environmental aridity via numerous mechanisms (e.g., soil salination, soil erosion and gullying due to overgrazing, or even change of atmospheric circulation patterns by surficial albedo changes), as documented by Sherbrooke and Paylore (1973*) and Paylore (1976*). Such desertification trends can narrow and even close a technoecosystem niche. History is full of examples.

15. Future of Technoecology

Technoecology, this conceptual framework I have just outlined, is not just an interesting way of looking at the world. It is pregnant with possibilities. It hints at an objective new basis for comprehensive analysis of the global human situation. And it may have numerous practical applications at all scales, from local to universal. In this chapter I have tried to suggest some of the potential excitement, poetry, and implications of the technoecological viewpoint. The chapters which follow explore the possibilities of technoecology in greater depth by using its insights to look at geothermal technoecosystems in arid lands.

Technoecology is a cognitive filter which reveals a different world. Macrovision, the direct experience which gives technoecology its intuitive depth, can become a habit, a perpetual mode of perception, even when one is involved in daily life at the surface. The technoecological vocabulary proposed in this paper can help solidify macrovision insights on the intellectual level. The use of these words can automatically lever perception, thinking, and action to the macroscale level. And it can help make macroscale systems more easily and intuitively comprehensible not only for scientists, but also for the general public.

Technoecology demands a holistic viewpoint. It takes one beyond the level of specialized, local, short-term profit seeking to a level of perception of whole systems evolving through macro-time. The rational design of a global technoecosystem which will work, survive, and maximize enjoyment cannot begin with increased specialization and narrowness of focus. Instead, it must start with a large jump upward to broad overview, in order to see what detailed knowledge and actions are needed and where they fit into the whole system. The purpose of technoecology is to facilitate such a jump. Technoecology may be a useful new paradigm for designing new global industrial strategies with maximum probability of success.

As I have sketched it, technoecology is a multi-disciplinary, almost omnidisciplinary field. Principles and observations from many traditional branches of knowledge can be synthesized into new insights and strategies within the technoecological framework. Numerous disciplines lucidly relevant to technoecology have been touched on in this paper: bioecology, systems and industrial engineering, ecological anthropology, cybernetics, history, economics, archaeology, bionics, geography, exobiology, paleontology, thermodynamics, evolutionary paleoecology, general systems theory, sociology, and diverse technological and design specialties.

In technoecology I am proposing a new idea matrix. Technoecological concepts and vocabulary are still in a very fluid state. If they are found to be useful they will solidify, and knowledge and energy flows will crystallize about them. There is some danger of misanalogies and misunderstandings occurring in early stages of the development of technoecology. But introducing technoecological concepts is worth the risk if they will be in the hands of humane, rational, intelligent men. Technoecology, like technoecosystem itself, is a neutral medium. It can be used to design, observe, and augment an unstable, omnimilitarized, polluted, and stressful world of fleeting human misery, or a secure, peaceful, and supremely enjoyable global utopia. I have tried to give technoecology its initial boost in the second, more humanistic direction.

Our global technoecosystem is currently far from utopia, but in spite of our frequently blind and inefficient management of its machinery, it has produced some remarkable results. Handler (1975*) pointed out that one billion humans now live in rich nations with average per capita GNP of $2,700 and technoecosystem energy consumption of 5,000 kilograms coal equivalent. This population of those who enjoy a high standard of living is equal to total <u>world</u> human population in 1850, only about six generations ago. The experience of the world's rich minority hints at the possibilities for enjoyment of life when technoecosystem takes over energy flow drudgery and lets men discover new mental patterns.

But there are numerous hurdles in the way of building such a high-energy technoecosystem for all the people alive in the world. For one thing, the present world population count is a huge number -- 4 billion, the approximate number of seconds in 127 years. And this population is scheduled to double (at 2% per year) in only 35 years. This means that the global technoecosystem must double in size in the same time period simply to stay even with population growth.

It is clear, however, that there are limits to the extent that technoecosystem can grow. As we discussed earlier, the fossil fuel energy niche is running its course and no other energy niche of equivalent size and of similar potential duration has yet been proven to exist. Diminishing mineral resource stocks further define the limits of the industrial technoecosystem niche. And serious disruption of environmental systems, as lucidly outlined by Handler (1975*), Holdren and Erlich (1974*), Wittaker and Likens (1975*), and many others, suggests that the limits of the global technoecosystem niche (at least with current technology and management strategies) are near, if not already surpassed.

As population continues to grow, our position on a finite technoecosystem niche production possibilities surface must shift toward shorter duration or lower quality of life or both. Unless a new, larger, flow-type energy niche is assured (which apparently is not the case), the obvious strategy for maximum quality and duration of human life is to stabilize or even decrease human population. On this point many concerned observers, including those just mentioned by name, agree. And if population does manage to stabilize or diminish, and a new, larger technoecosystem niche should open up, then nothing will be lost; men will still have the choice between greater wealth or more companionship. Our past experience indicates that there is no difficulty in quickly obtaining enough new humans to operate and overfill any new technoecosystem.

Over the centuries we have unconsciously combined countless specialized parts into a macroscale man-made ecosystem. Perhaps it is now time for us to consciously design and manage it like one. We are living in a span of history in which whole new technoecosystems must be engineered and constructed to replace and augment old ones, and we might as well become aware of what we are actually doing. Technoecology may help bring our aggregate human goals to the level of popular consciousness, and enable us to better focus our energies toward their achievement.

We can have any world we want and can imagine within physical technoecosystem niche constraints. Technoecology can free us from old macroscale habits. It can free us to be creative at the macroscale, to explore the possibilities of the extremely pliable technoecosystem macro-medium.

News media reverberate with stories about technoecosystem malfunctions, military technoecosystem buildups and activations, new technoecosystem configurations, and things macrotribal leaders have just said. But the real news, invisible to the media but obvious from the air and from space, is that there is intelligent life on earth, and that a new high-energy technoecosystem has just come into existence.

On planets with intelligent life and technoecosystems, a critical threshold may eventually be reached where continued survival is dependent on a phase transition in technoecosystem operational strategy. This crucial transition from unconscious to conscious technoecosystem design and management can be called the technoecological revolution. It is starting now.

II. EARTH CYCLES

Under brilliant sun we dip a wing to view more of the deep desert panorama. The geological landscape below manifests in many ways the diverse geothermal and solar energy flows which have molded it at their interface.

Folded metamorphic rocks silently remind us of their one-time presence deep in the earth, where high pressures and temperatures transformed their minerals and where regional stresses folded them as intricately as batter. Gray granitic batholiths, frozen remnants of ancient magmas, speak of vast geothermal heat energy conducted to the surface and radiated to space. Volcanic rocks are quiet evidence of violent eruptions long ago. And porphyry copper deposits, now being mined in huge open pits by highly-coordinated fleets of ore truck technoorganisms (they look like scurrying ants from these heights), manifest the operation of hydrothermal convection systems far below the surface in the past.

Passing beyond these lithological details to a deeper level of geological perception, we see evidence of the workings of the macroscale macro-time planetary engine which makes the continents dance about the globe at 1 to 10 centimeters per year. In unifying theories of continental drift and plate tectonics we find mechanisms for heat concentration, for generation of magmas and volcanoes, for creation of tectonic stresses and movements of rock masses at many scales. Here we find the source of the tectonic uplift which has exposed once-deep rocks to solar-driven weathering and erosion processes to produce the jagged ranges and sediment-filled basins we see in vivid three dimensions today. Here, too, we discover the mechanisms responsible for shape and position geometries of continents and mountain ranges, which profoundly influence the climatic characteristics and even the location of the desert we are exploring.

All these diverse geologic motions and all the orderly transformations, structures, and patterns they produce are driven by flows of geothermal heat outward through the earth's surface to space. It is this same heat which men seek to divert from earth cycles into geothermal technoecosystems.

1. Cosmic Heat

Most papers on geothermal energy start with the premise that there is much heat in the ground waiting to be tapped by "man." They proceed immediately thereafter to look at various technological structures and innovations for extracting and utilizing the heat as fast as possible.

But this subsurface heat energy has a long and venerable history. It has not been idle for the 4.6 billion years of earth history before the sudden appearance of energy-hungry technoecosystems. Understanding the origins of this heat and its myriad roles in geological processes can give us insight into 1) the present global distribution of prime geothermal resources, 2) the properties of different kinds of geothermal reservoirs (each with its unique technoecosystem requirements), 3) the ultimate limits and parameters of the geothermal niche, and 4) the possible consequences of channeling this heat from geological systems to technoecosystems.

That there is heat in the earth has been known to men for centuries; natural hot springs and spectacular volcanic displays were ample proof, and experience of heat in deep mines was supporting evidence. Let us follow this geothermal heat back to its astrophysical origins long before life on earth began.

Most of the near-surface heat flow, an estimated 80 percent (Kappelmeyer and Haenel, 1974), is heat released by radioactive decay of unstable elements, chiefly uranium and thorium. Atoms are fossils from the high-energy world of the interiors of stars (Wheeler, 1974*), where nuclear reactions, transmutations, and equilibria occur in much the same way that chemical reactions occur on planets like ours. Formation of light elements into heavier elements releases energy and is therefore spontaneous up to iron 56. But formation of elements heavier than Fe56 (including uranium and thorium) requires addition of outside energy. One hypothesis for heavy element nucleosynthesis (Arnett et al, 1968*) is that the only source of such extra energy is gravitational potential energy and that heavy elements form during gravitational collapse in supernova explosions. Another hypothesis (Clayton, 1968*) is that small traces of heavy nuclei are formed as byproducts of spontaneous exoergic reactions among light nuclei; this mechanism is analogous to energy concentration in many types of inorganic systems, biological systems, and technoecosystems.

Whether the nuclear structure of heavy elements represents stored stellar gravitational potential energy or stored stellar nuclear fusion energy, it is clear that stable heavy elements we find on earth are like the ashes, and radioactive elements are like the last embers of ancient stellar fires. Gradual radioactive decay time-releases this energy and slowly heats the earth. Geothermal technoecosystems, therefore, tap 80 percent old star fire and radiate it back to space.

The other fifth of geothermal heat flow is stored heat left from the formation of the earth; most of it is probably transformed from gravitational potential energy (Jacobs, Russell, and Wilson, 1974*). So if the supernova hypothesis for heavy element nucleosynthesis is correct, geothermal energy is largely gravitational potential energy transformed and stored via two pathways: planetary accretion (stored as heat), and supernova explosion (stored as nuclear structure). Minor primary heat sources are tidal friction (2 to 4 percent) and possible interstellar neutrino absorption (Kappelmeyer and Haenel, 1974). Secondary heat sources include friction of lithospheric plate motions (including earthquakes) and oxidation of sulfide minerals.

Direct and indirect effects of geothermal heat are ubiquitous in geologic systems. This heat drives the grand, majestic, macroscale earth cycles of continental drift and plate tectonics, and drives or influences countless fascinating, intricate microscale cycles. Earth is a thermodynamic energy system, and geothermal heat is responsible for diverse motions, pressure-temperature changes, and chemical and mineralogical transformations in the lithosphere. Convective heat engine mass transport produces orderly geometries and chemistries at various scales. Scarce elements are concentrated, ordered, and geochemically recycled, at least partly under geothermal influence. Rock masses are uplifted as primary energy input to fluvial geomorphic processes which carve the landscape. Even such phenomena as earthquakes (release of stored elastic stress), tsunamis (produced by earthquakes), and landslides (release of stored gravitational potential energy) are indirect results of geothermally-powered earth cycles. More direct manifestations are continents, mountains, volcanoes, geysers, fumaroles, hot springs, and many mineral deposits.

Geological systems are complex, hierarchical energy concentration systems quite analogous to biological systems and technoecosystems. Similar energy laws apply, although complexity, materials, and information mechanisms differ. Perhaps we could call geological systems "geoecosystems". But the biological analogy is not nearly so close for geological systems as for industrial systems. Figure 6 (next page) is an energy circuit diagram showing geological cycles in conceptually simplified form.

2. Concentration

Heat storage of this planet is large. For only the upper 10 kilometers of the crust, heat content (over 15^oC) is estimated to be 10^{24} BTU = 2.5×10^{26} calories (cal) = 3×10^{20} kilowatt-hours (kwh), or about 2,000 times heat content of world coal reserves (Berman, 1975*). This estimate does not consider higher energy quality of coal, however.

Heat flow rate of the planet is large, too. Total geothermal heat flow at the surface is estimated to be 2.8×10^{14} kwh/yr = 3.2×10^7 Mwt (Steinhart and Steinhart, 1974*). This is large, but it is only 5.6 times present global human and technoecosystem energy flow of 5.0×10^{13} kwh/yr = 5.7×10^6 Mw, again not considering energy quality (ibid.). And it is less than one five thousandth of total solar radiation striking the atmosphere, or 1.6×10^{18} kwh/yr = 1.8×10^{11} Mw (Sellers, 1965*), and less than one two thousandth of total average solar radiation striking the surface, or 6.6×10^{17} kwh/yr = 7.5×10^{10} Mw (Kappelmeyer and Haenel, 1974). Clearly, temperature at the earth's surface is almost totally controlled by solar radiation balance. In fact, Kappelmeyer and Haenel (1974) calculate that the average surface temperature rise due to normal geothermal heat flow is less than 0.014^oC.

Geothermal heat flow is generally diffuse like solar energy flux, only more so. Global average heat flow is approximately 1.5×10^{-6} calories/square centimeter/second (cal/cm^2 - sec) = 1.5 HFU (heat flow units) (Jacobs, Russell, and Wilson, 1974*), whereas global average insolation at the top of the atmosphere is 0.5 cal/cm^2 - min = 8.3×10^{-3} cal/cm^2 - sec = 8,300 HFU (Sellers, 1965*).

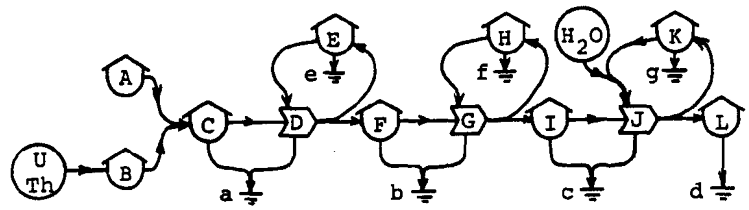

Figure 6. Energy diagram of geothermal-powered geological systems

A = Earth formation heat
B = Radioactive decay heat
C = Heat in crust and mantle (normal heat flow and gradient)
D = Mantle convection and plate motions
E = Structure of plates and mantle
F = Heat in geothermal regions -- convergent and divergent plate boundaries and hot spots (heat flow concentration 1.5 to 20 X normal)
G = Magma formation and rise toward surface as plutons
H = Plutonic and volcanic structures, magmatic mineral deposits
I = Heat in and around magma bodies and volcanoes (heat flow concentration 5 to 10^6 X normal)
J = Hydrothermal convection
K = Convection cell geometry, hot spring systems, geysers, and hydrothermal mineral deposits
L = Heat in and around hydrothermal convection systems and hot springs (heat flow concentration 10 to 10^9 X normal)
U, Th = Radioactive decay of uranium and thorium
H_2O = Water input from hydrological cycles

a, b, c, d = Heat flow to surface
e, f, g = Tendency for orderliness of structure to decrease

E, H, and K are storages of energy as orderly structure.
A, B, C, F, I, and L are storages of energy as heat.
F, I, and L are storages of heat as temperatures higher and temperature gradients steeper than would occur if heat flow were normal.

From left to right (downstream): Structures become smaller, closer to the surface, more localized, more highly organized, and more numerous. Total heat content and total heat flow decrease. But heat quality (temperature relative to normal conductive gradient temperature), heat flow rate, and mass flow velocity all increase. And accessibility and net-energy profitability for technoecosystem exploitation also increase.

Heat flow concentration figures are rough estimates, for illustrative purposes only.

Just as solar energy concentrates itself through hierarchical chains of energy systems (atmospheric, hydrologic, and biological) which it drives, so geothermal energy concentrates itself through hierarchical chains of geothermal powered geological systems (see Figure 6). Solar energy produces such orderly structures as clouds, air and water circulation patterns, fluvial networks, and biological systems to channel and concentrate its flows. Similarly, geothermal energy produces orderly geological structures like continents, volcanoes, ore deposits, and geysers. Solar energy is concentrated into such energy flow and storage forms as wind, rain, lightning, river flow, and wood; equivalent concentrated forms of geothermal energy are magma, hydrothermal fluids, earthquakes, and lithospheric plate motions.

Geothermal energy builds geologic order. Geological systems are open systems, thermodynamic engines, entropy jets, just as biological, hydrologic, atmospheric, stellar, and industrial systems are. All these types of systems channel large low quality energy flows, concentrate small amounts of energy to higher quality, and produce structure to maintain and maximize energy flow. They are all hierarchically organized. And all these systems undergo natural selection of random structural variability in order to maximize power (long or short run) -- they all evolve.

That geothermal energy is concentrated is well evidenced by spatial variations of heat flow. At many scales we find the pattern of large areas of relatively low heat flow and small areas of high heat flow. At global scale, for instance, 20 percent of total world heat flow is released in less than 1 percent of the area (more than 20x concentration) along oceanic spreading ridges (Williams, 1975). And similar concentration probably occurs along other divergent and convergent plate boundaries (the elongate, sinuous geothermal regions shown in the frontispiece map). At local scale, in Yellowstone Park, where average heat flow is perhaps several times higher than global average, Old Faithful geyser discharges heat at a rate of 1.34×10^6 cal/sec (Rinehart, 1970). Assuming a throat area of 10^3 cm^2, this represents a heat flow value of roughly 1.34×10^9 HFU or about one billion times the 1.5 HFU global average.

There are two primary mechanisms for geothermal heat concentration. The first is conduction. Heat diffuses through immobile materials at a rate which is proportional to their thermal conductivity and to the temperature gradient. Thermal conductivity of earth materials is generally quite low, so low that the last ice age has had significant thermal effect only as deep as 1,000 meters (Kappelmeyer and Haenel, 1974). Therefore, as heat is generated at depth it is partly stored and temperature rises until heat flow at all levels is equalized and a stable thermal gradient profile is established -- about 3°C per 1,000 m average on land near surface (ibid.). Geothermal gradient means that geothermal heat quality (temperature) increases with depth. Where different rock strata have different thermal conductivities, those with lower conductivity act as heat flow bottlenecks; they develop higher temperature gradient and greater heat is stored below them.

The second primary mechanism for geothermal energy concentration is convection. Fluid media in gravitational fields are unstable when vertical thermal gradient is greater than adiabatic thermal gradient. The result is cyclical flow in cellular modules whereby hot fluid rises, discharges some heat, and contracts, descends, stores more heat, and expands and rises again. The convection cell is probably nature's simplest heat engine (heat engines do work by transferring heat from high temperature heat source to low temperature heat sink) and may be among nature's simplest self-organizing, self-maintaining systems. Convection cells are found in rocks, oceans, atmospheres, stellar plasmas, and teapots. The work they do is to circulate and organize materials, accelerate and horizontally concentrate vertical heat flow, and maintain their own structure (often against competing convection cells). Convection tends to lower temperature gradients far below conduction temperature gradients. In geological systems convection cells occur in semi-solid salt domes and upper mantle rock (behave as fluids for long continued forces), in magma, and in groundwater and hydrothermal fluids.

The chief distinction between these two geothermal energy concentration mechanisms is that conduction (in low-thermal-conductivity materials) concentrates heat storage (by raising temperature) and retards heat flow, whereas convection concentrates heat flow and taps heat storage. Conduction heat storage is a prerequisite for convection heat flow. And conduction heat storages and convection heat flows in alternation can form hierarchical thermal energy concentration chains, as in Figure 6.

Geothermal technoecosystems seek high temperatures (with high heat recharge potential) at shallow depths. Clearly these optimum conditions occur when a convection system underlies a shallow, non-convecting, low-conductivity layer (e.g., hydrothermal convection system), or when a thick, high-conductivity layer or column underlies a shallow, low-conductivity layer (e.g., salt dome or geopressured system).

For the earth as a whole, conduction regions probably cover more area and produce more total heat flow than regions underlain by convection systems. Gabel (1975*) estimates global conduction heat flow to be 100 times convection heat flow. But he probably does not consider macroscale mantle and subsurface magma convection systems.

3. Rock Engine

As Bullard (1973) pointed out, it is not by chance that geothermal areas lie where they do. World distribution of geothermal regions (see frontispiece) largely reflects the operation and geometry of the macroscale thermal convection heat engine which drives sea floor spreading and continental drift. For a recent detailed review of such plate tectonics mechanisms see LePichon, Francheteau, and Bonnin (1973*).

The global heat engine propels lithospheric plate motions, but plate motion and structure, in turn, affect the heat engine (Bullard, 1973). Or, as Odum (1972, p. 240) expresses it, the continents (and plate geometry in general) act as "flow augmenting feedback structures." In other words, the global tectonics system appears to be a dynamic, self-organizing system. Furthermore, since there is evidence that plate tectonic mechanisms may have been operating for as long as 3 billion years (Hammond, 1975A), it appears that this global system is a self-regulating system, with negative feedback to balance convective heat flow with heat storage. Mantle convection cell geometry and lithospheric plate structures may be selected from randomly-generated alternative configurations in order to maximize heat flow magnitude and stability (what might be called "lithologic Darwinism"), given planetary parameters of composition, heat storage and formation rate, and some inertia of primordial structural precedents.

Apparently, no one has yet produced a detailed analysis of the global tectonic system as a heat engine, with energy budgets tabulated and mechanical efficiency calculated. Goguel (1976*) discusses some of the difficulties involved in such an analysis. Major hypotheses for convective plate driving mechanisms (Le Pichon, Francheteau, and Bonnin, 1973*) center on each of three types of tectonic areas as chief propulsive component: spreading ridges or rifts, mantle plumes or hot spots, and subduction zones. Interestingly, these three classes of tectonic areas also comprise all the major volcanic and geothermal regions of the world. Each in turn will now be discussed in more detail, with particular reference to occurrences in and near arid and semiarid lands [names of specific arid and semiarid locations are underlined].

There is a continuous global network of rifts or spreading ridges -- linear regions of crustal stretching and spreading with thin crust, high heat flow, and much basaltic volcanism (Milanovsky, 1972*). These divergent plate boundaries are areas where new oceanic crust is being formed by intrusive emplacement of basaltic lavas (Bullard, 1973).

Spreading ridges and adjacent oceanic crust go through six evolutionary stages (Jacobs, Russell, and Wilson, 1974*):

1) they start as rift valleys in the midst of continents (e.g., East African rift valleys, Salton Trough -- includes Imperial Valley, California, and perhaps the Rio Grande rift of southwestern U.S.)

2) they expand to form young, narrow intercontinental seas (Gulf of Aden, Red Sea, Gulf of California)

3) further expansion produces a wide ocean such as the Atlantic and Indian oceans (geothermally active Iceland is a particularly high part of the mid-Atlantic ridge)

4) finally, the ocean starts to shrink as its margins subduct below adjacent continents (Pacific Ocean)

5) complete closure of an ocean results in mountain belts like the sinuous belt which starts in the Mediterranean area (Canary Islands (?), Morocco, Algeria, Tunisia, Italy, Greece, Turkey) and continues into Asia (USSR near Caspian Sea, Iran, and probably Afghanistan and Pakistan)

6) an extreme example of ocean closure is the Himalaya region where continental crust thickness is doubled from continent collision (Toksoz, 1975*).

Most segments of active spreading ridges (stages 1 through 4) occur in oceans. These 55,000 km of submarine spreading ridges release 20 percent of total global heat flow, about equal to present technoecosystem gross energy flow (Williams, 1975), yet oceanic crust cools rapidly to average heat flow values away from them. Consequently, according to one hypothesis, here is the driving mechanism for plate tectonics: hot magma convects upward in curtains at spreading ridges, forms oceanic plates, and drives them apart; the plates cool rapidly for later descent at subduction zones (Jacobs, Russell, and Wilson, 1974*). In this scheme the rift is heat source and the ocean or atmosphere (and ultimately space)is heat sink.

Whether or not this is the true plate tectonic mechanism, non-submarine rift zones (Iceland, East African rift valleys, Salton Trough) are prime areas for geothermal technoecosystem operation. And if marine geothermal technoecosystems are ever developed, rift zones in narrow seas between arid lands (Gulf of California, Gulf of Aden, Red Sea)will also be of great interest.

A second hypothesis (Jacobs, Russell, and Wilson, 1974*) is that plate motions are propelled by upward convecting cylindrical plumes rooted deep in the mantle. At the surface these plumes form domes or hot spots, which are centers of volcanism and high heat flow. Two or more domes often become linked and split by rifts, and adjacent plates slowly slide downhill off them. In this scheme, magma intrusion along rifts (and thus formation of new oceanic crust) is only a secondary effect resulting from dome-generated tension. Heat source would be the mantle plumes, and heat sink would be the ocean or atmosphere. Examples of isolated hot spots which do not drive plates may be the Hawaiian Islands and the Tibesti Mountains of central Sahara. Domed areas spaced along the East African rift valleys may be hot spots which are driving plate motion.

New crust is created in spreading ridges; an equivalent amount must be destroyed somewhere, and this occurs at convergent plate margins known as subduction zones. A third hypothesis for plate motion (Le Pichon, Francheteau, and Bonnin, 1973*) is that plates move because they are pulled by subduction, the downward dipping plunge of cooled oceanic crust (now denser than underlying material) beneath another plate at its boundary. This is the downward component of the convection system, and since it seems difficult to imagine subduction starting and continuing without some driving force from the upward component of the convection system, a combination of this mechanism with one or both of the other mechanisms is most likely the case.

Subduction apparently recycles oceanic crust to the macroscale upper mantle convection system. But it also recycles sediments washed from continents back to them, thus helping to maintain the elevation of continents above sea level. It may also be responsible for maintaining the chemical-mineralogical differentiation of continental (granitic) crust from oceanic (basaltic) crust. And subduction may actually be the differentiation and accretion mechanism whereby continents originally formed.

In a simple convection system we would expect high heat flow where upwelling occurs and much lower heat flow where the convecting fluid is descending. But subduction zones, the descending components of plate tectonic convection, are linear zones of high heat flow (higher than friction can account for) and extensive volcanism and seismicity. In fact, heat flow magnitude and level of volcanism are roughly equivalent to those found at the spreading ridges, the ascending parts of the system. This is quite contrary to our predictions for simple convection. We might wonder how a convection cell can work as a heat engine if it has equally high heat flow in both ascending and descending compartments.

This apparent paradox seems to be resolved when we realize that we are not dealing with a single convection system, but with a hierarchical cascade of two convection systems. Low melting point material in oceanic crust is like a heat transfer fluid continuously fed into the subduction zone by the first, macroscale convection system. As the subducted plate descends, it is heated by conduction, compression, and mineral phase change (Toksoz, 1975*). Partial melting and differentiation occur, and relatively granitic magma bodies burble up toward the surface as the second, smaller-scale convection system. Through convective ablation the subducting plate is left cooler than it would otherwise be. Magmas which reach surface produce andesitic volcanism characteristic of subduction zones. Those which do not surface increase the regional heat flow, or drive hydrothermal convection systems, the next higher level in the cascading hierarchy of energy-concentrating convection systems (Figure 6). The abnormally low heat flow we would seek in a simple convection system is found in the oceanic trenches just seaward of subduction zones, where oceanic crust begins to descend but has not yet partially melted (ibid.).

An interesting analogy can be sketched between subduction zones in the geological world and warm fronts in the atmospheric world. They are mirror images of each other, with the planetary surface as symmetry plane. In the warm front, free energy is tapped as light warm air rises at a gentle angle over a wedge of cool air and cools adiabatically. In the subduction zone, free energy is tapped as dense cool oceanic crust descends at a gentle angle beneath lighter, warmer asthenosphere material and heats up by conduction and minor friction, and by adiabatic mineral compression and phase change. As the warm front dissipates large amounts of energy, it concentrates a small amount in the form of liquid water condensed from gas. Release of latent heat by condensation accelerates upward motion of warm air. Similarly, as the subduction zone dissipates large amounts of energy, it concentrates a small amount in the form of liquid magma melted from solid rock. Absorption of heat of crystallization by melting may cool the subducting plate and speed its descent. Liquid water is denser than air and it falls as rain; magma is lighter than surrounding rock and it rises as a subterranean upward rain of plutons. When the two meet at shallow depths the result is often a hydrothermal convection system, a potentially very high quality geothermal resource.

Subduction zones, known for active volcanism, earthquakes, hot spring activity, and geothermal potential, ring the Pacific, a stage 4 (closing) ocean. At the eastern margin of the Pacific, oceanic crust dips below continental crust along the western coast of Central America and South America (including the coastal deserts of Peru and Chile and a small semiarid coastal area in Ecuador).

The northern and western Pacific is lined by a complex subduction zone system dominated by island arcs (where oceanic crust sinks below more oceanic crust). This system includes the Aleutians, the Kurils, Japan, Taiwan, the Philippines, Papua-New Guinea, and a linear complex of islands extending through New Zealand. Other important subduction zones are where Indian Ocean crust plunges below Indonesia and where western Atlantic Ocean crust dives under the West Indies. Except along western South America, none of these subduction regions are arid.

Western North America, much of it arid and semiarid, is tectonically and geothermally active. Its complex role in global tectonics is still being unraveled.

In conclusion, our planet's crust and upper mantle form a self-organizing self-maintaining convective heat engine which runs on geothermal heat and concentrates it through several levels of a convection cell hierarchy, starting at global scale and ending at small local scale. The global tectonics convection system is responsible for the first level of concentration and results in the worldwide distribution of geothermal regions shown in the frontispiece map. These regions contain most of the world's high-quality geothermal resources (near surface, high temperature) and they are also the major areas of intense recent geological activity (mountain building and volcanism). Most of the geothermal regions are long and narrow "geothermal belts". They coincide with lithospheric plate margins, particularly divergent boundaries (rift zones and spreading ridges), convergent boundaries (subduction zones and island arcs), and the sinuous Eurasian mountain belt (Bullard, 1973; Hammond, 1975A; Koenig, 1973B, Lister, 1974; Tamrazyan, 1973). Isolated mantle hot spots, in contrast, create small, more equidimensional geothermal regions. Of all the land area included in these geothermal regions, a large fraction is semiarid or arid and therefore is particularly relevant to this report.

4. Earth Cycles and Life

H.T. Odum (1972, 1975) has proposed the novel idea that volcanic cycles and plate tectonics may be driven, at least in part, by solar energy channeled through the biosphere. Small amounts of oxidized and reduced substances (separated by photosynthesis in plants) would be laid down together in sediments and chemically recombined (burned) much later under conditions of higher temperature and pressure. In one figure (1972, p. 240) Odum shows biosphere, volcanic system, and industrial system competing in parallel for solar productivity. Actually, this is a new form of an ancient concept. The idea that subterranean fires power earthquakes and volcanoes can be traced from Werner in the 19th century back through many noted scientists and philosophers to Aristotle (Geikie, 1962*) and also to pervasive myths of subsurface infernos.

Although Odum's hypothesis is interesting, it may be hard to support solar energy as a significant geothermal heat source for several reasons: 1) There is sufficient radioactivity in the crust to account for most geothermal heat flow, 2) geothermal heat flow occurs in tectonically quiescent Precambrian shield areas far from subsiding sedimentary basins, 3) geometry of spreading centers does not support solar drive. Slow burning at depth might contribute a small amount of heat flow in subduction zones and subsiding sedimentary basins, but there is no mechanism proposed for slow burning under hot spots and spreading ridges rooted deep in the mantle, and 4) earliest evidence of plate tectonics (about 3 billion years ago) predates the appearance of the first photosynthetic plants around 2 billion years ago (Siever, 1975*). There may be "biovolcanism" on some planet somewhere, but probably not on this one.

Although the biovolcanism segment of Odum's (1972) world geochemical model may be incorrect, the rest of the model does provide valuable insights into the total energetic and geochemical interrelations of earth cycles in the lithosphere, hydrosphere, biosphere, and atmosphere. Siever (1974*) takes a similar general systems overview of earth cycles. He portrays the planet as a comprehensive worldwide system like a giant chemical engineering plant, with diverse heat-pressure-chemistry thermodynamic cycles, and with inputs and outputs of all the sectors in sensitive balance. Water is a ubiquitous, vital link in all these cycles. Geothermal heat drives the geologic subsystem.

One sector not included in either man's global model is the technoecosphere. The technoecosystem is starting to tap so many flows and storages in the planet's natural energy systems that the old, stable balance must inevitably change. How, when, and how fast are uncertain.

On earth, biological systems use geothermal heat only indirectly, for its influences on environmental geometry, geochemistry, and temperature. For instance, global geothermal cycles move continental stage props around and thereby influence divergent evolution of biological systems. But life here does not use geothermal heat directly for metabolism. This is not surprising considering the relative magnitudes of solar radiation and geothermal heat flow. Perhaps life evolves "thermosynthesis" (as exists in primitive form in convection cells) on planets where geothermal flux is relatively greater. We do not need to speculate about technoecosystems, however. Our own technoecosystem has bypassed biological limitations and can now augment its fossil-fuel industrial metabolism with geothermal heat stored and concentrated by eons of earth cycles. Geothermal technoecosystems may not compete with geological systems for solar energy, but they do compete for geothermal heat. And in the short run the technoecosystems are winning.

5. Ore, Oil, and Aridity

Natural geothermal-powered systems concentrate rare elements into mineral deposits and help concentrate organic material in sediments into petroleum deposits. These two types of geological plum are fundamental inputs to high-energy technoecosystems. Another function of natural geothermal-powered systems is to directly and indirectly influence climate, including aridity. It is hard to assign to this service a positive or negative value for technoecosystems.

From the disorderly jumble which this planet was at its beginning, we now have an exquisitely orderly geological system. The sun has done most of the rearranging in hydrosphere, surficial lithosphere, and biosphere. But mostly geothermal heat lies behind the multitude of dynamic mechanisms to which geologists ascribe the element concentrations and ordering of the deeper lithosphere.

Old models of metal ore genesis emphasized local operation of magmatic and hydrothermal mechanisms. Some metal deposits form solely within the magma phase through various magmatic differentiation processes. But most deposits involve hydrothermal convection systems (meteoric water or sea water) as transport mechanisms and as media for the physical-chemical gradients which separate elements.

New ore deposit theories place modified and expanded versions of the old models into the comprehensive framework of global tectonics, as recently summarized by Hammond (1975B, 1975C). Each environment in the global system is thought to produce unique types of mineral deposits. And every level of the hierarchy of geothermal-powered convection systems (Figure 6) seems to be involved at some stage.

Both magmatic and hydrothermal metal concentrations are formed at spreading ridges. For example, a large hydrothermal system is now active in the Red Sea, where hot brines concentrate copper, zinc, lead, and silver in the sediments (Ross, 1972). Some metals concentrated at spreading ridges are thought to be concentrated a second time in subduction zones and a third time in magma-driven hydrothermal convection systems to form porphyry copper deposits -- major world sources of copper, molybdenum, lead, zinc, silver, and gold. Similarly, in island arcs various types of massive sulfide ores form by submarine volcanic processes. Mantle plumes may run hydrothermal convection systems to form stratified lead-zinc deposits, and may bring diamonds and rare-earth elements from the mantle to the surface.

Geologic structures (e.g., faults, folds) which often localize mineral deposits are formed by geothermal cycles. And geothermal-powered plate tectonics often remobilizes and alters primary ores in diverse ways. Finally, it is geothermal-forced uplift of deep mineral deposits which enables sun-driven cycles to reduce their depth or expose them. Sometimes solar cycles add still more enrichment steps to make the mineral deposits into economically recoverable ore deposits.

Solar energy runs biological systems and geologic sedimentation processes which bury biological residues. But geothermal heat systems operate the framework within which these organic materials are concentrated to form fossil fuels. Geothermal heat helps concentrate coal (Steinhart and Steinhart, 1974*), but has more complex roles in the formation of petroleum and natural gas.

Geothermal mechanisms form suitable basins and influence sedimentation (Fischer and Judson, 1975*), but that is just the start. High geothermal gradients enhance processes of formation, migration, and entrapment of oil and gas (Klemme, 1975), and plate tectonic subduction mechanisms can help drive these hydrocarbons toward reservoir traps where they accumulate (Dickinson, 1974). Klemme (1975) observes that giant oil fields around the world coincide with areas of high heat flow, and that depth of hydrocarbon occurrence appears to be related to basin temperature history. Petroleum and gas often coexist with high-temperature, high-pressure (geopressured) water zones in sedimentary basins (Miller, 1974). Salt dome heat conduits, often part of the same system, help form structural traps (Jacoby, 1974).

The aridity of arid lands is an artifact of the solar-powered atmospheric system. Geothermal heat concentrations are artifacts of the geothermal-powered geological system. This paper is about the nexus of the two systems, and how they affect technoecosystems. Natural geothermal-powered systems appear to influence aridity more than aridity influences them.

Aridity is a special case, one pole of a small range of variation in earth's relatively stabilized climatic system. The difference between arid and humid climates is minuscule compared with the giant range of astrophysically possible differences (e.g., between star and planet, between planets of differing mass, chemical composition, and orbital parameters; between planets of different stellar systems, and even between stages in the history of one planet). Therefore, it does not take a great deal of energy flow change, relatively speaking, to transform one climate into another. Small geothermal heat flow in geological systems strongly influences climate, including aridity, by switching and modulating much larger solar-powered energy flows.

There are several major mechanisms by which this happens. Plate tectonics changes the distribution of continents and oceans over time, with major impact (through complex pathways) on global climatic regime and distribution of arid lands. (Actually, plate tectonics may be responsible for the fact that there is land at all.) Large clouds of dust periodically spewed into the upper atmosphere by volcanoes can temporarily alter the planet's albedo and thereby trigger climatic changes. Geothermal-driven uplift of high mountain barriers can create deserts in basins downwind. Uplift of an area can increase its effective precipitation and diminish its aridity (e.g., the Hoggar and Tibesti Mountains, islands of semiaridity within the extremely arid Sahara). And conversely, tectonic subsidence can enhance aridity (e.g., Death Valley). Finally, geothermal heat is an integral component of the dynamic, integrated global geochemical system (Siever, 1974*) which determines the gaseous composition of the atmosphere, the ultimate framework within which all climatic systems operate.

6. Geothermal Resource Configurations

Subsurface thermal energy concentrations (geothermal resources) occur in an endless variety of geological substances and settings. They are never simple or static. Geothermal reservoirs are always physically complex, three-dimensional, dynamic systems (Barnea, 1974).

Numerous classification systems have been applied to this diversity of resource types by various authors (e.g., Barnea, 1974; Hickel, 1973; and White and Williams, 1975). The classification system used in this paper, shown in Table 1, is modified to reflect the hierarchical energy concentration scheme summarized in Figure 6. Resource types (with the probable exception of subsiding sedimentary basin systems) are listed in order of increasing heat flow concentration, increasing ease of accesibility to high temperatures, and hence increasing likelihood of successful net energy yielding exploitation by geothermal technoecosystems. Each resource type is now briefly discussed.

TABLE 1. Geothermal Resource Types

1. Normal heat flow areas
2. Subsiding sedimentary basins
    a. Geopressured systems
    b. Salt domes
3. Igneous-related systems
    a. Magma
    b. Hot-dry rock
4. Hydrothermal convection systems
    a. Hot water systems
    b. Wet steam systems
    c. Dry steam systems

Most of the earth's surface (most uncheckered areas of frontispiece map) can be included in the category of normal heat flow areas. These areas have near-average heat flow (roughly 1.5 HFU, depending on subsurface concentration of radioactive elements) and therefore near-average temperature gradient, which varies with thermal conductivity (Diment et al, 1975). Upward convective movement in mantle, magma, or groundwater is absent or minor beneath these areas; conduction is the major or only heat transfer mechanism in operation. Compartment C in Figure 6 represents this type of resource. A vast amount of heat is stored, and it migrates very slowly upward (outward in the global sense) to the surface. Temperature, and therefore thermal energy quality, increases continuously with depth, reaching high values at depths of several kilometers.

But geothermal technoecosystems avoid normal heat flow areas because net energy ratio is either less than 1 or is less than can be obtained from other geothermal and non-geothermal resources. There is a large energy cost of depth for technoecosystem heat recovery: friction of fluid flow increases with depth, and drilling and casing costs increase exponentially. Furthermore, deep rock materials frequently have low permeability (heat transfer area must be created artificially) and are dry (heat transfer fluid, usually water, must be provided from above).

Subsiding sedimentary basins are geologically complex, dynamic environments which, despite normal (or slightly higher) heat flow, can produce more favorable geothermal heat concentrations. These are also the environments in which the world's major petroleum deposits are formed and found. Geothermal and hydrocarbon resources are closely interrelated in these systems. The most studied basin in terms of geothermal development is the northern Gulf of Mexico coastal and offshore region, including a semiarid portion of Texas. Similar basins are scattered around the world.

Jones (1973) summarizes the operation of geothermal-related geological systems in the Gulf of Mexico basin. Geopressured systems (hot water with pressure greater than hydrostatic) are created as subsiding clay layers inject low-salinity pore water, derived from thermal diagenesis of clay minerals, into confined sand strata. Temperature of geopressured water (up to 237°C) is especially high because temperature gradient is high in overlying low-thermal-conductivity saturated clay layers. This is an excellent example of conductive concentration of stored heat. Salinity of geopressured fluids is variable, increasing up to 90,000 ppm (parts per million) with depth. Geopressured fluid not only has thermal energy and mechanical energy (more than enough pressure to drive it to the surface), but it also is often saturated with natural gas, mostly methane (Papadopulos et al, 1975) formed by natural high-pressure high-temperature cracking of petroleum hydrocarbons (Hickel, 1973).

As mentioned earlier, high geothermal gradients (as found in geopressured systems) enhance hydrocarbon formation and concentration mechanisms (Klemme, 1975), and hydrocarbon concentrations often coexist with geopressured zones (Miller, 1974). Also, geopressure apparently helps force oil and gas to the surface, a free pumping service. Consequently, drilling by hydrocarbon-recovery technoecosystems has intersected many geopressured systems around the world, including such arid oil-rich regions as the Middle East and North Africa. Oilmen often consider abnormally high pressure to be a problem -- it causes drilling difficulties and blowouts. Fertl (1972*) compiled worldwide information about reported occurrence of abnormal formation pressure, and Rehm (1972*) discussed specific type examples in more detail. However, since no detailed map of global distribution of geopressured-geothermal reservoirs exists (to my knowledge), they are not included in the frontispiece map. Geopressured systems appear to be promising for geothermal technoecosystem operation because of 1) multiple energy value of the fluids, 2) ease of fluid extraction, and 3) abundance of fluid storage in highly permeable reservoirs.

Still another component of subsiding sedimentary basins is the salt dome. Thermal conductivity of rock salt is very high, so a salt dome can act as a vertical heat conduit through lower-conductivity sediments, with heat flow 5 to 8 times regional average (Jacoby, 1974). Presumably, the result is low temperature gradient in the dome and high gradient and high heat flow in the overlying low-conductivity sedimentary cover. Temperature is therefore unusually high in and near the tops of salt domes, another excellent example of conductive concentration of stored heat.

Salt domes are dynamic participants in the hydrocarbon-geopressure complex of subsiding sedimentary basins. Salt is lighter than normal sediments, and it behaves as a fluid over large time-spans. So large blobs and columns of it rise gradually to the surface from deep-lying evaporite beds, much as plutons of molten magma drip upward through continental crust. Salt domes probably increase local heat flow by upward convective mass transport, as well as by the conduction enhancement just mentioned. Since salt domes are relatively hot environments in their upper levels, they may enhance local petroleum formation and migration (they also act as structural traps), and they may accelerate clay diagenesis and thus geopressure formation. Geopressured systems, in turn, store heat and raise temperatures, and thus can amplify further salt diapirism (Jones, 1973) in what is apparently a positive feedback mechanism. Jacoby (1974) believes that salt domes will be valuable geothermal resources, and he suggests several technoecosystem configurations for exploiting their heat content.

Igneous-related systems, their heat storages shown as compartments F and I in Fig. 6, are what differentiate geothermal regions (frontispiece map) from the rest of the world. They represent the first and second levels of the earth's hierarchical energy concentration system. In this resource category I include high heat flow regions created by primary plate tectonic convection mechanisms, magma bodies (which are almost always produced in these regions), and hot-dry rock which surrounds magma bodies and which the magma bodies become when they cool. Heat flow due to primary mantle convection and heat flow due to deep secondary magma convection generally occur in the same areas, and in practice may be difficult to separate. Hence the high-thermal-gradient hot-dry rocks which they generate are combined here into one category.

Magma (compartments G, H, and I in Fig. 6) forms as two fundamental types in two major kinds of geologic environment. Spreading ridges generate basic (basaltic) magma which rises in small pulses through narrow pipes and fissures. Basic magma does not form large near-surface storage chambers except in large oceanic volcanoes, and therefore it does not contribute large amounts of stored heat to the crust. Subduction zones generate silicic (granitic) magma which does form large storage chambers, probably within 10 km of the surface (but below 3 to 6 km), from which volcanic eruptions take place (Smith and Shaw, 1975).

Magmas are probably emplaced at temperatures of 800 to 1,200°C and thus contain a large amount of thermal energy, 300 to 450 cal/gram (Norton and Gerlach, 1975*). In fact, for the U.S., molten or partly molten magma bodies at depths less than 10 km are estimated to contain about 15 times the thermal energy content of all hydrothermal convection systems (Peck, 1975). It takes 1/3 million years for steady-state temperature gradient to be established over a newly emplaced magma, and large bodies may take 2 to 10 million years to cool to ambient temperature by conduction, or somewhat less if significant hydrothermal convection occurs (Smith and Shaw, 1975). Even in low-permeability, seemingly dry country rocks, slow hydrothermal convection can take place, cooling small plutons of 5 km^3 (cubic kilometers) in around 100,000 years (Norton and Gerlach, 1975*).

Despite its great magnitude and high quality, thermal energy storage in molten igneous systems is not now recoverable by geothermal technoecosystems and may never be so (Peck, 1975). Suitable drilling and heat extraction technologies do not yet exist, but a number of U.S. scientists are trying to develop them.

Hot-dry rock, including solidified portions of magma bodies and surrounding rocks conductively heated by them, probably contains approximately the same amount of thermal energy as molten material contains (Peck, 1975; Smith and Shaw, 1975). Despite low permeability, slow hydrothermal convection may occur in the hot-dry rock environment (Norton and Gerlach, 1975*); however, conduction probably dominates total regional heat flow. This type of geothermal resource is similar to normal heat flow areas except that isotherms curve around plutons and the temperature gradient tends to be steeper. Therefore, high temperatures occur closer to the surface, perhaps within net-energy-yielding reach of geothermal technoecosystems. But the same low permeability and lack of sufficient heat exchange fluid which occur in the normal heat flow environment make exploitation of hot-dry rocks difficult and costly. Several possible technoecosystem design strategies for extracting heat from hot-dry systems have been pursued, and they will be discussed in the next chapter.

Hydrothermal convection systems (compartments J, K, and L in Figure 6) represent the highest level in the thermal energy concentration system hierarchy. Some such systems occur in normal heat flow areas, but practically all high-temperature hydrothermal systems occur over and are driven by igneous-related systems in geothermal regions (frontispiece map).

Three ingredients are required for establishment of a hydrothermal convection system: 1) a heat source which produces a temperature gradient higher than water's adiabatic temperature gradient, 2) water, mostly ordinary groundwater of meteoric origin, subject to all the same geologic factors that control occurrence and movement of groundwater (Geraghty and Miller, 1973), and

3) permeability sufficient to permit water circulation. High permeability is usually found as porosity in sediments deposited by solar-powered earth cycles, or as fault and fracture systems resulting from geothermal-powered tectonic strain. A gravitational field and subsurface temperatures above freezing are also required, but they presumably exist in all regions of interest.

Essentially all geothermal technoecosystems in practical operation to date exploit some form of hydrothermal convection system. Exploitation of every other type of geothermal resource is still just a dream or is only at the highly subsidized research stage. Hydrothermal convection systems are most used and most sought after largely because they contain water in some form. Water is the best low-viscosity geological medium for large heat storage and rapid mass-flow heat transport. It has the beneficial property of boiling at thermodynamically useful temperatures (100°C at sea level atmospheric pressure, higher at greater pressure). It is easily channeled, and many technoecosystem components are already adapted to its use. And water has many other energy values in addition to heat content, especially in dry lands (as discussed in the first chapter). When water and adequate permeability are present, large amounts of heat can be removed from underground storage in a very short time.

The hotter the water the better for technoecosystems because less flow of hotter fluid is needed for equal heat transfer, because higher temperatures represent higher-quality more concentrated energy value (and thus ability to do high-energy tasks with high thermodynamic efficiency), and because water hot enough can pump itself out of the ground. Therefore it is only natural to classify hydrothermal convection systems according to temperature-dependent variables.

Several classification schemes exist for hydrothermal convection systems, for example those used by Facca (1973), Hickel (1973), and Renner, White, and Williams (1975). Each scheme has a different number of categories (3, 2, and 4) and different dividing lines; names are often given different meanings. Classification variables can include the water's physical state, its behavior, and temperature limits of its usefulness in key technoecosystem processes.

Apparently every classification system separates the rare vapor-dominated or dry steam systems (steam controls pressure and convectively transports most heat) from the much more common liquid-dominated or hot water systems (liquid water is the dominant fluid). This is done on the basis of highly contrasting physical states of water and consequent very different technoecosystem designs required for exploitation. The several classifications differ only in the way that they group liquid-dominated systems.

In this paper Facca's (1973) scheme, slightly modified, is used (Table 1). Hot water systems contain water at temperatures ranging from slightly more than ambient surface temperature up to 150°C. And wet steam systems contain water hotter than 150°C, the lower limit for useful flashed steam generation.

Hot water systems (temperatures up to 150°C) are dominated by liquid phase but may contain some vapor bubbles in shallow low-pressure zones. Some small systems may be heated under normal temperature gradient conditions by slow convection down fault zones to depths of several kilometers. But most hot water systems, including large especially hot systems, are heated by igneous-related systems at depth. Systems above 90°C are attractive for space and process heating. Systems near 150°C are not hot enough to drive steam turbines, but can generate electricity through alternative thermodynamic cycles. Systems below 90°C may be used only where circumstances are locally favorable (Renner, White, and Williams, 1975); in fact, their water may be pumped for its own sake and not for heat content.

Wet steam systems (temperatures above 150°C) are essentially all heated by igneous-related systems. Water at depth can be much hotter than surface boiling temperature (temperatures up to 360°C are typical of Imperial Valley), yet boiling will be suppressed by sufficient pressure. When wells tap this water a fraction of it boils to steam -- "flashing" -- and a steam-water mixture (wet steam) is yielded at the surface (Nathenson, 1974). Depending on reservoir temperature and permeability, water flashes in the well, at well bottom, or in the reservoir itself. If flashing is deep enough, rapid well flow is spontaneous. Production rate and steam fraction can be controlled by varying wellhead pressure (Facca, 1973).

A "cap rock" of very low permeability overlies and confines wet steam systems. This cap rock can be an originally impermeable formation, or its pore spaces and fractures can be sealed by mineral deposition from the thermal fluids. If rate of fluid discharge through unsealed vents or technoecosystem drillholes is larger than water recharge rate, the flashing surface can migrate out and down from the openings and can eventually transform the system into a dry steam system (ibid.).

Wet steam systems are of interest to geothermal technoecosystem developers because they are hot enough to run high-energy processes like electricity generation and water distillation, and because they are many times more common than still more desirable dry steam systems. Furthermore, in arid lands, wet steam systems can be important sources of water -- water which can often pump itself out of the ground, distill itself, and still have enough heat left to generate electricity or warm greenhouses. Imperial Valley, California, and the arid Salton Trough (U.S. and Mexico) of which it is a part, are underlain by a large complex of wet-steam systems. Much work is being done to develop complex geothermal technoecosystems to exploit this resource; it will be reviewed in a later chapter.

Dry steam systems are the top of the line of natural geothermal resources, as far as geothermal technoecosystem developers are concerned. They are eagerly sought, but they are exceedingly rare. Dry steam systems are in such high demand because when tapped they yield just superheated steam (with minor gaseous impurities), which can be fed directly into steam turbine powerplants only slightly modified from well-known fossil fuel technology. A good example of a dry steam system is the Geysers geothermal field near San Francisco, where the largest geothermal power complex in the world (500 megawatts) is found.

As mentioned earlier, a dry steam system forms from an original wet steam system in porous or fractured rocks confined below impermeable cap rock and somehwere above a hot igneous-related system. Conversion from wet to dry tends to happen when heat supply is large but water supply is small (Renner, White, and Williams, 1975), such that net water discharge from the system exceeds recharge. Steam boils from a declining water table (White, Muffler, and Truesdell, 1971), creating a volume of permeable rock within which steam is the dominant fluid, pressure is lower than hydrostatic (Garrison, 1972), 85 percent or more of total heat is contained in reservoir rocks (Truesdell and White, 1973), and temperatures are close to 240°C (Renner, White and Williams, 1975). Steam rises and condenses at the top of the system, from where heat is then conducted upward, and the liquid condensate then trickles downward to complete the convection cycle (ibid.), as in a teapot. Through time, mineral deposits (carbonates and gypsum) seal water recharge channels and gradually isolate the system (White, Muffler, and Truesdell, 1971). Mercury may be separated from other elements, enriched in the vapor, and deposited in the condensation zone of a dry steam system; vapor is usually also enriched in carbon dioxide and hydrogen sulfide gases (ibid.). When such a system is discovered and tapped by geothermal technoecosystems it begins to change: water table and boiling zone move deeper, steam pressure decreases, and steam temperature rises (Truesdell and White, 1973).

Even though some wet steam systems may be hotter, dry steam systems represent higher energy quality for power generation technoecosystems because they have separated the higher energy quality steam phase from lower energy quality liquid water (and any salts it contains). Water need not be handled and separated above ground, so plumbing can be simpler. If large quantities of water are needed, however, as in an arid region, wet steam systems may be preferable. Such a case would be fortunate because wet steam systems are much more common than dry steam systems -- 30 times more common in the U.S. (White and Williams, 1975).

Hydrothermal convection systems often manifest themselves at the surface through such phenomena as hot springs, fumaroles, mud volcanoes, and geysers. Except for low-temperature hot springs, all these surface manifestations are only found in geothermal regions, where igneous-related systems exist at depth. Waring (1965) compiled information about thermal springs around the world. And Rinehart (1974) reviewed geology and behavior of geysers.

Faults play an important role in localizing natural geothermal systems. They serve as transport channels for magmas and hydrothermal fluids; in geopressured systems they act as barriers to form many confined, pressurized compartments (Rinehart, 1975*). Extensive faulting of volcanic areas induces high permeability and prepares the way for hydrothermal convection systems (Ellis, 1975). Koenig and Huttrer (1975) note that igneous and hydrothermal activity tend to localize along regional structural alignments (frequently faults) and especially at their intersections. Faults are structures which form to release stresses built up by geothermal-powered tectonic motions and igneous activity; they seem to be among the structures which geothermal-powered geological systems create to maximize their energy flow concentration (compartments E and H of Figure 6).

A persistent pattern in geothermal resources is that systems of lower energy quality are more numerous and contain more total heat than systems of higher energy quality. For example Koenig (1973B) wrote that useful energy in low-enthalpy fluids may be ten times or more larger than that in high-enthalpy fluids. And Kunze (1975) theorized that the amount of geothermal water and energy available increase logarithmically with decrease in temperature. Furthermore, it is well known that dry steam systems are rare compared to wet steam systems.

Renner, White, and Williams (1975) observed this trend for hydrothermal convection systems in the U.S. And they also noted that in any one resource category (roughly equal energy quality) just a few systems contain most of the stored thermal energy. They conclude that "geothermal convection systems may have the same log-normal relation between grade and frequency that metalliferous deposits and hydrocarbon reservoirs have."

Although it may not explain the relative dominance of a few systems in any one energy quality level, I think the hierarchical energy concentration scheme illustrated in Figure 6 may help explain the rapid decrease of heat storage with increasing energy quality. Large conductive heat storages (temperature gradient higher than normal) must be built up through time over large convective systems before smaller convective systems of the next higher level can begin effective operation and build smaller conductive heat storages above themselves. The result is progressively smaller and more localized storage of higher quality thermal energy (relative to normal gradient) up the cascaded hierarchy of convection systems.

Estimated heat content of U.S. geothermal resource base (White and Williams, 1975, Table 26, p. 148) for identified and estimated undiscovered resources may be typical of the pattern that will be found around the world. Heat storages for regional conductive environments (normal and high gradient areas, compartments C and F in Figure 6), hot igneous systems (igneous-related systems, compartment I), and hydrothermal convection systems (compartment L) in the U.S. are estimated to have values in the ratio 2623:33:1. Total heat flow over the different types of systems, although not inventoried in the report, should show a similar pattern (decreasing up the hierarchy). And average near-surface heat flow rates over the different areas will certainly demonstrate an inverse relationship (increasing up the hierarchy).

7. Roles of Water

Liquid water has been available on this planet for at least 3.5 billion years (Siever, 1975*). It was originally released to the surface by geothermally-driven thermodynamic, physical, and chemical cycles, and it continues to play an important part in them today. Water is almost ubiquitous in geological cycles and it serves in a great many capacities: as solvent, as chemical reactant and product, as catalyst, as heat and mass transport medium, as pressure equalizing fluid, as momentum storage and transfer medium, as evaporative coolant, as explosive. Water may facilitate partial melting of oceanic crust in subduction zones (Hammond, 1975B). And it is especially important as convective medium in hydrothermal convection systems, where the highest natural heat flow concentration can occur. Finally, it is a vital ingredient of present geothermal technoecosystems and their heat extraction and processing systems, which make possible still higher energy concentration.

Geothermal fluids are not pure water; their geochemistry is quite complex (see Ellis, 1975, for a brief review). Salinity can range from quite low to over 30 percent (near the Salton Sea), but it is most commonly between 0.1 and 1 percent (Renner, White, and Williams, 1975). Most geothermal fluid is meteoric in origin, but a small proportion may be derived directly from magma (Garrison, 1972). Steam at the Geysers, California, "is formed, at least in substantial part, from rainwater of recent origin" (Libby, 1975*).

A large fraction of the world's geothermally active area is under water, in the oceans. Among these regions the spreading ridges are important (Williams, 1975). But Palmer, Green and Forns (1975) pointed out that continental shelves are simply drowned extensions of land areas, and they probably have continuations of known onshore geothermal resources of all types. For example, the offshore geopressured-geothermal resources of the Gulf of Mexico may be of the same general size as onshore resources (Papadopulos et al, 1975).

Aridity seems to have little noticeable effect on the configuration of geothermal resources. Perhaps this is a manifestation of the slowness of the rate of change of geothermal systems relative to climatic systems. Aridity may in some cases result in a subsurface water table and therefore hide such usual thermal manifestations as hot springs. Renner, White, and Williams (1975) suggest that glaciation may increase water recharge rates and thereby make dry steam systems become wet steam systems again. We might speculate that aridity could produce just the opposite trend. Certainly if recent recharge is an important input to the geothermal system (as it apparently is at the Geysers), then aridity will have a major impact on system behavior. An unusual occurrence of non-aqueous thermal convection in a semiarid environment is reported by Calamai and Ceron (1973): air convection through fractured volcanic rock on Lanzarote, Canary Islands. However, Araña, Ortiz, and Yugeuro (1973) dispute their findings and suggest that the convection fluid is a mixture of steam and gases rising from a hydrothermal convection system at depth. Aridity probably influences geothermal technoecosystems much more than it affects subsurface natural geothermal systems.

For billions of years, thunderous geyser and volcano eruptions have been the peak of the hierarchical chain of geothermal energy concentration systems. But there is a new top to this pyramid -- geothermal technoecosystems. Concentrated storages of ancient heat, untouched by ice age effects, are now starting to be tapped at geologically unprecedented rates and concentrated still more into new energy forms for which geothermal origins are unrecognizable: electricity, distilled water, radio waves, city lights. The next chapter reviews technoecosystem configurations which are evolving to tap and transform the many kinds of geothermal resources.

III. GEOTHERMAL TECHNOECOSYSTEMS

1. General Characteristics

Human-controlled systems for using geothermal resources have always been complex, but only recently have they become large. Since ancient times men have been drawn to hot spring areas, the natural surface manifestations of hydrothermal convection systems. Heat and water flows have been used at naturally occurring flow rates for hot baths, medicinal treatments, mineral water for drinking, livestock watering and irrigation, some chemical recovery through distillation and evaporation, minor space heating, and, in a few locations, for cooking.

Evolution of high-energy technoecosystem components and complexes in the past century opened the possibility of tapping deep heat storages at rates much greater than occur in nature. Development of steel mass production, powerful drilling technology, and turbogenerators within the fossil fuel niche technoecosystem paved the way for evolution of high-energy geothermal technoecosystems. First large-scale geothermal power production was at Larderello, Italy, in 1904 (Berman, 1975*). Many new geothermal industrial forms have appeared since then, and the rate of evolution of geothermal technoecosystems is now accelerating rapidly. Power, complexity, sophistication, and number of geothermal technoecosystems will continue to increase as technology evolves and as fossil fuel net energy ratios continue to decline.

Geothermal technoecosystems now range in complexity from simple potable water condensation modules embedded in low-energy technoecosystems, as in eastern Africa (Saint, 1975), to large industrial complexes proposed for Iceland for chemical production, electricity generation, and space heating (Lindal, 1973 B).

Large geothermal technoecosystems are easy to see as technoecosystems from the macroscopic viewpoint. Stationary technoorganisms include power plants, office and control buildings, and greenhouses and other auxiliary industrial modules. Mobile technoorganisms include drill rigs, exploration vehicles, pickup trucks, and personal cars in the parking lot. Channels for energy, materials, and information include powerlines, pipelines, drillholes, drainage ditches, and telephone wires. Subsurface geothermal reservoirs, to the extent they are known and controlled, are technoecosystem storage components. Artificially created reservoirs are totally within technoecosystem.

It is hard to draw a sharp boundary around a geothermal technoecosystem. It is inseparably linked to the fossil fuel technoecosystem within which it is implanted. We might include in a geothermal technoecosystem those portions of the global technoecosystem which provide support for it (exploration, manufacturing, design, and repair) and its staff (houses, schools, stores). And we might include those parts of the technoecosystem which use geothermal power and products. As before, though, we must draw the boundary where it is useful, and that usually means including only exploration and exploitation components in action on site.

Geothermal technoecosystems are excellent examples of technoecosystems. They are very much like bioecosystems; the biological analogy is very good. As do bioecosystems, they have orderly networks of diverse, complex components (well-adapted modules and low-entropy channels) arranged according to environmental conditions, internal needs, and thermodynamic laws of energy systems. Geometries and materials are in optimum locations and optimum roles (for example, optimum arrangement of geothermal wells is a hexagonal grid, the same pattern which appears in bioecosystems, spatial economic systems, and many crystals). Like bioecosystems they are entropy jets, open systems which maintain homeostasis, have hierarchical energy transformation chains, and evolve. Like most technoecosystems, however, they use new non-biological geometries, materials, and physical properties (e.g., turbines, steam, heat, and pressure).

Like other high-energy technoecosystems, geothermal technoecosystems are consciously controlled and give much leverage to a few men--large power flows are controlled and maintained by a small crew. Specialists design geothermal technoecosystems, and they rapidly evolve new concepts for components and networks. On the inside, geothermal technoecosystems have cybernetic control rooms (inward sector). On the outside (outward sector) they deal with subterranean and subaerial environments--taking in energy, materials and technoorganisms, expelling waste, maintaining structures, shielding flows and storages from entropy increase, and exporting concentrated products to the main technoecosystem in payment for machinery investment and high-energy lifestyles of staff and managers.

Geothermal technoecosystems are governed by money flows; net energy is as uncertain as in any other part of the technoecosystem. Geothermal technoecosystems, though relatively new, have their own social networks and political power hierarchies. Many humans in industry, academics, and government have come to think of themselves as geothermal people, and they have become spokesmen for the technoecosystems they manage, develop, and dream of.

Original hot spring technoecosystems were, and are, largely for direct human support and comfort--inward sector components. But modern high-energy high-technology geothermal technoecosystems are mostly outward sector subsets. As such they are largely independent of cultural background, and are dependent chiefly on environmental conditions and local technoecosystem needs. In addition to this environmental determinism there is a major element of inertia of surface and subsurface precedents; drillholes and powerplants cannot be moved, and once established they influence future development geometry.

Geothermal technoecosystems consist largely of mechanical sector components: subsurface drillholes, and machinery and plumbing above ground. They also include inorganic sector parts: subterranean geothermal reservoirs, and surface flows and storages of water and chemicals. Finally, there can also be an interface with biological sector in diverse agricultural applications of geothermal products.

When we survey geothermal technology we see that there is a fabulous variety of technoecosystem components from which to choose: small parts, modules, technoorganisms, subsystems, small technoecosystems. Like toy armies or electronics modules, these separate components can be assembled, plugged into each other, and arranged in an infinite array of possible geothermal technoecosystem morphologies. Whole systems can be designed and adapted to fit almost any environment, available niche, purpose, or fantasy. If components available off the shelf are not sufficient, new ones can be designed on demand. With the energy flow that one or several million dollars control, new concepts for technoecosystem component configurations can be dreamed up and cyrstallized into solid hardware. For someone in the money, geothermal technoecosystem design and operation can be an enjoyable macroscale game.

Some design strategies earn lots of money, others make less, and some lose. The same situation exists for net energy. Optimally, large amounts of both net energy and money are generated. But with subsidies, money can be gained while net energy is lost.

Accelerating growth of geothermal technoecosystem numbers, size, and diversity seems to indicate that a new energy niche is opening. In some marginal cases it may not be clear whether this new niche is an actual competitive net energy niche or whether it is just another way to make money by expending large subsidies of fossil fuel wealth.

Geothermal technoecosystems, as just shown, have typical technoecosystem properties. But they also have peculiarities which differentiate them from other technoecosystems. Like most technoecosystems, geothermal technoecosystems are horizontally flattened in the land surface environment (solid-gas interface), where most humans live and where structures have solid foundations and energy cost of movement is low. Like plants, however, geothermal technoecosystems have a vertical dimension. They are vertical vectors along a vertical energy and materials gradient. Plants must send roots down for water and leaves upward for radiation input. Similarly, geothermal technoecosystems drill deep for heat and water, and run thermodynamic cycles by transferring heat upward by convection and evaporation to atmosphere and space.

The ultimate constraints of the geothermal energy niche are the temperature (wet or dry bulb) of the atmosphere, determined by solar radiation balance and atmospheric convection systems, and the temperature of rocks and fluid at exploitable depth, function of geological cycles. The difference between these temperatures determines the ultimate thermodynamic limits of exploitation. Useful potential energy, and therefore an energy niche, exist only because there is thermal contrast.

Additional constraints are geological in nature: size of heat storage, permeability of rocks, salinity of fluids, availability of water, rates of heat and water recharge.

Still other constraints on the geothermal niche are based on technoecosystem factors: energy requirements for exploration, drilling, and geothermal technoecosystem construction; energy costs of energy, materials, and information from the main technoecosystem; and energy payments the main technoecosystem makes for geothermal technoecosystem outputs. Technology, knowledge, and existing industrial capacity are also important niche-determining parameters.

Simple geothermal technoecosystems use geothermal resources as they naturally occur at the surface. But advanced, high-energy systems have a greater appetite for calories and high temperatures. They cannot tap heat flow, for it is too slow and cool and diffuse except in scattered natural concentration systems, like extremely rare geysers and intermittent volcanoes, both very difficult to exploit. Advanced geothermal technoecosystems, therefore, can only tap heat storage. They must gain access to heat at depth, they must drill, they must violate inner earth systems with rotary probes.

A drill hole is much like a plant root. The root taps energy storage in the form of soil moisture and salts, and concentrates and accelerates its flow upward through a narrow conduit. Similarly, the geothermal well taps energy storage in the form of heat and fluids and channels it upward at rates many times normal. Drill holes connect two worlds. They announce the low-energy surface world to the subsurface and introduce the high-energy subsurface world to the surface. Geothermal fluids are delicately adjusted to the pressure-temperature-composition conditions of their subterranean environment. When a drill casing, embassy and open conduit to the lower energy surface environment, penetrates to the fluid reservoir, rapid upward flow is often spontaneous.

Since geothermal resource types and properties are highly variable, geothermal technoecosystems must be flexible and take many forms. Each geothermal technoecosystem is a special case and must be custom fabricated of specialized components and materials to fit the unique properties of the reservoir it exploits: geometry, depth, temperature, pressure, fluid composition, permeability, recharge rates, and atmospheric and water supply characteristics at the surface. Needs and capabilities of the surrounding technoecosystem must also be taken into consideration.

Exploration complexity and ingenuity are major features of the geothermal energy niche, as they are of the petroleum niche. However, oil is structurally and stratigraphically controlled while geothermal heat is depth controlled. Oil does not occur at all beneath many areas, whereas there is always high-temperature heat at some depth. Once found, though, oil is easily transported long distances. Geothermal heat, in contrast, must be used near its source or transformed to a more easily channeled form like electricity or hydrogen.

Geothermal technoecosystems for power production are much simpler and smaller than systems which run on fossil or nuclear fuels. Geothermal heat is already concentrated and stored underground, whereas other systems involve complex large-scale fuel extraction, processing, transportation, storage, and finally heat production technoecosystem subsets.

There is a geothermal energy niche; geothermal technoecosystems which survive can be and have been built. But the next chapter shows how small the niche really is. It is apparently not large enough to run the entire global high-energy technoecosystem for very long. The geothermal niche is presently only a small subset of the fossil fuel niche; all of its technoecosystem components are manufactured by the largely fossil fuel powered global technoecosystem. It is likely that the geothermal energy niche will remain a small subsidiary niche as long as fossil fuels last and probably even after the hoped-for global conversion to some new long-lasting energy niche.

It is interesting to compare the configuration constraints and possibilities of geothermal technoecosystems and solar technoecosystems. Solar systems are upward oriented, collecting stellar radiation energy; geothermal systems reach downward, toward planetary thermal energy. Solar systems can exist solely at the surface, while geothermal systems must drill to higher temperature domains. The greatest differences between the two systems are based on the contrast between the energy sources: solar radiation and geothermal heat.

Solar flux, while diffuse, is strong enough to be collected directly for some technoecosystem uses, e.g., space and water heating, distillation. It has energy value, too, because of its photon wavelength properties; photon traps, such as certain thin film laminates, can produce high temperatures or generate electricity (solar cells). Plants capture photons and store chemical potential energy through photosynthesis. Perhaps most important for high-energy technoecosystems, solar radiation has geometric energy value. Direct insolation reaches us from its distant source in orderly, parallel rays. Thus direct solar flux can be geometrically concentrated with reflectors and lenses to very efficiently produce very high quality concentrated light and heat, limited only by collector parameters and the brightness of the sun. No inefficient thermodynamic energy concentration cycle is needed; the concentrating solar collector geometrically decodes the diffuse but orderly direct solar flux to approximately reproduce the radiant conditions of the sun's surface.

Geothermal heat flux, in contrast, is too weak globally to be collected for even low-energy technoecosystem uses. Geothermal technoecosystems have two options: collect heat flow where it has been concentrated by natural geological thermodynamic convection engines (e.g., hot spring areas), or drill deep to collect heat storage concentrated at relatively shallow depths by natural convection and conduction systems in hierarchical alternation. Most geothermal heat flow originates as very high quality energy (originally star energy) by nuclear fission of heavy elements. But these atoms are generally quite scattered, and the energy they generate is quickly dispersed as much lower quality heat. Heat energy, unlike radiant energy, cannot be geometrically and reversibly reconstituted to former higher quality; that is the second law of thermodynamics. Heat energy can only be concentrated locally by degradation of more heat elsewhere in some kind of limited-efficiency thermodynamic cycle, either in the earth or in the technoecosystem.

Geothermal technoecosystems, as integral parts of the global technoecosystem, inevitably contribute to energy flows in military technoecosystems. They may provide heat, water, and electricity directly to military systems, or indirectly through the civilian industrial complex. Concentrated synthetic fuels and hydrogen produced by geothermal technoecosystems could someday power high-energy military technoorganisms in combat, if military technoecosystems should continue their existence.

Water plays many roles in geothermal technoecosystems: drilling fluid, heat storage and transfer medium, thermodynamic cycle working fluid, chemical solvent and reactant, evaporative coolant for thermodynamic power and distillation cycles, and liquid product for drinking or crop irrigation.

In arid lands, geothermal technoecosystems tend to be specifically adapted, where possible, to produce fresh water for technoecosystem use. If subsurface water is scarce, they are designed to minimize water consumption. If subsurface water is absent (hot dry rock reservoir), it may have to be imported.

Geothermal technoecosystems are the top consumer in the earth heat cycle hierarchy. They can be voracious heat consumers. A 100 megawatt power plant at 16 percent conversion efficiency represents the equivalent normal gradient heat flow for an area of 10,000 square kilometers. Geothermal systems outcompete geysers and other earth systems because they extract heat so effectively and because they have self-amplifying feedback of concentrated energy investment. But by tapping storages they can easily outgrow sustained carrying capacity. Although the geothermal niche could be a flow niche at low exploitation rates, it is probably a stock niche at projected exploitation rates. Geothermal technoecosystem succession will probably be observed as high-grade reservoirs are depleted and competitive net energy ratios decline.

In 1976 geothermal technoecosystems are quite young, comparable to petroleum technoecosystems at the turn of the century (Ellis, 1975). Who in 1900 could have predicted the highly sophisticated global petroleum technoecosystem of today? Similarly, it is impossible to foretell with certainty what geothermal technoecosystems will be like at maturity. Their future forms are probably not yet dreamed of.

Several major aspects of geothermal technoecosystems are reviewed in following sections of this chapter. In some sections geothermal resource types are discussed in the reverse of their order in Table 1. This seems logical because hydrothermal convection systems, the nearest surface resources with highest heat flow, are also the most easily exploited and thus the best known. Deeper resources with lower heat flow (higher position in Table 1) are more difficult to tap, knowledge about them is more hypothetical, and exploitation systems are either experimental or still on the drawing board. Possibilities for advanced technoecosystem morphologies are pointed out where they are seen. And arid lands peculiarities of geothermal technoecosystems are emphasized. Specific applications are reviewed for developing countries and for Imperial Valley, California, in later chapters. For information about applications in other arid locations around the world, the Bibliography and its subject index should be consulted.

2. Exploration, the Macro-Hunt

In order to tap energy flows or storages, some energy must be invested. Exploration is the first and perhaps the most exciting step in developing a geothermal technoecosystem. High-quality near-surface geothermal resources are rare, unevenly distributed and often well hidden. A high degree of ingenuity, complex strategies, and large energy investments are required to find them. Geothermal exploration is a form of hunting, direct descendant of the bioecosystem hunting of early man. But instead of biological systems yielding meat and hide, the quarry is dynamic geological systems which bear water and steam. The prey is food for high-energy technoecosystems rather than for men. The hunting ground has expanded to global scale. Senses beyond the human six are utilized, and mechanical technoorganisms and instruments take the place of horses and spears.

Geothermal hunters are not just men of skill and experience; they have letterheads and advanced academic degrees in place of feathers and trophies. Geothermal exploration is a complex endeavor, and many specialists are needed: geochemists, geophysicists, remote sensing contractors, and drilling engineers. Heading the exploration team, though, are geologists, generalists who know earth systems intimately in all their aspects and at many scales. Geological experience gained in other sectors of technoecosystem is put into action, and each new geothermal hunt, successful or not, adds to the relatively young cumulative store of geothermal exploration knowledge.

Most geothermal fields now being exploited were found by observing relatively obvious surface manifestations such as hot springs, fumaroles, and altered rocks, much as oil seeps led to the first large oil field discoveries, and much as rich mineralized outcrops in unexplored territory revealed ore deposits at shallow depths. But underground reservoirs must be located precisely and their properties comprehended before exploitation can begin. And many geothermal reservoirs leave few traces at the surface.

Techniques more sophisticated than surface inspection are needed to gather information about subsurface conditions. Technoecosystem energy investment is required to pierce the geological fog by detecting patterns through non-human perceptual filters. Specialized techniques have been evolved; they are like senses more refined than those we are born with. Geochemical analysis is analogous to our senses of taste and smell. Remote sensing is an extension of sight. And geophysical methods are like touch, hearing, and the electrical senses of some fish. Specialized technoecosystem components and configurations are required for each exploration perception mode.

The only way to know for certain what lies below is to sample it by drilling. But drilling is extremely costly and there is an astronomically large number of possible drill sites on this planet. Hence, to maximize net energy output, exploration strategy has evolved into a hierarchically cascaded stochastic game. Maximum information is gained from minimum energy investment by narrowing down the possibilities in discrete steps. Exploration techniques are used in succession, in order of increasing cost per area, and from large to small scale. Combs and Muffler (1973) suggest this order of technique utilization: literature search, aerial survey, geological and hydrological survey, geochemical survey, geophysical survey, and drilling. McNitt (1975) reports a similar order. The actual optimum sequence may vary with specific geological circumstances, but deep drilling is always the last stage.

Geothermal exploration strategy is like military strategy in several ways. An elusive but not evasive target is sought through investment of finite resources. Previously gained knowledge is applied, and specially adapted technoecosystems and technoorganisms are deployed for sensing and manipulating the environment. Planning cascades from macroscale to microscale morphology and actions. And highest energies are used only where most effective, for the final kill. Similar patterns are found in the biological world, e.g., predation.

General reviews of geothermal exploration techniques and strategies are provided by Bodvarsson (1970), Combs and Muffler (1973), Crosby (1971), Ellis (1975), and Hickel (1973).

At the macroscale, general geological knowledge is the most valuable exploration asset. Probably more than 90 percent of the globe can be eliminated from consideration simply by understanding global tectonics and knowing where the geothermal regions are (frontspiece map; and Lister, 1974). Geothermal regions may look small on the world map, but they look quite large when we are there, even if in a jet plane. More sophisticated and detailed geological knowledge is needed to narrow down the choices within a geothermal region. Koenig and Huttrer (1975) suggest prospecting along subtle geological linear features and at their intersections. Faults, favorable stratigraphy, and young volcanic rocks are additional clues. McNitt (1973) reviews applications of geology and hydrology in various stages and scales of geothermal exploration. They form the framework within which detailed data are gathered and interpreted.

Remote sensing in diverse electromagnetic wavelength bands from aircraft and satellite technoorganisms can yield much useful information for narrowing down exploration target choices. Lithology and geological structure, hydrothermal alteration haloes, soil and vegetation anomalies, and general geography are revealed by photographs in visible and near-infrared bands (Hodder, 1973; Reynolds and Wagner, 1975). Plant moisture stress and rapid snowmelt can indicate high heat flow areas (Reynolds and Wagner, 1975; White, 1969). Passive thermal infrared imagery and passive microwave radiometry can detect surface temperature anomalies (Hodder, 1973). However, heat flow must exceed 300 to 500 times normal in order to show up on infrared imagery (Kappelmeyer and Haenel, 1974), which may limit the use of this method to only the hottest and most obvious thermal anomalies (hot springs, geysers, fresh lava flows).

Satellites provide remotely sensed information at lowest cost per unit area, but resolution is low so only macroscale patterns are discerned. Aircraft provide higher microscale resolution but at greater cost. Hence a natural cascading sequence (proposed by Hodder, 1975) suggests itself: 1) thermal infrared imagery from satellite for regional coverage, then 2) from aircraft at small scale, to choose just a few specific sites for 3) costly in-person field checks by geologists in exploration vehicle technoorganisms.

Geothermal systems are complex chemically as well as thermally. Elements, ions, molecules, and isotopes are concentrated and recombined under the influence of a great variety of equilibrium and solubility thermodynamic relationships. A geochemist samples some of a system's atoms either at the surface or in wells, and he attempts to deduce information about its physical properties from detailed chemical analyses. Geochemical determinations yield useful information at all stages of geothermal exploration and exploitation. Geochemical methods are reviewed by Mahon (1973) and Sigvaldason (1973). Geochemical sampling tools (Presser and Barnes, 1974) and laboratories are all technoecosytem components, optimally arranged and adapted for this purpose.

Some elements are good indicators of the presence of thermal waters and can be used for reconnaissance. Lithium can be traced to its source if a continuous surface drainage system exists (Brondi, Dall'Aglio, and Vitrani, 1973). Other elements more useful in arid regions are mercury (Matlick and Buseck, 1975) and helium (Roberts et al, 1975). Other elements, ions, and isotopes (geothermometers) equilibrate to temperature in specific ways, and their analyses can be used to estimate subsurface reservoir temperatures: sodium-potassium-calcium (Swanberg, 1974), silica, carbon isotopes, and oxygen isotopes in sulfate-ion-water pairs (Cortecci, 1974). However, assumption of negligible dilution and re-equilibration is often incorrect, so results are not certain (Fournier, White, and Truesdell, 1974). Noble gas content may indicate whether or not the reservoir is superheated and steam-bearing (Mazor, 1975*). Clever techniques have been devised to reconstruct the origins, paths, and mixing histories of geothermal fluids from geochemical data (Arnason and Tomasson, 1973; Fournier and Truesdell, 1974). Such knowledge may be important for estimating recharge potential and thus field lifetime in arid lands (Ellis, 1975).

Geophysical exploration techniques, reviewed by Banwell (1973) and Strangway (1973) are diverse and numerous. Electrical resistivity surveys are usually the most valuable. Low resistivity anomalies result from high water salinity, high temperature, and high rock porosity, all favorable reservoir characteristics (Ellis, 1975). Various electrode arrays and current pulsing strategies yield resistivity data for vertical and horizontal dimensions through different geological cover (Strangway, 1973).

Temperature measurements are also quite useful. Surface temperatures are easy to measure, but they are only significantly affected by very high heat flows. Temperature gradient and heat flow measurements are much more sensitive and helpful, but require costly shallow drilling.

Many other geophysical methods are used to answer specific questions in specific geological situations. Active seismic reflection, refraction, and frequency response surveys can point to geothermal activity; high attenuation and shift to lower frequencies are common characteristics of geothermal reservoirs (Hickel, 1973). Passive seismic observation can detect microearthquakes which occur in hydrothermal convection systems along faults (Hamilton and Muffler, 1972; Hill, Mowinckel, and Peake, 1975; and Ward, 1972). Aeromagnetic surveys can be used for studying geological structures, and they can pick up evidence of hydrothermal alteration (Evans, 1972; de la Fuente Duch, 1973). Finally, gravity surveys may yield information about subsurface structures when lithologic density contrast is great enough.

No one exploration method, other than drilling itself, offers unambiguous results. Each technique can be diagnostic in one setting and misleading in another. Meidav (1975A) suggests that exploration success can be improved by combining data from specific geochemical and geophysical methods which complement each other.

Igneous-related systems (magma bodies and associated hot-dry rocks) can be detected by surficial geological evidence: calderas, domes, fracturing, and volcanoes. Their existence at depth may also be indicated by the presence of hot springs and hydrothermal convection systems. Gravity and magnetic geophysical surveys can provide volume estimates for magma bodies (Smith and Shaw, 1975). Seismic noise surveys can locate areas of slow, deep hydrothermal convection, and electrical resistivity surveys can detect rock volumes in which high-conductivity sulfide minerals have been deposited (Norton and Gerlach, 1975*). Geochemical analysis of volcanic rocks can reconstruct magma crystallization history, and radioisotope dating techniques can reveal whether or not the igneous body is young enough to still contain significant heat. However, only drilling will tell for certain whether an exploitable resource exists. At Marysville, Montana, a geophysical prospect originally thought to be a hot rock reservoir at shallow depths fell far below expectations and research drilling was abandoned (Geothermal Energy, January 1975, p. 59).

Exploration for salt domes and geopressured formations in subsiding sedimentary basins is easiest of all--it is already done. Sedimentary basins are probably the most drilled, most geophysically surveyed, geologically best known real estate on the planet, because they are the prime petroleum reservoir domains. However, much of the subsurface information is held confidential by petroleum companies at present. Additional geothermal exploration in this geological environment could continue to use techniques evolved by the fossil fuel technoecosystem.

No exploration is needed for normal gradient resources. Drilling deep enough will reach any temperature desired. Certain tectonic provinces and rock types (granite with high uranium-thorium content is best) have heat flow slightly higher than others, and may be more favorable for exploitation. Thermal conductivity contrasts may result in conductive heat storages nearer to the surface.

Succession of geothermal exploration technoecosystems is seen on local and global scales. At the local level, for a single field, exploration systems start at the surface and work deeper, start with general reconnaissance and work toward the specific site. One exploration technoecosystem after another combs the area and zeroes in on the target, preparing the niche for a geothermal exploitation technoecosystem (the niche is not open until it is known to exist). At the global level, succession and evolution occur as the easiest-to-find, highest-quality resources are found and tapped. Exploration technoecosystems must become progressively more complex and subtle. And exploration strategies must also evolve toward increasing sophistication.

3. Drilling

If there were an easy way to rapidly extract large amounts of heat from great depths, geological systems probably would have done it long ago. The most effective natural configurations for rapid vertical heat flow are volcanic vents and geyser tubes; drill holes are their technological equivalent. In drilling, however, energy expenditure is cybernetically localized by exploration technoecosystems, and it is focused through high-energy technology and special materials to remove solids and form a fluid-flow channel at a precisely chosen position.

Exploration cost is the first energy tax imposed by depth: information becomes increasingly uncertain yet more expensive to gain. Drilling cost (for exploration and exploitation) is the second energy tax of depth. Energy cost of drilling increases exponentially with depth (Berman, 1975*) and temperature, and finally becomes so high that technology to go deeper and hotter has not yet been proven or used in practical work. Drilling cost is one limit of the geothermal energy niche. Almost anywhere on earth, in areas of normal temperature gradient, temperatures high enough for power production (200 to 300°C) exist at depths of only 10 or 12 kilometers (6 to 7 miles). It is easy for us to travel such distances horizontally within the atmosphere, but such depths can be reached by slender drill tools only by spending a fortune of kilocalories and dollars.

Matsuo (1973A, 1973B) and Cromling (1973) review operational first-generation drilling and well development technology for penetrating hydrothermal convection systems. Drill rig technoorganisms and associated equipment are borrowed directly from petroleum exploitation technoecosystems, although certain modifications have been necessary. Most commonly used are standard rotary rigs with mud circulation. To cope with high temperatures, pressures, and corrosiveness of geothermal fluids, specially adapted drilling muds, wellhead equipment, well casing, and operating procedures are required. Air circulation can be used in dry zones and for dry steam reservoirs; it is faster and cheaper, and may avoid water handling difficulties in arid lands.

Wells in wet steam and dry steam geothermal fields now being exploited for power production have average depths ranging from 300 to 1500 m, and the maximum depth reported is 2.9 km, at the Geysers (Ellis, 1975). Rotary drilling technology is tested and reliable for depths to 7.6 km (25,000 ft) and temperatures as high as 250°C (Hickel, 1973). Just a few oil and gas exploration wells have penetrated deeper (Berman, 1975*).

Shallow hot water wells (45 to 550 m) are so inexpensive to drill that they are used for a wide variety of small heating applications in Klamath Falls, Oregon. Standard rotary, air-rotary, and cable-tool drilling rigs are used (Storey, 1974).

A wide choice of methods is available for logging and completing wells (Matsuo, 1973A; Cromling, 1973). Flow rates into wells can be augmented in many situations by increasing permeability of surrounding rocks with chemical explosives (Austin and Leonard, 1973).

Much research is underway to develop new drilling technologies which will lower cost of standard geothermal drilling (present costs are two to four times as much as oil drilling) and permit penetration into deeper and hotter reservoirs (Narath, 1975). New design concepts include spark drills, projectile-firing drills, and drill bits which can change cutting edges while remaining at depth. One concept, the subterrene, involves melting rock with an electrically heated bit, slicing through it like butter, and leaving a smooth glass-lined hole surface behind. One advantage of the subterrene is that it works better the hotter the rock is, so very deep and very hot applications may be possible. Berman (1975*) provides a detailed review of limitations and possible improvements of present technology, lists several additional drilling methods, and presents concepts for deep drilling which include sinking shafts so drill rigs can be operated from successively deeper levels.

Drilling of geopressured-geothermal reservoirs can continue with present petroleum technology, including the use of offshore drilling platform technoecosystems. Minor modifications for high pressures and temperatures may be needed. It is possible that in many cases the drilling has already been accomplished--abandoned hydrocarbon wells may be revived for geopressured-geothermal use (Papadopulos et al, 1975).

Drilling technology appears to be the most critical feasibility limiting factor in development of technoecosystems which exploit energy from magma (Peck, 1975). Temperatures of 650 to 1200 °C, depths of 3 to 6 km, and a highly corrosive and stressed environment must be designed for.

Technological limitations of normal gradient area drilling include high costs, pressure limitations of casing, and tensile strength (and therefore depth) limitations of casing and drill steel alloys (Berman, 1975*).

4. Resource Extraction

Geothermal resources wait at depth; diverse geothermal technoecosystem modules are assembled at the surface. Somehow the two must be brought together. Geothermal resources vary greatly in quality and quantity; resource extraction systems must be designed to match them. Certain characteristics are probably always found in geothermal resource extraction systems: 1) The resource includes heat (it can also include fluids, gases, and chemicals), 2) drill holes are involved as resource channels, and 3) fluid flow is involved as the most effective resource transport mode. Heat exchangers are used in many extraction schemes.

In resource extraction we find a third energy tax of depth. Fluid flow through vertical conduits (wells) from depth to surface is a universal feature of geothermal resource extraction methods. And fluid flow is restricted by friction. Longer and deeper conduits require greater energy expenditure (by self-pumping fluid or by technoecosystem pumps) to overcome greater pipe friction. This effect is compounded because thicker casing is needed to withstand greater pressures at depth, and the consequently narrower opening increases friction per unit length. Thicker casing is more expensive, which further increases cost. Finally, long conduits serve as crude heat exchangers and result in cooling of fluids on their way to the surface; greater length may mean increased loss of thermal energy by cooling.

Resource extraction systems for hydrothermal convection systems range from simple to complex. Most present-day systems bring hot natural fluids to the surface, but some proposed systems would send artificial heat exchange fluids down instead. J.H. Smith (1973) describes typical systems in use for collection and transmission of geothermal fluids. They tend to consist of jungles of pipes and valves at wellhead, feeding into long, dendritically converging pipelines which zig-zag to allow for thermal expansion and contraction. Special materials, coatings, and enclosures must often be used to protect sensitive parts of geothermal technoecosystems from corrosive geothermal liquids, gases, and vapors (Marshall and Braithwaite, 1973).

Dry steam resources probably have the simplest resource extraction systems. The resource consists of heat and water in the form of superheated steam with minor gases, usually carbon dioxide and hydrogen sulfide, and it can be fed almost directly into pipelines (J.H. Smith, 1973) for power generation. Budd (1973) describes the simple wellhead equipment used at the Geysers. Due to reservoir pressure depletion, new wells must be added to the collection system periodically to maintain production rates.

Extraction systems for wet steam resources are more complicated. The resource consists of liquid water hotter than surface boiling temperature, and dissolved gases and salts. When chemistry of the fluid is favorable (low salinity and low CO_2 content), it can be flashed in the well and thus pump itself to the surface. A centrifugal "cyclone" separator separates water from steam. Steam is fed into a pipeline and water is discharged by flashing at atmospheric pressure directly into a pond, a noisy process. Or separated water can be flashed in a silencer and then drained by ditch to a disposal site (J.H. Smith, 1973). Such a system is used at Cerro Prieto, Mexico. Changes in pressure and temperature cause some underground geothermal fluids to deposit minerals, and the same thing happens when flashing occurs in wells. Scaling can reduce and eventually stop flow in wells (Nathenson, 1974). If scaling is slow, periodic cleaning will suffice to maintain production. However, if scaling is too rapid, an alternative extraction scheme is needed.

A large volume of hot hypersaline brine underlies Imperial Valley near the Salton Sea. Exploitation for power production has been discouraged, though, by the brine's corrosive and rapid-scaling properties, and by the undesirability of salt buildup at the surface (Ramley, Peterson, and Seo, 1974). Consequently much research is in progress to develop new methods for extracting thermal energy from such brines. Berman (1975*) summarizes several concepts for doing this. One concept is to expand the fluid to the surface and feed the combined brine-steam mixture directly to an impulse turbine (total flow concept). Other concepts involve suppression of flashing and extracting heat alone from the fluids through heat exchangers. Geothermal brines can be pumped to heat exchangers at the surface and then returned to depth (Ramley, Peterson, and Seo, 1974), or a heat exchange fluid can be pumped down to the brine and then back up to the surface (Engineering and Mining Journal, 1973). Furthermore, heat exchangers can be of two types: standard models where heat is conducted between fluids through thin walls of metal tubes, and direct contact heat exchangers in which the heat exchange fluid is immiscible with brine. Hutchinson (1974) invented a direct contact heat exchanger for use at the surface, and Hickel (1973) suggests direct contact between brine and an immiscible working fluid which is injected into the reservoir and then recovered.

Hot water resources can be exploited by pumping to the surface with standard pumping technology. High-temperature hot water resource can heat a low boiling point fluid through a heat exchanger to generate electricity.

Once a wet or dry steam hydrothermal convection system is found and drilled, the long, routine process of exploitation begins. The field responds to exploitation, and its behavior must be carefully monitored so that it can be managed to maximize production magnitude and duration. Numerous measurements are made to monitor exploitation progress: well pressure, temperature, and performance, fluid geochemistry, and ground level (Bolton, 1973). Dench (1973) reviews well measurement techniques (surface and downhole) which may be useful, and Mahon (1973) and Sigvaldason (1973) review geochemical methods for monitoring geothermal fields. Ground level measurement can detect subsidence due to removal of water or to thermoelastic contraction of rocks in response to subsurface temperature decline (Bodvarsson, 1975*).

Production lifetime of a reservoir (where natural recharge is limited) can be extended by reinjecting waste hot water in downward-convecting parts of the system (Bolton, 1973). Production rate and duration of a hydrothermal reservoir can be increased by explosive stimulation using nuclear or chemical explosives to increase fracture permeability and effective heat exchange surface area of subsurface rocks (Ewing, 1973; Ramey, Kruger, and Raghavan, 1973).

Hot-dry rock associated with igneous systems contains a great deal of thermal energy. One cubic mile of rock cooled from 350°C to 150°C would yield usuable energy equivalent to 300 million barrels of oil (Burnham and Stewart, 1973). But extracting heat from a cubic mile of hot-dry rock is easier said than done. Water is, by definition, scarce, so heat exchange fluid must be added. And permeability is generally low, requiring augmentation. Two major mechanisms have been proposed for generation of fracture permeability: hydraulic fracturing and use of nuclear explosives (Friz, 1973). Presumably, these methods will also work in deep zones of normal heat flow areas, if drilling can ever penetrate that far.

Most work on hydrofracturing for heat recovery has been done by the Los Alamos Scientific Laboratory, with field testing in hot granites underlying the Jemez Plateau, New Mexico. The basic technique is to pump water into a borehole until a vertical fracture forms. Continued pumping enlarges the crack until leakage rate (if any) equals pumping rate. Thermal stresses due to water-rock temperature contrast will theoretically create new cracks and enlarge the heat-exchange area (Berman, 1975*; M.C. Smith et al, 1973; Harlow and Pracht, 1972). Thermal energy might be extracted by injecting water through one hole and recovering steam or hot water through a second bore, perhaps by natural convection. Hydrofracturing in granite has proven successful, but the thermal stress fracture hypothesis has yet to be tested (Science, 1973; M.C. Smith et al, 1975).

Schemes for fracturing large volumes of hot rock with nuclear explosives were included in the large U.S. government Plowshare program, now defunct. Specialized nuclear bombs, designed for emplacement down drillholes, would be sequentially fired in a precisely planned array (Burnham and Stewart, 1973; Ramey, Kruger, and Raghavan, 1973). Water would be introduced to the hot, artificially fractured reservoir, flashed to steam, condensed at the surface in heat exchangers, and then reinjected in a closed cycle to extract heat for power generation (Nuclear News, 1971). Corrosion and scaling difficulties might be expected, so design and materials would have to take them into account (Krikorian, 1973). Severe environmental impacts and dangers would also be involved (Sandquist and Whan, 1973). Berman (1975*) provides a technical review of the Plowshare geothermal concept.

Where high permeability already exists, as in hot lava layers near volcanoes, water injection may be all that is necessary to create a hydrothermal reservoir (Furumoto, 1974). Water is not the only heat exchange fluid that could be used in extracting thermal energy from hot-dry rock reservoirs. Baciu (1975*) patented the idea of using supercritical CO_2 as a heat exchange and power fluid. Other fluids might serve as well in special situations.

Whatever technique is used to create permeability, and whatever fluid is injected for heat extraction, hot-dry rock reservoirs are created and controlled by human-controlled systems and are thus technoecosystem components. Fracturing hot-dry rocks is just another technoecosystem expansion activity, like clearing frontier forests to make agricultural fields. And fracturing is like building a transportation network in an economic landscape--access to heat storage becomes faster and more widespread, and energy flow accelerates.

Magma, with much higher temperatures than hot-dry rocks, has correspondingly greater thermal energy content per volume. But heat extraction may be quite difficult. Scientists at Sandia Laboratories, New Mexico, have been exploring some of the possible heat extraction technologies (Colp and Brandvold, 1975; Peck, 1975). A heat exchanger tube inserted directly into a magma chamber is the most likely configuration. Either water or gas could be the working fluid in a closed-cycle system. Materials which can survive in such a hot, high-pressure, corrosive environment would have to be found. And extraction feasibility will probably depend on how fast magma will convect near the heat exchanger (Peck, 1975).

Heat extraction from salt domes could be accomplished by drilling wells into a solution cavity and circulating water, steam, or some other fluid through it (Jacoby, 1974). Extraction of fluids from geopressured reservoirs is not difficult. Penetration by drill hole is all that is required; the fluid pressure forces it to the surface spontaneously (Papadopulos et al, 1975).

5. Power Cycles

Most commonly mentioned use for geothermal resources is the generation of electricity. Furthermore, most research and development emphasizes power generation technologies. This fixation on electrical use, particularly in the U.S., may stem from the great concentration of wealth controlled by electrical utility managers. And it may also be due to the fact that electricity is the highest quality energy form that geothermal technoecosystems can currently produce and transport long distances to other technoecosystems. Geothermal power production represents only about 25 percent of total global geothermal technoecosystem energy flow (Peterson, El-Ramly, and Dermengian, 1976*), but if energy quality is accounted for (they do not differentiate electrical from thermal megawatts), it may actually be the largest use of geothermal resources. World total geothermal generating capacity is now over 1300 Mwe, at 18 installations in 11 countries (Ellis, 1975).

Steam turbogenerators were the first technology used to generate electricity from geothermal steam, and they are still the most common. In the beginning they were borrowed directly from fossil fuel technoecosystems, and since then turbine and condenser system designs have been gradually adapted to fit the characteristics of geothermal steam. Wood (1973) summarizes geothermal steam turbine generating technology, including turbine design, condenser configurations, and machinery to extract noncondensible gases. Finney (1973) outlines the specific application of steam turbine technology at the Geysers, California, world's largest geothermal power installation.

Steam for driving turbines can come directly from a natural dry steam reservoir, or it can be separated from boiling water flashed from a wet steam reservoir. Multiple stage flash turbine systems are more efficient thermodynamically than single flash systems, but they are also more expensive. Steam can also be tapped from an artificially created reservoir in hot-dry rock, or from a closed-cycle heat exchanger inserted into a magma body.

A peculiarity of geothermal power production is that (unlike in the fossil fuel power industry) cost per kilowatt varies little from small powerplants to large ones; economies of scale do not apply beyond a small minimum size (James, 1973). In addition, where ample steam is supplied from underground, small turbogenerator plants can exhaust directly to atmosphere, eliminating the need for expensive condenser systems (Cataldi, DiMario, and Leardini, 1973). Both of these properties make geothermal power production ideal for small installations in rural areas and developing countries.

Where geothermal fluid is too corrosive for direct feed to a turbine, or where fluid temperature is too low, a binary (or vapor-turbine) cycle may be chosen for power production. In such a cycle, a working fluid is boiled in a heat exchanger, drives a turbine, and is cooled and condensed for return to the heat exchanger (Anderson, 1973; Wood, 1973). Such systems can be designed around a wide variety of working fluids, including refrigerants and diverse organic fluids. Multiple-stage binary cycle systems offer increased thermodynamic efficiency, but are more costly to build and maintain.

In addition to axial flow turbines used in most steam and binary cycles, there are numerous alternative geothermal prime mover configurations. Designs which can use unseparated brine-steam mixtures typical of wet steam reservoir output include the helical rotary screw expander (Wehlage, 1973) and total flow impulse turbines (Austin, Higgins, and Howard, 1973; Austin and Lundberg, 1975*). Another mechanical energy producer is the bladeless turbine (Kruger, 1975). Piston engines are not usually mentioned in the geothermal literature, but they might be considered. And there is a vast collection of other inventions which have been dreamed up for converting heat and pressure into mechanical energy to drive electric generators. Mechanical transducers are not the only means for power production; thermoelectric and thermochemical cycles can pump electron flows as well (Hickel, 1973).

To add to this variety, several energy conversion modes can be combined in a single power generation technoecosystem module. For instance, a wet steam system could drive a standard steam turbine with flashed steam and use the hot water residual to drive a binary cycle. And any system can be made more thermodynamically efficient (although not necessarily in net energy terms) by adding more cycles and heat exchangers in cascaded energy quality order.

In summary, geothermal power engineers are faced with a bewildering range of generation technology options, each with its unique combination of cooling water needs, equipment costs, corrosion susceptibility, geothermal fluid requirements, size, mechanical efficiency, and exhaust properties. Some components are readily available, while others have not yet been proven. Somehow, geothermal engineers must choose a power cycle which matches geothermal reservoir characteristics, environmental requirements, and input-output requirements of other modules in a geothermal technoecosystem. As an example, Witmer (1975) outlines the process of power cycle choice for hot brine reservoirs. According to his analysis, the best power cycles for such resources in arid lands, where cooling water is scarce, may be flashed steam and total flow systems.

6. Water Cycles

The many energy values of water in arid lands technoecosystems were summarized in the first chapter, and the many roles of water in geological systems were briefly reviewed in the second. Water plays numerous interlocking roles in geothermal technoecosystems, as well. Tracing water through geothermal technoecosystems is something like tracing it through biological systems or the hydrologic cycle--it follows a complicated maze of interactions and transformations at many scales which is difficult to unravel into a logical, orderly structure. Geothermal resources are complex and variable; possible geothermal technoecosystem morphologies and functions are infinite. This section surveys gross water inputs and outputs of geothermal technoecosystems, and it concentrates on water cycles in power production and desalination systems. The next section will include other specific water uses.

As discussed in Chapter I, water has several energy value roles relevant to technoecosystem functioning: gravitational potential energy reservoir, chemical fuel, photosynthesis amplifier, evaporative coolant, industrial energy flow amplifier, and thermal energy reservoir. Each energy value (except the first) is based largely on special physical and chemical properties of water which enable it to assume a wide range of thermodynamic energy states: different temperatures and pressures, different phases (liquid, steam, and vapor), and different contents and equilibria of dissolved salts and gases.

Geothermal technoecosystems, as entropy jets, change the nature of the water which flows through them. Water which exits is thermodynamically different from water which enters. In some processes, e.g., power production, the water does work on turbines and loses potential energy; it is used as a fuel. In other processes, e.g., desalination of surface water, work is done on the water and it gains potential energy; its energy quality is increased. In still other processes, e.g., self distillation of geothermal fluids, one thermodynamic property (temperature) undergoes potential energy loss while another (salinity) experiences potential energy gain; the water does work on itself. And in a few processes water may be continually recycled in an internal "closed system" heat engine. Geothermal water cycles and processes are thermodynamic transformations. Geothermal technoecosystems are specifically engineered to control, amplify, and channel these transformations to produce energy forms which are most useful for internal and external technoecosystem functions.

Water input to geothermal technoecosystems usually enters in two forms: as geothermal fluids from underground (either self-pumped by thermodynamic fluid expansion or pumped by some other technoecosystem energy source), or as imported cool water from surface or subsurface sources (technoecosystems or natural systems). Water output from geothermal technoecosystems is usually either exported to natural systems at the surface, injected into natural subsurface systems, evaporated into the atmosphere, or exported to other technoecosystem subsets. Within geothermal technoecosystems water acts as heat storage, transfer, and transport medium; as evaporative coolant; as amplifier of photosynthesis and other biological activity; as thermodynamic working fluid; and as chemical solvent and reactant. Solids and gases in geothermal fluids can follow any water input or output pathway, except that the solids will not evaporate; or they can exit as purified product materials to enter natural systems or other technoecosystems.

Geothermal technoecosystems can be designed to produce almost any water input-output combination within the constraints of thermodynamic feasibility, availability of materials, and technological capabilities. Geothermal technoecosystem designs in arid lands tend to minimize importation and maximize output of cool, low-salinity water within these constraints and within the strategy of maximizing net energy or net money profit.

In the simplest geothermal technoecosystem designs, water from natural underground systems is pumped (or it pumps itself) and is utilized directly. Some direct applications include use for space heating, hot baths, potable mineral water, and irrigation. Where heat and permeability exist at depth, but either water is not present or recharge is insufficient, water can be imported from another source, injected, and recovered for direct use of its added heat or mineral content.

Laird (1973) reviews water cycles in power production and their possible relationships to desalination systems. Power production will be discussed first, desalination second, and combined power-water systems third.

Geothermal technoecosystem modules for electricity generation can be either open or closed systems with respect to geothermal fluids (they are always open with respect to thermal energy). And they may or may not import water from other natural or industrial systems. Possible use of heat exchangers immersed in the ocean or other body of water is topologically equivalent to water importation.

Open systems which do not import water have been most common to date. These include most power systems which exploit dry steam, wet steam, and geopressured geothermal resources. Some of the potential energy of geothermal fluids is generally used for self-pumping, and at least some of the water content is evaporated to the atmosphere to provide cooling for the heat engine power cycle. At the Geysers dry steam plant, 75% of condensed steam is evaporated in cooling towers, while the rest (originally discharged into surface streams) is reinjected to the subsurface through injection wells (Budd, 1973). Wet steam powerplants produce still more excess water. At Cerro Prieto, Mexico, flashed steam (about one fourth, by weight of the fluid produced) supplies the turbines and cooling towers, and the residual hot water is discharged into a large pond. This excess of water from the power cycle means not only that such geothermal powerplants (unlike all other land-based thermal powerplants) do not compete with other uses of water (Bowen, 1971), but also that extra water may be exported to the technoecosystem either directly or through some desalination process. As geothermal resource temperature decreases, however, the power cycle becomes less thermodynamically efficient, and cooling water requirement per megawatt increases.

Open systems may import water for several reasons. Additional water may be required for large evaporative cooling needs. Imported cool water may reduce the size and cost of cooling towers. Water may be imported and injected to recharge the subsurface geothermal reservoir, and thereby prolong its lifetime or prevent subsidence; open systems proposed for Imperial Valley incorporate such a scheme. And for hot-dry rock and salt dome open systems, imported water may not only recharge the reservoir, but may also form it and fill it with fluid in the first place. Before imported water is injected into the reservoir, it can help cool steam condensers.

Closed systems are generally used where geothermal fluids have undesirable chemical properties, such as presence of excess salts, excess noxious gases, or chemical concentrations which would cause corrosion or scaling if pressure were released. Closed systems may also be used where geothermal fluids are not hot enough to produce much steam, where artificial permeability has been created and there is no natural recharge (hot-dry rock, magma, and salt domes), and where imported water and subsurface water are scarce.

Closed systems generally involve a binary cycle in which a working fluid, e.g., water, isopentane, or freon, flows in a continuous closed loop from a hot heat exchanger through a turbine to a cold heat exchanger, and back to the hot end again. In some closed systems, e.g., the new demonstration powerplant at Niland, Imperial Valley, hot geothermal fluid is pumped to surface heat exchangers and then pumped back down to the reservoir. In others the working fluid may be pumped down to the hot reservoir and then back to the surface. In either case, thermal energy is extracted but geothermal water is not.

Most closed power systems import water for filling, and sometimes for forming, artificial underground reservoirs, for providing evaporative or conductive cooling, or for both. Probably the only way such systems could avoid water importation would be to use dry cooling towers. However, the very high capital cost of these air-cooling structures, about 3 times cost of wet towers, may often exceed the combined cost of wet cooling towers and water importation.

Water's energy value as chemical fuel and as amplifier of photosynthesis and industrial energy flow increases greatly as content of salts, other solids, and gases decreases. Desalination of water is another thermodynamic transformation of which geothermal technoecosystems are capable. It can be done directly by distillation using geothermal heat, or it can be done indirectly by other techniques using electricity generated by a geothermal power cycle. Koelzer (1972) comprehensively reviews desalting technology, and Laird (1973) discusses geothermal applications. According to H.T. Odum's (1975) analysis, desalting water with fossil fuel energy is not an optimum use of scarce concentrated fossil fuel resources. In certain cases, however, geothermal desalination may be competitive in net energy terms, particularly if low-grade heat or off-peak power which otherwise would be wasted is utilized.

Distillation requires only saline water and thermal energy as inputs. Geothermal resources are characterized by thermal energy and often by saline fluids, so distillation is usually the simplest and most direct desalination pathway. In distillation, heat flow drives evaporation and condensation of water. Hence distillation is, like power generation, a thermodynamic heat engine cycle, driven by heat flow from source to sink. However, the concentrated energy product is not electricity, but water with decreased salinity. Other outputs (wastes or exhausts) are low-grade heat, noise, and salts or concentrated brine.

Geothermal distillation modules, like geothermal power modules, are small units which concentrate large thermodynamic transformations into a small space. In operation they are like a miniaturized high energy flux hydrologic cycle, with heat transfer by conduction, convection, boiling or evaporation, and condensation. As in power cycles, heat must be rejected to the atmosphere by dry or evaporative cooling towers, or to a cool body of water by heat exchanger.

Geothermal steam or water vapor can be cooled and condensed in a single step. But it is thermodynamically more efficient to use the heat of condensation to boil or evaporate still more saline water, whose heat of condensation is used in another boiling or evaporation step, and so on. Optimum thermodynamic efficiency is obtained in such a "multiple effect" system with many stages (Laird, 1973), but the actual number of stages used is practically limited by diminishing returns and net energy considerations. Here we see still another manifestation of hierarchical energy cascading for optimum energy conversion efficiency.

Two multiple effect design configurations being studied for geothermal application are the multistage flash (MSF) system (Barnea and Wegelin, 1973) and the vertical-tube evaporator (VTE) system (Standiford, 1972). Each has a distinctive convoluted arrangement of pipes, tanks, and heat exchangers, and each has its own pecularities of performance, thermodynamics, and economics. Murray (1972) describes an unorthodox but perhaps inexpensive single-stage distillation method: geothermal steam saturates dry desert air which is then passed through a large cool water reservoir to condense and recover the moisture.

Distillation can be used to directly desalt either geothermal fluids or imported saline water. Wet steam (including hot brine), hot water, and geopressured geothermal resources all can produce large amounts of fluid with enough heat to distill itself in an open cycle. Dry steam contains enough thermal energy to distill much additional (perhaps imported) water, but it is most likely to be used for power cycles instead of water cycles. Closed heat extraction systems which yield no geothermal fluids, as might be installed over a hot water, hot brine, igneous-related, or salt dome system, can provide heat for distillation of imported water. Jacoby (1974) suggests this possibility for salt domes. However, the high energy cost of building such heat extraction and water importation systems may preclude water conversion and make only power production feasible.

In some situations it may be advantageous to desalt water indirectly with electricity generated by geothermal power cycles. Water importation to the geothermal site may be too costly, saline water supply and fresh water need may be quite distant from the geothermal field, much extra power capacity may be available during off-peak load hours, or an indirect desalting arrangement may even be thermodynamically more efficient than distillation. Processes for decentralized desalination include vapor-compression distillation for certain relatively concentrated brines, reverse osmosis for saline waters with salt content of 2,000 to 5,000 parts per million (ppm), and electrodialysis for brackish water up to 3,000 ppm (Laird, 1973).

Power and desalting cycles can also be more directly linked than by electricity. Modules for power generation and distillation can be combined into a single thermodynamic unit by channeling heat or water flows directly from one to the other through pipes and heat exchangers (Laird et al, 1972; Laird, 1973). The possibility of using such a dual-purpose design for exploiting large wet steam resources of Imperial Valley has been investigated by the U.S. Bureau of Reclamation, Boulder City, Nevada, Region 3 (1974). The actual thermodynamic configuration used and the relative proportions of power and water produced can be determined on the basis of resource properties and relative values of the products to ambient technoecosystem. Optimum configuration for the East Mesa test site of Imperial Valley appears to be distillation at wellhead followed by binary cycle power production (ibid.).

Residual saline water or brine is a nearly universal output of geothermal technoecosystems which desalt water, use water for cooling, or exploit saline geothermal resources (especially wet steam) in open systems. Such brine is usually of little value to industrial technoecosystems and is actually harmful to agricultural technoecosystems (negative amplifier energy value).

There are several alternative ways to utilize or dispose of these surplus brines. In some cases they can be piped directly to a body of water. Fluids from the Wairakei plant are channeled into a river (Axtmann, 1975), and surplus fluid from geopressured-geothermal technoecosystems might be discharged into the Gulf of Mexico (Papadopulos et al, 1975). However, environmental impact of this disposal method can be severe, and perennial bodies of water are often not available to inland arid sites. Brines can also be collected in artificial ponds where solar-augmented evaporation (optimum in arid lands) can yield salts and other chemicals.

A third method for disposing of excess saline water is to reinject it into the subsurface geothermal reservoir. Driving forces for downward fluid flow can include gravity feed (sufficient at the Geysers steam field and presumably at most dry steam fields) and vapor pressure (Einarsson, Vides, and Cuellar, 1975). And in some cases (especially wet steam reservoirs) direct pumping may be necessary (Bowen, 1973). Brines are usually cooler than subsurface fluids, so injection wells should be sited away from production wells (ibid.; Bodvarsson, 1972). The optimum arrangement is to place production wells over upwelling parts of hydrothermal convection systems and injection wells over locations where cooler fluids are naturally descending (Laird, 1973). Not only salts but also gases (e.g., hydrogen sulfide) concentrated from geothermal fluid can be injected with brines and can thus be removed from the surface environment, as at the Geysers (Budd, 1973). Advantages of reinjection include conservation of thermal energy and prolongation of geothermal reservoir lifetime, especially where natural water recharge is limited, as in arid lands (Einarsson, Vides, and Cuellar, 1975).

In conclusion, water is an integral part of many geothermal technoecosystem designs. Water molecules found in many different parts of a geothermal technoecosystem have identical chemical structure. But their aggregate thermodynamic state can vary tremendously, and unique combinations of physical properties can be called into use from one place to another in the system, as water takes on its great diversity of roles. Scarcity of water in dry lands may limit the feasibility of technoecosystem configurations which require imported fresh water. On the other hand, water scarcity simultaneously enhances the favorability of geothermal technoecosystem designs which produce low salinity water, either directly from underground, or indirectly by using geothermal heat or electricity to desalt geothermal fluids or imported water.

7. Other Uses

Electricity and desalted water are universal energy currencies of technoecosystems. They can be channeled over great distances, and once they leave a geothermal technoecosystem they are indistinguishable from the products of other energy systems, they are lost in an infinite variety of technoecosystem patterns and processes. However, these and other energy forms easily produced from geothermal resources may be used directly in close proximity to their place of origin. Such adjacent utilization may be considered to be part of the operation of a geothermal technoecosystem.

Geothermal resources are extracted in many forms, and simple thermodynamic cycles can further increase their variety. A large amount of heat is available for use, either directly from the subsurface reservoir, or as waste heat from power production. Low temperature of most reservoirs causes low thermodynamic efficiency of power cycles, with resultant very large waste heat supply for other purposes. Wet steam, hot water, and geopressured reservoirs yield much hot fluid, and some geothermal fluids contain significant amounts of diverse salts, gases, and other chemicals. Electricity and desalted water can be produced as detailed in earlier sections of this chapter. Electricity can electrolyze water to produce hydrogen and oxygen, and can run heat pumps for cooling or extra heating. Hot fluids can drive thermodynamic cycles (e.g., lithium bromide or ammonia absorption systems) which paradoxically produce cold temperatures.

The versatility of geothermal energy is evident. Heat, cold, electricity, water, hydrogen, gases, salts -- these are energy and raw materials inputs for many technoecosystem functions.

Lindal (1973A) presents a major summary of direct uses of geothermal resources around the world. Peterson and El-Ramly (1975*) display a detailed classification and list of actual and feasible geothermal applications, itemize actual installations by country, and estimate individual and global geothermal energy consumption in each of several use categories. Armstead, Gorhan, and Muller (1974) list 24 direct uses of geothermal resources, and Tikhonov and Dvorov (1973) review diverse geothermal exploitation systems of the USSR.

Non-electrical uses of geothermal energy are not insignificant. Currently they represent an estimated 75 percent of the total thermal energy flow (energy quality not accounted for) through geothermal technoecosystems of both the U.S. and the rest of the planet (Peterson, El-Ramly, and Dermengian, 1976*). Furthermore, Reistad (1975) suggests that direct applications of geothermal energy will be more important in the long run than power production, even for a high-energy technoecosystem like that of the United States. A large fraction of the energy required for a high-energy technoecosystem is for heating at low to medium temperatures. High-quality fossil fuel energy is very inefficiently used for such low-quality energy needs. But geothermal fluid resources, coincidentally, are most abundant in this temperature range. Reistad estimates that geothermal resources of 200°C (if properly located and abundant enough) could directly supply more than 40 percent of total U.S. technoecosystem energy requirements. Similarly, 150°C fluids could supply 30 percent of energy needs and 100°C fluids could supply 20 percent.

Dry steam resources are ideal not only for power generation but also for certain high-energy industrial processes which require steam. However, wet steam and hot water hydrothermal convection systems are much more common than dry steam reservoirs, so direct applications of their lower-enthalpy fluids are likely to be larger and more widespread in the future, as they are now. Drilling and resource extraction technology is still being developed for igneous-related systems, geopressured systems, and normal heat flow areas, so speculation about use of their energy centers conspicuously on electricity production. However, if such power systems are ever built, they too will produce waste heat suitable for other applications. Energy cost of obtaining geothermal heat and fluids ranges from a small fraction of equivalent fossil fuel costs (for near-surface hydrothermal convection systems) to many times the fossil fuel cost (for deeper igneous-related and normal gradient area systems).

Electricity and low-salinity water can be easily transported long distances from the geothermal technoecosystem which produces them, although there is a non-zero energy cost for such transmission. In contrast, transportation energy cost is many times greater for geothermal heat and unprocessed hot fluids. Technoecosystem components which use these latter energy forms must be located near their source, and may be considered to be parts of a geothermal technoecosystem. Geothermal power, heat, and fluids are potential factors of production for many industrial processes. Therefore geothermal reservoirs, once found, may become growth nodes for industrial development on the planetary surface (much as oases in desert ecosystems attract and support isolated biomass concentrations). Transport of raw materials to geothermal areas for processing may become economically and energetically advantageous (Armstead, 1973).

Non-electric uses of geothermal resources may make power production from marginal reservoirs profitable (Kruger, 1975). And conversely, power generation system installation may unwittingly open niches for technoecosystems which can exploit "waste" heat and fluids.

Different technoecosystem processes require fluids at different temperatures. Lindal (1973A) presents a linear graph of some examples arranged by approximate temperature required. The graph reveals that industrial processes generally require high temperatures while agricultural and space heating applications need lower temperatures. The use of energy cascading for multiple purpose installations suggests itself -- hot fluids used in a sequence of processes, each at a lower temperature.

Many types of technoecosystem processes can be modified to use geothermal resources instead of other energy forms. However, mass production of geothermal technoecosystem components may not be feasible because of the variability of the resource. For each individual application, custom redesign of parts, modules, and entire geothermal technoecosystems may be necessary.

Often more than one geothermal energy form may be used in a single technoecosystem process. And often more than one process may use a single geothermal energy form. Such complex technoecosystems, and those which interface geothermal energy with other energy forms are discussed in the next section.

First, however, some of the individual processes which directly use geothermal resources will be reviewed. I have classified them into four categories modified from the system used by Peterson and El-Ramly (1975*): recreation and health, domestic heating and cooling, agriculture, and industry. These four categories are listed and discussed in order of generally decreasing intimacy to humans, from mostly inward to mostly outward sector involvement. For the world technoecosystem, according to estimates by Peterson, El-Ramly, and Dermengian (1976*), approximate shares of total geothermal technoecosystem thermal energy flow (energy quality not accounted for) are 41, 9, 21 and 4 percent, respectively, for roughly equivalent categories (remaining 25 percent is electricity generation). For the U.S. technoecosystem, corresponding figures are 33, 13, 25, and 5 percent (with 25 percent power production).

Natural hot spring systems have attracted men for recreation and health purposes since earliest recorded history. El Hamma and Tiberias hot springs, near the Sea of Galilee and the Dead Sea, are examples of natural systems used today as well as in ancient times (Meidav, 1975B). High energy technoecosystems now make possible discovery and exploitation of subsurface hydrothermal reservoirs for new health spas and tourist resorts (ibid.). Some cultural traditions employ geothermal hot baths, mud baths, and vapor inhalation for medical treatments (Chiostri and Balsamo, 1975; Combe, 1969). Hot spring mineral waters are often bottled and sold for drinking (Combe, 1969), and potable water has also been gathered by condensation of natural steam jets (Saint, 1975).

One relatively recent improvement in quality of human existence, made possibly by high-energy technoecosystems, is widespread and substantial use of heating and cooling in daily life. Where resources are available, geothermal technoecosystems can provide large amounts of heat directly, and can cool indirectly through a thermodynamic refrigeration cycle. Geothermal fluids can be used for heating enclosed spaces and swimming pools, for hot water supply, for cooking and clothes drying, and for warming roads and sewer lines in cold weather. Geothermal refrigeration can aid food storage and provide air conditioning in hot weather (Peterson and El-Ramly, 1975*). Examples of geothermal applications for domestic heating and cooling include: the space heating and cooling, hot water, and cooking system at a hotel in New Zealand (ibid.; Reynolds, 1973); integrated space and water heating systems for communities in Iceland (where 40 percent of the population was served in 1969) and the USSR (Einarsson, 1973); and space and road heating systems in Oregon (Bowen, 1972; Storey, 1974).

In technoecosystems for terrestrial and aquatic agriculture, geothermal resources can help amplify energy flows and storages in biological components. Water for irrigation of fields and greenhouses can be produced directly from the reservoir, as in the Santa Cruz valley of Arizona (Dellechaie, 1975), or indirectly through a desalination module. In cold climates, the natural heat in geothermal fluids may be beneficial for heating greenhouses (Head, 1970) and animal enclosures, warming soil, and protecting against frost. In hot climates, sprinkler irrigation can evaporatively cool warm water before it hits the ground (Peterson, El-Ramly, and Dermengian, 1976*), and geothermal water can provide evaporative cooling of greenhouses and animal facilities. Carbon dioxide separated from geothermal fluids may enhance greenhouse productivity (Barnea, 1974). Other applications for animal raising include water supply and steam cleaning of enclosures.

Heat and perhaps water from geothermal reservoirs can be channeled through aquaculture and mariculture technoecosystems to amplify productivity of aquatic and marine organisms: fish, mollusks, crustaceans, reptiles, algae, and seaweed (Peterson and El-Ramly, 1975*).

Technoecosystems for processing agricultural products can also utilize geothermal resources for energy and materials inputs. Diverse modules involving such processes as drying, steaming, distillation, cooking, boiling, cooling, refrigeration, freezing, and freeze-drying can be adapted to use geothermal resources. Numerous examples of actual and possible geothermal applications for agricultural products processing are presented by Wehlage (1974B) and Peterson and El-Ramly (1975*).

In industry, the possibilities for direct use of geothermal resources are so numerous and diverse that they can only be hinted at in this space. Processes using steam, electricity, heating, refrigeration, and water (all potential forms of geothermal energy) are ubiquitous in outward sector industrial technoecosystems. Some industries already using geothermal resources or well-suited to do so (ibid.; Lindal, 1973A) include: forest industry (lumber, pulp, paper), fiber and textile industries, chemical industry (Lindal, 1973B), sewage treatment, and minerals industry (e.g., mining of sulfur and diatomite, mining in any weather or at any depth, and refining of mineral products such as bauxite). Many industrial processes utilize steam and may therefore compete with power generation for high-enthalpy geothermal fluids. Lindal (1973A) lists steam requirements for 35 industrial processes and products.

Geothermal fluids, themselves, can yield useful chemicals. Dissolved gases produced from hydrothermal convection systems include abundant carbon dioxide and hydrogen sulfide, and minor hydrogen, methane, nitrogen, ammonia, helium, and argon. Carbon dioxide can be concentrated to form dry ice, and sulfur can be extracted from hydrogen sulfide. Geopressured geothermal fluids contain much methane (natural gas) in solution, which can be recovered as fuel. Geothermal heat, solar evaporation, and chemical equilibrium changes can extract numerous salts, metals, and other solid chemicals from geothermal fluids, especially hot brines (Lindal, 1973B; Blake, 1974). Unfortunately, relative abundance of many chemicals in geothermal fluids seems to mirror their availability from other sources -- abundant, easily extracted salts and gases have low market price and may not repay the cost of extraction and transportation to market (Blake, 1974). Chemical extraction systems must be specially designed around the unique fluid properties of each geothermal reservoir.

8. Complex Technoecosystems

Modules for two or more uses of geothermal resources can be combined to form complex (or multiple purpose) technoecosvstems. Configurations of such technoecosystems, according to Barnea (1974), are limited only by resource characteristics, local industrial conditions, and the designer's ingenuity. To this list we might add the constraints of thermodynamics, net energy profitability, and available technology. But within these boundaries, many possibilities are open to the clever technoecosystem designer. In this section, principles of complex technoecosystem design are reviewed, and examples of existent and hypothetical systems are discussed.

Roughly 13 percent of total thermal energy flow through geothermal technoecosystems of the world (excluding Japan and Hungary) is through multiple purpose systems. Of this multiple purpose fraction, 67 percent is in the USSR (Peterson and El-Ramly, 1975*). As geothermal technoecosystems multiply and evolve, the proportion of those with multiple purpose configurations is very likely to increase.

Earlier sections demonstrated that each form of geothermal energy or component of a geothermal resource has many uses. Similarly, some individual processes require more than one resource form. For instance, greenhouses can utilize geothermal heat, water, power, and carbon dioxide (Barnea, 1974). Furthermore, outputs of some processes, which otherwise might be considered pollutants, can serve as inputs for other processes. All these relationships combine to make complex technoecosystems not only feasible but also very practical. Within a geothermal technoecosystem, separate sub-niches synergetically form and expand each other as agglomeration economies (of money and energy) sequentially unfold.

There is no limit to the diversity of processes and forms which can be driven and created with any energy source (including geothermal) through a suitable chain of conversions and transfers of energy and materials. All that is necessary is to construct a suitable technoecosystem. Some transformations may be very inefficient. But energy loss in one part of the system can be compensated by an amplified energy gain which it makes possible elsewhere.

Consider now some of the components which might be assembled to form complex geothermal technoecosystems. Besides all the modules and components mentioned earlier in this chapter (for exploration, drilling, resource extraction, power generation, and desalination), we have all the technological fruits of global industrialization to choose from, combine, and modify as needed. Many parts and components run by the ambient fossil fuel technoecosystem are likely to be incorporated, at least at present (e.g., automobile, airplane, and drill rig technoorganisms). Some specialized technoorganisms can be modified to use geothermal energy forms--steam, electricity, hydrogen, methane. Heat exchangers, heat engines, and mechanical-electric, thermoelectric, electrochemical, and thermochemical energy transducers can be arranged in appropriate locations.

Channels within and extending from a complex geothermal technoecosystem might include cables, pipelines, ditches, cryogenic cables for long-distance power transport, roads, railroads, and canals. Hydrogen could be produced and fed by pipeline or cryogenic tanker into a planet-round hydrogen storage and transport network, part of a proposed global energy utility (Gabel, 1975*) for standardized technoecosystem metabolism.

Energy can be transformed and stored as hydrogen (Rex, 1974) or other synthetic fuel, as compressed air in salt domes (Jacoby, 1974), or as chemical potential energy in batteries. Thermal energy, perhaps concentrated by thermodynamic cycles, can be stored underground (as it is in nature) by using wells for injection and subsequent recovery of hot fluids (Meyer and Todd, 1973).

An important principle for design of efficient complex technoecosystems is that energy quality of an energy form should match as closely as possible the energy quality requirements of the process it drives. If energy quality is too high, energy is wasted, and if energy quality is too low, the process does not operate.

A practical embodiment of this principle is the practice of energy cascading: modules and processes which concentrate energy are arranged sequentially in order of increasing energy quality, and modules and processes which degrade and use energy are arranged in order of decreasing energy quality. In a utilization system, some energy can be reconcentrated at any stage by using a thermodynamic entropy jet cycle (e.g., a heat engine and heat pump), but maximum thermodynamic efficiency is obtained by uninterrupted downward cascading of energy quality.

Barnea (1974) explains one application of downward energy cascading in complex geothermal technoecosystems: arrangement of modules so that each uses geothermal fluids at a lower temperature. An example of both upward and downward energy cascading combined in one module is a multiple stage heat exchanger (such as might be found in a binary cycle geothermal powerplant) in which hot primary fluid and cold secondary fluid flow in opposite directions. Primary fluid, losing its heat, cascades to lower temperature (and energy quality), while secondary fluid, gaining heat, cascades to higher temperature. In any stage their temperatures (and energy qualities) are fairly closely matched, with primary slightly hotter than secondary.

An application of upward energy cascading in geothermal technoecosystems is the hybrid power or steam plant. High quality energy forms like fossil fuels and concentrated solar energy can heat water from a cold start, but they are much more effectively used at higher temperatures (where temperature increase gives heat engine efficiency a greater boost). In contrast, high temperature geothermal fluids are rare, and the more common low to medium temperature fluids yield little steam and drive heat engines at very low thermodynamic efficiency. Both geothermal and solar or fossil fuel energies can be used most efficiently by combining them in a cascaded hybrid energy system. Low-enthalpy geothermal fluid (or secondary fluid heated by it) can be raised to much higher temperature with solar energy or fossil fuel to yield steam for industrial processes or power production. The result is saving of geothermal fluid and fossil fuel supplies or solar collector area, but at the expense of increased plant complexity.

Conceptual designs for 10 Mw hybrid solar-geothermal power systems have been studied by Finlayson and Kammer (1975*). Theoretical thermodynamic efficiency, originally 5 percent, is boosted to 40 percent by adding concentrating solar collectors to a wet steam powerplant. An extra feature is that geothermal energy can sustain base load at night and on cloudy days, and solar energy can help meet daytime peak load power requirements. This study was made for the large wet steam reservoir of arid Raft River Valley, Idaho. However, solar-geothermal power systems would probably be more promising in a place like extremely arid Imperial Valley which has more consistent sunshine.

Many geothermal technoecosystem configurations are complex partly because they interface geothermal energy with other forms of energy and their technoecosystems. Hybrid power and steam plants are just one mode of energy sources interface.

<u>Solar energy</u> interfaces with geothermal resources can occur in several ways. Warm geothermal fluids can feed into solar stills for hybrid desalination (Peterson and El-Ramly, 1975*). Or hot brines can be discharged into solar evaporation ponds for extracting salts and other chemicals. Geothermal heat, water, and carbon dioxide can amplify solar energy collection by cultivated plants in fields and greenhouses. And geothermal heat can accelerate methane generation from sun-derived farm wastes and sewage (Lindal, 1973A).

<u>Coal</u> mining, gasification, and liquefaction processes can use geothermal energy in such forms as heat, steam, water, and electrolytic hydrogen. In Utah, promising geothermal areas are all near large coal deposits (Utah Geological and Mineral Survey, 1975*), so hybrid power, gasification, and liquefaction plants might be considered.

<u>Oil and natural gas</u> reservoirs are closely associated with salt domes and geopressured-geothermal reservoirs in subsiding sedimentary basin environments. Hence a great many technoecosystem energy interfaces are possible. Geopressured fluids contain much methane in solution, so simple extraction of fluids yields both geothermal energy and hydrocarbon fuel (plus minor high pressure mechanical energy). Economic analysis by House and Johnson (1975) suggests that geopressured reservoirs 5,000 to 10,000 feet deep (1,524 to 3,048 m) would profitably yield natural gas, while reservoirs 10,000 to 20,000 feet deep (3,048 to 6,096 m) would be suitable for combined power generation and gas production. Hybrid powerplants which separate natural gas and burn it to superheat hot geothermal fluid might be advantageous under some circumstances.

Salt domes offer more complex technoecosystem possibilities in this geological environment. Jacoby (1974) suggests using them as heat source for powerplants, or storing energy in them as compressed air. They could also be used to store methane separated from geopressured fluids, or hydrogen produced electrolytically by geopressured-geothermal powerplants, or even a mixture of both hydrogen and methane. Hot geopressured fluids could be passed through a hotter nearby salt dome to increase thermal energy quality before driving a power cycle.

Another interface between energy technoecosystems in subsiding sedimentary basins would be the use of abandoned hydrocarbon wells for production of geopressured fluids and for reinjection of waste fluids (Papadopulos et al, 1975). Geothermal fluids and warm waste water can be injected into oil-bearing horizons for repressurization, remobilization, and enhanced secondary recovery of petroleum. This has been done in USSR oil fields, as reported by Neprimerof (1975) and Sukharev, Vlasova, and Taranukha (1973).

Utilization of geothermal energy to produce heavy water for natural uranium nuclear reactors has been proposed for Iceland (Valfells, 1973), Japan, and New Zealand, but so far no plants have been built (Ellis, 1975).

Hot waste fluids self-pumped from the Wairakei wet steam field, New Zealand, are discharged into the Waikato River. Thus they contribute a small but significant fraction of the power produced by a hydroelectric plant downstream (Axtmann, 1975).

Geothermal resources can be an ideal foundation for complex industrial-agricultural-residential technoecosystems. Descriptions of some actual and hypothetical systems illustrate some of the possible configurations.

Combination of power production with various uses of its "waste" heat is a common example of energy cascading, and is highly efficient (Ellis, 1975). Lusby and Somers (1972) examine the technology and costs of combining electricity generation with integrated heating and cooling systems for towns. Municipal heating systems already exist in Iceland (Einarsson, 1973). A 1970 conference investigated specific uses of thermal discharges from powerplants for agriculture, aquaculture, and industry (Mathur and Stewart, 1970; Stewart and Carrigan, 1970-1971).

An integrated energy park demonstration project is proposed for the Raft River Valley, Idaho (Swink, Schultz, and Oswald, 1976*). Thermal discharge from a 10 Mw binary cycle powerplant would be used in several adjacent industrial modules in an energy cascading sequence of decreasing temperature. Industries being considered include potato dehydration, manure processing, cattle feedlot operation, greenhousing, fish farming, meat packing, and tree breeding.

At Namafjall, Iceland, geothermal steam has several roles in a diatomite production technoecosystem. Steam prevents freezing in settling ponds and tanks, dries diatomite, generates electricity, and provides space heating (Lindal, 1973A; Ellis, 1975).

At Kawerau, New Zealand, geothermal steam helps run a paper and timber mill. There it heats fresh water to produce process steam, dries timber, operates evaporators, and generates electricity (Ellis, 1975).

Lindal (1973B) proposes an elaborate chemical industry technoecosystem design for Iceland. Various salts, bromine, magnesium, and chlorine can be extracted from sea water and geothermal brine, and chlorinated hydrocarbons can be produced with the aid of geothermal steam and electricity. In energy cascading fashion, other high energy industrial processes (e.g., diatomite drying and heavy water production) might use steam before the chemical processing, and hot water effluent could provide space heating afterward.

Rappeport (1972) suggested the use of warm saline groundwater to heat greenhouses and then irrigate field crops in the Negev desert, Israel. Such a project is apparently now under way (Meidav, 1975B). On a much grander scale, giant power-water-minerals production technoecosystems to support still larger agricultural-industrial-residential-recreational technoecosystems have been proposed for arid Tularosa Valley, New Mexico (Reinig et al, 1973) and for extremely arid Imperial Valley, California (U.S. Bureau of Reclamation, Washington, D.C., 1972).

Submarine geothermal resources offshore from coastal deserts would require modified technoecosystem configurations. Siting electrolytic hydrogen generators on the seafloor at spreading centers (e.g., Gulf of California and Red Sea) and submarine volcanoes has been proposed (Furumoto, 1974). Palmer, Green, and Forns (1975) suggest the possibility of a submarine geothermal powerplant with storages of thermochemically produced hydrogen fuel or with power cables to shore, and with waste heat used for mariculture by seafloor heating.

Entirely different materials, modules, and configurations would be needed for offshore geothermal technoecosystems. Surface and submersible technoorganisms would be needed for construction and maintenance, but such marine technology is already being developed for seafloor fossil fuel and mining technoecosystem use. Some terrestrial geothermal technoecosystem technology might still be used if an offshore powerplant and associated systems were mounted on a platform.

Imagine for a minute a complex geothermal technoecosystem of the future, exploiting a geopressured-geothermal reservoir off the coast of an arid region. Geopressured fluid is passed through salt domes for extra heating and then channeled upward to platforms on long submarine stilts. Natural gas is separated from the fluid, and some of it is used in a hybrid power system to superheat the fluid to drive turbogenerators. Natural gas and electrolytic hydrogen from one platform are channeled through a sea bottom pipeline to onshore industrial complexes. Under another platform, these gases are stored in a salt dome cavity until they can be loaded onto an occasional cryogenic tanker technoorganism for transport to another continent's technoecosystem. Still another platform, near shore, sends its electricity by submarine cable to a coastal city.

On each platform, some of the hot fluid left after power production distills itself in a multistage flash module and is piped to shore. The rest of the fluid warms deep mariculture stations, and is then injected to help recover a small amount of petroleum (now a rare and precious commodity) from nearly exhausted sandstone reservoirs. The surrounding sea is alive at all levels not only with wild and domesticated biological organisms but also with hydrogen-fueled marine technoorganisms of every description -- crew shuttles, geophysical exploration ships, repair boats and submarines, gunboats, cargo ships, fuel transports, and fishing trawlers. A few hydrogen-powered aerial technoorganisms cruise in three dimensions on high.

Such a complex technoecosystem is a technological possibility. But should it ever come into existence, its niche might not last many decades.

9. Environmental Effects

Unfathomable is the course of action.

--Bhagavad Gita, IV-17

Human survival demands the existence of technoecosystems. And technoecosystems always affect their environment -- humans, natural systems, and other technoecosystems. Simply that a geothermal technoecosystem is present affects many things: photon flows (visibility from the air); gravitational, electrical, and magnetic fields; social and economic systems; geological, biological, and atmospheric systems; and even the fact that I am writing and you are reading about geothermal technoecosystems. Structure configurations, and flows and storages of energy and information are all affected by a geothermal technoecosystem in an endless, intricate web of causality -- simultaneously and sequentially, through complex feedbacks, and in different scales of time and space. However, untangling the whole web is inexpedient; practical environmental impact studies concentrate only on the most noticeable, most general, most easily traced outputs and effects.

Energy form extraction, transport, processing, storage, distribution, and consumption activities are the most significant sources of environmental degradation in the high-energy technoecosystem of the United States (Hughes, Dickson, and Schmidt 1974). Many writers assert that geothermal power technoecosystems have less detrimental effect on environment than do power technoecosystems using other energy sources. The U.S. Environmental Protection Agency (ibid.) suggests that geothermal power technoecosystems may have this reputation for minimum impact simply because the systems, to date, have been small.

Study of environmental effects of geothermal technoecosystems is difficult because of limited global experience with the systems, and because of the extreme variability and range of ecological, geological, and geographic conditions involved (U.S. Dept. of the Interior, 1971). We can add to this list the multitude of possible geothermal technoecosystem configurations, and the several stages in development of a single system. Each component, each activity, and each developmental stage of a geothermal technoecosystem has its own effects on the environment. The U.S. Department of the Interior (1971) outlines environmental effects at six stages of development of a geothermal power system which taps hydrothermal fluids: exploration, test drilling, well testing, development drilling, technoecosystem construction, and full scale technoecosystem operation. A seventh stage, geothermal technoecosystem termination, is discussed in the next chapter.

Most of the literature on environmental effects of geothermal technoecosystems seems to focus on systems which exploit wet or dry steam hydrothermal convection systems; these are the technoecosystems which are best known, since they are now the most common. Furthermore, most of the literature concentrates on the effects of systems which generate electricity. In fact, the Environmental Protection Agency (EPA) assumes that "virtually all exploitation of geothermal energy will be for production of electricity" because of low fluid temperatures and difficulty of heat transport (Hughes, Dickson, and Schmidt, 1974, p. 22). This limitation of scope seems to ignore the fact that a large proportion of geothermal energy (and probably a similar proportion of geothermal fluid) utilization in the world and the U.S. is for non-electric purposes (Peterson, El-Ramly, and Dermengian, 1976*). It also ignores the apparently growing proportion of multiple-purpose technoecosystems which utilize power cycle heat effluent.

This is not the place, however, to investigate and review the primary environmental effects of all stages of development of the many possible geothermal technoecosystem configurations in the many possible locations. Discussion here is limited to the effects most frequently and specifically mentioned in the literature. It is further limited to short-term environmental effects; long-term effects will be covered in the next chapter.

Bowen (1973) offers a good general review of the environmental effects of power stations exploiting hydrothermal convection systems. Axtmann (1975) investigates in detail the environmental impact of a single wet steam powerplant, Wairakei, New Zealand. The U.S. Department of the Interior (1971, 1973A, 1973B) studied environmental impact of geothermal technoecosystems at several stages in their development, in light of the federal geothermal leasing program. Hughes, Dickson, and Schmidt (1974) of the EPA estimate environmental effects of standard geothermal powerplants per unit of electrical energy output, based on experience at Cerro Prieto and the Geysers. These figures are readily compared with those for other energy sources. General papers by Goldsmith (1971), Hickel (1973), and Ellis (1975) review environmental effects along with other topics. For additional sources which discuss environmental impacts, the Bibliography and its index should be consulted.

The global technoecosystem has an insatiable and growing appetite for energy. Where conditions are favorable, geothermal technoecosystems can be built, or else, as pointed out by the U.S. Department of the Interior (1971), other energy technoecosystems would have to be constructed to meet energy needs. And these other systems could have a greater impact on the environment. The official position appears to be that technoecosystem energy requirements must and will be met, that the environment will be affected, and therefore that energy might as well be harvested by systems with the least environmental impact, these apparently being geothermal technoecosystems.

Detailed comparison of power technoecosystems which use different energy sources is beyond the scope of this paper. In general terms, though, Bowen (1971, 1973) and the University of Arizona (1975) point out that geothermal technoecosystems do not include the complex cycles of mining, concentrating, transportation, and reprocessing of fuel that are involved in other energy technoecosystems. Instead, geothermal technoecosystems can be locally self-contained (except for inputs of materials, parts, fossil fuel technoorganisms, and humans) because natural geological systems have already concentrated heat storage (as described in the second chapter), and because water for cooling is often part of the geothermal resource and does not need to be imported. This simplicity may also contribute to a more favorable net energy ratio for geothermal power production. According to Bowen (1973), electrical energy technoecosystems (including fuel cycles) appear to be ranked in the following order, from least environmental impact to the greatest: geothermal, natural gas, oil, coal, and nuclear (with by far the greatest impact, mostly in massive fuel cycles and radioactive waste storage).

In a letter responding to Axtmann's (1975) article, J. Barnea points out that geothermal resources pollute the environment even in their natural state. He further suggests that they may be the only natural resource which does so, and that their natural pollutant output should be subtracted from geothermal technoecosystem pollutant output to yield net technoecosystem pollution. Although it is true that hydrothermal convection systems and volcanoes (where magma bodies breach the surface) release solid, liquid, and gaseous effluents to the surface environment, other geothermal resources (deep or confined hydrothermal systems, non-leaky geopressured systems, hot-dry rock, deep magma, salt domes, and deep normal heat flow reservoirs) do not. Furthermore, other energy resources, too, can pollute in their natural state (natural venting of gas, oil seeps, coal leaching, and slow erosion of surficial uranium deposits). In almost all cases, however, technoecosystem pumping of energy resources increases pollution rates at least several fold and in some cases by orders of magnitude. Specific environmental effects of geothermal technoecosystems will now be reviewed.

Most basic of environmental effects is that a geothermal technoecosystem exists where one has not been before. Land surface (which may have been occupied by a different technoecosystem or by none at all) is required, its technoecosystem or bioecosystem use is changed, its surface is modified, and its aesthetic nature is irreversibly altered. EPA scaling factor for land use, based on experience at the Geysers, is 30 square kilometers of land area per 1000 Mw (Hughes, Dickson, and Schmidt, 1974). Although this is quite a large land requirement (perhaps small compared with other energy sources), most of it represents either well fields, in which pipelines, wellhead equipment, and service roads occupy a small fraction of the area, or land held in reserve for future wells as the first undergo production decline. Bowen (1973) points out that most of this well field area can be used for other purposes. For example, agriculture coexists with powerplants and pipelines at Larderello, Italy, and the Geysers field is devoted largely to wildlife habitat and cattle grazing.

Geothermal technoecosystems can be noisy, which may affect wildlife behavior and quality of human life. The noisiest phase of operation is the drilling and development of wells. Controlled blowout during air drilling of dry steam productive zones is very loud and difficult to muffle; however it is only an intermittent occurrence. Mud drilling of dry rocks and wet steam or hot water reservoirs is much quieter. Once a well is completed, blowdown directly to atmosphere (sounding like a jet airplane roar) is required to clear it of dust and rocks before production. Routine operation of a geothermal powerplant is far from silent; cyclone separators, pipelines, pumps, cooling tower fans, and other machinery all emit sounds (Blake, 1974). However, with the exception of the separators and long pipelines, all these noisy components are present at other types of thermal powerplants.

Land subsidence may occur as a geothermal field is exploited. Mechanisms for subsidence include net withdrawal of hot water from porous reservoirs (sediments, sedimentary rocks, or volcanic rocks) and thermal shrinking of cooling rocks (Bodvarsson, 1975*). Dry steam fields (with low fluid pressures) are immune to fluid withdrawal subsidence, whereas wet steam fields (fluids at hydrostatic pressure) are more susceptible (Bowen, 1973). Subsidence at Wairakei affects more than 25 square miles

(65 square kilometers) and reaches a maximum rate of 1.3 feet (0.4 meters) per year (Hatton, 1973; Axtmann, 1975). Geopressured reservoirs (fluid pressure greater than hydrostatic) are virtually certain to undergo subsidence -- a great potential hazard for coastal technoecosystems. Papadopulos et al (1975) estimate that total subsidence could range to over 7 meters during exploitation of geopressured resources of the northern Gulf of Mexico basin.

Subsidence can disrupt natural surface drainage patterns (Axtmann, 1975), cause local earth tremors (Ellis, 1975), and affect the configurations and functioning of technoecosystems, including irrigation systems and fluid transmission channels of the geothermal technoecosystem itself (e.g., pipes and drains at Wairakei -- Hatton, 1973). Subsidence due to fluid withdrawal may be ameliorated by reinjecting waste fluids or imported water (Bowen, 1973). It is unlikely, however, that subsidence due to thermal contraction of rocks can be assuaged.

Geothermal resource exploitation may cause or modify seismic activity, which in turn can damage technoecosystem structures and affect flow from geothermal wells. Igneous-related and hydrothermal convection systems are usually associated with earth movements, and are often localized by faults, along which movement can occur. Furthermore, microearthquakes are so common in hydrothermal convection systems that they can be used as an exploration guide. Changes in subsurface fluid pressure due to geothermal technoecosystem operation can affect seismic behavior. Pressure drop from fluid removal may decrease the number of microearthquakes but increase the likelihood of larger earthquakes (Ward, 1972). Pressure increase from fluid injection (by analogy to effects of oil field repressurization and of waste disposal near Denver, Colorado) may trigger earthquakes and increase their frequency (ibid.; Bowen, 1973). However, Bowen points out that reinjection of fluids into a geothermal reservoir which is at pressures less than hydrostatic is unlikely to increase seismicity because it is only replacing fluids which have been removed.

Effluents of open geothermal technoecosystems and natural geothermal systems are similar in kind but different (locally) in magnitude: heat, water, gases, dissolved chemicals, and solid materials. Any one of these items can be either an undesirable pollutant or a valuable input to associated technoecosystem components, depending on technoecosystem configuration and needs. And since specific nature of the resource is highly variable, each geothermal technoecosystem configuration, location, and development stage has its own unique effluent mix. Axtmann (1975) points out that open system geothermal powerplants pollute the environment whether or not electricity is being generated because the wells discharge continuously to avoid restarting blowdown delays. Chemical effluents are usually released both to the atmosphere and to water at the surface and underground.

Air pollution results from release of gases contained in geothermal fluids, mostly hydrogen sulfide and carbon dioxide. Hydrogen sulfide is a human health hazard, has an unpleasant odor, and corrodes metals in and around geothermal technoecosystems. In the atmosphere it oxidizes to sulfur dioxide (one of the harmful gases emitted by fossil fuel powerplants and sulfide ore smelters) in 2 to 48 hours, and output per megawatt can be similar to magnitude of fossil fuel powerplant emissions (Hughes et al, 1974; Axtmann, 1975). Carbon dioxide output can range from a fraction to 10 times the output per megawatt of a fossil fuel plant (Axtmann, 1975). These gases cease to be pollutants if they are reinjected in solution, if they are recovered for further technoecosystem use (hydrogen sulfide recovered as sulfur or sulfuric acid, carbon dioxide as dry ice or greenhouse growth stimulant), or if a closed system binary power cycle is used.

Water pollution occurs when dissolved gases, salts, and other chemicals contained in geothermal fluids are discharged at the surface or into fresh groundwater reservoirs. Components harmful to biological systems include large amounts of salts and small amounts of hydrogen sulfide, arsenic, mercury, boron, fluorides, and ammonia (Ellis, 1975; Axtmann, 1975). Saturated silica and calcium carbonate precipitate out of solution as scale, and are a nuisance to technoeocsystems. All these materials (except dissolved gases) can enter the atmosphere in rapidly - evaporating water droplets from cooling towers (drift losses), silencers, and wells being cleared, and be blown away as dust (Hickel, 1973).

The impact of water pollutants depends on their concentration and on the water cycle configuration chosen for the geothermal technoecosystem. Concentrations may be low enough that the water can be discharged into a river or the ocean without ill effect, or even used for irrigation or domestic water supply. Or desalination can purify the water and concentrate the dissolved solids. The solids cease to be pollutants if they are reinjected, if they are recovered and stored or purified for further technoecosystem use, or if a closed binary cycle is used.

In arid lands, water effluent from a geothermal technoecosystem can hardly be considered a pollutant if its salinity is low either naturally or by desalination; it has great energy value for powerplant cooling and for many other technoecosystem functions. Similarly, heat rejected by powerplants is not a pollutant if it enters the atmosphere through cooling towers, is reinjected, or is utilized in some auxiliary technoecosystem module.

Wells are ubiquitous in geothermal technoecosystems. Ever-present hazards of wells are the possibilities that subsurface leaks may contaminate groundwater supplies, and that inadvertent, noisy well blowout at the surface may contaminate surface water, crops, and air. Careful well design and drilling procedures should make such occurrences less likely.

Radioactive isotopes, residue of gradual decay of uranium and thorium at depth, are present in geothermal fluids (Bowen, 1973; and a letter by T.F. Gesell and J.A.S. Adams responding to Axtmann, 1975). Their concentration in steam at the Geysers is small (Bowen, 1973), but amounts may vary from one reservoir to another.

Geothermal technoecosystems affect the natural geothermal systems which they exploit. Over a period of years to decades: pressure, temperature, and water level of wet steam reservoirs decline; temperature of dry steam may temporarily increase, while gas content goes down; well output decreases; and chemicals may precipitate in open spaces around well bores (Bolton, 1973). Surface manifestations of hydrothermal convection systems (hot springs, geysers, and fumaroles) usually change or dry up in response to deep resource exploitation (ibid.; Ellis, 1975; Axtmann, 1975). And steam which fills voids over wet-steam fields can create large blowout craters at the surface by spontaneous hydrothermal explosions, as at Wairakei (Ellis, 1975).

Nuclear stimulated geothermal technoecosystems have their own unique set of expected and potential environmental effects, reviewed by Sandquist and Whan (1973) and Berman (1975*). Seismic ground motion is a violent shock wave phenomenon which immediately follows subterranean nuclear explosions and which can destroy or damage technoecosystem structures. It is often followed by a series of seismic aftershocks. Other possible effects of nuclear explosions include the triggering of: large earthquakes where strain has built up along faults, landslides where slopes are oversteepened, volcanic eruptions where magma is near the surface, or hydrothermal explosions where subsurface water is just below the boiling point. The greatest danger by far, however, is posed by the accidental release of extremely toxic radioactive materials into groundwater reservoirs, onto the surface, or into the atmosphere before or during powerplant operation -- or even millenia after technoecosystem abandonment.

10. Thermodynamics, Succession, and Evolution

What is the geothermal energy value of a specific volume of the earth's crust? Such a question has numerous possible interpretations, and therefore many answers which are based on assumptions and information ranging from simple to complex.

The simplest meaning for "geothermal energy value" is the thermal energy content of the volume, usually with reference to a certain minimum temperature. The U.S. Geological Survey (White and Williams, 1975) defines "geothermal resource base" in this manner, as stored heat above 15°C (average surface temperature).

But of this stored heat, only a fraction -- called "geothermal resources" by the USGS -- may be recoverable using current or near-current technology. And of this fraction, only a part -- "geothermal reserves" -- may be recoverable at money cost competitive with other energy sources; the rest consists of "paramarginal geothermal resources" (recoverable at 1 to 2 times competitive cost) and "submarginal geothermal resources" (recoverable at 2 or more times competitive cost). These last three definitions of thermal energy value hinge on money costs of technoecosystem design and operation, as well as on the nature of the reservoir.

Because of the Carnot thermodynamic limitations of heat engine efficiency, not all heat content in or recovered from the ground can do useful work (e.g., power generation). Bodvarsson and Eggers (1972) define "exergy" as the theoretical amount of mechanical work which can be derived from heat content. For any of the heat content parameters, we can determine an "ideal exergy", based on ideal heat engine efficiency, or "practical exergy", based on small efficiency of real heat engines. We can also determine these for different heat sink temperatures -- wet bulb and dry bulb, or summer and winter temperatures, for example. And we can make a more sophisticated exergy analysis in which the effects of temperature decline with production are modeled and accounted for -- one thermal calorie yields more mechanical work at high than at low temperatures (USGS does not take this into account in its calculations). Multiplication of exergy by a simple conversion factor (usually 80 to 90 percent) produces an estimate of potential electrical power production.

As Kunze (1975) points out, whether a certain amount of geothermal energy can be utilized is not as important as how much it costs. Benefit accrues to the technoecosystem not according to its output but according to the difference between the output and the necessary input -- profit if money is of interest, and net energy if technoecosystem survival value is of concern. Profit and net energy analyses, qualitatively similar, involve detailed accounting of geothermal technoecosystem input money or energy costs (B in Fig. 7) and technoecosystem output prices or energy values (A in Fig. 7). Money and energy flow in opposite directions along arrows A and B; arrows show direction of energy flow. Technology and energy values of different geothermal resource components need to be studied in order to choose the technoecosystem configuration which will yield either maximum financial (money) rate of return $(A - B)/B = A/B - 1$ (can be warped by market inequalities or legislated subsidies) or maximum net energy ratio (A/B). Such analyses can be very complicated. Bradbury (1971) and Armstead (1973A) present economic analyses of geothermal powerplants and Gilliland (1975) and Norton and Gerlach (1975) offer preliminary net energy analyses.

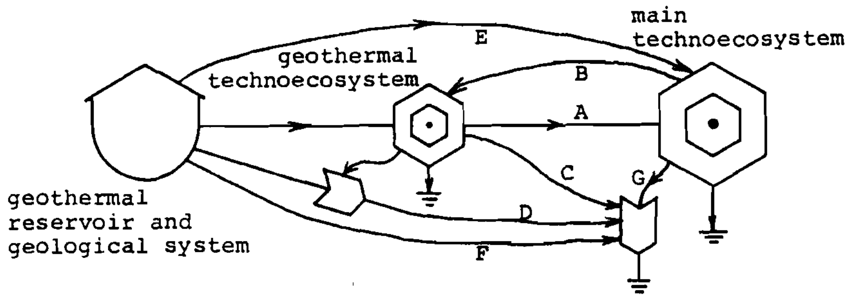

Figure 7. Environmental effects and net energy of geothermal technoecosystems

Letters are explained in the text.

As already mentioned, the USGS has defined various categories of geothermal resources on the basis of economics of recovery. Gilliland (1975), in contrast, defines them in terms of net energy. Geothermal "net reserves" are resources of high enough energy quality to yield net energy with current technology. "Economic reserves" are those which have a net energy ratio competitive with other energy sources.

Analysis of resource energy value does not have to stop at net energy, however. Environmental effects can be considered, too. In Fig. 7, destructive impacts on the main technoecosystem are shown by arrow G. They can be triggered by direct effects of geothermal technoecosystems (e.g., damage from effluents -- arrow C), by natural destructive effects of geothermally-driven geological systems (e.g., volcanoes -- arrow F), or by destructive effects of natural geological systems which are triggered by geothermal technoecosystems (e.g., earthquakes touched off by injection -- arrow D). Natural geological systems also provide free beneficial services to the technoecosystem (e.g., ore deposits, hot springs, and geysers -- arrow E).

Increase of geothermal technoecosystem activity has the following effects in the Fig. 7 model: 1) direct and triggered impacts (C and D) increase. 2) Beneficial natural services (E) decrease because geothermal technoecosystem outcompetes natural geological systems for heat and water. And 3) destructive natural impacts (F) may also decrease. An example of decrease of destructive natural effects is the possibility that geothermal exploitation might quiet volcanoes (suggested by Tikhonov and Dvorov 1973).

At any instant, the net energy flow rate or "net power" including environmental effects is the standard technoecosystem net energy flow rate (A - B) plus the change from natural conditions of environmental net energy flow components ($\Delta E - \Delta G$), or:

1) instantaneous net power $= (A + \Delta E) - (B + \Delta G)$

Similarly, the ratio is taken for instantaneous net energy (or net power) ratio:

2) instantaneous net power ratio $= \dfrac{(A + \Delta E)}{(B + \Delta G)}$

Over time, as resource conditions and technoecosystem configurations change, and as delayed environmental effects manifest themselves, all the variables in these equations may change. The total net energy obtained from the geothermal reservoir, then, is the instantaneous net power integrated over time, from the time of exploration commencement (To), through the time interval of resource exploitation, until the time (Tf), long after geothermal technoecosystem abandonment, when the environment returns to an equilibrium state:

3) total net energy $= \displaystyle\int_{To}^{Tf} [\,(A + \Delta E) - (B + \Delta G)\,]\; dt$

Similarly, average net energy ratio, including environmental effects, is expressed by the following equation:

$$4)\quad \text{average net energy ratio} = \frac{\int_{To}^{Tf} (A + \Delta E)\ dt}{\int_{To}^{Tf} (B + \Delta G)\ dt}$$

There is a subtle but important difference between standard net energy analysis and analysis which includes environmental effects. Standard net energy analysis is parallel to standard economic analysis; they both consider only flows A and B (Fig. 7), along which flows of both energy and money in opposite directions take place. But net energy analysis which considers environmental effects deals also with energy flows C through G, and (unlike A and B) no money streams along these vectors. Furthermore, this second type of analysis includes environmental impacts which affect global technoecosystem survivability long after the last profit dollar has been banked by geothermal technoecosystem managers.

For constant geothermal technology, potential net energy ratio of natural geothermal systems varies horizontally around the spheroidal planetary surface. Geothermal technoecosystems will optimally develop first over systems which yield maximum net energy ratios (probably instantaneous ratios, since they are easiest to estimate). Subsequent developments will exploit reservoirs with successively smaller ratios, until the minimum ratio equals ambient technoecosystem net energy ratio. These marginal reservoirs and their technoecosystem configurations constitute boundaries of the <u>competitive</u> geothermal energy niche. A competitive energy niche is based on economic reserves (in Gilliland's terminology), whereas the larger <u>absolute</u> energy niche is based on net reserves (which offer positive but not necessarily competitive net energy ratios). As in the biological world, the lure of an empty niche for which an exploitation system has evolved is irresistible, and it is soon filled by rapid sigmoidal growth.

If other energy technoecosystems become less efficient (e.g., by resource depletion), then ambient net energy ratio will decline and formerly submarginal geothermal net reserves can be exploited; the competitive geothermal energy niche expands. Conversely, should other energy technoecosystems become more efficient (e.g., by major technological-evolutionary innovation), then competitive net energy ratio will increase and some marginal geothermal technoecosystems may be abandoned; the competitive geothermal energy niche contracts.

In our present world, geothermal technoecosystem managers tend to use short-term money profit, and not net energy ratio, as basis for resource exploitation strategies (Peterson, 1975). Hence, under their management, the energy niche dynamics just outlined currently operate with "financial rate of return" substituted for "net energy ratio". In the presence of hidden money subsidies, global technoecosystem success might be served better if instantaneous net power ratio (A/B) were the criterion used in decision making (Gilliland, 1975), still better if instantaneous net power ratio including environmental effects (equation 2) were used, and perhaps best of all if long-term average net energy ratio including environmental effects (equation 4) were the decision basis.

Exploitation of geothermal reservoirs with progressively smaller net energy ratios (lower energy quality) can be called <u>succession</u> (see section I-12). Succession of geothermal technoecosystems can occur in five situations: (1) when the geothermal energy niche is filled to the competitive margin, ambient net energy ratio declines, competitive niche boundary expands, and new marginal technoecosystems are built; (2) when the niche is new and unfilled, and new technoecosystems are built, starting with the highest net energy ratio and progressing to successively lower ratios; (3) when, in an unfilled niche, highest net energy ratio (highest energy quality) reservoirs are depleted and replacement technoecosystems are built to exploit lower quality reservoirs; (4) when the energy quality and the instantaneous net energy ratio of a single reservoir decline with use, and new exploitation configurations are required, and (5) when technological improvement (evolution) increases net energy ratio for every reservoir and thereby expands the energy niche (absolute and competitive).

During succession, geothermal technoecosystems tend to exploit progressively deeper, cooler, saltier, more remote, and less permeable geothermal reservoirs within a single resource type. And they tend to tap geothermal resource types of ever greater exploitation difficulty, approximately Table 1 in reverse. In the scheme of Fig. 6, technoecosystems would tap heat storages successively in the order L, I, F, C (hydrothermal convection systems, igneous-related systems, high heat flow areas of geothermal belts and hot spots, and normal heat flow areas). Some resource types may have overlapping exploitability. For instance, geopressured systems (included in F or C in Fig. 6) may be competitive with wet steam hydrothermal convection systems (included in L).

As succession proceeds, geothermal technoecosystem configurations change to match the resources they exploit. And the magnitude of available resource increases rapidly with decreasing energy quality (Kunze, 1975; White and Williams, 1975), so lower net energy ratio technoecosystems should come to outnumber any coexisting high net energy ratio technoecosystems. As an example, wet steam powerplants now outnumber original (and higher net energy ratio) dry steam powerplants.

We can use the term evolution for the development of new technoecosystem components and configurations which make possible extraction of net energy from previously unexploitable resources, or more efficient extraction of net energy from previously tapped reservoirs. Evolution means technological improvement, and it results in larger net energy ratio and thus expanded boundaries of both the absolute energy niche and the competitive energy niche (for unchanged net energy ratio of other energy sources). Hence evolution can make room for and encourage succession of geothermal technoecosystems. Evolution of geothermal technoecosystems has expanded the competitive geothermal energy niche from hot springs to dry steam systems to wet steam and geopressured resources. And this evolution appears to be continuing as exploitation experience accrues and research budgets increase.

So far this discussion has dealt chiefly with horizontal resource distribution. The vertical dimension is important, also, since thermal energy quality increases with depth within a single geothermal reservoir. Kremnjov, Zhuravlenko, and Shurtshkov (1973) discuss economic cost-benefit relationships of the vertical dimension, and their argument can be modified for net energy relationships. Resource temperature (energy quality) increases with depth, but so does exploitation energy cost (combined costs of exploration, well development, heat extraction, and energy conversion). At shallow depths the first may increase faster than the second, so deeper drilling is advantageous. At much greater depths, the second generally increases faster than the first, so shallower wells are better. Somewhere in between these extremes is an optimal well depth for best technical-economic performance. For greatest short term technoecosystem energy profit, this would be the depth of maximum instantaneous net energy ratio. And for most complete use of the resource it would be the depth of maximum net energy output, where marginal energy output equals marginal energy input (equal rates of increase). Optimum depth can also be determined by using instantaneous or integrated net energy and net energy ratios which include environmental effects (equations 1 through 4).

Technology evolution, and succession due to resource depletion can result in drilling to ever greater depths. Banwell and Meidav (1974) state that mechanical energy (exergy) in normal gradient areas is proportional to the cube of the depth, and that if drilling cost beyond 5 km depth increases at less than this rate, deeper drilling will be increasingly profitable. In making this hopeful suggestion they are expressing the ultimate dream of many geothermal enthusiasts -- a thermodynamic window or technological conduit into the deep crust and upper mantle, where temperatures are hot as blazes and total heat content is stupendous beyond imagining.

It appears, however, that this dream of exploiting very deep thermal energy will not be fulfilled in the near future, if ever. There are several arguments to support this conjecture:

1) Only a few holes have ever been drilled as deep as 9 km, and it is now considered daring just to drill a few research holes that deep (each hole requiring $4 million to $10 million and almost 3 years drilling time), without even thinking of trying to produce thermal energy from them (Hammond, 1975A),

2) there is much thermal energy in geothermal systems with higher heat flow much nearer the surface, and these would certainly be exploited before technoecosystem succession reached extreme depths,

3) technology and materials for routine, low-cost drilling and well development to great depths have not yet evolved,

4) as discussed in section III-4, deep resource extraction by fluid flow is hindered by the required exotic materials and thick walls of deep casing, by large pipe friction, and by potentially significant heat loss through casing walls,

5) little is known about the deep environment, so drilling of each extremely expensive well is a major risk, and

6) fracturing of hot dry rocks and establishment of closed fluid cycles at such great depths and pressures may be quite difficult. Only a small fraction of thermal energy storage could be tapped in any case, and net energy loss would be a strong possibility.

11. Portrait of the Industry

There were 1300 participants from 59 countries at the Second United Nations Symposium on the Development and Use of Geothermal Resources, held in San Francisco, California, in May, 1975 (Saint, 1975*). Geothermal energy, no longer just the dream child of a few visionaries, had arrived at global respectability.

Expansion of the geothermal energy niche has brought rapid, accelerating growth to the geothermal industry -- the group of humans and their social organizations who are responsible for evolution, construction, and management of geothermal technoecosystems. This growth, in turn, has helped accelerate the expansion of the niche. The population of geothermal professionals -- scientists, engineers, businessmen, politicians, consultants, bureaucrats, industrialists, promoters, corporations, economists, professors, and lawyers -- involved with this infant industry has expanded and diversified at a great rate in recent years. An industrial directory (Meadows, 1972 to date) has been established, and the growth of its annual lists of individuals and commercial firms indicates a current industry doubling period of only 1 to 3 years. Some geothermal oldtimers apparently feel that they are being pushed out of the center stage of the industry by newly arrived academic and government people.

Also symptomatic of geothermal industry growth is the explosion of geothermal information produced and stored in the global technoecosystem's information network. Many conferences on geothermal energy topics have been held, and their proceedings have often been published (e.g., United Nations, 1970, 1975; Geothermal Resources Council, 1972; and Kruger and Otte, 1973). Over 20 conferences have met since 1972, and more are held every year. Several general books about geothermal resources have been published (Armstead, Ed., 1973; Small, 1973; Berman, 1975*; and Wehlage, 1976), and more are in the works. A magazine (Geothermal Energy Magazine) and at least one journal (Geothermics) have been published. And the annual number of articles and reports published on geothermal subjects is now at least several hundred, increasing each year.

Much effort has been expended to organize and catalog this flood of information. Several bibliographies have been published (Summers, 1971; Talbot, 1971; Tompkins, 1972; University of Arizona, Tucson, Office of Arid Lands Studies, 1973 -- predecessor of this paper; and U.S. Energy Research and Development Administration (ERDA), Technical Information Center, 1975). And at least three large information systems exist which continuously gather, organize, and store geothermal information, and which make the information available by computer-aided retrieval and by printed compilations.

ERDA maintains an immense, frequently updated computerized data file of references to the literature for all energy sources; geothermal energy items now number over 5,000. These data are periodically compiled and published as indexed bibliographies like the one just listed. And they are continuously available for searches on ERDA's on-line computerized retrieval system, RECON. Lawrence Berkeley Laboratory and the U.S. Geological Survey are establishing a National Geothermal Information Resource which will not only collect bibliographic information and make it available in printed form and by computerized recall, but will also compile, interpret, and critically evaluate published and unpublished information (Henderson, Phillips, and Trippe, 1975). Finally, the Water Resources Scientific Information Center (WRSIC) of the U.S. Department of the Interior compiles bibliographic information on water-related subjects, including geothermal resources and exploration. This information is published in a semimonthly bulletin, Selected Water Resources Abstracts (SWRA), and is also available for computer searches on ERDA's RECON system. Both ERDA and WRSIC-SWRA data files (among other sources) were consulted in preparation of this paper's Bibliography.

Clearly, the pace of publication in the geothermal field is now so great that a single investigator may no longer be able to read everything written on the subject. The Bibliography following this paper represents a small selection from the rapidly accreting geothermal literature. It concentrates on geothermal publications which are especially relevant to water, arid lands, and geothermal technoecosystem diversity. All but 9 of the references are dated 1970 or later, reflecting the swift expansion of knowledge, experience, and innovation in the field of geothermal studies.

A look at Geothermal Energy Magazine, studying the advertisements between articles, can help develop insight into the workings of the industry and the self image of the people and organizations within it. Countless diverse, specialized geothermal technoecosystem parts and services are offered on these pages. There are ads for drilling services, general consulting, engineering, geophysical surveys, general exploration programs, small (10 Mw) geothermal turbogenerator modules, short courses, books, news bulletins, corrosion-resistant valves, specially adapted drill bits, and so on. Each ad represents a potential link for geothermal technoecosystem information, energy, and money flow. A person or government with money can get into geothermal energy fast!

Most of the writing, conferences, and research of the global geothermal industry occur within the high energy United States technoecosystem. Ironically, though, most of the innovative, practical applications of geothermal technology take place in other nations with technoecosystems that are less energy rich (Wehlage, 1974A). It is difficult to determine the reason for this state of affairs, but responsibility for it has been attributed by some to at least two parties: the government and big business.

Whatever the ultimate net energy constraints on a technoecosystem niche are, and whatever its optimum configuration is, the actual configuration chosen (perhaps with an energy and money subsidy required) depends on what people decide to do. And two great modifiers of such decisions are weightless information patterns: law and money. And these, in turn, are the domain of government and business, information processing social institutions.

Some authors (e.g., Kaufman, 1971) assert that legal entanglements are responsible for retarding geothermal technoecosystem development in the U.S. Legal definitions of geothermal resources and legal structures for leasing geothermal reservoirs beneath federal land (U.S. Congress, 89th, 1st Session, 1965; U.S. Code Congressional and Administrative News, 1970; Godwin et al, 1971) may not be suitable for the great diversity of geothermal resource types and geothermal technoecosystem configurations (Allen, 1972). Barnea (1974), for instance, believes that the legal definition of geothermal resource, which emphasizes steam, is too restrictive and should be expanded. Preexisting laws, upon which ownership disputes and money subsidies can depend, treat underground deposits of water, minerals, metals, petroleum, and natural gas in different ways. But geothermal resources combine properties of each of them and more, so complex litigation has been inevitable. However geothermal technoecosystems develop, it is certain that they will help support courthouses, lawyers, politicians, and government administrators.

Large energy companies, too, may be partly responsible for slow geothermal technoecosystem growth. Oil companies now control a large proportion of federal geothermal leases. It has been suggested that by controlling several energy sources at once, large multinational energy companies may stifle interfuel competition (Netschert, 1971). Thus, by deliberately stalling geothermal technoecosystem development, energy companies may protect more money-profitable (and perhaps less net energy-profitable) fossil fuel technoecosystems from fierce competition. Energy companies have consistently denied using such a practice, and they tend to blame restrictive laws and legal complexities for delayed geothermal development in the U.S. Whatever the true situation is, both geothermal and fossil fuel niches have finite physical limits which will probably be met someday.

The ongoing boom of geothermal technoecosystem research and construction has its own internal logic. There is money to be made in the geothermal industry, as Birsic (1974) seeks to demonstrate to the discerning American investor. And money will flow, if not by producing net energy, then by channeling still-abundant fossil fuel subsidies.

IV. LIMITS OF THE NICHE

In the first chapter, I introduced the concept of technoecosystem. In the second, the vital roles of geothermal energy in natural geological systems were reviewed. And in the third, the diverse components and strategies which technoecosystems are evolving to exploit these same geothermal energy forms were surveyed. Now I propose to investigate the macroscale and macro-time interactions between geological systems and geothermal technoecosystems: characteristics of geological systems determine properties and magnitude of the geothermal technoecosystem niche; and geothermal technoecosystems, in turn, profoundly affect geological systems. Perhaps a compromise can be worked out between these two types of systems which exploit the same energy supply.

1. Magnitudes

Turning the valve of a geothermal well to release its thunderous discharge gives one the awesome feeling that the potential for geothermal power is limitless. Hence, expressions like "virtually unlimited" have appeared often in the geothermal literature. Indeed, we are finding the planet's geothermal fuel tanks full and overflowing.

Similar cries of "unlimited resources" were heard a century ago as Europeans and their rapidly evolving technoecosystems spread inexorably across the North American continent. But there were limits, and many are being met in our own lifetime, as the effects of man and technoecosystem on natural systems acceleratingly accumulate.

Geothermal resources and the geothermal technoecosystem energy niche have limits, too. It is difficult to determine their precise boundaries, since exploration of the deep geological world and evolution of geothermal technoecosystems have just begun. But the fact that there are limits is easy to demonstrate.

Sections of the last chapter discussed some of the parameters which determine the magnitude and configuration of the geothermal energy niche: resource content of heat, water, and chemicals; resource geometry and distribution; evolving technological capabilities; physical and thermodynamic constraints; properties of industrial materials; environmental effects; net energy yield and net energy ratio; and net energy (or money) ratio of ambient technoecosystem.

However, all these complexities merely modify the ultimate geothermal niche bounding parameters -- the distribution, concentration, and magnitude of thermal energy flows and storages in geological systems. Estimates of these parameters are widely scattered through the literature; they are expressed in many forms and units, and often they conflict with each other. Most estimates are of heat content, heat flow, and potential geothermal technoecosystem energy flows and durations. Apparently no one has yet estimated net energy reserves; the technology is evolving so rapidly and geological systems are so variable and poorly known that such estimates would be exceedingly difficult to make.

Geothermal energy flows through and is stored in natural systems; therefore both a flow niche and stock niche exist. Magnitudes of flows (first) and storages (second) of geothermal energy will now be discussed, each at global, national (U.S.), and local (Geysers field, California) scale.

Table 2 compares global scale energy flow rates of natural geological systems with flow rates of technoecosystems and biological systems. Magnitudes have been compiled from several sources and converted into a common power unit, megawatts (Mw). Many interesting comparisons can be made between the different items once their energy flow rates are expressed in the same units.

Table 2. Global energy flow rates of geological, industrial, and biological systems / 1

Phenomenon	Energy Flow Rate (Mw)	Notes
Total earth heat flow	3×10^7	/2,3,4
(mostly conductive)	4×10^7	/5
Submarine spreading ridges heat flow	8×10^6	/5
Volcanoes heat flow	3×10^5	/3
Terrestrial hydrothermal convection systems heat flow	1×10^5	/6
Earthquakes, mechanical power	3×10^4	/2
Crustal relief, mechanical power	8×10^4	/2
Plate motions, mechanical power	6×10^4	/2
Total mechanical power, all geological systems	2×10^5	/2
Geothermal technoecosystems (thermal) . . .	1×10^4	/7
Global technoecosystem	6×10^6	/4
Military technoecosystems	4×10^5	/8
Global technoecosystem if at U.S. per capita level	5×10^8	/9
Solar radiation at earth's surface	8×10^{10}	/3
Biosphere net primary production	9×10^7	/10
Human metabolism	4×10^5	/11

Notes:
1. Energy quality is not accounted for. Some numbers are very rough estimates.
2. Goguel (1976*)
3. Kappelmeyer and Haenel (1974)
4. Steinhart and Steinhart (1974*)
5. Williams (1975)
6. White (1965)
7. Non-electric (3380 Mwt) from Peterson, El-Ramly, and Dermengian (1976*); plus electric (1390 Mwe) from Ellis (1975), converted to thermal equivalent at 16% efficiency.
8. Assume 7 percent of global technoecosystem energy flow.
9. Assume 4×10^9 humans, 116 kw per capita in U.S. (Steinhart and Steinhart, 1974*).
10. Wittaker and Likens (1975*).
11. Assume 4×10^9 humans, 0.1 kw per capita metabolism.

Terrestrial geothermal regions (spreading ridges, subduction zones, and hot spots) probably have heat flow magnitude similar to that of submarine spreading ridges, although the figure given in Table 2 seems too high. In any case, the first four items in the table clearly manifest the cascaded convection systems hierarchy of geological cycles: total energy flow decreases with increasing flow concentration. Comparison of total earth heat flow with magnitude of geological systems mechanical power suggests that gross mechanical efficiency of the global heat engine is around one half percent. Total earth heat flow is probably at least three times larger than what is available to present technoecosystems, because 71 percent of the global surface is ocean.

More relevant to this chapter is comparison of geological energy flows and technoecosystem energy flows. Rapidly growing energy flow of geothermal technoecosystems is already within a power of ten of heat flow through hydrothermal convection systems (the type of system now being exploited), and mechanical power of earthquakes is only about three times as large. Global technoecosystem energy flow (probably larger than shown because some of its energies are very high quality) is now approximately one fifth the size of total earth heat flow; it dwarfs the heat flow through volcanoes and hydrothermal convection systems, and overshadows the mechanical power of plate tectonics. Even the military technoecosystem subset, alone, has more power than the world's volcanoes. And a technoecosystem for today's world population, modeled after the U.S. technoecosystem, would use energy more than ten times as fast as heat flows from the earth's surface to space.

Biological systems and their solar drive are included in Table 2 to provide additional perspective. As discussed earlier, solar input at the surface is around 2,000 times global geothermal heat flow. Biosphere net primary production is two to three times total global heat flow, 15 times global technoecosystem energy flow, and only a fifth of hypothetical technoecosystem energy flow at U.S. per capita level. Human metabolism, seemingly so small in the individual, attains significant magnitude when multiplied by billions -- it is approaching one half percent of biosphere net primary production, it is comparable to military technoecosystems energy flow (without accounting for energy quality), and it is apparently larger than the estimated heat flow through all the world's volcanoes.

More detailed geothermal resources information is available for geological systems of the United States, particularly in a recent inventory of geothermal systems and their heat content by the U.S. Geological Survey (White and Williams, 1975). This USGS review concerns itself almost exclusively with heat storage, but area estimates from its tables can be used to estimate heat flow, as has been done in Table 3. Geological systems are listed in this table in probable order of decreasing exploitation difficulty, and thus of increasing net energy yields and ratios.

In Table 3, the most likely source of error for each calculated total heat flow magnitude is the value chosen for average heat flow per unit area. Estimates for this parameter (except the 1.5 HFU values) may be off by a factor of two or possibly more. As better data become available, the table can be revised.

All of the hydrothermal convection systems and igneous-related systems considered for Table 3 are located west of 105 degrees longitude, in 11 western states, Alaska, and Hawaii. Many (if not most) of these systems occur in the arid and semiarid regions which predominate in the western portion of the conterminous United States. And the Gulf Coast subsiding sedimentary basin (a normal gradient area) includes portions of semiarid southern Texas and its adjacent continental shelf.

Total heat flow estimate for U.S. igneous-related systems is smaller than the estimate for hydrothermal convection systems, contrary to what might be expected from the convection systems hierarchy hypothesis. This may be because:

1) area data are not available for most of the known igneous systems,
2) many systems may not be known,
3) some igneous systems may be so deep that heat flow spreads out to subtly increase regional heat flow,
4) conductive heat flow affects a larger area at the surface than the horizontal area of the deep magma body,
5) heat flow from many igneous systems may be counted as heat flow in overlying hydrothermal convection systems, and
6) estimated heat flow per unit area (5 HFU) may be too small, partly because mass flow heat transfer (volcanic eruptions) is not considered.

Now compare estimated natural geothermal energy flow rates with technoecosystem energy flow rates for the U.S. The present immature geothermal technoecosystem taps geothermal energy more than twice as fast as heat flow from known hydrothermal convection systems, and about half as fast as heat flows from all hydrothermal systems (known and undiscovered), the onshore part of the Gulf Coast geopressured system, and all igneous-related systems. Even the single power development at the Geysers, California, taps heat at a greater rate than heat flow from known hydrothermal systems. Furthermore, projected geothermal exploitation rates for the near future (1985 and 2000 A.D.) surpass by a factor of four to ten the combined heat flows of hydrothermal convection, igneous-related, and Gulf Coast geopressured systems, and approach the level of geothermal heat flow for the entire United States.

The rest of the U.S. technoecosystem energy flow rates (total, electrical, and military) are all larger than total U.S. heat flow (over 40, two, and two times larger, respectively). Finally, it may be of interest that total U.S. human metabolism is about ten times the natural heat flow from all identified hydrothermal convection systems.

The main point of Tables 2 and 3 is that there is a geothermal flow niche, but that it is small compared with technoecosystem flows and can easily be surpassed by geothermal technoecosystem development. Actual flow niche dimensions are probably much smaller than the heat flow values in these tables because only a few systems in each resource category may ever be accessible and suitable for net energy production at competitive net energy ratio. The simple fact that the USGS tabulated geothermal storages rather than flows is a good indication that the geothermal energy flow niche is relatively insignificant.

Table 3. United States energy flow rates of geological and industrial systems / 1

Type of Geological System	Area /2 (km^2)	Heat Flow Rate/3 (HFU)	Total Heat Flow (Mwt) /4	Notes
Normal gradient areas	9×10^6	1.5	6×10^5	/5
Igneous-related systems				
Identified	1×10^4	5	2×10^3	/6
Undiscovered	3×10^4	5	6×10^3	/7
Total	4×10^4		8×10^3	
Subsiding sedimentary basins				/8
Onshore Tertiary beds	1×10^5	1.5	9×10^3	
Cretaceous and Offshore	2×10^5	1.5	1×10^4	
Total	3×10^5		2×10^4	
Hydrothermal convection systems to 3 km, over 90°C				/9
Identified	4×10^3	10	2×10^3	
Undiscovered	2×10^4	10	7×10^3	
Total	2×10^4		9×10^3	
Total U.S. heat flow	9×10^6	1.5	6×10^5	

Technoecosystem Phenomenon	Energy Flow Rate (Mw)	Notes
U.S. geothermal technoecosystem (1975)	5×10^3	/10
U.S. geothermal technoecosystem (1985)	2×10^5	/11
U.S. geothermal technoecosystem (2000)	4×10^5	/12
Geysers powerplant (1975, thermal)	3×10^3	/13
U.S. technoecosystem	3×10^7	/14
Average U.S. electric power (thermal)	1×10^6	/15
U.S. military technoecosystem	2×10^6	/16
U.S. human metabolism	2×10^4	/17

Notes:

1. Energy quality is not accounted for. Some numbers are very rough estimates. Inventory is to depth of 10 km unless otherwise specified.
2. Horizontal area data from various papers in White and Williams (1975).
3. Values are estimated averages. 1 HFU = 10^{-6}cal/cm^2·sec.
4. Product of area and heat flow rate, converted to thermal megawatts (Mwt).
5. Northern Gulf of Mexico basin is included in a separate category.
6. Total area of identified volcanic systems for which data are given by Smith and Shaw (1975).
7. Area of undiscovered systems assumed to be three times area of identified systems on the basis of Table 26 in White and Williams (1975).
8. Northern Gulf of Mexico basin, only, to 10 km depth. Area data from Papadopulos et al (1975).
9. Area data from Renner, White, and Williams (1975).
10. Non-electric (1120 Mwt) from Peterson, El-Ramly, and Dermengian (1976*); plus electric (600 Mwe) from Ellis (1975), converted to thermal equivalent at 16 percent efficiency.
11. Thermal equivalent of average 1985 goal of U.S. Federal Energy Administration, 25,000 Mwe (Kruger, 1975), at 16 percent efficiency.
12. Thermal equivalent of 60,000 Mwe power predicted by EPA (Hughes, Dickson, and Schmidt, 1974) for 2000 A.D., at 16 percent efficiency.
13. Thermal equivalent of 500 Mwe, at 16 percent efficiency.
14. 116 kw per capita (Steinhart and Steinhart, 1974*) for population of 2.2×10^8.
15. Thermal equivalent of 224,500 Mwe power in 1974 (U.S. Bureau of the Census, 1975*), at 16 percent efficiency.
16. Assume 6 percent of U.S. technoecosystem energy flow.
17. Assume 2.2×10^8 population, 0.1 kw per capita metabolism.

That geothermal flow niches are easily outgrown is demonstrated best by the examples of individual geothermal fields now being exploited. Most fields are tapped at rates several to many times the natural heat flow rates (White, 1965). For instance, thermal energy is now produced at the Geysers at about 80 times the total natural heat flow rate (Renner, White, and Williams, 1975, p. 9). Calculating backwards from 500 Mw electrical (Mwe) at 16 percent conversion efficiency, current heat extraction is about 3125 Mw thermal (Mwt) and natural heat flow rate was only 39 Mwt.

Consider now the thermal energy output of just one typical well at the Geysers. According to Koenig (1973B, p. 24), average fluid enthalpy is 670 calories per gram and typical well output is 7×10^4 kilograms per hour. The product of these values yields thermal energy flow rate of the well -- about 55 Mwt. This single well produces thermal energy faster than the natural heat flow of the entire field. And more than 100 wells have been drilled there (Renner, White, and Williams, 1975), although production has declined in the older ones. Looking at this well another way, its output is equivalent to normal heat flow (1.5 HFU) of an 870 square kilometer (km^2) area, and high heat flow (10 HFU) of a 130 km^2 area. And it is almost 10 times the total heat flow output of Old Faithful geyser. For 22.2 cm drill hole diameter at the top of the producing zone (Budd, 1973), well thermal flux is 3.4×10^{10} HFU, which is 25 times the flux estimated in Chapter II for Old Faithful, and 22 billion times global average heat flow per unit area. Steam flow rates at the Geysers may seem normal (or even low) to technoecosystem engineers, but they are exceedingly rare (if not unprecedented) in natural geological systems.

Since it is apparent that geothermal technoecosystems can easily outgrow the geothermal flow niche and have done so in numerous locations, it is important that we investigate the geothermal stock niche and its limits. The stock niche is limited chiefly by the magnitude of thermal energy storage in geological systems (which is relatively easy to estimate) and the amount of this storage that can be extracted with current technology (which is more difficult to estimate), either with net energy yield (net reserves) or with competitive net energy ratio (economic reserves).

Tables 4 and 5 list some estimates of geothermal energy storages for the world and for the United States. Storage magnitudes are expressed in units of thermal megawatt-years (Mwyrt) for convenience; a rough estimate in years of maximum time duration of energy storage exploitation can be obtained by dividing a thermal energy total content magnitude from Table 4 or 5 by a technoecosystem energy flow magnitude from Table 2 or 3. Actual duration will be a small fraction of gross calculated duration because only a small percentage of total heat content can be extracted under even the best conditions.

Global information in Table 4 is highly speculative and will not be discussed in detail here. By comparison with more certain information for the U.S. in Table 5, the world hydrothermal convection systems magnitudes in Table 4 should be roughly 10 times larger than shown. Global hydrothermal reserves (recoverable at or near present costs) would then be 3×10^7 Mwyrt (less than 1/2 percent of original coal resources heat content), enough to run present geothermal technoecosystems for 2,200 years, but only enough to run the entire global technoecosystem for 5 years.

United States geothermal energy storage magnitudes were estimated from an elaborate compilation by the U.S. Geological Survey (White and Williams, 1975). These data (Table 5) are probably much more accurate than any global estimates, and analysis of them can give a better idea of what to expect in other continental areas of the world.

Total assessed thermal energy content of the U.S. (first column) is indeed very large, equivalent in gross magnitude to present U.S. technoecosystem operation for around 42,000 years. But most of this thermal energy is very low quality storage in normal gradient areas and is unlikely ever to be extracted.

With present and near-current technology and without regard to cost, only hydrothermal convection systems and geopressured geothermal reservoirs can now be tapped. The combined magnitude of these recoverable resources is 3×10^8 Mwyrt, equivalent to geothermal technoecosystem operation for 55,000 years at present scale, 1,700 years at 1985 scale, and 700 years at projected 2000 scale. And it is equivalent to only 10 years of operation of the entire present U.S. technoecosystem.

Finally, only hydrothermal convection systems are exploitable at presently competitive money cost. Total magnitude of high-temperature (over 150°C) identified reserves is 2×10^6 Mwyrt, equivalent to geothermal technoecosystem operation for 450 years at present scale, 14 years at 1985 level, and only 6 years at projected 2000 exploitation level. Hickel's (1973) estimate for 2000 A.D. geothermal power level, 395,000 Mwe = 2.5×10^6 Mwt at 16 percent efficiency, would exhaust these reserves in only one year. This reserves magnitude is also equivalent to just one month of present U.S. technoecosystem metabolism, and only 0.2 percent of U.S. original coal resources heat content. Undiscovered reserves may be about 5 times as large, and paramarginal resources (recoverable at 1 to 2 times present competitive cost) may have the same magnitude as reserves (Renner, White, and Williams, 1975). But the total of all reserves and paramarginal resources (identified and undiscovered) would still only be 2.5×10^7 Mwyrt, equivalent to just one year of present U.S. technoecosystem energy flow, and only 2 percent of U.S. coal resources heat content.

Table 4. Global geothermal energy storage magnitudes

Phenomenon	Heat Content (Mwyrt) /1	Notes
Total earth heat content	4×10^{17}	/2
Outer 100 km of crust	3×10^{15}	/3
Outer 10 km of crust	4×10^{13}	/3
Igneous-related systems (outer 10 km) . .	5×10^{11}	/4
Hydrothermal convection systems (outer 10 km).	1×10^{9}	/3
Hydrothermal convection systems (outer 3 km)	3×10^{8}	/3
Hydrothermal convection systems (reserves, outer 3 km)	3×10^{6}	/3,5
World original coal resources	7×10^{9}	/6
World original crude oil resources . . .	4×10^{8}	/7

Notes:
1. Heat content above 15°C. 1 Mwyrt = 1 megawatt·year thermal. These magnitudes are all very rough estimates.
2. Kappelmeyer and Haenel (1974).
3. White (1965). Hydrothermal convection systems estimates may be too low by a factor of 10 (compare with Table 5).
4. Assume same ratio (1:80) as in the U.S. for igneous-related heat content to normal gradient heat content (White and Williams, 1975). This assumption could be off by a factor of 10.
5. Reserves are resources recoverable at or near present economic costs.
6. Assume 7.6×10^{12} metric tons of coal (Hubbert, 1969*), with heat content assumed to be 7.2×10^{3} cal/gm = 7.2×10^{9} cal/metric ton (White and Williams, 1975).
7. Assume 2.1×10^{12} barrels (bbl) of crude oil (Hubbert 1969*), with heat content of 1.46×10^{9} cal/bbl Steinhart and Steinhart, 1974*).

Nathenson and Muffler (1975) present calculated estimates of total electrical energy production potential for numerous high-temperature hydrothermal convection systems of the U.S. Of these systems only the Geysers field is producing electricity on a regular basis at present. The estimated electrical energy potential is 477 electrical megawatt centuries (47,700 Mwyre), or just 95 years at current 500 Mw electrical production rate. Only legal barriers are preventing expansion of the power system at the Geysers (Kaufman, 1971), which would result in a still shorter field lifetime. Estimates of maximum power production rate range from 1,000 to 4,000 Mwe (Goldsmith, 1971), corresponding to field lifetime of 48 to only 12 years. These apparent time limits may be misleading, however, because the reservoir may extend below the assumed 3 km depth (Renner, White, and Williams, 1975), and also because fluid recharge could facilitate recovery of heat stored in reservoir rock (although at lower temperature and energy quality).

The foregoing maze of numbers serves to illustrate these points:

1) At projected exploitation rates and with present technologies, the geothermal energy niche is a finite stock niche,
2) size of the stock niche is difficult to determine precisely, but it appears to be small relative to technoecosystem needs and geothermal technoecosystem capabilities, and
3) improved technology could greatly expand thermal energy storages available for exploitation, but available natural heat flows would probably still be small compared with exploitation rates.

When a system's heat storage magnitude (Table 5) is divided by the magnitude of its natural heat flow (Table 3), the result is the approximate time duration which would be required for natural heat flow to replenish the system. Such time values range from tens of thousands to millions of years. Barnea (1975*) criticizes White and Williams (1975) for not including thermal energy recharge in their resource estimates. But it appears that heat recharge is too slow to make much difference. Clearly, at projected exploitation rates, geothermal energy is yet another depletable fossil fuel. The technoecosystem has outgrown the geothermal energy flow capacity of earth systems.

Table 5. United States geothermal energy storage magnitudes

Type of Geological System /1	Resource Base /2 (Mwyrt)	Resources /3 (Mwyrt)	Reserves /4 (Mwyrt)	Notes
Normal gradient areas (same as total U.S. storage)	1×10^{12}			
Igneous-related systems				
Identified	3×10^{9}			
Undiscovered	1×10^{10}			
Total	1×10^{10}			
Subsiding sedimentary basins				/5
Onshore Tertiary beds	2×10^{9}	7×10^{7}		
Other reservoirs	4×10^{9}	1×10^{8}		
Total	7×10^{9}	2×10^{8}		
Hydrothermal convection systems to 3 km, over 90°C				/6
Identified	1×10^{8}	2×10^{7}	2×10^{6}	
Undiscovered	3×10^{8}	7×10^{7}	1×10^{7}	
Total	4×10^{8}	9×10^{7}	1×10^{7}	
U.S. original coal resources		1×10^{9}		/7
U.S. original oil resources		4×10^{7}		/8

Notes:

1. Geothermal storage magnitudes derived from papers in White and Williams (1975). Inventory is to to depth of 10 km unless otherwise specified.
2. Resource base is thermal energy content of entire system without regard to recoverability. Magnitudes are from Table 26 of White and Williams (1975), except magnitudes for subsiding sedimentary basins, which are from Table 28 and Papadopulos et al (1975, p. 130).
3. Resources are thermal energy, both identified and undiscovered, that is recoverable using current or near-current technology, and without regard to cost.
4. Reserves are resources that are recoverable at present competitive economic cost.
5. Resources magnitudes are for fluid resource only and include not only thermal energy but also thermal equivalents of methane content and mechanical energy. Resources magnitudes are from Table 28 of White and Williams (1975). Resources magnitude for onshore Tertiary formations of northern Gulf of Mexico basin is the maximum recoverability of 3 extraction plans calculated by Papadopulos et al. Resources magnitude for other reservoirs (includes Cretaceous formations, offshore reservoirs, and other geopressured environments, all to 10 km depth) is a minimum estimated value.
6. Resources and reserves magnitudes are from Table 27 of White and Williams (1975). Reserves include high-temperature (hotter than 150°C) systems only. Identified reserves magnitude is thermal equivalent of 3.5×10^5 Mwyre at 16 percent efficiency. Undiscovered reserves are assumed to have the same ratio to identified reserves as undiscovered resources to identified resources, which is 4.7:1.
7. Assume 1.5×10^{12} metric tons of coal (Hubbert, 1969*), with heat content assumed to be 7.2×10^3 cal/gm = 7.2×10^9 cal/metric ton (White and Williams, 1975).
8. Assume 1.9×10^{11} barrels of crude oil (Hubbert, 1969*), with heat content of 1.46×10^9 cal/bbl (Steinhart and Steinhart, 1974*).

2. Killing the Goose

"In principle, at least, the present accelerating civilization of man may be running on energies stolen from the mountain building cycle."

-- Howard T. Odum (1972, p. 241)

This statement by Odum, made in the context of his biovolcanism hypothesis (that industrial and geological systems compete for solar-derived energies), is not just figuratively but literally true in the case of geothermal energy. As shown in Chapter II, thermal energy is the driving force and lifeblood of many subsurface geological processes. Some fruits of these processes are destructive to local bioecosystem and technoecosystem patterns at the surface. But most are beneficial, creating and maintaining the entire geometric and chemical framework within which biological and industrial life exist. For ages, men have been awed by earth cycles and their results. Now, with newly extended technoecosystem leverage, they seek to bring the very energy source which drives these cycles under human control as a new technoecosystem component. Odum's (1972) question "Is man a better volcano... ?", originally asked in biovolcanism context, is particularly appropriate here if "geothermal technoecosystem" is substituted for "man".

A discovered and tapped geothermal reservoir becomes part of the inorganic outward technoecosystem sector. When natural systems are engulfed by a technoecosystem, they change because their energy flows are modified to provide maximum yield. Technoecosystem almost always degrades the environment as it channels energies away from other systems and toward its own purposes. Geothermal technoecosystems can tap thermal energy faster than (and therefore can outcompete) such geological systems as geysers, hydrothermal convection systems, and volcanoes. Since heat drives these natural systems, its withdrawal can cool them off, dry them out, and halt their natural functioning. Geothermal exploitation can alter geological systems on an unprecedented scale.

The exact effects of geothermal exploitation on subsurface phenomena are difficult to predict, but significant impact is certain. Chemistry, structures, and energy flows can be affected in many ways, sometimes through complex causation pathways, and often with long delays.

In the last chapter, the probable sequence of geothermal technoecosystem succession was suggested to be from near-surface to deep resources, roughly in the cascaded sequence L, I, F, C in Fig. 6. At each successional stage the effects on environmental systems are longer delayed and longer lasting than those at the previous stage. Furthermore, as each successive storage is tapped and degraded, the systems downstream are competed with and perhaps driven out of existence. For instance, tapping a hydrothermal convection system can interfere with fumaroles at the surface, and removing the heat from a magma body can end the possibility of hydrothermal convection systems above it.

Local, short term environmental effects of geothermal exploitation were reviewed in the last chapter. They include subsidence, modification of seismic activity, contamination of groundwater, and disappearance of surface hydrothermal phenomena. Longer-term effects will now be examined. The meaning of "environment" is expanded here from the usual surficial and short-term limitations to include the subterranean environment and long time spans typical of geological change.

Exploitation of hydrothermal convection systems can alter thermodynamic, chemical, physical, and behavioral properties of hydrothermal reservoirs over a short time interval (years to decades). But these effects can linger for a much longer period because thermal and aqueous recharge are slow, and because exploitation can change permeability and thus fluid flow pathways. Alteration of thermodynamic fluid properties can cause precipitation of minerals in new locations and may terminate long-term epithermal ore deposit formation processes. Injection of cooled, concentrated brines may permanently modify the chemical and thermodynamic state of a hydrothermal system.

Axtmann (1975) suggested that thermal energy and carbon dioxide output from hydrothermal convection system exploitation could have a major effect on global climate (including aridity). Heat output would probably have to be at least as large as present world technoecosystem energy flow (Table 2) to make a dent in the earth's energy balance. And total heat content of hydrothermal convection systems reserves, if ten times the value in Table 4, would sustain such power for only 5 years. So it seems likely that any significant thermal pollution (in the global sense) would be from exploitation of other, larger geothermal reservoirs. Carbon dioxide, a sensitive atmospheric radiation balance control substance, may have a greater effect, however. An inventory of potential yield of the gas from all exploitable hydrothermal systems could help determine its maximum possible climate effects.

Exploitation of geopressured geothermal resources permanently withdraws pressurized fluids from saturated sediments and causes immediate subsidence. Fluid withdrawal can irreversibly increase thermal conductivity of saturated shales, cause subtle long-term changes in subsurface thermal gradients, and perhaps alter slow ongoing processes of petroleum and natural gas formation and concentration.

Hot-dry rock exploitation would leave permanent scars in the subsurface environment -- immense volumes of artificially fractured and cooled rock. If nuclear explosives were used, these underground cavities would be peppered with artifically created, long-lived radioactive elements. Millions of years of erosion might someday expose these strange geological phenomena at the surface. Porphyry copper deposits form in deep hot-dry rock environments (Norton and Gerlach, 1975*); thermal energy extraction on a massive scale could interfere with or end this slow process. Artificial fractures could channel subsequent igneous intrusions.

Exploitation of magma reservoirs, if it were ever to become feasible, would result in premature cooling and solidification of molten rock, and could interfere with magmatic mineral deposit formation processes. Tikhonov and Dvorov (1973) point out that geothermal exploitation could silence volcanoes, presumable by cooling magma. This might be advantageous to local technoecosystems in the short run, but could have diverse negative impacts in the long run.

Normal heat flow areas have total thermal energy flows which are small compared with overlying high-energy technoecosystems (as in the U.S., Table 3), but they represent large heat storages which have high energy quality at great depths. Exploitation, if net energy yielding technology could be developed, would be similar to tapping of hot-dry rock and would have similar results -- great volumes of artificially fractured rock underlying large areas of the planet. Extraction of heat from high-thermal-conductivity salt domes which are connected at depth with thick, extensive salt beds may be the most efficient method of harvesting heat from large normal gradient areas, and may have the smallest impact on subsurface materials.

Huge thermal storages in lower crust and upper mantle are presently far beyond the reach of geothermal technoecosystems. But should the dreamed-for technological window to these depths ever open, it is almost certain to be eagerly used. And such deep heat extraction could have the greatest, longest lasting, and longest delayed effects on earth cycles. For it is at these depths that the earth's main engines lie. Indeed, global tectonics mechanisms might be modified by such profound exploitation at production rates comparable to present technoecosystem energy demands. The precise effects seem difficult to predict, but they would probably occur on a grand time scale of thousands to millions of years. In the long run, no system on the planet (climate, life, atmosphere, topography, etc.) could escape being influenced by significant alteration of deep geothermally-powered geological cycles.

The ultimate extension of heat removal from great depths is the cessation of mantle convection and the global tectonic motions which it drives. Earth would then become a tectonically dead planet, and the consequences for global geochemical, atmospheric, and biological cycles would be manifold.

Such potential long term effects of geothermal resources exploitation are of little concern to most of us today. But they should at least be in our awareness. Geological feedback response to geothermal exploitation is very slow. In our lifetime the environmental effects are likely to be slight. But expansion of geothermal resource extraction rates far beyond their present limits could in the long run bring to an end many of our planet's free services.

Consider geothermal technoecosystems now from the viewpoint of deep geological systems looking upward. Little that technoecosystems have done has ever had much effect on the sluggish pace of subterranean life. Recently a few deep mines and a few oil wells have plunged into the spherical geological pudding. Other than that, the only events of note have been sporadic seismic shocks from nuclear explosions. Thermal news travels slowly underground; effects of the last ice age have as yet penetrated no deeper than 1 or 2 kilometers.

Suddenly, geothermal technoecosystems begin their rapid evolution. Airborne remote sensors, geochemical sniffers, and geophysical shockers probe the surface, and a curtain of cold, low-pressure drill hole heat pipe filaments rapidly descends from the outer world to tap near-surface heat concentrations. Hydrothermal convection systems are force-cooled and pumped dry and left bloated with a cool burden of reinjected brine. Geopressured reservoirs are depressurized. New underground cavities are blasted out and pumped cold. And plutons are prematurely frozen on the spot. In many places the geothermal gradient is altered so much that the effects will last for millions of years. It is a swift, inexorable global geological massacre.

Drill holes are subterranean fingers of human control, of technolife, which penetrate the permeability and conductivity barriers that have formed and protected the subsurface heat storage systems. By taking heat out, these linear conduits can kill geological systems as inevitably as spears kill mammoths. Ancient geological heat floods out through these wounds in a geological instant, creating temporary order in technoecosystems at the surface. Geothermal technoecosystems bring wealth to men by controlling and destroying structures and energy patterns underground.

Indeed, geothermal technoecosystems are the new top to the hierarchically cascaded energy pyramid of geothermal energy concentration systems. They are predators of geological systems. When entropy jet meets entropy jet, one often wins and takes over the parts and flows of the other. When technoecosystem and geological system meet, technoecosystem must win, at least in the short run, because of its high energy concentrations, sophisticated information systems, exotic materials and geometries, and most importantly because of the omni-adaptable planetary intellect of the humans who sit at its controls.

Geothermal technoecosystems hunt their quarry, then exploit and eventually kill it. The unconscious geological prey cannot hide for long from the rapidly evolving technoecosystem with its aggregate sense of self, its diverse cybernetic probes, and its use of torque, the strength of drill steel, the power of fossil fuels, and the hardness of diamonds in optimum configurations. There is little defense against such a system but the inaccessibility of depth.

The present era of geothermal exploitation is like the entrance of men into a new hunting ground populated with many giant wild beasts. We may expect a great hunt orgy, and the near extinction of the prey which is easiest to track down and exploit. Tracking and exploitation technology must then evolve to pursue more difficult quarry, because new storages form at rates which are diminutive compared to technoecosystem appetites and exploitation rates. Eventually, the entire hunting ground may be reduced to being a managed technoecosystem subset, harvested with a few docile, controlled technoorganisms, perhaps domesticated survivors of the wild breed. In geothermal terms, these survivors might be "herds" of hydrothermal convection systems or plutons at spreading ridges, which are carefully managed at renewable output rates. Surface thermal manifestations are already an endangered species; they are now protected in Yellowstone and Mount Lassen national parks.

The ancient, venerable thermal energy we tap was formed in large part long before apes began to speak and tools evolved to become technoecosystems. For eons, geological systems powered by this energy have helped order the surface environment. When the heat is removed, these ordering processes come to a halt. The heat storages seem large, but they are the accumulations of very slow flows through geological time. For relatively small, ephemeral energy yield to technoecosystems, the cost of long-lived geological damage at depth may be very great.

Technoecosystem, once content to pick at near-surface geological concentrations of minerals and fuels, is now beginning to penetrate the deep engines which helped form them. Massive geothermal exploitation is like killing the goose that laid the golden eggs. Not only does it damage subterranean systems, but also, by pre-empting free geological services, it may actually cut into future life support and thereby contract the long term technoecosystem niche.

Is tapping the heat really worthwhile? Do men have no respect for natural geological systems in the nearly pristine subsurface environment? Exploiting geothermal energy and fluids alters the underground environment as much as clearing forests, damming rivers, and strip mining coal transforms the surface environment. Yet no environmentalists demand a stop to geothermal exploitation; in fact many support it. There are no stickers on the bumpers of our automobile technoorganisms which say "SAVE THE HYDROTHERMAL CONVECTION SYSTEMS".

Apparently geological systems are so large and deep and slow that they are beyond the time and space perception of most humans. Environmentalists, environmental impact statements, and even the U.S. Environmental Protection Agency (Hughes, Dickson, and Schmidt, 1974) concern themselves only with short term surface effects. Men don't habitually think about what happens beneath their feet; geothermal heat and fluids are from another world, foreign and mysterious. And humans don't have to pay the earth cycles for the concentration work they have done. All that is needed is to sink a well in the right place, and free fuel spouts forth.

Everyone seems to be fascinated with the ease of tapping geothermal heat without much disruption of the surface environment. No one has asked if it should be done. Geologists, who have the greatest appreciation for the subterranean world, might be expected to realize that their beloved geological systems are threatened like wildlife. But even the geologists are encouraging, assisting, and often directing the subsurface carnage. And they are learning a great amount of geology in the process.

3. A Better Volcano?

Biological systems and geological systems made their peace long ago, to reach a stable but delicate geochemical-geological balance. However, newly evolved technoecosystems have been altering natural patterns in the surface environment at an ever accelerating rate. And now that they are beginning to penetrate deep into the geological heat engines, it must certainly be the start of a new geological era. We may be seeing the end of a long period of geological equilibrium. With geothermal technoecosystems coming on the scene, the old near-surface geothermal convection patterns may no longer be stable configurations. In extreme slow motion, earth systems may gradually and allometrically adjust and adapt to a new steady state -- either with geothermal technoecosystem predators, or without them.

Exploitation of geothermal energy cannot expand forever; eventually it must either level off at a steady production rate which is in equilibrium with earth cycles (a flow niche), or else it must exceed geological carrying capacity and exploit itself out of existence (a stock niche). Oscillations are possible, but unlikely, in view of quick predator reactions and extremely slow prey response.

There is a geothermal flow niche. Natural geological systems do such a good job of concentrating diffuse geothermal heat flow that it may be advantageous to let earth cycles continue their work while technoecosystems harvest the high quality fruits. Geothermal technoecosystems can comfortably maintain this position at the pinnacle of the natural energy concentration pyramid as long as concentrated energy is used no faster than it forms.

However, exploitation at faster rates transforms flow niches into finite-duration stock niches, and technoecosystem succession is forced toward new configurations which gather fuels of progressively lower quality. The energy cost of energy concentration is thereby transferred from natural systems to technoecosystems. In such a case, net energy ratio declines until either exploitation rate levels off at renewable rate, or else technoecosystem abandonment is forced. Unfortunately, the technology which can exploit geothermal storages at natural flow rate can just as easily exploit them more rapidly. And the temptation to do so is very great, because natural heat flows are exasperatingly slow compared with rampaging technoecosystem appetites.

An entire global technoecosystem could be operated on geothermal energy in a steady state renewable flow niche. But such a technoecosystem would probably have to be much smaller than ours is today. For present and projected technoecosystem size, accomodating present and projected billions of humans, the geothermal energy niche must in all probability remain a subsidiary energy niche.

At present, industrialized technoecosystems are based on the fossil fuel energy niche. Geothermal technoecosystems are simply one way (agriculture is another) for concentrated fossil fuel energies to be invested in order to harvest an amplified energy profit from natural systems, often in remote locations. Geothermal technoecosystems would probably yield much less net energy if they had to support the entire high-energy industrial superstructure which makes them possible -- mines, steel mills, cities, and so forth. Hence the survival of high energy geothermal technoecosystems depends on successful transfer of the global technoecosystem from the finite fossil fuel stock niche to some new major energy niche, perhaps a flow niche.

The geothermal energy niche is just opening now. But, assuming that it will be exploited rapidly as a stock niche, and assuming that the global technoecosystem will survive into the distant future (although this is by no means certain), now is not too soon to start to think about the end of the niche. As discussed in Chapter I, exploitation of finite resources does not occur as a square wave through time -- instantaneous start, long plateau, instantaneous stop. Instead it tends to follow a bell curve -- acceleration and excitement at the start, worry and controversy at the peak, and decay during a long decline. This can happen at many scales of space and time: a short exploitation pulse for a local resource, a much longer pulse on global scale. Since the geothermal energy niche is likely to be a stock niche, we might as well plan now for eventual obsolescence, succession, abandonment, and perhaps recycling of geothermal technoecosystems at local and worldwide scales.

At the surface we may expect not only abandonment of geothermal technoecosystem components, but also changes or decay of other technoecosystem configurations which develop around the geothermal base. Industries designed around a geothermal niche will have to move, adapt, or disappear when it comes to a close. Agricultural fields irrigated and maintained by exploitation of a geothermal power and water niche will very likely have to be abandoned, perhaps leading to severe local desertification. The more geothermal resources are used in energy flow amplification roles, the greater the effects of eventual niche termination are likely to be.

Fossil evidence of geothermal technoecosystem abandonment will also be left in the subsurface environment, where it is likely to last long after all traces at the surface have vanished. Just one or two human generations of high energy geothermal technoecosystem operation could irreversibly foul the subterranean geological nest, leaving a legacy of chilled, depressurized, blasted, and abandoned geothermal reservoirs. Scars at the surface, even in delicate desert environments, heal quickly compared with scars underground. Far in the future, long-abandoned geothermal bores may be found embedded in rocks exposed at the surface, much as today we find worm burrows preserved in sedimentary formations -- fossil remains of ancient energy systems and their environments.

Should we let geothermal exploitation proceed? Must all potential energy stocks within technoecosystem's reach be exploited? Perhaps a new technoecosystem management ethic is called for here: avoid dissipation of finite, irreplaceable energy storage on routine maintenance and expansion of technoecosystems. Feeding appetites just enables them to grow, and it makes the eventual bust more severe. Instead, save the energy pulse for later need, or use it to develop technoecosystem configurations for some new flow niche.

Can geothermal exploitation be stopped? Probably not. There seems to be an adaptive drive in humans to enthustiastically explore and exploit any new technoecosystem niche which presents itself. Population growth and globally-communicated appetites for high energy lifestyles enhance this impulsion. Unless laws or dollars intervene, tapping of potential energies can hardly be stopped, even if the resource is a limited stock. Except in special cases (like protected thermal systems in national parks), there is little negative feedback but net energy or money ratio to slow geothermal exploitation. Where economically competitive, geothermal technoecosystems will probably expand until the niche is filled beyond long-term carrying capacity.

Should geothermal technoecosystems evolution and succession proceed so far that thermal energy is tapped from deep crust or upper mantle, some new technoecosystem possibilities could open up. Geothermal energy is the currency of subsurface processes. As our knowledge of earth systems expands, we may discover that there are certain key components of macroscale geological systems which are highly sensitive to thermal energy withdrawal -- and which could be used to manipulate global tectonic forces and motions over long periods of time. Judging by past and present technoecosystem management philosphies, if men can control something, and thereby expand the technoecosystem, they will. There is only a difference of time and space scale between managing a hydrothermal convection system and modulating convection in the mantle. If men and technoecosystems should survive so long on this planet, we might imagine projects lasting millions of years for global engineering of spreading centers, continental geometry, mountain architecture, and arid climatic zones. If this should happen, then earth's only independent variables would be mass, chemical composition, and orbital parameters; everything else would be subject to human decisions and their uncertain consequences.

Such global geological management would probably be for peaceful purposes. Although geological phenomena like volcanoes and earthquakes have been suggested as environmental weapons (Barnaby, 1976*), and thus as military technoecosystem subsets, it seems unlikely that intercontinental grudges could be held long enough to sustain plate tectonic warfare.

Will continental drift become still another phenomenon which must be managed by social systems just to avoid the peril of overexploitation? Will all the cycles of our planetary spaceship eventually become part of the technoecosystem? Perhaps some natural systems are best left alone.

V. IMPERIAL VALLEY

There is perhaps no example better than Imperial Valley, California, to illustrate in concrete form the facts and principles presented in the preceding four chapters. Imperial Valley is the site of a complex but unified very-high-energy agroindustrial fossil-fuel-niche macroscale technoecosystem, carefully adapted to topography, soils, extreme aridity, and a large, but finite water flow niche. The valley's macroscale geological framework is a unified system incorporating all levels of the convective heat flow concentration hierarchy; yet the large geothermal resources it has produced are sufficiently varied to require specialized adaptations in exploitation systems. Geothermal technoecosystems have been present in Imperial Valley for 50 years or more, and their evolution and growth are currently experiencing an unprecedented boom. Current plans for future geothermal technoecosystem development in Imperial Valley may be the most elaborate, ambitious, largest-scale of any geothermal development scheme in the world. As is the case with most geothermal exploitation plans, however, the geothermal niche is small compared with technoecosystem energy appetites.

A special feature of Imperial Valley is that it occurs along the U.S.-Mexico international boundary. Thus its geothermal and agroindustrial developments can be studied in conjunction with those of adjacent Mexicali Valley, Baja California, which is a continuation of the same physical setting.

Much has been written about geothermal resources and exploitation in the Imperial Valley-Mexicali Valley region -- probably more than has been written about any other arid geothermal location. At least 65 items in the Bibliography and the Supplementary References list deal specifically with this area; most of them are cited in this chapter.

With the four past chapters as background, the stage is set. Now, as we fly over Imperial Valley, we can truly appreciate the macroscale drama of the geological systems and technoecosystems evolving there below.

1. Natural Environment

Imperial Valley is located in the Salton Basin physiographic province, more specifically in the Salton Trough, a 150 km long northwest-trending, deep, sediment-filled structural trough or rift valley, the landward extension of the Gulf of California. The Salton Trough is one of the most tectonically active areas in the world, exhibiting rapid deformation, frequent earthquakes, volcanism, and high heat flow. It is a major geothermal province (Palmer, Howard, and Lande, 1975).

From northwest to southeast, subdivisions of the Salton Trough are: Coachella Valley, the Salton Sea, Imperial Valley, Mexicali Valley, and the Colorado River delta. Coachella, Imperial, and Mexicali valleys are in large part below sea level. The Salton Basin, which includes them, drains internally to its lowest part, the Salton Sea (elevation -71 m, area 930 km^2).

Boundaries of Imperial Valley are: Salton Sea and Imperial County border to the north, hills and mountains to the west, Algodones sand dunes and Chocolate Mountains to the east, and the international boundary to the south. The valley occupies southeasternmost California and northwesternmost Sonoran Desert. Imperial Valley is extremely arid; average yearly rainfall is only 6.4 to 7.6 cm, while annual evaporation from Salton Sea is around 180 cm (Werner and Olson, 1970). Precipitation occurs mostly from October to February. Mean annual temperature is 23°C. Sparse natural vegetation, where still undisturbed, consists of alkali sink community near the Salton Sea, and creosote bush scrub community elsewhere (U.S. Bureau of Reclamation, Washington, D.C., 1972 -- henceforth abbreviated USBRDC, 1972; Denver, Colorado office is shortened to USBRC, and Boulder City, Nevada office to USBRN).

Most of our knowledge of subsurface systems in the area has accumulated, partly as a result of geothermal exploration, in just the last two decades. Palmer, Howard, and Lande (1975) present a good overview of the geology of the Salton Trough, which has been drawn on for much of the following discussion.

On the scale of global tectonics (first stage in the convection systems hierarchy), the Salton Trough and the Gulf of California represent the transition from rifting and new oceanic crust formation (along the northeast-trending East Pacific Rise spreading ridge) to right lateral strike-slip motion (along the northwest-trending San Andreas fault system). The result of this transition is a complex series of short northeast-trending spreading centers (segments of East Pacific rise) offset by en echelon northwest-trending right lateral transform faults (of which the San Andreas fault is the last and largest), laid out in stairstep fashion from the mouth of the Gulf of California to the Salton Sea. High heat flow measurements in the Gulf indicate the positions of at least two spreading centers (Lawver, 1975), and a map (Palmer, Howard, and Lande, 1975) shows nine spreading centers. This structural system has facilitated global convection-driven separation of Baja California from the mainland (forming the Gulf) and northwestward sliding of coastal southern California relative to the rest of North America. These motions are very slow, on the order of 6 cm per year. They have been going on for a long time -- Gulf of California has been a tectonic depression for the last 15 million years (ibid.). And they will probably continue for more millions of years if not disturbed.

The Salton Trough is an actively growing rift valley. But it is a complex rift valley, not a simple one like the Red Sea or East African rifts. It is really an extension of the Gulf of California, complete with discrete spreading centers offset by en echelon northwest-trending faults. The major difference from the Gulf is that the Salton Trough is filled with sediments and sedimentary rocks, mostly of continental origin and 3 to 6 km thick (Austin, Higgins, and Howard, 1973). Palmer, Howard, and Lande (1975, p. 16) show three inferred spreading centers in the Salton Trough: one under Cerro Prieto, Mexico, a second under the Brawley geothermal area, and a third under the southeastern end of the Salton Sea. An aeromagnetic survey (De la Fuente Duch, 1973) suggests the presence of a fourth spreading center, Pango de Abajo, on the Colorado River delta.

Under the Salton Trough, the crust is thin; the mantle is only 15 to 20 km deep (Koenig, 1973B). Additional thinning occurs where the crust pulls apart at spreading centers, allowing magmas to form and leak upward, the second stage in the convection systems hierarchy. The only surface manifestations of magma systems (Quaternary volcanoes, hot springs, fumaroles, and mud volcanoes) occur at Cerro Prieto and Salton Sea southeastern end. However, numerous hydrothermal convection systems, third stage in the convection systems hierarchy, are scattered through the Salton Trough, hidden (except to geophysical surveys) by impermeable cap rock.

Three major northwest-trending fault systems -- San Andreas, San Jacinto, and Elsinore -- cut through Imperial Valley and the Salton Trough, giving the trough and even the Salton Sea their northwestern alignment. Since 1931 about 2 m of differential right lateral movement has taken place in southern Imperial valley (Palmer, Howard, and Lande, 1975), equivalent to an average rate of 4.5 cm per year. This motion is accompanied by much seismic activity. More than 12 earthquakes greater than magnitude 6.0 (Richter scale) have occurred since 1900 (ibid.), and hundreds of microearthquakes (magnitude 1.0 or less) are triggered each year (USBRN, 1972C). Hill, Mowinckel, and Peake (1975) present a map of locations of moderate and small earthquake epicenters; they are most common along faults and below geothermal anomalies. In general, microearthquakes occur in hot areas and medium to large quakes occur in cool areas of Imperial Valley (USBRDC, 1972). Along with its horizontal movement, Imperial Valley is undergoing tectonic subsidence at a rate of about 1 cm per year (Goldsmith, 1971).

While subsiding, the Salton Trough has been filling with sediments, most derived from the Colorado River. The Colorado, entering from the east at Yuma, has over millions of years alternately discharged sediments and water south into the Gulf of California and north into the Salton Basin (Palmer, Howard, and Lande, 1975). Vast amounts of deltaic sediments (sands, silts, clays, and pebble conglomerate, eroded from the Grand Canyon and elsewhere in the Colorado River Basin), along with some fine-grained lake beds, eolian deposits, and alluvial fan sediments from nearby mountains, have gradually filled the trough, generally keeping pace with subsidence.

Sediments in the Salton Trough are mostly unconsolidated. However, some sediment volumes have been metamorphosed to hard, dense greenschist facies by deep, hot portions of hydrothermal convection systems (Combs and Muffler, 1973). This transformation greatly decreases porosity and permeability, and thus also decreases fluid recharge rates and storage (Dutcher, Hardt, and Moyle, 1972).

Deep groundwater reservoirs, which contain the hydrothermal convection systems, are well separated from shallow aquifers by impermeable cap rocks. Such impermeability is usually caused by presence of lacustrine clays, but can also result from self sealing by hydrothermal convection systems (Palmer, Howard, and Lande, 1975). Geochemical testing (Na-K-Ca geothermometry) at East Mesa shows clearly that the geothermal system is tightly confined (Swanberg, 1974).

The entire Salton Trough sediment fill is saturated with water to within a few meters of the surface. Most of this water is from Colorado River underflow, but some is from adjacent mountain ranges, as shown by hydrogen and oxygen isotope studies (Combs and Muffler, 1973). Recharge is very slow (Reed, 1973). Total volume of available groundwater in Imperial Valley is estimated to be 1400 km^3 (1.1 billion acre-ft) by Dutcher, Hardt, and Moyle (1972), and 2000 to 5900 km^3 (1.6 to 4.8 billion acre-ft) by Rex (1970). This would represent 81, 119, or 356 years of average original Colorado River flow at Lees Ferry, Arizona, 16.7 km^3 (13.5 million acre-ft) per year (Jacoby, 1975*).

Salinity of deep groundwater increases along a gradient to the northwest (Meidav and Furgerson, 1972), from around 1,000 ppm at Yuma to around 300,000 ppm at the Salton Sea (Austin, Higgins, and Howard, 1973). (Sea water salinity is around 35,000 ppm.) Salt content raises boiling temperature of water, which allows higher temperatures at shallower depths; this effect is most significant for extremely hot hypersaline brines of the Salton Sea geothermal system. Shallow groundwater, except in Coachella Valley, is too saline for agricultural use. Werner and Olson (1970) comprehensively review physical properties and magnitudes of surface and subsurface waters in the Salton Sea area.

In deep groundwater of Salton Trough, a number of hydrothermal convection wet steam systems have established themselves. One is known at Cerro Prieto in Mexicali Valley, and approximately ten are known in Imperial Valley. Renner, White, and Williams (1975) tabulate estimated temperature, subsurface area, volume, and heat content of 8 hydrothermal convection systems of Imperial Valley. Combined, they represent about 1 percent of the estimated heat content of all U.S. hydrothermal convection systems (identified and undiscovered), and about 6 percent of identified systems heat content. The U.S. Geological Survey has established 6 known geothermal resource areas (KGRAs) in Imperial Valley.

The hottest hydrothermal convection systems (Salton Sea and Cerro Prieto systems) occur over inferred spreading centers. And all the systems seem to be at least partly localized by vertical permeability in fault zones (Rex, 1970).

With the exception of Salton Sea and Cerro Prieto systems (which have surface thermal manifestations), Salton Trough hydrothermal systems can be detected only with geophysical exploration techniques. Diagnostic geophysical features of the convection systems include high seismic noise and microearthquake activity, high temperature gradient and heat flow, high residual gravity anomalies, and low electrical resistivity (Combs and Muffler, 1973; Palmer, Howard, and Lande, 1975; and Meidav and Furgerson, 1972). Gravity highs (density highs) may be due to intrusion of igneous rocks, or due to baking of clays, low-grade metamorphism, or silica cementation by hydrothermal fluids (USBRN, 1971*; Combs and Muffler, 1973; Reed, 1973). Evans (1972) suggests that linear magnetic low anomalies may indicate places where hot fluids convect upward in fault zones. All these geophysical properties have been present for eons, but it was not until geophysical sensors were evolved by technoecosystem and then brought to Imperial Valley that they became sensory realities.

Of all the hydrothermal convection systems in Salton Trough, only three have been extensively explored and reported in the literature: Salton Sea, East Mesa, and Cerro Prieto systems. Each has unique physical properties which profoundly influence possible configurations of successful exploitation technoecosystems. The three systems will now be discussed in turn.

The Salton Sea geothermal system (also known as Niland, Buttes, or Obsidian Buttes anomaly, geothermal field, or geothermal system), located at the southeastern end of the Salton Sea, is a global geological rarity -- it contains very hot hypersaline brine. Of all known Salton Trough hydrothermal systems, it is the saltiest, largest, northernmost, and next-to-hottest. Salinity ranges from 250,000 up to 350,000 ppm (25 to 35 percent) (Austin, Higgins, and Howard, 1973). The fluids are nearly saturated Na-Ca-K chloride brine, contain anomolously high concentrations of certain metals (Fe, Mn, Cu, Zn, and Pb), and have the highest salinity found in geothermal fluids in the world to date (Ellis, 1975). Temperatures over 300°C and ranging up to 370°C occur at depths of 1.3 km and greater (Koenig, 1973B). This is by far the highest temperature reported in Imperial Valley, and is second only to the highest temperature at Cerro Prieto, 388°C (ibid.). Hydrothermal metamorphism reaches shallowest depths in the Salton Sea system (Palmer, Howard, and Lande, 1975).

According to estimates by Renner, White, and Williams (1975), not only does this system have the largest area, volume, and thermal energy content of all Imperial Valley hydrothermal systems, but also its heat content is half of total heat content and its recoverable electrical energy content is 60 percent of the total for all Imperial Valley systems. Subsurface area of the system is estimated to be 54 km^2 (ibid.), but the area of anomalous heat flow is about ten times as great. Heat flow contours (USBRDC, 1972) form a bull's-eye pattern centered on the southeastern shoreline of the Salton Sea; more than half of the anomalously hot area is inferred to underlie the sea.

At the center of the Salton Sea geothermal system, along the Salton Sea shore, stand the Salton Buttes, five small extrusive rhyolite domes, the only surficial volcanic features in Imperial Valley. Aeromagnetic data, as interpreted by Griscom and Muffler (1971), show that these domes are small extensions of a large northwest-trending igneous ridge 29 km long, 5 to 8 km wide, and 2.0 to 2.3 km below the surface. Dating of rocks indicates that the last eruption was less than 55,000 years ago and possibly only 16,000 years ago (Smith and Shaw, 1975, p. 68). The igneous body is still hot, and is the heat source which drives convection in the Salton Sea hydrothermal system.

Another distinctive feature of the Salton Sea system is that a large amount of carbon dioxide (CO_2) has been concentrated at shallow depth just north of the Salton Buttes. Muffler and White (1969*) suggest that this gas has been liberated from carbonate minerals by hydrothermal metamorphism of sediments at depth. Because of this CO_2 reservoir, and especially because of the hypersalinity of deep geothermal fluids, the configurations and evolutionary history of geothermal technoecosystems at the Salton Sea field have been and will continue to be very different from those at any other system in the Salton Trough.

The East Mesa hydrothermal system, smaller, cooler, and less saline than the Salton Sea system, is located (at its center) in desert terrain 12 km east of Holtville, California, 2.5 km east of the East Highline Canal (eastern boundary of Imperial Valley's irrigated area), and 10.5 km north of the international boundary. This system, which ranks third in size among Imperial Valley systems, is known largely through extensive exploration efforts by the U.S. Bureau of Reclamation. Published geophysical and geological information (e.g., USBRN, 1971, 1971*, and 1974; USBRDC, 1972) is more complete for this system than for any other in Imperial Valley. Subsurface area is estimated to be 28 km^2 (Renner, White, and Williams, 1975), and area of anomalous heat flow is about 140 km^2. There are no obvious thermal manifestations at the surface. Sediments are about 3.5 km deep (USBRN, 1971*; Combs and Muffler, 1973). Convective heat transfer dominates below relatively impermeable sediments about 800 m thick (USBRN, 1974). Geothermal fluids tapped by wells up to 2.4 km deep have bottom hole temperatures of 154 to 204°C and surface flow temperatures of 154 to 166°C, salinity ranging from about 2,500 to 26,800 ppm, and CO_2 content of 600 to 2,000 ppm (Fernelius, 1975*; Mathias, 1975*). The East Mesa system may be typical (except in size) of Imperial Valley hydrothermal convection systems other than the Salton Sea system.

The Cerro Prieto hydrothermal system, of uncertain size, has high temperatures comparable to (but deeper than) those of the Salton Sea system, and lower salinity comparable to East Mesa fluids. It is located about 35 km south of the Mexico-U.S. border town of Mexicali-Calexico, near Cerro Prieto, a dacite-basalt volcano (Koenig, 1973B). The presently explored area (about 31 km^2 -- Mercado, 1969*) is just west of a spreading center between San Jacinto and Imperial faults (Palmer, Howard, and Lande, 1975). A single well on the eastern side of the San Jacinto fault indicates that the present well field may be only on the periphery of a much larger system over the spreading center (Isita, Mooser, and Soto, 1975).

Sediments roughly 4.5 km deep (Reed, 1973) at Cerro Prieto consist of a sealing cap of clays and sandy clays, the producing horizon of sands and sandy shales at 900 to 1500 m depth (ibid.), and another permeable sandy zone below 2400 m (Koenig, 1973B). The producing horizon is 500 m deeper east of the San Jacinto fault (Isita, Mooser, and Soto, 1975). Wells up to 2.5 km deep yield fluids over 300°C. One measurement, 388°C (Koenig, 1973B), is the world's hottest recorded temperature for a wet steam reservoir (Ellis, 1975). Fluid chemistry is similar to that of the Salton Sea system, but total salinity is only a tenth as great (Werner and Olson, 1970). Salinity ranges from 13,000 to 25,000 ppm. The Cerro Prieto field was discovered as a result of fumaroles and mud volcanoes nearby.

In conclusion, the contrasting physical characteristics of Salton Trough geothermal systems have exerted a strong influence on specific exploitation technoecosystem configurations and development histories, and will continue to do so. The Salton Sea system has high temperatures well suited to power production; but high salinity and corrosiveness of its fluids necessitate the use of specially adapted technology, as yet unproven. On the other hand, its high salt content and its CO_2 concentrations make it a good source of chemical products. East Mesa system has much lower salinity, but also lower temperatures. Thus, it may be most favorable for water desalination and possibly some power generation. Finally, the Cerro Prieto system is ideal for electricity generation; its fluids are very hot like the Salton Sea system but have low salt content like East Mesa fluids. The technoecosystems actually developing over these three systems closely reflect these physical niche constraints. In addition, because they have obvious hydrothermal manifestations at the surface, Salton Sea and Cerro Prieto systems were the first to be exploited. Hidden systems like East Mesa, most known less than a decade, are still under study, and their technoecosystems are still at exploration or research and development stage.

2. Macroscale Technoecology

> "Not only the very lives of people of Imperial Valley depend upon the safe and secure flow of water through the irrigation system, but also their social welfare, their culture, their ability to pursue and attain happiness and success."
>
> --Otis B. Tout, as quoted by Tracy Henderson (1968*, p. 131)

Flying at high altitude, we can perceive Imperial Valley as a whole system. Here in the midst of extremely arid terrain -- barren, chocolate-colored mountain ranges and expansive, sandy basins -- we see this incongruous patchwork of green touching a pear-shaped pool of blue. The north-oriented square grid, which organizes the green, indicates that this is a technoecosystem; the green color itself tells that this technoecosystem's main function is to collect solar energy with chlorophyll-bearing biological technoorganisms. Looking closer, we see canals, roads, railroad tracks, and powerlines, which are like veins of a macroscale leaf. Scattered cities and towns are blocky patches less green, nerve centers where control systems and human life support systems are concentrated. The sky-blue Salton Sea is a metabolic waste sink for the Imperial Valley technoecosystem. A slender dark thread angling across dunes and desert plains from Yuma to the east -- the All-American Canal -- is the key to survival for this technoecosystem; without the water it brings the fields would become desert again, and the Salton Sea would dry up to resume its former state as a salt flat. Imperial Valley is much like what Arizona astronomer Percival Lowell (1908*) thought he saw on Mars -- a macroscale technoecosystem of croplands and scattered settlements, surviving in an extremely arid land on the basis of a limited macroscale water niche fed by canals.

Area of Imperial Valley is 4430 km^2. Area of the Imperial Irrigation District, largest irrigation district in the western hemisphere, is 3940 km^2 (89 percent of valley total). Of this horizontal space, 2480 km^2 (63 percent of the district) is irrigable, and 2020 km^2 (81 percent of the irrigable land) is actually irrigated (USBRDC, 1972; Henderson, 1968*). The area of land actually cultivated is limited by several factors:

1) It is restricted to the area of favorable soils, generally the area of Quaternary and Tertiary lake beds (see geological map, USBRN, 1971, p. 23A).
2) It is restricted to the space of favorable water supply, generally the area below or only slightly above the main water distribution canals, and above the elevation of the Salton Sea.
3) It is limited by competing space requirements of other technoecosystem components (channels, cities).
4) And most importantly, it is limited by the quantity and quality of water available to it via the All-American Canal from the Colorado River -- the macroscale water niche.

Imperial Valley is an excellent example of a high-energy technoecosystem. Its specialization is agriculture, so the most important components are its square solar collector modules -- diverse biological technospecies monocultures rooted in soils carefully leveled and furrowed by fossil fuel powered tractor technoorganisms. Because of the warm, sunny climate, almost any kind of crop grows well here -- cotton, vegetables, grains, fruits, and sugar beets -- and planting and harvesting can be scheduled for any month (Henderson, 1968*). Livestock technoorganisms, fed on local vegetal harvest, add additional diversity to agricultural production capabilities.

But these fields and biological components require intricate support facilities. Soil and sun, naturally present, require addition of water, fertilizers, biological controls, and high quality information and organization in order to support growth of productive green plant technospecies. Accordingly, a complex high-energy network of technoecosystem channels and modules is woven around and through the agricultural checkerboard. High quality water input ("horizontal rain") is provided by a complex, cybernetic, hierarchical, rectangular distributary system of canals. And low quality saline water exhaust is collected from the fields by a similar hierarchical tributary system of tile drains and drainage canals which ultimately discharges into the Salton Sea. A hierarchical, mostly rectangular grid of roads facilitates access of diverse terrestrial mobile high-energy mechanical technoorganisms: tractors, harvesters, trucks for fertilizer delivery and crop transport, and pickup trucks bearing human technoecosystem managers. A few landing strips maintain aerial crop duster technoorganisms for rapid and precise application of biological control chemicals.

On a somewhat larger (valley-wide) scale, there are scattered concentrations of still higher-energy technoecosystem modules for servicing, harvesting, and managing the surrounding primary production surfaces. Seven cities and several towns, including the Calexico-Mexicali international border crossing, are gridded constellations of stationary commercial, residential, and industrial building technoorganisms, and provide high-energy life support services for human inhabitants of the Imperial Valley technoecosystem. Their streets bustle with highly mobile car, truck, and motorcycle technoorganisms.

Light industry modules, concentrated in these cities and along major transport channels, perform vital services for the agricultural technoecosystem: sugar refineries, food processing plants, packing houses, cotton gins, agricultural chemical storage and distribution facilities, and plants for manufacture of concrete pipe and cardboard boxes. Small highways and railroad branch lines (transport channels) connect these industrial and residential technoecosystem centers. Electricity from fossil fuel steam plants and from hydropower drops on the All-American Canal is distributed throughout the valley by an extensive hierarchical cybernetic power grid. Other notable technoecosystem subsets are: water-costly golf courses; dense settlements of trailer technoorganisms, especially around warm springs northeast of Salton Sea; U.S. Navy test base and gunnery ranges; pleasure boat technoorganisms on the Salton Sea, supported by shoreline marinas; and weekend populations of dune buggies and other off-road technoorganisms in sand dunes and desert spaces.

At macroscale regional level, the entire Imperial Valley technoecosystem is linked to the national and global technoecosystems by macroscale channels. Water is imported from the Colorado River via the All-American Canal. East-west trending interstate highways, one north and one south of the Salton Sea, channel diverse road vehicle technospecies traffic to and from the macroscale metropolitan technoecosystems of San Diego, Los Angeles, Phoenix, and Tucson. Railroads channel freight train technoorganisms into the valley with agricultural chemicals and heavy machinery, and out of it loaded with agricultural products headed to market. Pipelines and powerlines bring fossil fuel and electricity inputs. And the county airport handles regional traffic of aircraft technoorganisms.

As seen with macrovision, Imperial Valley is a macroscale entropy jet. High quality energy inputs include flows and storages from natural systems (soils, topography, sunlight, atmospheric circulation, and minor rainfall) and from technoecosystems (Colorado River water, fossil fuels, agricultural chemicals and machinery, manufactured components and materials, information, and humans). High quality energy outputs include these flows and storages: agricultural products, technoecosystem structure, information, humans, and enjoyment of life. And low quality energy exhausts include: waste heat; evaporated water; fossil fuel exhausts; and salts, chemical wastes (agricultural, municipal, and industrial), sediment, and low quality water discharged into and stored by the Salton Sea. The possible future effects of geothermal technoecosystems (still rather insignificant components of the Imperial Valley technoecosystem) on these inputs and outputs will be discussed in later sections.

From our airplane we see the Imperial Valley technoecosystem from the outside, at macroscale. In contrast, Tracey Henderson, in her book Imperial Valley (1968*), describes it from the inside, at the intensely personal human microscale. She intimately reviews the experience of living within the system (old stories; local lifestyles and culture; communal experiences in earthquakes, floods, and war years) and the accomplishments and involvements of the individual inhabitants (local leaders, historical founders and organizers of the technoecosystem, and even those who left the valley to man military technoecosystems in global technoecosystem conflicts). In addition, she sketches the history of the technoecosystem and its social systems, as seen from the usual human level: Cocopah Indians, then the Spaniards, then the Anglos; entrance of the fossil fuel technoecosystem (first railroad service in 1903, first automobile in 1907, and first airport in 1927); and the development of roads from dirt trails to superhighways. Her book was published just before the recent boom of geothermal technoecosystem experimentation and development began.

Of particular interest here is Henderson's review of the history of Imperial Valley's water transport technoecosystem. O.M. Wozencraft in 1849 was the first human to envision the possibility of an Imperial Valley agricultural technoecosystem fueled by water from the Colorado River. But the first water diversion did not take place until 1901. Flooding of the Colorado in winter, 1904-1905, overwhelmed the Alamo Canal diversion system, and soon the entire flow of the river was flowing into the Salton Sink (as it has done frequently in geological history). Prodigious efforts to rechannel the flow were not permanently successful until 1907. Meanwhile, the Salton Sea was born. After salt buildup had forced abandonment of many fields, construction of the drainage system was started in 1937. And the All-American Canal, replacing the Alamo Canal (which runs through Mexico) as water channel to Imperial Valley, was completed in 1940 and opened in 1942.

The Colorado River is the "most highly regulated and intensively utilized river system in the U.S." (Palmer, Howard, and Lande, 1975). Through dams, aqueducts, and numerous diversions (as outlined by Irelan, 1971* and USBRDC, 1973), this river has become a technoecosystem subset. Thompson (1972) reviews California's macroscale use of water from the Colorado. The Colorado River Aqueduct, a giant straw which sucks water from behind Parker Dam, pipes about 1.4 km^3/yr of water hundreds of kilometers to urbanized southwestern California, and will supply that area for at least the next 20 years (Goldsmith, 1971). Of 11.5 km^3/yr 1956 to 1965 average total Colorado River flow at Lees Ferry (boundary between Upper and Lower Colorado River Basins), only about 7.4 km^3/yr reaches Imperial Dam, near Yuma, the last dam before the river enters Mexico.

At Imperial Dam, most of the flow is diverted to the All-American Canal, some feeds into the Gila Gravity Main Canal, and the rest flows downstream to Mexico. Some All-American Canal water branches off into the Yuma Main Canal (Irelan, 1971*). And the remainder, about 3.7 km^3/yr (Werner and Olson, 1970), continues on to the Salton Basin; under human control, the Colorado still flows (in part) into the Salton Sea. Of this amount, 0.4 km^3/yr is diverted through the Coachella Canal to Coachella Valley, and 3.3 km^3/yr (more than one fourth of flow at Lees Ferry) continues on to Imperial Valley (ibid.). This 3.3 km^3 per year is the Imperial Valley technoecosystem's finite water flow niche.

From its arrival at Imperial Valley, the water is managed by the Imperial Irrigation District, which is in charge of water distribution, drainage, and power production technoecosystems. The water (3.3 km^3/yr) is distributed by 2900 km of canals (Henderson, 1968*). Evaporation from fields is about 1.9 km^3/yr (Goldsmith, 1971). And the remaining water, about 1.4 km^3/yr, eventually reaches the Salton Sea, mostly as direct irrigation return, but also as effluent from small non-agricultural technoecosystems, and as subsurface seepage (Werner and Olson, 1970). Irrigation water is channeled to the Salton Sea through 29,000 km of tile drains and 3,000 km of main and lateral open drains; more tile drains are installed at a rate of 1600 km per year (Henderson, 1968*; USBRDC, 1973).

The Salton Sea is in allometric equilibrium with the technoecosystem which has inadvertently formed it; it expands or contracts until average evaporation equals average inflow of water. And salts progressively accumulate. The history of the Salton Sea mirrors the irrigation history of its basin. During the 1904-1907 floods, the sea grew swiftly to about twice its present depth. Then it declined slowly until the 1920's, when evaporation again equaled inflow. As irrigation flow increased until the late 1960s, the Salton Sea gradually expanded to balance its water budget. At present the Salton Sea is relatively stabilized, with evaporation and inflow of 1.6 km^3/yr (mostly surface inflow from Imperial

Valley -- 1.4 km^3/yr -- and Coachella Valley -- 0.16 km^3/yr), area of 930 km^2 (largest body of water in California), and volume of 7.4 km^3 (Werner and Olson, 1970).

Although it is only the macroscale exhaust of a macroscale irrigated agriculture technoecosystem, the Salton Sea has technoecosystems of its own. It has a state park, a naval test base, an Indian reservation, and a national wildlife refuge, all at least partly submerged. Resorts and marinas dot its transient shoreline. Introduced and managed fish populations swim as a submarine bait for fishermen in pleasure boat technoorganisms. And clamorous throngs of waterfowl and migratory birds splash and play in the Salton Sea National Wildlife Refuge, many directly (and obliviously) over the very center of the Salton Sea hydrothermal convection system.

Such was the Imperial Valley technoecosystem in the late 1960s and early to middle 1970s. But the system, beautiful as it is, is not in equilibrium. The water niche is threatened at both intake and exhaust ends. And geothermal technoecosystems, still rather inconspicuous, are evolving rapidly. As in technoecosystems everywhere, succession and evolution of the Imperial Valley technoecosystem is inevitable, inexorable.

The magnificently wild Colorado River, now become docile technoecosystem component, is on the verge of bankruptcy. The Colorado River Compact allocates more water to upper and lower basin states than the average total flow, and the river's flow is already almost completely utilized. With increasing water demands upstream for growing energy requirements (Bowden, 1975), with impending large diversions of Arizona's entitlement through the Central Arizona Project technoecosystem, and with national commitment (Mexican Water Treaty) to deliver 1.9 km^3/yr of limited-salinity water downstream, California diversions will almost certainly have to be reduced (USBRDC, 1972, 1973). We might expect that agricultural Imperial Valley's water allotment will be curtailed before that of the urban population centers supplied by the Colorado River Aqueduct.

Not only quantity but also quality of the water diverted to Imperial Valley is threatened with decrease in future years. From salinity of less than 50 ppm at its headwaters, the Colorado River becomes progressively saltier downstream. This increase is due largely to three mechanisms: salt loading (addition of salt from drainage of natural systems and irrigation technoecosystems), salt concentration (removal of water but not salts by evapotranspiration), and diversion of high quality water upstream (USBRDC, 1973; Irelan, 1971*). In the early 1970s, salinity of water at Imperial Dam (where All-American Canal diversion takes place) was around 900 ppm. With planned water use increase upstream, and without implementation of major salinity control programs, salinity at Imperial Dam could reach 1200 to 1300 ppm by 2000 or even by 1985 (Goldsmith, 1971; USBRDC, 1973). [U.S. drinking water standard is 500 ppm TDS, with 1000 ppm maximum permissible (Werner and Olson, 1970).]

Salinity increase compounds the effect of water supply decrease, because higher salt content is partly compensated for by applying additional water (Moore, Snyder, and Sun, 1974*). Salt decreases the photosynthesis and industrial energy flow amplification value of water. Thus irrigation water salinity of 1200 ppm or more could have a major impact on the Imperial Valley technoecosystem. At best, crop quality would decrease and new crop species would be used. At worst, some fields might have to be abandoned. The U.S. Bureau of Reclamation estimates economic losses to be $190,000 to $400,000 per year per 1.0 ppm salinity increase at Imperial Dam (USBRDC, 1973). And Moore, Snyder, and Sun (1974*) predict a 14 percent decrease in crop revenues of Imperial Valley by 2000 A.D. Agricultural technoecosystems in Mexicali Valley already suffer from the effects of water from Morelos dam with 1200 ppm salinity (Goldsmith, 1971). This may be what is expressed at macroscale by a distinct color contrast between fields on each side of the international border, quite noticeable in photos taken from high altitude and orbital technoorganisms.

Not only is Imperial Valley's water intake threatened with change, but so is its exhaust reservoir, the Salton Sea. Whereas water balance is easily maintained by evaporation (modulated by rise and fall of the Sea's level), nonvolatile components accumulate. The same water inflow which maintains the reservoir (irrigation and natural drainage, treated and untreated sewage) also continuously loads it with salts, nutrients, organic material, and agricultural chemicals.

The Salton Sea in 1970 contained 272 million metric tons of salt. Of this amount, 103 million metric tons of salt had dissolved from bottom sediments, where it was deposited as Lake Coahuilla, ancient precursor of the Salton Sea, dried up. Solution of salts from the bottom sediments occurred rapidly during the Salton Sea's first decades, and it is now still proceeding at a much slower rate. However, the majority of the salt in the sea, 169 million metric tons in 1970, has been added in this century by drainage water from irrigated fields. Current rate of salt input is approximately 5.1 million metric tons per year (Werner and Olson, 1970).

Salinity of the Salton Sea in 1970 was around 36,000 ppm (ibid.), slightly saltier than sea water (35,000 ppm). Extrapolating from the numbers in the preceeding paragraph, salinity level should now (1976) be about 40,000 ppm. The biological ecosystem of the Salton Sea (including such components as game fish and birds, upon which much of the sea's recreational technoecosystem is based) is threatened by this progressive buildup of salts and chemicals. Kim (1973*) predicts that salinity level will be at critical level for fishing and water sports by 1980. And should canal water become saltier as predicted, and should Imperial Valley's water allotment be reduced, then the Salton Sea's trend toward higher salinity will accelerate.

All this should come as no surprise, however. Even at its birth, the days of the Salton Sea as a brackish to saline lake were numbered. Salt buildup in any basin with water inflow but no outflow is inevitable, as shown by the Dead Sea, the Great Salt Lake, undrained irrigation projects, and countless other examples around the world. This process is especially rapid in extremely arid lands, characterized by high rates of net evaporation.

The Salton Sea, left alone, can hardly escape a similar fate. But it may not be left alone. Although the Salton Sea formed inadvertently, certain biological and industrial ecosystems are now dependent on it, and many humans hope that it will be stabilized in nearly its present state. A proposal to build a dike across part of the sea was made in 1969 (USBRDC, 1972). In effect, this diked sector would become the ultimate sink for salts; the rest of the sea would at last have an outlet, and salinity would be stabilized. Another set of proposals (Rex, 1970; USBRDC, 1972), discussed more fully later in this chapter, would stabilize Salton Sea salinity as just one of many side benefits of a large Imperial Valley geothermal technoecosystem for desalination and power production. In this case, the sea's outlet would be through the geothermal technoecosystem, and the ultimate sink for the salt would be the deep geothermal reservoir. Both schemes would prolong the life of the Salton Sea as a moderately saline lake, but not forever. Eventually a diked sector will hold no more salt. And the Imperial Valley geothermal niche, too, has its limits.

3. Geothermal Niche Opening

"WELCOME TO IMPERIAL VALLEY, GEOTHERMAL CAPITAL OF THE NATION"

--billboard at Imperial County airport in 1972 (California Department of Conservation, 1972)

In the midst of this macroscale agricultural technoecosystem run on solar energy, Colorado River water, and fossil fuels, a new kind of technoecosystem, one which taps geothermal energy, has been developing -- very slowly at first, and now with great rapidity and acceleration. Palmer, Howard, and Lande (1975) present a general review of the history and ongoing activities of geothermal technoecosystems in the valley; their paper is a major reference for the chronological overview which follows.

Early in this century, almost nothing was known by men about subsurface geological systems in Imperial Valley. A few hot springs and mud volcanoes at the Salton Sea's southeastern end stimulated only limited recreation and health activity. The first geothermal investigations in the Salton Trough were undertaken in the 1920s near these obvious thermal systems. And as geothermal technoecosystems have evolved and geological knowledge has grown, geothermal projects have spread to other areas, particularly in the 1960s and 1970s.

Worldwide interest in geothermal power was stimulated after World War I by the example of Larderello, Italy (Koenig, 1973B). In 1927, three exploration wells were drilled on Mullet Island, one of the five Salton Buttes, by Pioneer Development Company (Reed, 1973). The wells, deepest of which was 449 m, yielded some steam and hot water, but not enough for power production; they were abandoned.

However, high CO_2 output of the first wells stimulated development of the Imperial Carbon Dioxide Field and technoecosystem. Over 65 shallow wells averaging 150 m deep (Koenig, 1973B) produced CO_2 from hot water in shallow sands. Some published estimates of total production, from 1933 to 1954, are 18 (Muffler and White, 1969*), 71 (Reed, 1973), and 100 (Koenig, 1973B) million cubic meters. In two processing plants, the gas was converted to dry ice for refrigeration and for cooling of railroad cars, presumably for storing and transporting fresh produce grown in Imperial Valley. The field was abandoned in 1954, in part due to submergence of some of the wells by gradual expansion of the Salton Sea (Goldsmith, 1971; Reed, 1973).

A few years later, in 1957-58, the first deep geothermal well (1440 m), originally a wildcat oil well, was drilled nearby. A small pilot powerplant to run on flashed steam was installed in 1959 and abandoned after four months of testing when severe scaling plugged the well. Perhaps encouraged by this activity north of the border, Mexican exploration drilling at Cerro Prieto began in the same year (Reed, 1973).

The early 1960s brought a new wave of technoecosystem activity to the Salton Sea geothermal system. This time the primary interest was extraction of salts, although auxiliary power production capability was still hoped for. Subsidiaries of Morton International and Union Oil Co., among other companies, drilled more wells in 1961-64, and built large solar evaporation ponds (solar-geothermal energy interface) for salt production trials. A 3 Mw powerplant was installed by Morton in 1965, for flashed steam operation. But soon scaling and corrosion made this attempt at power production into another failure. Union had similar difficulties with a small power module. In the mid to late 1960s, small amounts of calcium chloride, potassium chloride, and other salts were produced from the hypersaline geothermal fluids. Most processing involved sequential precipitation of salts in the evaporation ponds, though one procedure for sodium chloride (table salt) production tried by Morton involved flash drying the salt with geothermal steam (Blake, 1974). When salt prices dropped in the late 1960s, these facilities, too, became inactive.

And thus geothermal technoecosystem development at the Salton Sea came to a temporary standstill. The industrial landscape along the sea's southeastern shore had grown into a geography dominated by storage buildings and evaporation ponds with high earth banks, and dotted with very costly inactive geothermal wells (each with a curious name, a set of idiosyncratic fluid properties, and a colorful history of production and corporate sales). Development of geothermal technoecosystems had been frustrated not only by low salt prices and difficult waste disposal, but also because of incompatibility of existing pipes and turbine modules with corrosion and scaling characteristics of the Salton Sea geothermal system's hypersaline brines -- what might be called "technoindigestion". However, interest in this geothermal reservoir has persisted because of its high energy content and large area, and because of the very high yield rate from wells -- approximately 200 metric tons per hour per well (Koenig 1973B), equivalent to around 56 Mwt or 9 Mwe (at 16 percent efficiency), enough power for roughly 9,000 U.S. power consumers.

One offshoot of this early geothermal activity is that discharge of geothermal brines into the Salton Sea was prohibited in 1963 by the Colorado River Basin Regional Water Quality Control Board No. 7 (Werner and Olson, 1970). This has encouraged development of injection techniques. The reason for the prohibition is clear: a single typical well tapping the Salton Sea geothermal system discharges salt amounting to 0.42 million metric tons per year (ibid.), over eight percent of total salt inflow to the Salton Sea. Only 12 such wells would double the sea's annual salinity increase.

Scale formed in some Salton Sea field geothermal wells contains high concentrations of copper, iron, and silver sulfides, as well as significant amounts of antimony (Ellis, 1975; Blake, 1974). Blake lists three major reasons to extract these and other chemicals from geothermal fluids: 1) to help pay power development costs, 2) as part of water desalting operations (irrelevant for hypersaline brines of Salton Sea system), and 3) to avoid salt disposal costs and damage. Werner (1973) optimistically suggests that chemicals extracted from Salton Sea system brines, especially metals (zinc, lead, tin, titanium, copper, silver, gold, and beryllium), might be worth even more than the electric power produced from the same fluids. Blake, in contrast, asserts that although chemical recovery is technically feasible, it is not now economically attractive, due to low prices of major brine constituents and low content of more valuable elements. Events seem to indicate that Blake's assertion is presently correct.

During the 1950s and 1960s more than twelve deep wildcat oil wells were drilled in Imperial Valley. All were unsuccessful in achieving their original purpose, but they did succeed in indicating that hot water reservoirs are not limited to the Salton Sea area and that deep fluids elsewhere are much less saline (Reed, 1973). In this way, fossil fuel exploration triggered the next phase of geothermal activity in Imperial Valley.

Encouraged by wildcat well results, successful geothermal well drilling at Cerro Prieto, and growing concern about Colorado River salinity increase, the U.S. Bureau of Reclamation and several other groups joined in backing a preliminary valley-wide geophysical study by the University of California at Riverside. Starting in 1968, the program consisted of gravity, electrical resistivity, and seismic surveys, as well as temperature gradient and heat flow measurements in more than 100 shallow drill holes. By 1970 the results were in. The surveys, and particularly the temperature gradient study, revealed nine major hydrothermal convection systems underlying Imperial Valley. These geological systems, completely hidden for so long, were suddenly laid bare by geophysical macrovision.

Since 1970 there has been a boom of geothermal activity in Imperial Valley. It has been fueled by the new geophysical revelations and by new technological developments. And it has been further accelerated by the new consciousness of energy systems resulting from altered global oil distribution strategies (the "energy crisis"). Still another stimulant to geothermal projects has been the successful operation of the Cerro Prieto geothermal powerplant since 1973.

Imperial Valley activity has taken on the appearance of a technoecosystem free-for-all. Without any central coordinating system, many organizations are involved: at least four federal agencies (U.S. Bureau of Reclamation, Office of Saline Water, U.S. Geological Survey, and U.S. Bureau of Mines), three California State agencies (Division of Mines and Geology, Department of Water Resources, and Division of Oil and Gas), one university (California at Riverside), four oil companies (Chevron, Phillips, Standard, and Union), two geothermal companies (Republic Geothermal Co. and Magma Energy Co.), one chemical company (Morton), one utility (San Diego Gas and Electric), and at least several other technoecosystem management organizations (Berman, 1975*; Palmer, Howard, and Lande, 1975; Van Huisen, 1976*). The list continues to grow each year.

Many projects are under way in Imperial Valley to explore geothermal systems and to develop and test geothermal technoecosystem methods, materials, and modules. New wells are often being drilled.

U.S. Bureau of Mines is working on hot brine uses, improvement of drilling muds and cements, and methods for brine chemical recovery (Berman, 1975*). A subsidence survey network has been set up, and a seismic observation network is in operation. Over the Salton Sea geothermal system, chemical recovery experiments continue, and new power production modules are being developed and tested. Oil and energy companies are studying Heber and Brawley geothermal systems for possible power production. In the rest of this section, power production developments at Salton Sea and Cerro Prieto systems will be looked at more closely. And in the next section, the U.S. Bureau of Reclamation's geothermal projects and plans will be reviewed.

Previous attempts to generate electricity from geothermal brines of the Salton Sea system failed. Now, new technology specifically designed for these unusual fluids is being developed and tested.

San Diego Gas and Electric Company (SDG&E), concerned about diminishing natural gas supplies and aware that Imperial Valley is within economic power transmission distance of its service area, has been conducting geothermal power experiments in the Salton Sea area since 1972. Diverse components for multiple flash and binary power cycles, including heat exchangers designed to resist corrosion and scaling, were tested. And in 1975, in collaboration with the U.S. Energy Research and Development Agency (ERDA), construction was begun on a 10 Mwe pilot plant near the Salton Sea's shore; test operation is in progress as this paper goes to press. This power module uses pumps to lift brine to the surface without flashing (to avoid scaling in wells), sends it through a complex and modifiable power cycle (multistage flash and isobutane binary hybrid cycle), and then reinjects it, avoiding salt disposal difficulties at the surface -- a closed or semi-closed system. Cooling for the power cycle is provided by imported canal water in a cooling pond with sprays. If it can be adequately cleaned, some condensed geothermal steam may also be fed into the pond for cooling purposes.

This SDG&E-ERDA pilot powerplant, although small, is still a technoecosystem. Channels include geothermal production and injection wells, zigzagging brine pipelines, a road, a canal, and powerlines. Technoorganisms include cars and trucks of workers and visitors, trailer offices, and the power module itself -- a tangle of pipes, tanks, pumps, heat exchangers, turbines, and valves, roughly 5 m high and 20 m square. Inorganic storages include the tapped reservoir at depth and the cooling pond at the surface. High energy inputs are machinery, information, geothermal brine, and cooling water. High energy outputs are electricity and information. And low energy exhausts are waste heat, evaporated water, and cooled brine.

Another power cycle technology designed specifically for Salton Sea field brines (but useful for exploiting any wet steam reservoir) is the total flow concept, being developed by Lawrence Livermore Laboratory (LLL) (Austin, Higgins, and Howard, 1973; Palmer, Howard, and Lande, 1975). Instead of flashing the brine in wells or passing it through heat exchangers, it is pumped unflashed to the power module. There, by expanding the fluid through a nozzle, thermal energy content is very efficiently converted to kinetic energy, and the fluid jet drives an impulse turbine, as in hydroelectric power stations. The cycle is a closed one; brine and steam are cooled and reinjected. Major advantages of this scheme are the simplicity and maintenance ease of impulse turbines relative to axial flow expansion turbines in standard steam power modules, and ability to produce 1.6 times as much power as flashed steam or binary cycles from the same fluid flow (18 percent versus 11 percent conversion efficiency).

Austin, Higgins, and Howard (1973) estimate that 92,000 Mwe could be generated for 20 years from the already drilled portion of the Salton Sea geothermal system, enough for 92 million U.S. power consumers. A less ambitious 10 Mwe total flow pilot plant is planned for completion in 1979. Ongoing research at LLL includes testing of turbine and nozzle designs, scale and corrosion controls, and corrosion-resistant materials. Palmer, Howard, and Lande (1975, p. 40) reproduce photographs of an intriguing technoecosystem module built at the laboratory to assist this research: a complex system of pipes, valves, pumps, dials, and tanks which produces imitation geothermal fluids (up to 0.1 Mwe equivalent) with variable salinity, pressure, and temperature.

Whatever closed power systems are developed for the Salton Sea system, a cooling water source must be provided. Air cooling is not only more capital costly than water cooling, but it lowers the efficiency of power cycles which may already be inefficient. This is because dry bulb air temperature, especially in hot, dry weather typical of Imperial Valley, is much higher than wet bulb temperature. Canal or drainage water, perhaps with minor flashed steam augmentation, may suffice for small pilot plants like the SDG&E-ERDA system, but is probably insufficient for large scale development. Salton sea or ocean water destined for injection in large scale desalination-power production schemes involving other less saline geothermal systems in the valley (described in the next section) might first be utilized for cooling of powerplants tapping the Salton Sea geothermal system. Since about half of this geothermal system's area is submerged by the Salton Sea, some geothermal technoecosystem modules of the future may be built on stilts or mounds of earth off shore.

The 75 Mwe Cerro Prieto demonstration geothermal powerplant, operated by the Mexican Comisión Federal de Electricidad, is considered to be "a great success" (Guiza, 1975*). In fact, it is the most successful and largest geothermal development in the entire Salton Trough. This may be due in great part to auspicious physical properties of the deep geothermal system itself: high temperature and low salinity of the fluids, good sandy reservoir horizon at convenient depth, apparently large areal extent of the system, and natural hydrothermal manifestations at the surface. The system is well suited to power production using slight modification of technology already proven at wet steam fields of Japan and New Zealand. Setting of the plant is the irrigated agriculture grid of Mexicali Valley, which uses water diverted from the Colorado River downstream from Imperial Dam. Exploration drilling started in 1959 (Reed, 1973), and production drilling in 1964 (Goldsmith, 1971). And electricity generation began in 1973.

Cerro Prieto well field, about 2.5 km^2 in area (Palmer, Howard, and Lande, 1975), has some 37 wells ranging from 600 to 2600 m deep (Isita et al, 1975) and averaging 1500 m deep (Koenig 1973B), arranged in a hexagonal grid. For full capacity operation (75 Mwe), only 13 wells are needed. Thus, average output is equivalent to 5.8 Mwe per well. Wells vary, however, and one produces fluid equivalent to 15 Mwe (ibid.). Geothermal fluid salinity is 13,000 to 25,000 ppm (1.3 percent to 2.5 percent) (Koenig, 1973B) and water to flashed steam weight ratio at wellhead ranges from 0.5:1 to 4:1 (Guiza, 1975*). Roughly 39 kg of Cerro Prieto fluid (9kg steam, 30 kg water) is required to produce 1 kwhr of electricity (Hughes, Dickson, and Schmidt, 1974). Thus the well field discharges around 0.5 to 1.0 kg of salt per kwhr, or (for 75 Mwe) roughly 70,000 metric tons of fluid including 900 to 1800 metric tons of salt per day. Gradual scaling of wells necessitates periodic cleaning (ibid.).

Geothermal fluid at Cerro Prieto is flashed to the surface, and steam is separated from water in a cyclone separator at each wellhead. The hot water is brought to atmospheric pressure in tall silencer barrels and then discharged into ditches. This post-flash water has salinity of about 33,000 ppm, slightly less than oceanic salinity. It is saturated with silica, which precipitates out as a milky gel in the ditches. Originally, geothermal water waste was channeled by ditch to the Rio Hardy, a Colorado River distributary which empties into the Gulf of California (Koenig, 1973B; Goldsmith, 1971). Now, however, the hierarchically converging ditch system empties into a 9 km^2 artificial evaporation pond. This pond may be the only major adaptation of the whole system to arid conditions; only in arid lands do evaporation ponds not overflow. When power output is decreased for repairs, steam-water mixture from idle wells is piped directly to the pond, where it discharges horizontally with a roar like a jet aircraft, in graceful plumes of spray.

The steam separated at wellhead is channeled through a hierarchically converging zigzag pipeline system to the powerplant. Inside the large metal enclosure are two 37.5 Mwe turbogenerator modules, imported from Japan, with special alloy turbine blades (Mercado, 1974). After expanding through these units, the steam is condensed in barometric condensers. This condensate is ample water supply for the forced-draft wet cooling towers. In fact, it represents eight percent extra water in winter and two percent to three percent in summer (Ingeniero Samuel Paredes, personal communication), which has been used for construction and maintenance operations (Koenig, 1973B).

Adjoining the turbine room is an electronic cybernetic control room with many dials, switches, and lights. The Cerro Prieto powerplant manifests great human leverage of high-energy technoecosystems -- the plant is run by a staff of only six men, including one supervisor (Paredes, personal communication). The electricity, highest-quality energy form in the regional technoecosystem, passes through a switchyard and then is channeled along high voltage powerlines northwest to Mexicali. There it is distributed to the high-energy urban technoecosystem by a hierarchically diverging power grid, to power factories, homes, bright neon lights at night, and numerous radio stations. Power use in Mexicali is 190 Mwe in summer (high air conditioning load) and 90 Mwe in winter; power in excess of the 75 Mwe continuous geothermal plant output is at present provided by a standard oil-steam powerplant in Rosalito (ibid.).

This Cerro Prieto geothermal development, too, can be seen as a technoecosystem. Channels include production wells, pipelines, roads, ditches, and powerlines. Mobile technoorganisms include cars, trucks, and drill rigs. Stationary technoorganisms include the powerplant (with cooling towers, switchyard, and cybernetic control room modules) and assorted offices and support buildings. Inorganic storages include the subterranean geothermal reservoir and the large waste disposal pond. High quality energy inputs include geothermal fluid, petrofuel, machinery, and human control. High quality energy output is chiefly electricity. And low quality energy exhausts are evaporated water, waste heat, and hot post-flash brines.

Variations in this basic technoecosystem configuration have been tried and are being considered. There has been some experimentation with condensing steam to produce fresh drinkable water (DeAnda, Reyes, and Tolivia, 1973). Saline fluids stored in the large pond are being considered for potassium chloride, lithium carbonate, and other chemical production (Palmer, Howard, and Lande, 1975), and for possible reinjection (Mercado, 1974). Koenig (1973B, p. 46) reports that a steam-powered drill rig was brought to Cerro Prieto on an experimental basis to run on natural steam and thus save petrofuel. Although apparently the rig is no longer in use, it suggests the future possibility of an entire geothermal technoecosystem (including its technoorganisms) running on geothermal energy alone, without any imported chemical fuels.

Plans for the future at Cerro Prieto include a second 75 Mwe power module by 1980 (Koenig, 1973B; Tolivia, 1975*), resulting in a total capacity of 150 Mwe. Mercado (1974) estimates a power capacity (ignoring duration) of 400 Mwe from the present exploitation area. Tolivia (1975*) estimates that minimum proven reserves would support 150 Mwe for 33 or possibly 90 years (4,950 to 13,500 Mwe), assuming a closed geological system. Assuming an open system, however, with thermal and hydraulic recharge, he expects a much longer resource lifetime. Furthermore, as pointed out by Isita, Mooser, and Soto (1975), the known geothermal reservoir may be just the western periphery of a much larger geothermal system over the inferred spreading center east of San Jacinto fault. This whole Cerro Prieto geothermal system may be comparable in size and geothermal content (but not in salinity) to the giant Salton Sea geothermal system some 90 km to the northwest. The Panga de Abajo spreading center (inferred by De la Fuente Duch, 1973), southeast of Cerro Prieto, is apparently still unexplored.

4. Macroscale Geothermal Water and Power Technoecosystems

The Imperial Valley technoecosystem, where water has especially high value as photosynthesis amplifier, is an ideal market for high quality water produced by geothermal technoecosystems (Wong, 1973). The large volume of moderately saline groundwater underlying the valley (Dutcher, Hardt, and Moyle, 1972) is too deep for normal pumping. But where this deep water is hot, its thermal energy content may be able to pay the energy cost of pumping, desalting, and replacement water importation and injection, all in a complex macroscale geothermal technoecosystem. Possible auxiliary processes in such a system include power generation, space heating, and chemical production.

Geological conditions in Imperial Valley impose some constraints on such water and power technoecosystems. Salton sea system hypersaline geothermal brines cannot be effectively desalted, except perhaps for condensation of flashed steam. However, these very hot fluids might be used to desalt imported cooling water as part of a macroscale power production scheme. Less saline fluids yielded by other hydrothermal systems in Imperial Valley are suitable for direct self-distillation, and surplus geothermal energy content can drive power cycles and even indirect desalination of geothermal or imported fluids. These less salty fluids can be concentrated roughly 10 times before salts precipitate (Rex, 1970). Whatever technoecosystem configurations develop, there must certainly be a great difference between systems exploiting these two geothermal fluid types.

Another probable characteristic of any geothermal technoecosystems in Imperial Valley is that they will involve injection of cool, salty water exhaust. This is necessary to remove salt from a surface environment where it is certainly undesirable, and to prevent subsidence due to net fluid withdrawal. Subsidence could have disastrous effects on the irrigated agriculture technoecosystem, which is dependent on controlled gravity flow of water in canals and fields. Injected fluid will probably be geothermal brine in Salton Sea field technoecosystems, and mostly imported water in technoecosystems over other hydrothermal systems.

There are a number of characteristics which make Imperial Valley susceptible to development of geothermal technoecosystems which are very large. Because of the flat topography and dense road network, access of exploration and drilling technoorganisms is easy. Relative geological simplicity eliminates most of the difficult geological unraveling usually required. Relative geological uniformity means that technology and information from one part of the valley is readily adapted to another location. Although there are numerous hydrothermal convection systems in the Valley, all but one (the Salton Sea system) are quite similar in all aspects but size; hence similar technoecosystems can be built to exploit them all. Finally, there is the fact that Imperial Valley occupies a corner of one of the highest-energy technoecosystems in the world. Compared with other energy developments in the U.S. technoecosystem, large-scale geothermal exploitation in Imperial Valley does not seem overwhelmingly large.

The 1968 Colorado River Basin Act authorized the U.S. Department of the Interior, largely through one of its branches, the U.S. Bureau of Reclamation (USBR), to study the feasibility of augmenting the flow of the Colorado River from sources within its basin by 3.1 km^3/yr (2.5 million acre-feet per year) (Fernelius, 1975*; Berman, 1975*). Methods for augmentation of Colorado River flow and water quality considered by the USBR include weather modification, desalination, water reuse and salvage, irrigation management, watershed management, brine diversion, river channelization, and phreatophyte control (Fairchild, 1972; USBRDC, 1973; USBRC, 1973). Of greatest interest in our present context is the USBR's ongoing investigation of a possible complex macroscale geothermal technoecosystem in Imperial Valley for desalination of geothermal brines (for dilution of Colorado River water) and for accompanying power production.

The USBR geothermal plan is a highly imaginative and ambitious scheme. It would involve production of enough high quality water to meet projected Lower Colorado River Basin needs and fulfill the Mexican Water Treaty obligation. In the most studied configuration, geothermal fluids would drive first a distillation plant and then a powerplant. Extra heat could be used for various auxiliary purposes, and salts concentrated by distillation might be recovered for export. Desalted water from many such units would eventually be piped from Imperial Valley to the Colorado River, and replacement fluids would be imported by aqueduct from the Pacific Ocean or the Gulf of California for cooling and injection (USBRN, 1971; USBRDC, 1972).

Tentative plans consist of three stages:

1) Research and development stage, currently in progress, and tentatively seven years in duration (FY 1972-1979), in which technology is developed and tested,
2) demonstration stage in which 0.12 km /yr of water is desalted and 420 Mwe of electricity is

generated to demonstrate technological feasibility, and finally,

3) large-scale development stage, in which 3.1 km^3/yr of desalted water and 10,500 Mwe of power are produced from geothermal brines of Imperial Valley (USBRDC, 1972).

Such a system would be truly macroscale, truly complex, and truly a technoecosystem.

Who but the U.S. Bureau of Reclamation could pursue such a grandiose scheme? As builder and operator of dams, canals, aqueducts, and other major waterworks, as engineer and manager of countless diverse water and power niches in the arid southwestern U.S., this agency is the one most apt to coordinate the design and construction of such a macroscale geothermal technoecosystem. To the U.S. Bureau of Reclamation, the Southwest is like a macroscale cybernetic arid lands pinball machine in which quicksilver water is shunted about a cybernetic landscape of watersheds, rivers, canals, pipelines, pumping plants, irrigation districts, and cities, and in which the score is rung up as millions and billions of dollars. It is entirely in character for the agency to take on the macroscale water cycle exploitation of Imperial Valley's geothermal resources.

The Imperial Valley geothermal scheme is also in keeping with the USBR philosophy of multiple-purpose projects and comprehensive regional planning (Fairchild, 1972). Fulcher (1975*) points out that because of the many technical, environmental, social, and economic factors involved in the Imperial Valley project, input from all disciplines is needed. Might we add technoecology to the list of disciplines which are applied in this interdisciplinary effort?

The research and development stage, now in progress, consists of resource investigations (exploration, well drilling and testing) and desalting studies (desalination and power module construction and testing, and injection tests). Development and construction of desalting modules is planned in 3 stages (USBRDC, 1972): 1) two 190 m^3/day test units (installed in 1973), 2) a 1900 m^3/day pilot plant (construction may begin in 1976), and 3) a 7600 to 11,000 m^3/day prototype plant. Total cost of the research and development stage was estimated to be $16 million (ibid.).

The U.S. Office of Saline Water (OSW) is cooperating with USBR by studying brine chemistry, corrosion, scaling, and resistant materials, and by developing the desalination module technology (Standiford, 1972; Berman, 1975*). Most previous desalination technology is for desalting sea water; geothermal fluids require new configurations and materials. The geothermal desalting technology developed by OSW and USBR may be applicable to heat exchanger and desalting modules for exploiting any wet steam system on the planet (Mathias, 1975*). An early assumption in the USBR-OSW program was that they would develop water production systems while non-federal organizations would develop the accompanying power generation and chemical recovery system (O'Brien, 1972).

As first step in the research and development stage, the USBR helped finance geophysical studies in Imperial Valley by the University of California at Riverside, starting in 1968. A report (USBRN, 1971) summarized results of this study and presented some preliminary USBR project ideas. On the basis of these early studies, USBR decided to concentrate its efforts on the East Mesa geothermal anomaly. A second report (USBRN, 1971*) reviewed results of detailed surveys of this anomaly, and suggested an optimum site for a deep geothermal test well. In January 1972, two important reports were issued, one a draft environmental statement for the proposed well (USBRN, 1972A), and the other a detailed presentation of concepts for Imperial Valley geothermal technoecosystems from research and development to large-scale development stage (USBRDC, 1972). In April, the final environmental statement was issued (USBRN, 1972C), and drilling of test well Mesa 6-1 started in June and finished in August.

Results of testing of the new well were published early in 1973 (USBRC, 1973). Drilling to 2443 m cost about $507,400, or $208 per meter. Bottom hole temperature is 204°C, and temperature of flashed fluid flowing at the surface is 166°C. Soon a site was chosen for a second well, Mesa 6-2 (USBRC, 1973*). It and three other wells (one an injection well) had been completed by mid-1974.

Test data for the five wells are presented in a report (USBRN, 1974) and two papers (Fernelius, 1975*; Mathias, 1975*). It turns out that the first well (Mesa 6-1) is both the deepest and the hottest. The USBR expected 200°C fluids on the basis of temperature gradient studies. But the gradient is not linear at depth, due to convection, and surface flow temperatures of the fluids actually only range from 154 to 166°C (Fernelius, 1975*). Well depths range from 1.8 to 2.4 km and bottom hole temperatures range from 154 to 204°C (ibid.; USBRN, 1974).

Two desalination modules, a multistage flash (MSF) unit and a vertical tube evaporator (VTE) unit, were installed at the East Mesa test site in 1973. Each unit was designed to produce 75 to 190 m^3/day of distilled water. But because feed fluid temperature is below the 200°C planned, the best performance achieved by mid-1975 was 40 m^3/day for MSF and 27 m^3/day for VTE. Both units have been used to test water cycle configurations and thermodynamics, heat exchanger designs, and heat exchanger materials. Imported electric power is required to operate valves and pumps, and cooling is now provided by groundwater from shallow (60 m) wells. Information from testing of these units will be used to design a larger pilot desalting plant capable of using fluids as cool as 120°C (Fernelius, 1975*).

Now consider the East Mesa test site as a technoecosystem. Channels include geothermal wells, pipelines, shallow wells, and incoming powerlines and roads. Technoorganisms include cars, trucks, drill rigs (occasionally present), trailer offices, an office-storage building, and the desalting modules themselves. Each desalting unit is a tangle of pipes, pumps, valves, tanks, cables, scaffolding, and a cybernetic control panel with dials and switches. Inorganic storages include a 29,000 m^2 evaporation pond for fluid disposal (47,000 m^3 capacity), and the East Mesa hydrothermal system at depth. Other components are: cyclone separators and silencers, tanks, pumps, and spare parts, all inside a chain-link fence (analogous to a cell wall).

Modifications and additions are planned for this embryonic desert technoecosystem. Installation of an anti-corrosion fiberglass pipeline is planned to bring geothermal fluids to the test site from a distant well (Fernelius, 1975*). Use of desalted geothermal water for irrigation of crops (biological sector) is being tested in an adjacent area (USBRN, 1974). Construction of the 1900 m^3/day pilot desalting plant is expected to start in 1976 (Fernelius, 1975*). And a power module may be installed to complement the desalting units; a 0.3 Mwe unit is being considered by USBR (ibid.). Furthermore, a corporation is considering the possibility of setting up on the East Mesa field a 10 Mwe binary cycle pilot powerplant with downhole pumps and dry or wet-dry cooling towers (Mueller, 1976*). Cooperation with USBR might be considered in such an undertaking. Finally, the East Mesa site may be converted to a national test site where many public and private organizations could test geothermal technoecosystem components and materials with genuine geothermal brines (Fernelius, 1975*).

Present USBR thinking favors integration of power and water cycles at least cost by using steam first for desalting and then for driving a binary power cycle (USBRN, 1974; USBRDC, 1972). However, for lower salinity wells (around 2000 ppm) a different procedure might be more efficient: use all steam for power production and then use the power to drive a membrane desalting module (USBRN, 1974; Fernelius, 1975*).

Conceptual plans for demonstration stage and final large-scale development stage of the USBR scheme are outlined in a USBR report (USBRDC, 1972). Both stages would utilize multiples of a standard geothermal module (desalting plant, powerplant, and 12 geothermal wells), and they differ only in number of modules, source of imported cooling water, and destination of desalted water.

The geothermal module would be the ultimate product of the present research and development stage. As envisioned in 1972, the module consists of 12 geothermal wells (1.4 to 1.8 km deep, laid out on a square grid with 244 m spacing, and each producing 218 metric tons/hr of brine and 54 metric tons/hr of steam) connected by radial pipelines and cyclone separators to two centrally located VTE desalting units and a 70 Mwe powerplant. Imported saline water (70,400 m^3/day) is used to cool power and desalting units; some is evaporated in cooling towers (14,100 m^3/day), and the rest is mixed with concentrated brine (desalting residual) and piped from the module to about 17 injection wells. Total fresh water output (20 ppm) of the module, including desalted water and steam condensed from power cycle, is 56,300 m^3/day or 0.0206 km^3/yr. Special components of the module would include units to remove residual gases (CO_2, H_2S, NH_3) and silica from brine, remove boron from desalted water, and chemically treat residual fluid before injection. Also, facilities for separating valuable minerals could be included in the module.

As conceived, each geothermal module is octagonal (each vertex is a well), and 823 m in largest dimension. Modules can be assembled like octagonal tiles, with powerlines, access roads, and conduits (for imported, desalted, and injection fluids) weaving between rows. Such linking of closely packed identical modules by energy and materials channels is a common pattern in biological systems. Although the USBR report does not suggest it, the wells might also be drilled in a triangular grid for hexagonal modules.

The proposed demonstration stage technoecosystem consists of six geothermal modules (72 production wells, 12 desalting units, six powerplants, and 100 injection wells on field periphery), presumably contiguous and tapping the East Mesa geothermal reservoir. USBR estimates its total cost to be $209 million. Some 0.154 km^3/yr of saline water is imported (by 77 km pipeline and two pumping plants) from the Salton Sea for cooling and injection, and of this amount 20 percent or 0.031 km^3/yr evaporates in cooling towers. High quality outputs are 0.123 km^3/yr of desalted water and 420 Mwe of electricity. Net power output is actually only 390 Mwe because 30 Mwe is needed for internal pumping functions. Desalted water is piped 13 km to the All-American Canal upstream of power drop No. 4; it thus generates some hydroelectric power while augmenting and diluting the imported Colorado River water. This 0.123 km^3/yr of desalted water represents almost four percent of present canal flow to Imperial Valley (3.3 km^3/yr).

Pumping water from the Salton Sea in this scheme would have the effect of stabilizing its salt content by providing an outlet and using the geothermal reservoir (through injection wells) as the salt's ultimate sink. Projected withdrawal rate might lower the sea's level by about a meter (Rex, 1970; Goldsmith, 1971), but shrinkage would probably be less because inflow would be augmented by drainage of some of the desalted water from fields (Laird, 1973).

Alternative sources of demonstration stage imported water have been considered by USBR. Pumped local shallow groundwater would probably have the lowest primary cost; but its use beyond very limited amounts might cause costly side effects -- subsidence, increased seepage from All-American and Coachella Canals, reduced inflow to Salton Sea, and increased pump lift for Mexican irrigation wells. Saline drainage water from the Wellton-Mohawk irrigation district (along the Gila River east of Yuma), amounting to 0.247 km^3/yr, could supply cooling and injection water to a system of nine geothermal modules (585 Mwe net power and 0.185 km^3/yr desalted water output), possibly at less cost than Salton Sea water importation.

Alternative destinations for desalted water have also been considered by USBR. In order of increasing cost they are: All-American Canal below drop No. 4 (lower cost than above the drop), Coachella Canal, and Colorado River at Imperial Dam. The water could also be supplied to municipal and industrial technoecosystems, either locally or through regional water exchanges. Because of its extremely high quality, the desalted water has high amplification value; it is worth more than ordinary water because through blending it can dilute much larger volumes of brackish water enough to be usable.

The 390 Mwe net power output of the demonstration stage system is smaller than the 500 Mwe capacity at the Geysers. But if desalting modules are included, the USBR demonstration stage system (if operating today) would be the largest geothermal technoecosystem in the world. And yet as large as this proposed demonstration system is, it is only 1/25 the size of the USBR-proposed technoecosystem in its large-scale development stage.

Large-scale development stage concepts are very much in keeping with the macroscale technoecosystem traditions of the USBR. The full scale system envisioned for 1990 A.D. consists of 150 geothermal modules, entailing 1800 geothermal wells, 300 desalting units, 150 powerplants, and 2400 injection wells. Net power output is 8500 Mwe (total 10,500 Mwe output minus 2000 Mwe internal pumping and process requirements), around 8.5 million times U.S. per capita power use. Distilled water output is 3.1 km^3/yr, a full third of total average (and legal minimum) Colorado River flow at Lees Ferry anticipated by 1990 (9.3 km^3/yr), and nearly the same magnitude as present All-American Canal flow into Imperial Valley (3.3 km^3/yr). And imported saline water input is 3.9 km^3/yr, of which 0.8 km^3/yr evaporates in cooling towers (25X proportional increase from demonstration stage). Total cost of the system, by analogy to demonstration stage, is probably over $5 billion.

Area of each proposed geothermal module design is 0.68 km^2, so total area of 150 modules is 102 km^2. Renner, White, and Williams (1975) estimate subsurface area of seven known geothermal systems in Imperial Valley (not including Salton Sea and East Brawley systems) to be 111 km^2, and area of all but the smallest three (West Glamis, Border, and Glamis) to be 102 km^2. Therefore it seems likely to me that the large-scale development would involve exploitation of at least four distinct geothermal systems (including East Mesa system) which are widely separated spatially. However, the USBR conceptual report (USBRDC, 1972) does not take this complexity into account, but assumes exploitation of only the East Mesa system.

Water for cooling and injection in the large-scale system can continue to be imported from the Salton Sea (0.154 km^3/yr) and the Wellton-Mohawk drain (0.247 km^3/yr). But only the ocean can supply enough water for the full macroscale requirements of this macroscale technoecosystem (3.9 km^3/yr). At least 3.5 km^3/yr of ocean water must be imported from the Pacific Ocean or the Gulf of California.

Alternative routes considered by USBR for a water import aqueduct include:

1) A southern route from the Pacific, 203 km from an intake south of San Diego over the San Ysidro and Jacumba mountains to East Mesa, including 80 km of tunnels and three pumping plants. Right of way cost would probably be high.
2) A northern route, from the Pacific north of San Diego to the Salton Sea, and a second aqueduct from Salton Sea to East Mesa. Such a system would stabilize the Salton Sea at ocean water salinity level.
3) And an aqueduct from the Gulf of California. Such a route would entail the lowest pumping lift and thus the lowest cost, but an international agreement would be required. Furthermore, extremely high tides at the head of the Gulf might make water intake design difficult (Goldsmith, 1971). Partial macroscale integration of geothermal technoecosystems on both sides of the border could be one result of such a route.

Although the 3.1 km^3/yr output of distilled water in the large-scale development stage could simply be channeled into the All-American Canal, it is most valuable for augmenting and lowering the salinity of the larger flow of the Colorado River; All-American Canal flow is freshened and increased only indirectly. The plan studied in detail in the USBR report is for a 210 km aqueduct from East Mesa over the Chocolate, Mule, and West Riverside Mountains to Lake Havasu, including a 3 km tunnel and four pumping plants. After cooling to 24°C, the desalted water would be disgorged into Lake Havasu far enough upstream from Parker Dam to allow adequate mixing before the water reaches the intakes of the Colorado River Aqueduct and the Central Arizona Project Aqueduct.

Alternative routes for desalted water delivery have also been considered by USBR. They involve aqueducts to Imperial Reservoir (84 km), Lake Mohave (346 km), and Lake Mead (405 km). Delivery farther upstream offers greater benefits but is also more costly. Delivery of 3.1 km^3/yr of desalted water to the Colorado River somewhere above Parker Dam could lower salinity at Imperial Dam (and thus in the All-American Canal) from projected level of 1200 ppm to presently acceptable 900 ppm.

The complexity of this macroscale geothermal technoecosystem in Imperial Valley may be necessary to make the system feasible; several beneficial functions combined may be practical where just one might not be (Laird, 1973). Multiple functions of the proposed technoecosystem would include stabilization of Salton Sea's size and salinity, generation of electricity, prevention of subsidence due to geothermal fluid withdrawal, and augmentation of Colorado River flow to forestall imminent shrinkage of the water niche of the Lower Colorado River Basin technoecosystem (ibid.; USBRDC, 1972).

Several concepts for additional complexity of the system have been considered by USBR. Desalination of sea water using heat from geothermal fluid (which is then reinjected) is much more costly than directly desalting moderately saline geothermal fluid and injecting the sea water (USBRDC, 1972). (However, it is my suggestion that the former water cycle might be more practical for high temperature hypersaline brines of the Salton Sea geothermal system). Energy cascading beyond the simple desalt-power system proposed is possible. Residual thermal energy in the sea water could drive low-efficiency power or desalination cycles before being injected. Or this low-grade thermal energy could be used (as in technoecosystems elsewhere in the world) for space heating, greenhouse warming, hot water irrigation, low-temperature industrial processes, or hot bath resorts (ibid.).

Other technoecosystem variations have been proposed by Rex (1970) and Goldsmith (1971). It was Rex's paper which originally triggered widespread interest in the possibility of a macroscale geothermal power and water technoecosystem in Imperial Valley. He envisioned a system with 2000 to 5000 wells which would produce 20,000 to 30,000 Mwe of electricity and 6.2 to 8.6 km^3/yr of distilled water, more than twice the size of the USBR large-scale design. Rex also suggested the construction of a dredged ship canal from the Gulf of California to Yuma, up the course of the Colorado River. Benefits of such a canal would include a direct source of sea water for cooling and injection, a convenient seaport for loading low-value salts (extracted from geothermal fluids) onto ocean-going ship technoorganisms, and an excellent inducement for formation of an international geothermal-powered electrochemical manufacturing technoecosystem center. Another possibility suggested by Rex is the integration of geothermal and nuclear desalination plants in the area; nuclear plant effluent would be injected into the Imperial Valley geothermal reservoir for pressure maintenance.

Goldsmith (1971) suggested that the Salton Sea could be used as a cooling pond for once-through flow cooling of geothermal water and power cycles. For a 1000 Mwe powerplant, the sea's mean temperature might rise 0.5°C if thermal effluent is well mixed. However, larger developments will result in correspondingly greater temperature increase. Goldsmith also mentions the unmentionable -- that irrigation drainage could be used for cooling and injection, thereby sacrificing the Salton Sea.

Beyond the limitations of pure geothermal technology is the possibility of hybrid solar-geothermal technoecosystems (Finlayson and Kammer, 1975*). Imperial Valley seems to have the best environment for such systems -- extremely sunny climate and large wet steam geothermal reservoirs. Direct solar collectors and geothermal power and water cycle modules could coexist in a manner reminiscent of symbiosis in lichens.

The macroscale industrial system envisioned by the U.S. Bureau of Reclamation for geothermal power and desalination easily qualifies as a technoecosystem. If it were to be built by 1990 or 2000 and if we were to fly over it we would see several previously hidden hydrothermal convection systems manifested at the surface by kidney-shaped domains tesselated with octagonal, radially or bilaterally symmetric geothermal modules -- like cells of a leaf, or colonies of coral polyps, or closely packed bushes. Flying lower, we would see: multitudes of wells arranged on a grid; hierarchically branching pipelines, service roads, and powerlines (channels); repetitive and geometrically arranged powerplants, desalting plants, switchyards, control centers, and storage buildings (stationary technoorganisms); and cars, trucks, drill rigs, and inspection helicopters (mobile technoorganisms). Flying higher again, we would see the macroscale configuration, with aqueducts angling like strings from the Pacific and the Salton Sea and another aqueduct winding its way to Lake Havasu. And we would know that the system taps large geothermal fluid storages at depth. It is all a macroscale arid lands plumbing system.

Of particular interest might be the local coexistence patterns of geothermal, agricultural, industrial, and municipal technoecosystems in Imperial Valley. Unless pipelines from wells to desalination plants are buried or on stilts, they will severely segment whatever fields they cross, thereby interfering with large-scale operations of tractor and harvester technoorganisms. Any crops grown on these fields will probably require little technoorganism traffic (e.g., orchard or vine crops). Such adaptation is likely to occur over the Brawley geothermal system. Geothermal modules will probably not coexist well with municipal technoecosystems because of noise, esthetics, and the interference of square street grids with radial pipeline patterns. Spatial competition between these two types of technoecosystems is likely to occur in at least one place in Imperial Valley: the town of Heber is located near the center of the Heber geothermal system. Industrial technoecosystems and geothermal technoecosystems would probably coexist well as long as their transport and energy channels did not interfere. A close symbiosis could occur if waste geothermal heat were used in industrial processes. On East Mesa, currently an area of natural desert vegetation, geothermal technoecosystems might develop alone, without competition or symbiosis with other technoecosystem subsets.

Consider now the macroscale metabolism of the proposed large-scale geothermal technoecosystem. High quality inputs are machinery, modules, and materials, petrofuel for technoorganisms, and geothermal fluids. Cool ocean water is a moderate quality input. High quality outputs are electricity, desalted water, purified valuable chemicals, and possibly process heat. Low quality exhausts are evaporated water, waste heat, injected warm ocean water and brine, and low value salts.

While interfering little with the agricultural technoecosystem, the geothermal technoecosystem helps maintain its water niche and that of other agricultural technoecosystems in the Lower Colorado River Basin. And fossil fuel energy is partly replaced by geothermal power. Superficially, the Imperial Valley technoecosystem changes very little, and the Salton Sea technoecosystem's decline is halted. But while all this order is maintained at the surface, geothermal reservoirs at depth are being depleted and laden with imported salt in cool injection brine. This macroscale geothermal technoecosystem envisioned by the U.S. Bureau of Reclamation is a human-controlled hydrologic cycle contained within pipelines and thermodynamic modules. Like the natural hydrologic cycle, it is an entropy jet. But unlike the natural solar-powered system, it is driven by a sudden flood of ancient geothermal energy escaping to space.

5. Niche Limits

The geothermal niche in Imperial Valley, as elsewhere, is limited. Tables 6 and 7 are presented to help clarify discussion of geothermal resource magnitudes in relation to exploitation plans. Table 6 is an inventory of energy flow and storage magnitudes for individual geothermal systems in the valley; it is based on a temperature gradient map (USBRDC, 1972, Plate 3), heat content and system volume data from Renner, White, and Williams (1975), and several assumptions which are outlined in the notes. Table 7 lists resource storage magnitude estimates made directly by other workers or calculated from figures they present. And Table 7 also tabulates exploitation rates of geothermal technoecosystems which either exist now or have been suggested for the future. Interesting comparisons can be made between Tables 6 and 7, and between these tables and Tables 2, 3, 4, and 5. A few such comparisons will be made in the following discussion.

Perhaps the most remarkable feature of Table 6 is the small size of the heat flow and power flow magnitudes. Salton Sea geothermal system heat flow of 78.6 Mwt is exceeded by flow from just two typical wells tapping the system (56 Mwt each, as derived from Koenig, 1973B). And East Mesa system heat flow of 20.3 Mwt is also exceeded by open flow from two typical wells (12 Mwt each, as derived from figures given by Mathias, 1975*). Total renewable power flow from all tabulated geothermal systems is 24.4 Mwe (assuming 16 percent conversion efficiency), only enough power for a single town of 24,000 people, and less than one third of the power already generated at the Cerro Prieto geothermal powerplant. Salton Sea system power flow (12.6 Mwe) is only slightly larger than the 10 Mwe capacity of the small pilot plant now being tested there.

The macroscale geological engine is likely to keep supplying these energy flow rates for a long time. But even small-scale exploitation likely in the next few years is certain to exceed this flow niche and start to tap stock niche storages. And exploitation schemes conceived of by some authors (Table 7) would pump storages at more than a thousand times natural flow rate.

Another notable relationship apparent in Table 6 is that the Salton Sea system represents roughly half of the total energy flow and storage of all the systems, and 60 percent of the total recoverable power content listed. This seems to suggest that two specially-adapted geothermal technoecosystem populations of roughly equal size may develop in two contrasting geological habitats: hypersaline Salton Sea system, and all other systems (only saline).

Roughly logarithmic sequence of heat content values among the four largest systems seems to reflect the logarithmic resource magnitude trend noticed by Renner, White, and Williams (1975).

Total heat content of the hydrothermal systems tabulated in Table 6 is around 1.5 percent of total U.S. hydrothermal convection systems resource base, 0.6 percent of thermal energy content of U.S. coal resources, and 15 percent of U.S. original oil resources heat content (Table 5). Total recoverable power content of all hydrothermal systems in Table 6 (139,400 Mwyre) is three percent of total recoverable power content of discovered and undiscovered hydrothermal convection systems in the U.S. (4,600,000 Mwyre) and 40 percent of power content of identified U.S. hydrothermal convection systems reserves (350,000 Mwyre) estimated by Nathenson and Muffler (1975). Comparing the 139,400 Mwyre recoverable content from Table 6 with U.S. technoecosystem energy flow rates from Table 3, we see that the Imperial Valley geothermal systems would power the predicted 1985-level geothermal technoecosystem for less than one year, the predicted 2000-level system for only four months, present U.S. power output for less than two months, and the entire present U.S. technoecosystem for less than two days.

Table 6. Natural geothermal energy flows and storages in Imperial Valley, California

Hydrothermal System Name	Heat Flow /1 (Mwt)	Power Flow /2 (Mwe)	Heat Content /3 (10^4Mwyrt)	Power Content /4 (10^3Mwyre)	Recoverable Power Content /5 (10^3Mwyre)	Recoverable Hot Fluid Volume /6 (km^3)
Salton Sea	78.6	12.6	278	445	83.4	21.6
Heber	22.2	3.6	146	234	29.2	20.0
East Mesa	20.3	3.2	73	117	14.6	11.2
Brawley	12.9	2.1	40	64	10.0	5.4
East Brawley	10.5	1.7	--	--	--	--
Border	3.3	0.5	3	5	0.6	0.4
Dunes	2.5	0.4	8	13	0.8	1.8
Glamis	1.1	0.2	5	8	0.5	1.2
West Glamis	0.8	0.1	3	5	0.3	0.6
TOTALS	152.2	24.4	556	890	139.4	62.2
TOTALS EXCLUDING SALTON SEA	73.6	11.8	278	445	56.0	40.6
Salton Sea Volcanic System			1525 /7			

Notes:

1. Total heat flow estimated from planimetric analysis of temperature gradient map (USBRDC, 1972, Plate 3), calibrated to heat flow units by comparison with heat flow map of East Mesa system (USBRN, 1974, p. 5A). Thermal conductivity assumed to be 3.5×10^{-3} cal/cm·sec·°C, so $1^{\circ}F/100$ ft = 0.633 HFU = 0.0265 Mw/km^2. Contours extended where needed.
2. Total electrical power equivalent calculated from total heat flow at 16 percent conversion efficiency.
3. Heat content values, to 3 km depth, from Renner, White, and Williams (1975). No storage data are available for the East Brawley system.
4. Power content is electrical equivalent of heat content at 16 percent conversion efficiency.
5. Recoverable power content to 3 km depth. Data for first 4 systems from Nathenson and Muffler (1975). Border system figure is two percent of heat content. Last 3 figures are one percent of heat content.
6. Recoverable hot fluid volume is assumed to be 20 percent of total reservoir volume (sediments and fluid) to 3 km depth. Total volume figures obtained from Renner, White, and Williams (1975).
7. Smith and Shaw (1975). Heat content to 10 km depth.

Table 7. More geothermal energy flows and storages in Imperial Valley

Exploitation Systems (1st section), and Miscellaneous Resource Estimates (2nd section)	Power Output (Mwe)	Hot Fluid Output (km^3/yr)	Recoverable Power Content (10^3 Mwyre)	Recoverable Hot Fluid Content (km^3)	Notes
Salton Sea pilot plant	10				
Cerro Prieto powerplant	75	0.03	5	1.7	1
USBR demonstration stage	420	0.15			2
USBR large-scale stage	10,500	3.9			2,3
Rex (1970) scheme (min)	20,000	12	2000		4,5
Rex (1970) scheme (max)	30,000	19	9000		4,6
Salton Sea, total flow	92,000	1.4	1840	28	7
1975 drilled resource			5		8,9
1975 total resource			100		8,9
Future resource (min)			200		8
Future resource (max)			500		8
pre-1975 estimates (min)			20		8
pre-1975 estimates (max)			1800		8
Water estimate (Dutcher)				250	10
Water estimate (Rex min)				790	11,12
Water estimate (Rex max)				4146	11,13

ft =

Notes:
1. Fluid output assumes 39 kg = 0.039 m^3 per kwh (Hughes, Dickson, and Schmidt, 1974). Power content: minimum proven reserves of 33 yr at 150 Mw (Tolivia, 1975*). Minimum fluid content calculated from other three figures.
2. USBRDC (1972). Hot fluid output = replacement fluid input.
3. Fluid output is desalted water output (3.1 km^3) multiplied by 1.25 to correct for evaporative cooling losses, as in demonstration stage.
4. Rex (1970) figures. Excludes hypersaline brines.
5. Assumes 100 year field lifetime.
6. Assumes 300 year field lifetime.
7. Austin, Higgins, and Howard (1973) scheme for exploitation of Salton Sea field, only, with total flow technology. Assumes 20 year field lifetime.
8. Towse (1975).
9. Resource shallower than 1.8 km, and hotter than 230°C.
10. Dutcher, Hardt, and Moyle (1972). Water hotter than 150°C and less than 3.5 percent salt content (35,000 ppm).
11. Rex (1970). Non-hypersaline water hotter than 260°C.
12. Assume 1974 km^3 total volume, of which 40 percent is hot.
13. Assume 5923 km^3 total volume, of which 70 percent is hot.

The Imperial Valley geothermal power resource appears to be small indeed compared with macroscale technoecosystem energy flow rates. Now compare it with power output rates of existing and proposed Imperial Valley geothermal technoecosystems (Table 7) actually designed to exploit the Imperial Valley geothermal reservoirs listed in Table 6. The technoecosystems and resources are divided into two groups, those of the hypersaline Salton Sea geothermal system, and those of all the other systems. Salton Sea system recoverable power content (83,400 Mwyre) could power the 10 Mwe pilot plant now being tested over it for 8,340 years. But it could power the large (92,000 Mwe) total flow technology system envisioned by Austin, Higgins, and Howard (1973) for less than one year, compared with their estimate of 20 years.

Similarly, recoverable power content of non-hypersaline hydrothermal systems (56,000 Mwyre) could run 75 Mwe powerplant like the one at Cerro Prieto for some 750 years, and the six powerplants of the proposed USBR demonstration stage development (420 Mwe) for 133 years. But it could run the 150 powerplants of the USBR full-scale development (10,500 Mwe) for only five years, and the 20,000 to 30,000 Mwe scheme proposed by Rex (1970) for only two to three years (compared to his estimate of 100 to 300 years field lifetime).

Clearly, the Imperial Valley geothermal resources are not only miniscule compared with U.S. technoecosystem energy flows, but also very small compared with the energy flow rates of the geothermal technoecosystems specifically envisioned to exploit them. The Imperial Valley geothermal stock niche appears to be much more limited than some men have supposed.

Now compare Table 6 recoverable power content magnitudes with those of Table 7. Towse (1975) estimates that total resource in Imperial Valley proved by drilling is 5,000 Mwyre, and that the total recoverable power resource is 100,000 Mwyre, which is quite comparable to the 139,400 Mwyre estimate of Table 6. He also estimates that future technical and economic developments may expand the total recoverable resource by a factor of two to five (200,000 to 500,000 Mwyre). According to Towse, previous estimates of Imperial Valley recoverable power content range from 20,000 Mwyre (1/5 of his present estimate) to 1,800,000 Mwyre (18 times his present estimate and 3.6 times his estimated future maximum value). Compared with estimates of Table 6 and those by Towse, the recoverable power resource magnitudes implied by Rex (2,000,000 to 9,000,000 Mwyre for just the non-Salton Sea systems) and Austin, Higgins, and Howard (1,840,000 Mwyre for the Salton Sea system alone) seem very optimistic.

Consider next estimates of the volume of hot geothermal fluids in Imperial Valley geothermal systems. Salton Sea hot fluid volume estimated by Austin, Higgins, and Howard (1973) is 28 km^3 (Table 7), very close to the 21.6 km^3 estimate of Table 6. For the non-hypersaline systems, however, the agreement between estimates is not so good. The total estimate in Table 6 of hot fluid volume (hotter than 150°C for most of the systems, but only 90 to 150°C for Dunes, Glamis, and West Glamis systems) is 40.6 km^3. In contrast, volume estimates by Dutcher, Hardt, and Moyle (1972) and Rex (1970) for non-hypersaline fluids are 250 km^3 and 790 to 4146 km^3, respectively -- larger than the Table 6 estimate by factors of 6, 19, and 102. In addition, the Dutcher and Rex volume estimates are for water hotter than 260°C, much hotter than the minimum temperature used for the Table 6 figure (mostly 150°C, but 90°C in some cases). If Dutcher and Rex had chosen a 150°C minimum temperature, their volume estimates, already large, would presumably be much larger. Even if we assume that the correct hot fluid volume is 160 km^3, four times the Table 6 estimate, the Dutcher and Rex estimates seem very optimistic.

In an earlier paragraph, recoverable power content was found to be small compared with projected Imperial Valley geothermal technoecosystem power output rates. Now compare projected hot fluid rates (Table 7) with estimated hot fluid storage volume (Table 6). Assuming a non-hypersaline hot fluid volume of 40.6 km^3, the USBR demonstration stage technoecosystem, tapping fluid at a rate of 0.15 km^3/yr, could operate for 271 years. But the macroscale USBR technoecosystem could maintain its exploitation rate (3.9 km^3/yr geothermal fluid discharge) for only 10 years! And the scheme proposed by Rex (12 to 19 km^3/yr hot fluid output) would exhaust the hot non-hypersaline reservoir in only 2.1 to 3.4 years. Even if we assume a true geothermal fluid volume four times as large (160 km^3), these durations increase to only 41 years and 8.4 to 13 years. Clearly, compared to the Lower Colorado River's flow magnitude at Lees Ferry (9.3 km^3/yr legal minimum), the Imperial Valley geothermal water stock niche is quite small.

Dr. Robert W. Rex (1970) presented by far the most optimistic estimates of geothermal fluid and energy storages in Imperial Valley; his estimates for sustainable exploitation rates and their duration are correspondingly large. His optimism stems partly from his belief that more hydrothermal convection systems await discovery on the flanks of the valley, and his theory that the heat stored in sediments, approximately equal to thermal energy in brines, could be recovered by circulation of injected replacement fluids.

Geophysical studies in unexplored portions of the valley may indeed discover more hydrothermal convection systems; but in light of the geology of the valley (faults and spreading centers), it seems unlikely to me that total known resources will be increased by as much as a half. The prospects for secondary thermal energy recovery, however, may not be nearly as favorable as Rex supposed. Additional heat could be recovered from sediments only by the flow of cooler fluids through them. Temperature and thus energy quality of these fluids would thus be significantly lower than the corresponding values of the original fluids. Net energy ratio would therefore be lower, and it is likely that temperature-dependent thermodynamic modules of the geothermal technoecosystem would have to be redesigned.

Actual geothermal energy and fluid storages are probably larger than the magnitudes listed in Table 6 because these estimates are to 3 km maximum depth, while sediments in Imperial Valley are up to 6 km deep. Therefore total recoverable fluid and energy content of some systems may be up to two times larger than the Table 6 values. However, not all estimates will be changed much by including storages below three km depth. Sediments at East Mesa, for instance, are only about 3.5 km deep.

The grand, magnificent macroscale geothermal water and power technoecosystem envisioned by the U.S. Bureau of Reclamation and reviewed in the preceding section, may never come into existence. As just demonstrated, the total exploitable resource is quite small compared with USBR-planned exploitation rate; if actually built, the system would probably be able to operate for only a fraction of one human lifetime. The USBR may also run into other difficulties. Geothermal wells are all very individualistic; each has a unique combination of temperature, production rate, and fluid chemistry. Each well, therefore, requires careful, intimate attention, and integration of hundreds of them into a single technoecosystem may be troublesome. In addition, geothermal fluids throughout Imperial Valley's low salinity systems may not be as hot as the USBR expected. This has been the case for the East Mesa system, where 200°C fluids were expected but actual fluids tapped were only 154 to 166°C.

Furthermore, the USBR may have difficulty gaining access to most of the low-salinity geothermal systems of Imperial Valley. Most of these areas are subject to geothermal leasing by the federal government to private corporations. And the prime geothermal areas, including parts of the East Mesa system, have already been leased. Corporations may be most interested in power production and may consider less profitable desalted water to be only a possible by-product. USBR, with just the opposite order of priorities, may have difficulty convincing these companies to choose a technoecosystem configuration which maximizes water output and generates electricity as only a secondary output.

Finally, another possible barrier to the USBR project may be its cost. In this paper I have intentionally avoided discussions of prices and money costs. For they vary rapidly from year to year and from place to place under the influence of the vagaries of inflation, international monetary strategy, materials availability, diverse subsidies, and innumerable other factors. Net energy variables would be a more solid basis for study of Imperial Valley geothermal technoecosystems, but net energy theory is still in its infancy, and net energy analyses of Imperial Valley systems have yet to be undertaken.

However, a preliminary economic analysis of geothermal water and power production in Imperial Valley has recently been presented by Vaux and Nakayama (1975*). They conclude that geothermal power production in the valley may be economically attractive (depending on power price, capital cost, and willingness to accept risk), but that geothermal water production is not. They base their conclusion about the unprofitability of geothermal water production on the comparison between the present (subsidized) price of canal water in Imperial Valley ($1 to $30 per acre-ft, or $0.8 million to $24 million per km^3) and their minimum cost estimate for geothermal water ($127 per acre-ft, or $103 million per km^3). Other estimates of Imperial Valley geothermal water costs are Rex's (1970) figure of $33 per acre-ft ($27 million per km^3), comparable to present canal water cost, and the USBRDC (1972) large-scale development estimate of $100 to $150 per acre-ft ($81 million to $122 million per km^3), comparable to the geothermal water cost estimate of Vaux and Nakayama.

Although money cost of geothermal water may be non-competitive, its production can be subsidized, perhaps by money income from power production (Laird, 1973). The total money cost of 3.1 km^3/yr of desalted water exported to the Colorado River under the macroscale USBR large-scale plan (at the maximum estimated unit cost of $122 million per km^3) would be $378 million per year. This amount of money is certainly within the subsidizing capabilities of the U.S. national technoecosystem; it is comparable to the money cost of a single medium-sized military technoorganism.

A macroscale geothermal technoecosystem the size of USBR's large-scale development plan will probably never be built. But we may expect a geothermal system to develop which is of a size somewhere between the USBR's large-scale development system and the pilot-scale systems planned for the near future. It seems rather unlikely that geothermally desalted water sufficient to save the Lower Colorado River will ever be piped to Lake Havasu from Imperial Valley. But enough desalted water may eventually be produced by Imperial Valley geothermal technoecosystems to significantly improve the water quality of the local All-American or Coachella Canals, or at least to freshen the water supplies of local municipal technoecosystems.

Thus, geothermal technoecosystems in Imperial Valley are likely to help extend the niche of the Imperial Valley technoecosystem, the timespan over which it can remain an energy-rich oasis. Towns will continue to be lit at night, produce-laden trains will still roll, crop dusters will continue to fly low over green fields, and recreation in and around the Salton Sea will persist.

Successional changes are likely in the geothermal technoecosystems, on a time scale which depends on exploitation rate. Exploitation systems may have to evolve to tap cooler, deeper, saltier fluids. Inputs and outputs and internal cycle configurations will change over time. Perhaps, when the hydrothermal reservoirs are depleted, geothermal technoecosystems which tap hot-dry rock or magma will spring up over the Salton Sea volcanic system. Its thermal energy content is three times as great as that of all the hydrothermal systems in the valley (see Table 6).

The Imperial Valley technoecosystem will not be unaffected by radical changes in the global technoecosystem's energy environment. Petrofuel technoorganisms and their support facilities may adapt to synthetic fuels. And diverse populations of inorganic solar collector modules are likely to burgeon. Crop vigor and species may change as salinity and quantity of imported canal water vary, reflecting the state of the water economy of the entire Colorado River Basin technoecosystem.

The geothermal niche, though, is finite. Geothermal exploitation beyond renewable heat flow rate is almost certain; therefore, the end of Imperial Valley geothermal technoecosystems must come. Various authors write of exploitation durations of decades to centuries; but these are just a flicker of geological time. When the geothermal wells finally shut down, systems which are totally dependent on them must fall into disuse and decay. Geothermal industries may be abandoned, some fields may return to desert, and the Salton Sea may finally turn hypersaline, its last reprieve ended. And the subterranean geothermal systems, pierced, cooled, and polluted, will be released from human control to resume their spontaneous passage through geological history.

VI. DEVELOPING REGIONS

1. Roles of Geothermal Technoecosystems

Developing regions are countries, territories, and other areas which have low-energy technoecosystems. Within a developing region there may be local concentrations of wealth and high-energy technoecosystem components. But more inhabitants have relatively low per capita technoecosystem energy flow, relatively low-level technology, and very little high-energy-quality technomass. In some developing regions, per capita technoecosystem wealth may actually decrease as population growth rate exceeds technoecosystem growth rate.

When we fly over a developing region, the contrast with high-energy technoecosystems is unmistakable. Energy channels (such as powerlines, pipelines, and all-weather roads) which intricately lace high-energy technoecosystems are small and sparsely distributed here. High-energy mobile techno-organisms, ubiquitous in developed regions, are rare here, and are outnumbered by biological vertebrate technoorganisms. And they tend to be of technospecies suited for communal rather than personal purposes (trucks and buses rather than automobiles). Agricultural technoecosystems predominate; manufacturing technoecosystems tend to be small, simple, and concentrated in one or two main cities. At night, towns and cities do not glow as brightly here as they do in developed regions, and villages of low-energy stationary technoorganisms may be completely dark in visible wavelengths.

It is clear that this developing region is an integral part of the global technoecosystem, but that it is only distantly peripheral to the highest-energy fossil fuel niche hub of the global system. Preassembled high-energy technoecosystem components suitable for integration into the developing region's technoecosystem are usually imported whole, along with technical advice, from distant developed regions. Such technology transfer can be a gift, or it can be subsidized by financial loans or grants from developed regions and their agencies.

For developing regions with favorable geological conditions (and such places are numerous), geothermal technoecosystems may be of great value for increasing local energy flows and energy quality. Small geothermal developments, which might be inconsequential in the midst of a high-energy technoecosystem, can have great beneficial impact on energy flows of a developing region. Geothermal electricity, when channeled to homes, can directly increase the energy wealth of domestic technoecosystem inhabitants. It can also act as an energy flow amplifier by powering industrial technoecosystems (perhaps at newly established industrial growth poles), or by driving irrigation pumps for solar-energy-collecting agricultural technoecosystems in arid lands. Water and chemicals from geothermal technoecosystems can have numberless uses in any technoecosystem, as discussed in Chapter III.

Developing countries, according to Wehlage (1974A), take an innovative, practical approach to geothermal technoecosystem development, while the high-energy U.S. tackles it from a conservative, academic angle. This difference in attitudes could be due partly to the relatively much greater beneficial impact that geothermal development can have on a low-energy technoecosystem.

The United Nations, Energy Section (1972) summarized the specific advantages that geothermal technoecosystem development can have for developing regions. Perhaps most important, geothermal energy can decrease dependence on imported oil, with its price and supply uncertainties. Although petroleum energy must be imported (as fuel or in the form of machinery) in order to construct the geothermal technoecosystem, this large investment can repay itself many times in the form of a continuous, reliable, low cost, high quality geothermal energy flow. Where optimum resource conditions occur, power can be produced at very competitive cost and with only minor pollution of the surface environment. Other advantages are simplicity and multiple purpose capabilities of geothermal technoecosystem configurations. Small, simple turbogenerator units which exhaust to atmosphere can be installed in rural areas with little difficulty, and the waste heat they produce is suitable for secondary uses (Cataldi, DiMario, and Leardini, 1973). Because there are no major economies of scale in geothermal power production (James, 1973), small generating modules can be added one at a time as field development and local technoecosystem enrichment proceed.

Armstead, Gorhan, and Muller (1974) outline a logical sequence of steps which a developing region might take in a systematic geothermal resources development program. Any such project would utilize the services of a large international pool of specialists in multidisciplinary cooperation. Funds, technical expertise, and hardware for geothermal development in developing regions have been provided by local and colonial governments, the United Nations, private organizations, the U.S. Agency for International Development, other agencies of developed countries, and the World Bank (Koenig, 1973B, and Burnside, 1973).

The United Nations, in particular, has been an international catalyst for geothermal development in developing countries around the world (Saint, 1975*). Major geothermal projects have been undertaken by the U.N. in Chile, El Salvador, Ethiopia, Kenya, and Turkey (United Nations, Energy Section, 1972). McNitt (1975) reviews the five consecutive phases of a U.N. project, from geological reconnaissance to powerplant feasibility study. Four projects were completed by 1975, each at an average cost of $3 million and each with a duration of four to seven years (ibid.).

2. Specific Applications

Many publications have been written about geothermal resources and projects in developing regions. They range from simple reports of hot spring locations to descriptions of completed geothermal powerplants and ambitious plans for future geothermal technoecosystems. Geothermal developments in arid developing regions will now be reviewed. The discussion is organized by geothermal region type and then by geographical location.

The only subduction zone geothermal belt which coincides with arid and semiarid lands occurs along the western coast of South America. As Uyeda and Watanabe (1970) point out, high heat flow values of the continent are concentrated in the Andes region and are often associated with geothermal manifestations.

In the arid volcanic interior of northern Chile (Atacama Desert), a United Nations exploration program which started in 1967 located three promising geothermal prospects. More detailed investigations, slowed by difficult access and high elevation (over 4,000 m), have centered on the El Tatio geothermal field (Koenig, 1973B). Geophysical studies and drilling reveal a large wet steam reservoir 30 square kilometers in area. Pilot production wells now yield steam equivalent to 18 Mwe, and power production of up to 50 Mwe is planned (Lahsen and Trujillo, 1975).

It is likely that the geothermal technoecosystem to be built at El Tatio will combine electricity generation with fresh water production, possibly by multistage flash distillation (Barnea and Wegelin, 1973). Power could be transmitted to the giant Chuquicamata copper deposit, 80 km away, for smelting and mining operations, and might also be used for recovering chemicals from the adjacent fumarole field (Koenig, 1973B; Saint and Jasso, 1976*).

Southern Peru is the geological continuation of the Chilean geothermal region, complete with volcanoes, fumaroles, geysers, and hot springs. Consequently, several arid Peruvian localities may have good potential for geothermal energy exploitation (Parodi, 1975).

The mountain belt geothermal region which extends from the western Mediterranean through southern Asia crosses arid parts of several developing regions. Hot springs are exploited at the surface in Morocco (1968), and preliminary exploration has revealed a promising geothermal region in northeastern Algeria near the Tunisian border (Cormy and D'Archimbaud, 1973). The Canary Islands, which may also be part of this geothermal belt, are the site of recent volcanic eruptions and extremely high temperature gradients (Calamai and Ceron, 1973; Araña, Ortiz, and Yuguero, 1973). Thermal springs have been reported in India by Balasundaram (1972) and Iyengar (1973), but the only systems near or above boiling point are in the non-arid Himalayan region.

Most reported geothermal projects and resources in and near arid developing regions occur over spreading ridges and rift zone geothermal belts. Submarine spreading ridges in the Gulf of California (discussed in the previous chapter), the Red Sea, and the Gulf of Aden occur in narrow seas adjacent to arid lands, and represent possible sites for underwater geothermal exploitation (Williams, 1975). Perhaps most intriguing is the Red Sea, where an active metal-rich hot brine convection system has been concentrating copper, lead, and zinc in sediments. Saudi Arabia and Sudan have agreed to share these sea bottom resources (Ross, 1972; Hammond, 1975C).

Largest of all rifts on land is the system of East African rift valleys. Kenya and Ethiopia appear to have the greatest geothermal exploitation potential, and U.N. exploration projects have been undertaken in both countries. Natural steam jets are already used for space heating, drying of pyrethrum flowers, and livestock water supply, but high-energy geothermal technoecosystems are now being planned and developed for power production and other purposes (Saint, 1975).

Tanzania has numerous hot springs associated with rift systems, indicating that high-energy geothermal exploitation may be possible in the future (Nzaro, 1973). Exploration in Kenya in the 1950s and 1970s has located three prime geothermal targets, but drilling has tapped formations with only low-to-moderate steam production rates (Koenig, 1973B; Noble and Ojiambo, 1975).

The Afar triangle, a triple junction spreading center where East African, Red Sea, and Gulf of Aden rifts all meet, has received a great deal of attention from geothermal technoecosystem developers. It is a low-lying land area roughly in the shape of a 30-60-90 right triangle, and it is the scene of active volcanism, hot springs, and ongoing formation of oceanic crust (Tazieff, 1972B; Stieltjes, 1975). Climate ranges from arid to extremely arid. The Afar triangle includes the northwestern tip of Somalia, and the French territory of Afars and Issas, where geothermal exploration has been in progress since 1970 (Stieltjes, 1975). However, most of the triangle's area occurs in Ethiopia.

Electrical power in Ethiopia has traditionally been produced by hydroelectric plants, which depend on varying seasonal streamflow, and fossil fuel thermal plants, which are sometimes fueled by oil trucked more than 480 km from the coast (Mechanical Engineering, 1972*). However, much of our planet's prime geothermal territory falls within this country's boundaries, so geothermal resources may provide an outstanding energy base for high-energy technoecosystem development.

Geothermal exploration in Ethiopia since 1969, incorporating the skills of U.N. experts and Ethiopian technicians, has discovered over 600 hydrothermal areas in a survey region of 300,000 square kilometers. About 15 percent of the prospects are low-temperature thermal springs in the highlands, and the rest are high-temperature thermal springs and fumaroles in the rift zone and in the Afar triangle (Demissie and Kahsai, 1975; Mechanical Engineering, 1972*). High altitude airborne infrared imaging was a prime reconnaissance tool in this exploration effort (Hodder, 1975).

Three outstanding geothermal regions have been outlined by Ethiopian exploration (Koenig, 1973B; Mechanical Engineering, 1972*; Tazieff, 1972A):

1) The Danakil depression, covering more than 10,000 square kilometers in the arid northern part of the Afar triangle, is a volcanic trench mostly below sea level. Salt-laden hot springs in the area include one which is saturated with pure magnesium chloride. This material could be sold either in its natural state, or as refined magnesium metal for ten times the price. Geothermal power could run a magnesium plant (Lindal, 1973B) and might make extraction of potash deposits (150 million tons have been discovered in the area) feasible and economically attractive.
2) The Tendaho depression, an area of about 5,100 square kilometers in the Afar valley, contains geothermal resources which could provide water and power for pumped irrigation in agricultural technoecosystems. A U.N.-sponsored agricultural development program is already in progress there.
3) The lakes district, in the rift valley south of Addis Ababa, shows good geothermal potential, particularly around the Aluto caldera. A 10 Mwe powerplant is now planned for this region (Saint and Jasso, 1976*).

Geothermal resources development shows great promise for helping to raise energy flow quantity and quality levels in the low-energy technoecosystems of those developing regions which have favorable geology. Unlike the situation in high-energy technoecosystems, a little geothermal energy can go a relatively long way in increasing the per capita technoecosystem wealth of these energy-starved regions. Yet as geothermal technoecosystems in developing regions quickly grow, they too may exceed natural flow rates and thus face the ultimate, finite limits of a stock niche. Geothermal energy may help give these developing regions a strong initial boost. But long term survival of the high-energy technoecosystems that they evolve will depend entirely (as in already developed regions) on the near-future opening of some new long lasting global energy niche.

VII. EPILOGUE

Night has fallen, after an irridescent three-dimensional macrovision sunset, to reveal a different world. We are flying beneath the stars across the dark, open desert, from the Imperial Valley geothermal developments back to our home city.

Highways angling across the desert floor beneath us are visible as beaded strands of pinprick lights of tiny slow-moving technoorganisms. The miniature sign of an isolated gas station oasis lavishes photons in all directions just in case a technoorganism driver whose vehicle needs potential energy refill should look its way. Scattered grids of lights in the distance show where fossil fuel energies and a water niche have been organized to grow crops. Above the horizon, white strobing pinpoints of light moving between stars reveal the distant positions of airborne technoorganisms like our own. And our desert city destination, straight ahead but hidden from direct view by mountains, emits a luminous skyglow which blends indistinguishably with the glimmering nebulous arc of the Milky Way galaxy. Here in the atmosphere we are flying low over the spheroidal floor of an immense room with no walls or ceiling.

On our omni-band receiver we scan the electromagnetic communication spectrum and tune in on technoecosystem. Radio stations burble into the distance. We catch a slice of all the transmissions -- messages to sell technoecosystem products and philosophies, news of technoecosystem and social ecosystem affairs, encoded chirping of communications between machines, saxophones crooning, and songs of social linkups. We are near the international border and several of the Mexican programs we hear are broadcast from Mexicali, perhaps with electricity generated from ancient geothermal heat at the Cerro Prieto powerplant. Of this modulated radio energy (with origins traceable to the seething interiors of ancestral stars), a small fraction reaches its audience. But most of it radiates exhuberantly into space in ever-widening spherical waves; we intercept a tiny sample on its way out of the solar system.

Over the mountains we pass, and there before us is glittering metropolis. This high-energy pinnacle of the technoecosystem energy pyramid is all aglow, a blazing galaxy of numberless lights which scintillate in the heat waves of evening. As we fly over it we see this urban membrane in exquisite three-dimensional macrovision. Crowded rivers of cars, modulated by multicolored stop-and-go lights, flow down gridded networks of broad flood-lit avenues. Isolated autos weave through the darker streets of residential areas. Winking TV and radio towers and multistoried office buildings pass by in perceived three dimensions. Searchlights sweep the dark sky. We see technoecosystem not only as technology but also as superb, unconscious art.

This city does not have twelve gates, but it is nevertheless the city of a vision. A desert nomad from a low-energy technoecosystem might easily think this water and energy rich technoecosystem to be a glimpse of paradise.

This city does not have foundations of polished gemstones, but in its jewel-like varicolored lights we see spectral evidences of mercury, sodium, rare noble gases, and special phosphors concentrated by high-energy technoecosystem components of the fossil fuel niche. Looking deeper we recognize the high technology of copper concentration, wire fabrication, fuel processing, turbine design, and complex powerplant engineering which underlies this dazzling photon display.

This city may not be made of pure gold, but it is a sparkling treasure beyond price. Dollars are meaningless and invisible to us in the air, but in one sweep of the eyes we take in the spontaneously organized results of many billions of dollars invested and spent, each dollar representing the product of vast energy flows and eons of evolution in life and earth cycles. In what other solar systems is such treasure to be found?

This is the living, complex technoecosystem in its full reality, directly perceived. It is real wealth, real life support, the unified actuality which lies beyond all the reports and statistics which line our bookshelves.

We cannot remain objective outside observers for long, however, because this city is our home. This is where we happen to live now, as creatures called human, during one infinitesimal instant of life's evolution. Each of us has a different microscale life down in that macroscale system. Each of us has special friends, connections, possessions, and memories there below. For the moment, we still perceive with macrovision, but instinctively we look for familiar microscale geometries -- our office, our neighborhood and house, the back porch light, or the glow of the bedroom window. It is time to return to life at our usual scale in the human world. There are so many roles to play, so many experiences to have, so many people to be down there in the technoecosystem.

Although we return to microscale life we must not lose our grasp on macroscale insights. Macroscale technoecosystem configurations determine the parameters of small individual lives. Whatever happens to technoecosystems will eventually have a profound effect on all of us, for technoecosystem is the skin we share.

Flying low over the city, we might wonder about its future. How long can this city live? How long can these lights shine and these sleeping gardens be watered? Will these high-energy structures continue to be inhabited, like Rome during the Middle Ages, as energy levels change? Or will they disintegrate into ruins reclaimed by the desert? Can the water niche in this arid region be extended into the long run by modulating natural systems and by modifying technoecosystem designs? Will vast expanses of desert soils nearby continue to produce large crop yields with technoecosystem subsidies of concentrated energy, technoorganisms, fertilizers, and water?

We might also wonder about the global technoecosystem within which this city is embedded. Can a new global energy niche be found to replace the finite fossil fuel niche as foundation for high-energy technoecosystems? Can technoecosystems effectively recycle and reconcentrate finite supplies of essential metals? Can high-energy technoecosystems be constructed for all the humans on earth? How long can technoecosystems around the world continue to increase in size and energy level without irreversibly crippling natural energy systems? What new technoecosystem configurations will be evolved? How will quality of human life change? How many human heirs will we assemble, and how many will we destroy?

Another thing to wonder about is how long high-energy military jet technoorganisms can continue to roar in formation over the city. Will this technoecosystem and its inhabitants (including us) be incinerated and flattened in moments by multimegaton nuclear air bursts, as multitudes of long-dormant cybernetic missile technoorganisms are belched from nearby underground silos onto fiery intercontinental trajectories of revenge? Or will the thousands of plutonium concentrations sleep on indefinitely?

Perhaps technoecology will help us answer many of these questions. Perhaps it will help us engineer answers we like through comprehensively and insightfully planned actions.

We do not know the specifics, but we do know that this technoecosystem must change. The fossil fuel niche is ending as net energy ratios decline. Essential minerals are becoming scarcer and more energy-costly to recover. Arid lands groundwater storages are being plundered toward exhaustion. Superficially, the configurations of this urban technoecosystem may remain stable for a while. But cars will probably shrink, houses will sprout solar panels and gardens of well-adapted desert plants, and powerlines and pipelines will start to bring electricity and fuels from diverse new energy technoecosystems.

Nuclear power technoecosystems may illuminate the city for a while. But they may serve only as a sink of inefficiency for accelerated depletion of dwindling fossil fuel wealth. And they will bring with them the threat of reactor accidents and plutonium terrorism which could transform the city and the surrounding desert into stygian, cancer-wracked abomination. Solar technoecosystems are in their infancy, but they may represent a new long-term flow niche for global technoecosystem operation.

Geothermal technoecosystems may channel energy of various forms into the city for a while: Paradisio powered by Inferno. Knowledge and opinions about geothermal resources and technoecosystems may resound increasingly (for a while) through books, university courses, TV programs, newspaper articles, and casual conversations in the urban technoecosystem below us. Electricity, water, minerals, and manufactured goods from geothermal technoecosystems may be intimately woven into the industrial fabric -- while the niche lasts.

Whatever shape the technoecosystems of the future take under our guidance, their influence will permeate every aspect of our daily lives. As they always have in the past, technoecosystem changes will alter our production roles, our news topics, our language, our lifestyles, our social systems, our information systems, and our consciousness.

Runway lights flash in linear sequence to guide us in. Airport toys grow large again. We decide on a place for dinner as the wheels smoothly meet the surface.

Where shall we fly next?

SUPPLEMENTARY REFERENCES

Wherever reference is made to SWRA throughout the Supplementary References and the following Bibliography, a complete abstract will be found in the appropriate issue of Selected Water Resources Abstracts (SWRA), a semimonthly publication of the Water Resources Scientific Information Center, Office of Water Research and Technology, U.S. Department of the Interior, Washington, D.C. 20240. Users interested in these abstracts can access them through any regional RECON terminal or any library file of SWRA.

SUPPLEMENTARY REFERENCES

[Indicated in text by asterisk (*) following citation date]

Arnett, W.D. et al, eds. (1968) Nucleosynthesis. Proceedings of a 1965 conference at Institute for Space Studies, Goddard Space Flight Center, New York. Gordon and Breach Science Publishers, New York. 273 p.

Austin, A.L. and A.W. Lundberg (1975) Electric power generation from geothermal hot water deposits. Mechanical Engineering 97 (12) : 18-25.

Baciu, P. (1975) Geothermal powerplant with high efficiency. U.S. patent 3,875,749. 10 p. U.S. Patent Office, Official Gazette 933 (2) : 576. See SWRA W75-10845.

Barnaby, F. (1976) Environmental warfare. Bulletin of the Atomic Scientists 32 (5) : 36-43.

Barnea, J. (1975) Assessment of geothermal resources of the United States--1975: a critique. Geothermal Energy 3 (12) : 35-38.

Berman, E.R. (1975) Geothermal energy. Noyes Data Corporation, Park Ridge, New Jersey, Energy Technology Review 4. 336 p.

Bodvarsson, G. (1975) Thermoelastic phenomena in geothermal systems. In United Nations Symposium on the Development and Use of Geothermal Resources, 2d, San Francisco, 1975. Abstracts III-9.

Boulding, K.E. (1968) Business and economic systems. In J.H. Milsum, ed., Positive feedback: a general systems approach to positive/negative feedback and mutual causality, p. 101-117. Pergamon Press, New York.

Braudel, F. (1972, 1974) The Mediterranean and the Mediterranean world in the age of Phillip II. Translated from French by S. Reynolds. Harper & Row, New York. 2 vols.

Bronowski, J. (1971) The identity of man. Natural History Press, Garden City, New York. 145 p.

Caswell, H. et al. (1972) An introduction to systems science for ecologists. In B.C. Patten, ed., Systems analysis and simulation in ecology, Vol. 2, p. 3-78. Academic Press, New York.

Clayton, D.D. (1968) Principles of stellar evolution and nucleosynthesis. McGraw-Hill Book Co., New York. 612 p.

Cloud, P. (1974) Evolution of ecosystems. American Scientist 62 (1) : 54-66.

Committee of Inquiry on the Plutonium Economy (1975) The plutonium economy: a statement of concern and background report. National Council of Churches of Christ in the U.S.A., New York. 29 p.

Fernelius, W.A. (1975) Production of fresh water by desalting geothermal brines -- a pilot desalting program at the Mesa geothermal field, Imperial Valley, California. In United Nations Symposium on the Development and Use of Geothermal Resources, 2d, San Francisco, 1975. Abstracts IX-3.

Fertl, W.H. (1972) Worldwide occurrence of abnormal formation pressures, part I. Paper presented at Third Symposium on Abnormal Subsurface Pore Pressure, Baton Rouge, Louisiana, May 15, 1972. Society of Petroleum Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers, Dallas, Texas. Paper SPE 3844. 14 p.

Finlayson, F.C. and W.A. Kammer (1975) Integrated solar/geothermal power systems -- conceptual design and analysis. Aerospace Corporation, El Segundo, California. Report No. ATR-75 (7512)-1. 90 p.

Fischer, A.G. and S. Judson, eds. (1975) Petroleum and global tectonics. Princeton University Press. 322 p.

Fischer, L.K. (1973) Environmental aspects of energy-water relationships. In K.E. Stork, ed., The role of water in the energy crisis, proceedings of a conference at Lincoln, Nebraska, 1973, p. 47-59. Nebraska Water Resources Research Institute, Publication.

Foin, T.C., Jr. (1972) Systems ecology and the future of human society. In B.C. Patten, ed., Systems analysis and simulation in ecology, Vol. 2, p. 475-531. Academic Press, New York.

Fulcher, M.K. (1975) Interdisciplinary approach to geothermal development. In Conference on Interdisciplinary Analysis of Water Resource Systems, University of Colorado, Boulder, June 19-20, 1973, proceedings, p. 194-208. American Society of Civil Engineers, New York. See SWRA W76-00070.

Fuller, R.B. (1963) No more secondhand God. Southern Illinois University Press, Carbondale and Edwardsville. 163 p.

Fuller, R.B. (1975) Synergetics, explorations in the geometry of thinking. Macmillan Publishing Co., New York. 876 p.

Gabel, M. (1975) Energy earth and everyone. Straight Arrow Books. 160 p.

Geikie, Sir A. (1962) The founders of geology. 2nd ed. Dover Publications, New York. 486 p. (Originally published in 1905).

Geonomics, Inc. (1975) Geothermal regions of the world [Map, mercator projection, approximate scale at equator = 1:77 million]. Berkeley, California.

Georgescu-Roegan, N. (1975) Energy and economic myths. Southern Economic Journal 41 (3) : 347-381.

Gerardin, L. (1968) Bionics. McGraw-Hill, New York. 254 p.

Goguel, J. (1976) Geothermics. McGraw-Hill, New York. 200 p.

Guiza, J. (1975) Power generation at Cerro Prieto geothermal field, Mexico. In United Nations Symposium on the Development and Use of Geothermal Resources, 2d, San Francisco, 1975. Abstracts VII-13.

Handler, P. (1975) On the state of man. BioScience 25 (7) : 425-432.

Henderson, T. (1968) Imperial Valley. Same as author, Calipatria, California. 240 p.

Holdren, J.P. and P.R. Erlich (1974) Human population and the global environment. American Scientist 62 (3) : 282-292.

Hubbert, M.K. (1969) Energy resources. In National Academy of Sciences/National Research Council, Division of Earth Sciences, Committee on Resources and Man: Resources and man, a study and recommendations, p. 157-242. W.H. Freeman, San Francisco.

Irelan, B. (1971) Salinity of surface water in the Lower Colorado River - Salton Sea area. U.S. Geological Survey, Professional Paper 486-E. 40 p.

Jacobs, J.A., R.D. Russell, and J.T. Wilson (1974) Physics and geology. 2nd ed. McGraw-Hill, New York. 622 p.

Jacoby, G.C., Jr. (1975) Overview of water requirements for electric power generation. In Conference on water requirements for Lower Colorado River Basin energy needs, Tucson, Arizona, 1975, Proceedings, p. 15-47. University of Arizona, Tucson, Arizona.

Johansson, G. (1975) Visual motion perception. Scientific American 232 (6) : 76-80, 85-88.

Kim, J. (1973) Ecosystem of the Salton Sea. In W.C. Ackerman, G.F. White, and E.B. Worthington, eds., Man-made lakes: their problems and environmental effects, p. 601-605. American Geophysical Union, Washington, D.C., Geophysical Monograph 17. See SWRA W74-08752.

Laszlo, E. (1972) Introduction to systems philosophy: toward a new paradigm of contemporary thought. Gordon and Breach, New York. 328 p.

Layzer, D. (1975) The arrow of time. Scientific American 233 (6) : 56-69.

Leonard, G.B. (1968) Education and ecstasy. Delacorte Press, New York. 239 p.

LePichon, X., J. Francheteau, and J. Bonnin (1973) Plate tectonics. Elsevier Scientific Publishing Co., New York. 300 p.

Libby, W.F. (1975) Letter to editor. Science 190 (4221): 1246, 1248.

Loucks, O.L. and A. D'Alessio (1975) Energy flow in simple, man-occupied ecosystems: a summary for the Second Workship on Energy Flow. The Institute of Ecology, Office of Ecosystem Studies, Madison, Wisconsin. 53 p.

Lowell, P. (1908) Mars as the abode of life. Macmillan Company, New York. 288 p.

Margalef, R. (1968) Perspectives in ecological theory. University of Chicago Press. 111 p.

Mathias, K.E. (1975) The Mesa geothermal field -- a preliminary evaluation of five geothermal wells. In United Nations Symposium on the Development and Use of Geothermal Resources, 2d, San Francisco, 1975. Abstracts VI-31.

Mazor, E. (1975) The atmospheric noble gases as potential multitracers in geothermal prospection and steam production studies. In United Nations Symposium on the Development and Use of Geothermal Resources, 2d, San Francisco, 1975. Abstracts III-62.

McGinnies, W.G., B.J. Goldman, and P. Paylore, eds. (1968) Deserts of the world, an appraisal of research into their physical and biological environments. University of Arizona Press, Tucson. 788 p.

McLuhan, M. (1964) Understanding media: the extensions of man. McGraw-Hill, New York. 318 p.

Mechanical Engineering (1972) Geothermal power: Ethiopia. Same as author 94 (8) : 41.

Mehra, J. (1973) Quantum mechanics and the explanation of life. American Scientist 61 (6) : 722-728.

Mehta, V. (1976) Worldwide geothermal energy resource development [Map, mercator projection, approximate scale at equator = 1:63 million]. Geothermal Energy 4 (2) : cover.

Mercado, G.S. (1969) Cerro Prieto geothermal field, Baja California, Mexico. American Geophysical Union, EOS 50 (2) : 59.

Milanovsky, E.E. (1972) Continental rift zones: their arrangement and development. In R.W. Girdler, ed., East African Rifts, p. 65-70. Elsevier Publishing Co., New York.

Moore, C.V., H.H. Snyder, and P. Sun (1974) Effects of Colorado River water quality and supply on irrigated agriculture. Water Resources Research 10 (2) : 137-144. See SWRA W74-08014.

Mueller, D.L. (1976) TRW sees promise in geothermal energy -- a look at East Mesa. Geothermal Energy 4 (4) : 9, 11-14, 16.

Muffler, L.J.P. and D.E. White (1969) Origin of CO_2 in the Salton Sea geothermal system, southeastern California. International Geological Conference, 23rd, Prague, 1968, Report 17: 185-194. See SWRA W71-13487.

Nicholson, M. (1972) Conservation and wildlife. In J. Benthall, ed., Ecology in theory and practice, p. 204-221. Viking Press, New York.

Norton, D. and T. Gerlach (1975) Characteristics useful in exploration for hot dry rock thermal energy resource as suggested by field observation and computer models. In United Nations Symposium on the Development and Use of Geothermal Resources, 2d, San Francisco, 1975. Abstracts II-35.

Novick, S. (1975) The electric power industry. Environment 17 (8) : 7-13, 32-39.

Odum, E.P. (1971) Fundamentals of ecology. 3rd ed. W.B. Saunders Co., Philadelphia. 574 p.

Odum, H.T. (1970) Energy values of water resources. In Southern Water Resources and Pollution Control Conference, 19th, Proceedings, p. 56-64.

Odum, H.T. (1971) Environment, power, and society. Wiley-Interscience, New York. 331 p.

Odum, H.T. (1972) An energy circuit language for ecological and social systems: its physical basis. In B.C. Patten, ed., Systems analysis and simulation in ecology, Vol. 2, p. 139-211. Academic Press, New York.

Olson, H.J. and W.M. Dolan (1976) Geothermal energy -- an industry appraisal. Geothermal energy 4 (1) : 12-13, 15-18.

Paylore, P., ed. (1976) Desertification: a world bibliography. University of Arizona, Tucson, Office of Arid Lands Studies. 644 p.

Peterson, R.E. and N. El-Ramly (1975) The worldwide electric and nonelectric geothermal industry. Geothermal Energy 3 (11) : 4-9, 11-15.

Peterson, R.E., N. El-Ramly, and J.M. Dermengian (1976) The electric and nonelectric geothermal industry in the United States. Geothermal Energy 4 (1) : 20-24.

Plattner, S. (1975) Rural market networks. Scientific American 232 (5) : 66-68, 70, 72-79.

Rappaport, R.A. (1971) Nature, culture, and ecological anthropology. In H.L. Shapiro, ed., Man, culture, and society, p. 238-267. Oxford University Press.

Rehm, B. (1972) Worldwide occurrence of abnormal pressures, part II. Paper presented at Third Symposium on Abnormal Subsurface Pore Pressure, Baton Rouge, Louisiana, May 15, 1972. Society of Petroleum Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers, Dallas, Texas. Paper SPE 3845. 8 p.

Rinehart, J.S. (1975) Faulting in geothermal areas. Geothermal Energy 3 (12) : 7-15, 17-24.

Rowland, R. (1968) Evolution of the MG. Nature 217 (5125): 240-242.

Sagan, C. and F. Drake (1975) The search for extraterrestrial intelligence. Scientific American 232 (5) : 80-89.

Saint, P.K. (1975) Review of 2nd United Nations geothermal symposium. Geothermal Energy 3 (6) : 30-33.

Saint, P.K. and A. Jasso (1976) Worldwide geothermal resource development. Geothermal Energy 4 (2) : 5, 8-14.

Sellers, W.D. (1965) Physical climatology. University of Chicago Press. 272 p.

Sherbrooke, W.C. and P. Paylore (1973) World desertification: cause and effect. University of Arizona, Tucson, Office of Arid Lands Studies, Arid Lands Resource Information Paper 3. 168 p.

Shugart, H.H., Jr. and B.C. Patten (1972) Niche quantification and the concept of niche pattern. In B.C. Patten, ed., Systems analysis and simulation in ecology, Vol. 2, p. 283-327. Academic Press, New York.

Siever, R. (1974) The steady state of the earth's crust, atmosphere and oceans. Scientific American 230 (6) : 72-79.

Siever, R. (1975) The earth. Scientific American 233 (3) : 83-90.

Stanford, P. (1975) The automated battlefield. New York Times Magazine, February 23, 1975, p. 12-13, 34, 36-40.

Steinhart, C.E. and J.S. Steinhart (1974) Energy: sources, use, and role in human affairs. Duxbury Press, North Scituate, Massachusetts. 362 p.

Steward, J.H. (1955) Theory of culture change: the methodology of multilinear evolution. University of Illinois Press. 244 p.

Swink, D.G., R.J. Schultz, and A.J. Oswald (1976) Geothermal energy -- an integrated use plan. Geothermal Energy 4 (4) : 21-25.

Toksoz, M.N. (1975) The subduction of the lithosphere. Scientific American 233 (5) : 89-98.

Tolivia, E. (1975) Evaluation of the geothermal potential of Cerro Prieto, B.C., Mexico. In United Nations Symposium on the Development and Use of Geothermal Resources, 2d, San Francisco, 1975. Abstracts I-38.

Trask, M. (1971) The story of cybernetics. E.P. Dutton and Co., New York. 157 p.

U.S. Bureau of Reclamation, Boulder City, Nevada, Region 3 (1971) Geothermal resource investigations, Imperial Valley, California. Site location report, deep geothermal test well. 44 p.

U.S. Bureau of Reclamation, Denver, Colorado, Lower Colorado Region (1973) Geothermal resource investigations, Imperial Valley, California. Site selection report, geothermal test well Mesa 6-2. 10 p.

U.S. Bureau of the Census (1975) Statistical abstract of the United States, 1975. 96th ed. Washington, D.C. 1050 p.

U.S. Department of the Interior (1975) Mining and minerals policy: annual report of the Secretary of the Interior under the Mining and Minerals act of 1970. 63 p.

Utah Geological and Mineral Survey (1975) Energy resources map of Utah [Map, scale 1:500,000].

Van Huisen, A.T. (1976) 1975 year-end geothermal report. Geothermal Energy 4 (2) : 19-21.

Vaux, H.J., Jr. and B. Nakayama (1975) The economics of geothermal resources in the Imperial Valley: a preliminary analysis. California Water Resources Center, University of California, Davis, Contribution 153. 34 p.

Von Bertalanffy, L. (1968) General system theory: foundations, development, applications. George Braziller, New York. 289 p.

Wheeler, J.A. (1974) The universe as home for man. American Scientist 62 (6) : 683-691.

Wittaker, R.H. and G.E. Likens (1975) The biosphere and man. In H. Lieth and R.H. Wittaker, eds., Primary productivity of the biosphere, p. 305-328. Springer-Verlag, New York.

BIBLIOGRAPHY

Wherever reference is made throughout this Bibliography to SWRA, a complete abstract will be found in the appropriate issue of Selected Water Resources Abstracts (SWRA), a semimonthly publication of the Water Resources Scientific Information Center, Office of Water Research and Technology, U.S. Department of the Interior, Washington, D.C. 20240. Users interested in pursuing such abstracts can access them through any regional RECON terminal or any library file of SWRA.

BIBLIOGRAPHY

1

ALLEN, D.R.

1972

LEGAL AND POLICY ASPECTS OF GEOTHERMAL RESOURCE DEVELOPMENT

WATER RESOURCES BULLETIN 8(2):250-256. EIA 72-05199.

SEE: SWRA W72-08976

GEOTHERMAL STUDIES/LEGAL ASPECTS/ENVIRONMENTAL EFFECTS/WATER LAW/
THERMAL POWERPLANTS/REGULATION/WATER POLLUTION/LAND SUBSIDENCE/EARTHQUAKES
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT/NOISE

2

ANDERSON, D.N./AXTELL, L.H.

1972

GEOTHERMAL RESOURCES IN CALIFORNIA. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER B, 33 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03421.

GEOTHERMAL STUDIES/ENERGY/SUBSURFACE WATERS/THERMAL WATER/CALIFORNIA/
THERMAL SPRINGS/BOREHOLE GEOPHYSICS/WATER TEMPERATURE/THERMAL PROPERTIES/
THERMAL POWER/THERMAL POWERPLANTS/ELECTRIC POWER PRODUCTION/LEGAL ASPECTS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEYSERS FIELD, CALIFORNIA/POWER CAPACITY

3

ANDERSON, J.H.

1973

THE VAPOR-TURBINE CYCLE FOR GEOTHERMAL POWER GENERATION. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 163-175.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13222.

ELECTRIC POWER/THERMAL POWERPLANTS/DEEP-WELL PUMPING/TURBINES/THERMAL WATER/
ELECTRIC POWER PRODUCTION/INJECTION/GEOTHERMAL STUDIES/EQUIPMENT/EFFICIENCIES/
WATER POLLUTION CONTROL/HEAT EXCHANGERS
/IDENTIFIERS: /VAPOR TURBINES/ISOBUTANE/HOT WATER SYSTEMS

4

ARANA, V./ORTIZ, R./YUGUERO, J.

1973

THERMAL ANOMALIES IN LANZAROTE (CANARY ISLANDS).

GEOTHERMICS 2(2):73-75.

TEMPERATURES MEASURED 3 METERS DEEP AT ABOUT 100 LOCATIONS VARY FROM 16 TO 350 DEGREES C., AND TEMPERATURE GRADIENT IN WELLS IS 0.2 DEGREES C. PER METER. SURFACE TEMPERATURE CAN REACH 100 DEGREES C. THE AUTHORS DISPUTE THE HYPOTHESIS OF CALAMAI AND CERON (1970) THAT HEAT TRANSFER IS BY AIR CONVECTION, AND SUGGEST INSTEAD THAT STEAM AND GASES ESCAPE THROUGH FRACTURES FROM A SEA WATER HYDROTHERMAL CONVECTION SYSTEM BELOW AN IMPERVIOUS ROCK LAYER AT DEPTH. SUCH A CAPPED HYDROTHERMAL SYSTEM MIGHT BE IDEAL FOR POWER PRODUCTION. (OALS)

TEMPERATURE/GEOTHERMAL STUDIES/VOLCANOES/SURVEYS/HEAT TRANSFER/CONVECTION/
SEA WATER/HYDROTHERMAL STUDIES
/IDENTIFIERS: /CANARY ISLANDS/TEMPERATURE GRADIENT/GEOTHERMAL RESOURCES/
HYDROTHERMAL CONVECTION SYSTEMS

5

ARMSTEAD, H.C.H.

1973

GEOTHERMAL ECONOMICS. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 161-174.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

GEOTHERMAL ENERGY PRODUCTION HAS HIGH FIXED INVESTMENT COST (EXPLORATION, PLANT CONSTRUCTION), AND LOW OPERATING COST. TO JUSTIFY DEVELOPMENT, GEOTHERMAL COST (INCLUDING EXPLORATION) MUST COMPETE WITH OTHER ENERGY SOURCES. A DETAILED, BUT THEORETICAL ANALYSIS IS MADE OF MANY EXPLORATION, CONSTRUCTION, PRODUCTION, AND MAINTENANCE COSTS OF GEOTHERMAL HEAT AND GEOTHERMAL POWER PRODUCTION. THEORETICAL COSTS ARE COMPARED WITH ACTUAL COSTS AT SEVERAL POWERPLANTS. GEOTHERMAL HEAT AND POWER APPEAR TO BE COMPETITIVE WITH FOSSIL FUELS (AT 1970 PRICES). IT SHOULD BE POSSIBLE TO DESALT WATER AT ONLY 29 CENTS PER 1000 GALLONS. FURTHER ADVANTAGES OF GEOTHERMAL EXPLOITATION ARE POSSIBILITIES OF MULTIPURPOSE PROJECTS AND LOWER IMPORTED FUEL NEEDS. IT MAY BE ADVANTAGEOUS TO SHIP RAW MATERIALS TO GEOTHERMAL FIELDS FOR PROCESSING. (OALS)

GEOTHERMAL STUDIES/ECONOMICS/FIXED COSTS/EXPLORATION/CONSTRUCTION COSTS/COSTS/OPERATING COSTS/COMPARATIVE COSTS/ANALYSIS/MAINTENANCE COSTS/DESALINATION/MULTIPLE-PURPOSE PROJECTS
/IDENTIFIERS: /GEOTHERMAL ENERGY/ENERGY COSTS/ALTERNATIVE ENERGY SOURCES/GEOTHERMAL HEAT/GEOTHERMAL POWER

6

ARMSTEAD, H.C.H./GORHAN, H.L./MULLER, H.

1974

SYSTEMATIC APPROACH TO GEOTHERMAL DEVELOPMENT.

GEOTHERMICS 3(2):41-52.

OUTLINES THE LOGICAL SEQUENCE OF STEPS WHICH A COUNTRY MIGHT TAKE WITH MINIMUM EXPENSE AND EFFORT IN A SYSTEMATIC GEOTHERMAL RESOURCES DEVELOPMENT PROGRAM. A FLOW CHART AND COMMENTARY STRUCTURE THE VARIOUS ACTIONS TO BE TAKEN AND QUESTIONS TO BE ANSWERED. MAJOR STEPS INCLUDE INVENTORY OF ECONOMICS, POLITICS, ALTERNATIVE ENERGY COSTS, AND POTENTIAL INDUSTRIAL SYSTEMS; EXPLORATION (SURVEYS AND DRILLING); RESERVOIR EVALUATION (CORROSION, ENERGY POTENTIAL); AND ENGINEERING CONSIDERATIONS (WASTE WATER DISPOSAL, ENVIRONMENTAL EFFECTS, PLANT DESIGN). GEOTHERMAL DEVELOPMENT REQUIRES THE SERVICES OF A LARGE INTERNATIONAL POOL OF SPECIALISTS IN MULTIDISCIPLINARY COOPERATION. (OALS)

GEOTHERMAL STUDIES/ECONOMICS/POLITICAL ASPECTS/EXPLORATION/SURVEYS/DRILLING/ENGINEERING/WASTE WATER DISPOSAL/ENVIRONMENTAL EFFECTS/PROFESSIONAL PERSONNEL
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT/DEVELOPING COUNTRIES/ENERGY COSTS/ALTERNATIVE ENERGY SOURCES

7

ARMSTEAD, H.C.H. ED.

1973

GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT.

UNESCO, PARIS. EARTH SCIENCES SERIES 12. 186 P.

OFFERS A GENERAL INTRODUCTION TO GEOTHERMAL ENERGY AND THE VARIOUS PHASES OF GEOTHERMAL WORK. TOPICS INCLUDE GENERAL GEOLOGY AND HYDROLOGY; GEOLOGICAL, GEOCHEMICAL, AND GEOPHYSICAL EXPLORATION; DRILLING AND FIELD DEVELOPMENT; UTILIZATION FOR POWER, SPACE HEATING, AND OTHER PURPOSES; AND GEOTHERMAL ECONOMICS. THE FIFTEEN CHAPTERS ARE WRITTEN BY SPECIALISTS IN VARIOUS RELATED DISCIPLINES. AN EXTENSIVE BIBLIOGRAPHY, AT THE END OF EACH CHAPTER, PROVIDES REFERENCES FOR FURTHER READING. (OALS)

GEOTHERMAL STUDIES/REVIEWS/GEOLOGY/GEOCHEMISTRY/GEOPHYSICS/HYDROGEOLOGY/EXPLORATION/DRILLING/ELECTRIC POWER PRODUCTION/HYDROLOGY/ECONOMICS/REVIEWS/RESEARCH AND DEVELOPMENT
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT/SPACE HEATING/INDUSTRIAL USES

8

ARMSTRONG, E.L.

1971

THE ROAR FROM AN EMERGING RESOURCE.

RECLAMATION ERA 57(3):1-8. EIA 71-05393.

ACCORDING TO THIS STATEMENT BY THE COMMISSIONER OF RECLAMATION, GEOTHERMAL ENERGY SOURCES OFFER THE POSSIBILITY OF POLLUTION-FREE, ODORLESS, NOISELESS POWERPLANTS IN THE FUTURE. WORLDWIDE THERE IS NOW 675 MW OF GEOTHERMAL ELECTRIC

POWER IN PRODUCTION. PRESENTLY, THE BUREAU OF RECLAMATION IS PREPARING TO CONSTRUCT A STEAM WELL AND DESALTING PLANT TO EXPLOIT THE 2 TO 5 BILLION ACRE-FEET OF HOT STEAM BENEATH IMPERIAL VALLEY, CALIFORNIA FOR ELECTRICITY AND POTABLE WATER. LIFESPAN OF THE FIELD IS ESTIMATED AT TWO TO THREE CENTURIES. THE PAPER ALSO CONSIDERS USES OF GEOTHERMAL RESOURCES IN FOREIGN COUNTRIES, IMMEDIATE AND LONG RANGE PROGRAMS FOR THE VALLEY, AND THE PROBLEMS PRESENTED BY GAS EMISSIONS, SUBSIDENCE, WASTE WATER DISPOSAL, AND SEISMIC ACTIVITY.

GEOTHERMAL STUDIES/EXPLORATION/THERMAL POWER/ELECTRIC POWER PRODUCTION/DESALINATION/CALIFORNIA/ENVIRONMENTAL EFFECTS/WATER POLLUTION/ENERGY CONVERSION/CALIFORNIA/RESEARCH AND DEVELOPMENT/LAND SUBSIDENCE/WASTE WATER DISPOSAL/EARTHQUAKES
/IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL POWER/HOT WATER SYSTEMS/GEOTHERMAL RESOURCES

9

ARNASON, B./TOMASSON, J.

1973

DEUTERIUM AND CHLORIDE IN GEOTHERMAL STUDIES IN ICELAND. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1405-1415.

SEE: SWRA W74-09022.

THERMAL WATER/HYDROTHERMAL STUDIES/DEUTERIUM/CHLORIDES/GROUNDWATER MOVEMENT/HYDROGEOLOGY/WATER CHEMISTRY/TRACERS/CHEMICAL ANALYSIS/GEOCHEMISTRY/SEA WATER
/IDENTIFIERS: /ICELAND

10

AUSTIN, A.L./HIGGINS, G.H./HOWARD, J.H.

1973

THE TOTAL FLOW CONCEPT FOR RECOVERY OF ENERGY FROM GEOTHERMAL HOT BRINE DEPOSITS.

UNIVERSITY OF CALIFORNIA, LIVERMORE, LAWRENCE LIVERMORE LABORATORY, REPORT UCRL-51366. 39 P. AVAILABLE NTIS AS UCRL-51366. NSF-RANN ENERGY ABSTRACTS 1(8)2171.

OF THE THREE FORMS OF GEOTHERMAL ENERGY, THE HOT BRINE RESOURCE HAS THE GREATEST POTENTIAL FOR DEVELOPMENT OF A VIABLE LONG-RANGE GEOTHERMAL ENERGY SUPPLY. IT IS A LARGE ENERGY SOURCE WITH RECOVERY AND CONVERSION REQUIRING ONLY MODERATE EXTENSIONS OF EXISTING TECHNOLOGIES. THE PROPOSED METHOD IS DEVELOPED SPECIFICALLY FOR APPLICATION TO THE BRINES OF THE SALTON SEA GEOTHERMAL AREA, WHERE ENOUGH ENERGY IS STORED TO PROVIDE AT LEAST 100,000 MEGAWATTS ELECTRICAL GENERATION CAPACITY FOR MORE THAN 20 YEARS. THESE BRINES CONTAIN UP TO 30 PERCENT DISSOLVED SALTS AND ARE VERY CORROSIVE. ONCE DEVELOPED, THE PROPOSED METHOD, THEN, WILL CERTAINLY BE APPLICABLE TO OTHER GEOTHERMAL DEPOSITS. EXPLAINED IS THE TOTAL FLOW CONCEPT, WHICH, THEORETICALLY, SHOULD PRODUCE 60 PERCENT MORE POWER THAN OTHER SYSTEMS, EITHER OPERATIONAL OR PROPOSED, FOR THE HOT BRINE APPLICATION. THE AUTHORS ESTIMATE THAT AN ELECTRICAL POWER GENERATION STATION USING THIS CONEPT WILL REQUIRE A CAPITAL INVESTMENT OF APPROXIMATELY 200 DOLLARS PER KILOWATT AND SHOULD PRODUCE POWER AT A COST OF APPROXIMATELY 3 MILLS PER KILOWATT HOUR. THE ESTIMATED INTERNAL RATE OF RETURN IS BETWEEN 10 PERCENT AND 20 PERCENT, DEPENDING ON THE METHOD OF TAXATION AND ROYALTY CHARGES. (AUTHOR)

GEOTHERMAL STUDIES/BRINES/ENERGY CONVERSION/CALIFORNIA/COSTS/ELECTRIC POWERPLANTS/CORROSION/IMPULSE TURBINES/ELECTRIC POWER COSTS
/IDENTIFIERS: /HOT BRINES/TOTAL FLOW/SALTON SEA/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL RESOURCES/POWER CAPACITY/GEOTHERMAL POWER/ENERGY COSTS

11

AUSTIN, C.F./LEONARD, G.W.

1973

CHEMICAL EXPLOSIVE STIMULATION OF GEOTHERMAL WELLS. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 269-292.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13229.

GEOTHERMAL STUDIES/EXPLOSIVES/WATER WELLS/WELLS/INJECTION WELLS/ELECTRIC POWER/HYDROGEOLOGY/WATER RESOURCES DEVELOPMENT/FLOW RATES/FRACTURE PERMEABILITY
/IDENTIFIERS: /GEOTHERMAL POWER/WELL STIMULATION/CHEMICAL EXPLOSIONS

12

AXTMANN, R.C.

1975

ENVIRONMENTAL IMPACT OF A GEOTHERMAL POWER PLANT.

SCIENCE 187(4179):795-803.

EACH GEOTHERMAL POWERPLANT HAS A UNIQUE EFFLUENT MIX. WAIRAKEI PLANT, NEW ZEALAND, DISCHARGES 6.5 TIMES THE HEAT, 5.5. TIMES THE WATER VAPOR, AND HALF THE SULFUR DISCHARGED PER UNIT POWER BY AN EQUIVALENT COAL PLANT. ADVERSE QUANTITIES OF HYDROGEN SULFIDE, ARSENIC, CARBON DIOXIDE (CO_2), AND MERCURY ARE DISCHARGED INTO THE WAIKATO RIVER. CO_2 ATMOSPHERIC EMISSION FROM A COAL PLANT IS 60 TIMES WAIRAKEI EMISSION, BUT ONLY A TENTH OF CO_2 FROM MONTE AMIATA, ITALY. OTHER ENVIRONMENTAL EFFECTS INCLUDE DRYING UP OF NATURAL HOT SPRINGS, LAND SUBSIDENCE, RESOURCE DEPLETION (REINJECTION OF HOT WASTES COULD SLOW THIS), AND STRESSING OF RIVER ECOLOGY. UNIQUE ENVIRONMENTAL ASPECTS OF GEOTHERMAL POWER ARE: POLLUTION IS INDEPENDENT OF INSTANTANEOUS POWER PRODUCTION, EFFLUENT PATHWAYS CAN CHANGE ABRUPTLY, WELL TESTING HAS MAJOR IMPACT, AND WASTE HEAT BEGS TO BE USED. LETTERS TRIGGERED BY THIS ARTICLE [SCIENCE 189(4200):328-330] POINT OUT THE POSSIBILITIES OF RADIOISOTOPE EMISSION AND USE OF CO_2 FOR AGRICULTURAL PRODUCTIVITY AUGMENTATION, AND INDICATE THAT GEOTHERMAL RESOURCES POLLUTE THE ENVIRONMENT EVEN WHEN UNEXPLOITED. (OALS)

GEOTHERMAL STUDIES/ENVIRONMENTAL EFFECTS/THERMAL POWERPLANTS/EFFLUENTS/ THERMAL POLLUTION/AIR POLLUTION/WATER POLLUTION/SULFUR/HYDROGEN SULFIDE/ ARSENIC COMPOUNDS/MERCURY/CARBON DIOXIDE/LAND SUBSIDENCE/INJECTION/RIVERS/ RADIOISOTOPES
/IDENTIFIERS: /GEOTHERMAL POWER/WAIRAKEI/NEW ZEALAND/WASTE HEAT/ WATER-DOMINATED SYSTEMS

13

BALASUNDARAM, M.S.

1972

THERMAL SPRINGS OF INDIA AND THEIR DEVELOPMENT.

INDIAN GEOHYDROLOGY (CALCUTTA) 8(1):1-9.

SEE: SWRA W73-14125.

THERMAL SPRINGS/THERMAL WATER/GEYSERS/HOT SPRINGS/GEOTHERMAL STUDIES/ SPATIAL DISTRIBUTION/WATER TEMPERATURE/HYDROGEOLOGY/GEOLOGY
/IDENTIFIERS: /INDIA

14

BANWELL, C.J.

1973

GEOPHYSICAL METHODS IN GEOTHERMAL EXPLORATION. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 41-48.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

SEE: SWRA W74-11762.

GEOPHYSICS/GEOTHERMAL STUDIES/THERMAL WATER/THERMAL POWER/EXPLORATION/ INVESTIGATIONS/MAPPING/REVIEWS/RESISTIVITY/ELECTRICAL STUDIES/DRILLING/ PHYSICAL PROPERTIES/HEAT FLOW/SURVEYS
/IDENTIFIERS: /TEMPERATURE GRADIENT

15

BANWELL, C.J./MEIDAV, T.

1974

GEOTHERMAL ENERGY FOR THE FUTURE.

GEOTHERMAL ENERGY 2(12):53-58.

A BROAD OVERVIEW OF GEOTHERMAL POTENTIAL FOR THREE RESOURCE AREA TYPES: HYDROTHERMAL CONVECTION SYSTEMS, GEOTHERMAL BELTS (USUALLY PLATE BOUNDARIES), AND AREAS OF NORMAL TEMPERATURE GRADIENT. AVERAGE TEMPERATURE GRADIENTS ARE USED TO ESTIMATE TOTAL THERMAL ENERGY STORED IN EACH TYPE OF AREA WORLDWIDE. TAKING CARNOT HEAT ENGINE EFFICIENCY INTO ACCOUNT, POWER STORAGE TO 7.5 KILOMETERS DEPTH IN NORMAL TEMPERATURE GRADIENT AREAS IS 7,500 MW YEARS (21 MILLION TONS OF OIL) PER SQUARE KILOMETER. WORLD TOTAL IS THUS ABOUT TWO ORDERS OF MAGNITUDE GREATER THAN MAXIMUM ESTIMATED FOSSIL FUEL AND URANIUM RESERVES. MECHANICAL ENERGY IN NORMAL GRADIENT AREAS IS PROPORTIONAL TO DEPTH CUBED. THUS, IF DRILLING COSTS BEYOND 5 KM DEPTH INCREASE AT LESS THAN THIS RATE, DEEPER DRILLING WILL BE INCREASINGLY PROFITABLE. (OALS)

GEOTHERMAL STUDIES/HYDROTHERMAL STUDIES/EFFICIENCIES/DRILLING/COST ANALYSIS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/PLATE BOUNDARIES/GEOTHERMAL BELTS/ TEMPERATURE GRADIENT/NORMAL TEMPERATURE GRADIENT AREAS/WORLD/GEOTHERMAL ENERGY/ ALTERNATIVE ENERGY SOURCES/DRILLING COSTS/HYDROTHERMAL SYSTEMS

16

BARNEA, J.

1972

GEOTHERMAL POWER.

SCIENTIFIC AMERICAN 226(1):70-77.

SEE: SWRA W72-04172.

GEOTHERMAL STUDIES/THERMAL POWERPLANTS/ELECTRIC POWER/STEAM/CONDENSATION/ MULTIPLE-PURPOSE PROJECTS/RESOURCES DEVELOPMENT/EXPLORATION/STEAM TURBINES/ DISTILLATION/ECONOMICS/ENVIRONMENTAL EFFECTS
/IDENTIFIERS: /DRY STEAM FIELDS/WET STEAM FIELDS/GEOTHERMAL RESOURCES DEVELOPMENT

17

BARNEA, J.

1974

ECONOMICS OF MULTI-PURPOSE USE OF GEOTHERMAL RESOURCES.

GEOTHERMAL ENERGY 2(11):29-34.

SIX TYPES OF GEOTHERMAL RESOURCES ARE: DRY STEAM, WET STEAM, LOW TEMPERATURE, AND GEOPRESSURED FIELDS, HOT-DRY ROCK AREAS, AND AREAS IN AND AROUND VOLCANOES. GEOTHERMAL RESOURCES OCCUR IN COMPLEX 3-DIMENSIONAL DYNAMIC RESERVOIRS. MULTIPLE-USE INDUSTRIAL COMPLEXES ARE LIMITED ONLY BY RESOURCE CHARACTERISTICS, LOCAL INDUSTRIAL CONDITIONS, AND PLANNER INGENUITY. GEOTHERMAL ENERGY IS FAR MORE SUITABLE FOR ENERGY CASCADING OR SEQUENTIAL USE (EACH SUBSEQUENT USE AT LOWER TEMPERATURE) THAN OTHER ENERGY SOURCES. GREEN-HOUSE AGRICULTURE CAN USE RELIABLE CONTINUOUS SUPPLY OF GEOTHERMAL HEAT, WATER, AND CARBON DIOXIDE. GEOTHERMAL RESOURCES BASE IS IDEAL FOR AGRO-INDUSTRIAL COMPLEXES. WATER, ELECTRICITY, FERTILIZERS, HEATING, AND COOLING CAN BE SUPPLIED TO THESE SYSTEMS AND ASSOCIATED SETTLEMENTS. LEGAL DEFINITION OF GEOTHERMAL RESOURCE SHOULD BE EXPANDED BEYOND ITS PRESENT EMPHASIS ON STEAM. (OALS)

GEOTHERMAL STUDIES/DRY STEAM FIELDS/WET STEAM FIELDS/HOT WATER SYSTEMS/ HOT-DRY ROCKS/VOLCANOES/MULTIPLE-PURPOSE PROJECTS/GREENHOUSES/AGRICULTURE/ LEGAL ASPECTS/COOLING
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL RESERVOIRS/INDUSTRIAL USES/ GEOTHERMAL HEAT/GEOTHERMAL WATER/GEOTHERMAL POWER/SPACE HEATING

18

BARNEA, J./WEGELIN, E.

1973

PROSPECTS OF GEOTHERMAL DESALINATION. IN A.A. DELYANNIS AND E. DELYANNIS, EDS., INTERNATIONAL SYMPOSIUM ON FRESH WATER FROM THE SEA, 4TH, HEIDELBERG, 1973, PROCEEDINGS 2:449-461.

ATHENS TECHNICAL UNIVERSITY. DESALINATION ABSTRACTS 74-223.

ABUNDANT HOT-WATER AND GEOPRESSURED GEOTHERMAL RESERVOIRS BOTH YIELD HEAT AND BRACKISH OR SALINE WATER IN GREAT QUANTITIES AT VERY LOW COSTS. THE HEAT CAN DRIVE MULTISTAGE FLASH DISTILLATION OF THE WATER AT LESS THAN HALF THE COST OF CONVENTIONAL DISTILLATION METHODS. SCALING IN HEAT EXCHANGERS WILL BE THE MAIN DIFFICULTY. POSSIBILITIES FOR EL TATIO IN NORTHERN CHILE ARE DISCUSSED ON BASIS OF WELL DATA.

GEOTHERMAL STUDIES/DESALINATION/BRACKISH WATER/SALINE WATER/FLASH DISTILLATION/COMPARATIVE COSTS/SCALING/WELL DATA
/IDENTIFIERS: /GEOPRESSURED SYSTEMS/HOT WATER SYSTEMS/CHILE/GEOTHERMAL WATER/EL TATIO FIELD

19

BIRDSEYE, H.S.

1969

GEOTHERMAL POWER RESOURCES IN THE SOUTHWEST.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES, CIRCULAR 101:86-96. ANAG(1970)04953. GA 71A-0706.

GEOTHERMAL POWER PROSPECTING INCLUDES DETAILED GEOLOGIC MAPPING, GEOCHEMICAL SURVEYING (BECAUSE AS MUCH OF THE WATER IS DETECTABLE CHEMICALLY), AND GEOPHYSICAL SURVEYING (BY DETECTING ANOMALIES WITH VERY SENSITIVE HEAT-SENSING DEVICES). THE GEOTHERMAL AREAS OF THE WORLD ARE CONFINED TO VOLCANIC REGIONS WHICH HAVE UNDERGONE FAULTING. IN THE U.S., SUCH FAULT CONTROLLED AREAS ARE FOUND IN UTAH AND NEW MEXICO. IN UTAH, HYPERTHERMAL OCCURRENCES ARE, ALMOST ALL, IN PROXIMITY TO THE STATE'S NORTH-TRENDING FAULT SYSTEMS AND ARE CLOSELY RELATED TO CENOZOIC IGNEOUS ROCKS. HOT SPRINGS ARE COMMON IN NEVADA ALONG NORTH-TRENDING FAULT LINES. NUMEROUS THERMAL ANOMALIES OCCUR IN NEW MEXICO IN THE RIO GRANDE STRUCTURAL TROUGH, AND SOME IN SMALLER TROUGHS WEST OF THE RIO GRANDE.

GEOTHERMAL STUDIES/SOUTHWEST U.S./EXPLORATION/UTAH/NEVADA/NEW MEXICO/ FAULTS(GEOLOGIC)/HOT SPRINGS/GEOLOGIC INVESTIGATIONS/GEOCHEMISTRY/ GEOPHYSICS/SURVEYS
/IDENTIFIERS: /RIO GRANDE TROUGH/VOLCANISM

20

BIRDSEYE, H.S.

1971

GEOTHERMAL POWER IN NEW MEXICO.

NEW MEXICO ACADEMY OF SCIENCE, BULLETIN, SPRING, 1971. P. 1-8.

THE GEOPHYSICAL FACTORS RESPONSIBLE FOR THE FORMATION OF GEOTHERMAL STEAM ARE BRIEFLY DISCUSSED. GEOTHERMAL STEAM MAY BE AN INTEGRAL PART OF THE PROCESS BY WHICH METALLIC DEPOSITS SUCH AS COPPER, LEAD, ZINC, GOLD, AND SILVER FORM. THE CHARACTERISTICS OF GEOTHERMAL AREAS ARE EXAMINED AND DIFFERENCES BETWEEN SATURATED AND DRY GEOTHERMAL SYSTEMS ARE POINTED OUT. THE LATTER IS TO BE PREFERRED BECAUSE OF ITS GREATER ECONOMIC VALUE AND LACK OF ENVIRONMENTALLY-DELETERIOUS BY-PRODUCTS. MAPS OF WORLDWIDE GEOTHERMAL AREAS AND NEW MEXICO HYPER-THERMAL AREAS ARE PRESENTED. OF THE ROUGHLY 60 KNOWN THERMAL AREAS IN NEW MEXICO, THE ONLY SYSTEMATIC DRILLING HAS BEEN IN VALLES CALDERA, A DRY STEAM FIELD OF POSSIBLY SEVERAL MILLION KW POTENTIAL. SIX OR SEVEN THERMAL PROSPECTS ALONG THE RIO GRANDE TROUGH ALSO APPEAR TO HAVE ECONOMIC POTENTIAL.

GEOTHERMAL STUDIES/THERMAL POWER/STEAM/NEW MEXICO/EXPLORATION/DRILLING/MAPS/ ENVIRONMENTAL EFFECTS
/IDENTIFIERS: /DRY STEAM FIELDS/VALLES CALDERA/RIO GRANDE TROUGH/GLOBAL DISTRIBUTION/MINERAL DEPOSITS

21

BIRSIC, R.J.

1974

THE GEOTHERMAL STEAM STORY, OR A HOT TIP FROM MOTHER EARTH.

SAME AS AUTHOR. FULLERTON, CALIFORNIA. 123 P.

PAST AND PRESENT GEOTHERMAL STEAM POWER GENERATION IN THE U.S., ITALY, NEW ZEALAND, AND JAPAN ARE REVIEWED IN OVER 60 PHOTOGRAPHS OF DRILL RIGS, WELL FIELDS, PIPELINES, AND POWERPLANTS, PLUS ACCOMPANYING TEXT. THE BOOK AIMS TO INTEREST THE 'DISCERNING AMERICAN' IN GEOTHERMAL ENERGY AS A SOLID INVESTMENT OPPORTUNITY. TO THIS END, THE FINAL SECTION EMPHASIZES THAT MONEY CAN BE MADE ON GEOTHERMAL STEAM, SUMMARIZES THE HISTORY, ASSETS, AND PROFITS OF EIGHT U.S. GEOTHERMAL COMPANIES, AND LISTS STOCK PRICES FOR FOUR OF THEM FROM 1962 TO MID-1974. (OALS)

GEOTHERMAL STUDIES/PHOTOGRAPHY/ECONOMICS/COSTS/ELECTRIC POWER COSTS/ELECTRIC POWER DEMAND/INVESTMENT/PROFIT/EXPLOITATION/RETURN(MONETARY)/UNITED STATES/ INDUSTRIAL PLANTS/ELECTRIC POWERPLANTS/THERMAL POWERPLANTS/STEAM
/IDENTIFIERS: /ITALY/NEW ZEALAND/JAPAN/GEOTHERMAL STEAM/GEOTHERMAL POWER/ GEYSERS FIELD, CALIFORNIA

22

BLAKE, R.L.

1974

EXTRACTING MINERALS FROM GEOTHERMAL BRINES: A LITERATURE STUDY.

U.S. BUREAU OF MINES, INFORMATION CIRCULAR 8638. 25 P.

THIS STUDY IS BASED ON A SURVEY OF THE LITERATURE DEALING WITH EXTRACTION OF MINERALS FROM RESIDUAL GEOTHERMAL BRINES AFTER THEIR HEAT CONTENT AND SOME DEMINERALIZED WATER HAVE BEEN RECOVERED. IT EXAMINES POTENTIAL OF DOMESTIC GEOTHERMAL MINERAL RESOURCES, CONSIDERS TECHNICAL PROBLEMS, AND OUTLINES POSSIBLE EFFECTS ON THE ENVIRONMENT FROM RESERVOIR FLUID WITHDRAWAL AND REINJECTION. INTEREST IN RECOVERY OF MINERALS AND SALTS FROM GEOTHERMAL FLUIDS WANED AFTER EXTENSIVE EXPLORATION EFFORTS OF THE 1960'S BECAUSE OF CORROSION AND SCALING PROBLEMS, AND LOW OR NO MARKET VALUE OF MINERAL PRODUCTS. MOST OF THESE PROBLEMS CAN BE CONTROLLED WITH EXISTING TECHNOLOGY AND CAREFUL PLANNING OF PROCESSES AND EQUIPMENT. WHILE TECHNICALLY FEASIBLE, THEREFORE, THE PROBLEMS OF LOW OR NO MARKET VALUE AND INSUFFICIENT AMOUNTS OF MORE VALUABLE MINOR PRODUCTS MAKE MINERAL RECOVERY UNECONOMICAL AT PRESENT. 67 REFERENCES.

BRINES/INJECTION WELLS/CORROSION CONTROL/SURVEYS/ENVIRONMENTAL EFFECTS/WASTE WATER TREATMENT/MINERAL WATER/SALTS/ECONOMIC FEASIBILITY/CORROSION/SCALING/ CHEMICAL INDUSTRY/REVIEWS/MARKET VALUE
/IDENTIFIERS: /GEOTHERMAL POWER/CHEMICAL RECOVERY/GEOTHERMAL RESOURCES

23

BODVARSSON, G.

1970

EVALUATION OF GEOTHERMAL PROSPECTS AND THE OBJECTIVES OF GEOTHERMAL EXPLORATION.

GEOEXPLORATION 8(1):7-17.

THIS REVIEW LEANS HEAVILY ON THE AUTHOR'S EXPERIENCE IN ICELAND. IT IS FELT THAT THE MAIN FIELD CONDITIONS CHARACTERIZING HIGH-POWER GEOTHERMAL RESERVOIRS ARE: RESERVOIR TEMPERATURE, RESERVOIR VOLUME, RESERVOIR PERMEABILITY, AMOUNT OF RESERVOIR WATER, GROUNDWATER LEVEL, TYPE AND AMOUNT OF CHEMICAL IMPURITIES, DRILLABILITY, AND THE PRESENCE OF HIDDEN RESERVOIR. BECAUSE OF LOW TEMPERATURE AND PRESSURE, GEOTHERMAL STEAM IS ONLY ABOUT ONE-HALF AS EFFICIENT AS STEAM FROM FUEL IN PERFORMING MECHANICAL WORK. INDIRECT AND DIRECT METHODS OF GEOTHERMAL RESOURCE EXPLORATION ARE OUTLINED.

GEOTHERMAL STUDIES/EXPLORATION/STEAM/THERMAL POWER/TEMPERATURE/VOLUME/PERMEABILITY/WATER QUALITY/PRESSURE/EFFICIENCIES
/IDENTIFIERS: /ICELAND/GEOTHERMAL RESERVOIRS

24

BODVARSSON, G.

1972

THERMAL PROBLEMS IN THE SITING OF REINJECTION WELLS.

GEOTHERMICS 1(2):63-66.

SEE: SWRA W73-03286.

WASTE DISPOSAL WELLS/THERMAL POLLUTION/INJECTION WELLS/HYDROGEOLOGY/PATH OF POLLUTANTS/HEAT TRANSFER/GEOTHERMAL STUDIES/HEAT FLOW/THERMAL WATER
/IDENTIFIERS: /GEOTHERMAL ENERGY

25

BODVARSSON, G./EGGERS, D.E.

1972

THE EXERGY OF THERMAL WATER.

GEOTHERMICS 1(3):93-95.

SEE: SWRA W73-05296.

GEOTHERMAL STUDIES/THERMODYNAMICS/THERMAL WATER/THERMAL POWER/HYDROTHERMAL STUDIES/ENERGY TRANSFER/ENTHALPY/WATER TEMPERATURE
/IDENTIFIERS: /EXERGY(GEOTHERMAL ENGINEERING)/GEOTHERMAL POWER/GEOTHERMAL FLUIDS

26

BOLTON, R.S.

1973

MANAGEMENT OF A GEOTHERMAL FIELD. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 175-184.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

AFTER THE EXCITEMENT OF EXPLORATION AND DISCOVERY COMES THE EXTENDED PERIOD OF ROUTINE EXPLOITATION. MINIMUM ENERGY POTENTIAL OF A GEOTHERMAL FIELD (NEVER AS PRECISELY KNOWN AS HYDROCARBON RESERVOIR CONTENT) IS ESTIMATED BY MEASURING NATURAL HEAT FLOW, AND BY ESTIMATING TOTAL HEAT STORAGE FROM WELL DATA. ENERGY MAY BE USED MORE EFFICIENTLY BY PRODUCING FLUIDS FROM RESERVOIR TOP, AND BY REINJECTING WASTE HOT WATER. FIELD DEVELOPMENT SHOULD PROCEED IN STAGES TO AVOID OVERSHOOTING RESERVOIR PRODUCTION CAPACITY. EFFECTS OF WET STEAM FIELD EXPLOITATION ARE REDUCED PRESSURE, TEMPERATURE, AND WELL OUTPUT. IN DRY STEAM FIELDS DEGREE OF STEAM SUPERHEAT MAY INCREASE. HOT WATER FIELDS BEHAVE LIKE NORMAL GROUNDWATER SYSTEMS. OTHER EFFECTS OF GEOTHERMAL EXPLOITATION ARE: CHANGES OR DISAPPEARANCE OF SURFACE MANIFESTATIONS (HOT SPRINGS, GEYSERS), LAND SUBSIDENCE, POLLUTION, AND CHEMICAL DEPOSITION BOTH BELOW AND AT THE SURFACE. NUMEROUS MEASUREMENTS, INCLUDING WELL PRESSURE, TEMPERATURE, AND PERFORMANCE, GEOCHEMISTRY, AND GROUND LEVEL, SHOULD BE MADE TO MONITOR EXPLOITATION PROGRESS. (OALS)

GEOTHERMAL STUDIES/RESOURCES DEVELOPMENT/MANAGEMENT/EXPLOITATION/HEAT FLOW/INJECTION/PRESSURE/TEMPERATURE/WELL DATA/GROUNDWATER/ENVIRONMENTAL EFFECTS/LAND SUBSIDENCE/GEOCHEMISTRY/HOT SPRINGS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL RESERVOIRS/HEAT CONTENT/POWER CAPACITY/PRODUCTION WELLS/WET STEAM FIELDS/DRY STEAM FIELDS/SUPERHEATED STEAM/HOT WATER SYSTEMS

27

BOWDEN, C.

1975

THE IMPACT OF ENERGY DEVELOPMENT ON WATER RESOURCES IN ARID LANDS: LITERATURE REVIEW AND ANNOTATED BIBLIOGRAPHY.

UNIVERSITY OF ARIZONA, TUCSON, OFFICE OF ARID LANDS STUDIES, ARID LANDS RESOURCE INFORMATION PAPER 6. 278 P.

SEE: SWRA W75-05471.

BIBLIOGRAPHIES/ARID LANDS/COLORADO RIVER BASIN/SOUTHWEST U.S./ WATER SHORTAGE/ENERGY/GREAT PLAINS/FOSSIL FUELS/SOCIAL ASPECTS/ WATER ALLOCATION(POLICY)/ENERGY CONVERSION/WATER DEMAND/STRIP MINES/ STRIP MINE WASTES/OIL SHALES/COALS/MISSOURI RIVER/ROCKY MOUNTAIN REGION/ ENVIRONMENTAL EFFECTS/WATER QUALITY/GEOTHERMAL STUDIES/NUCLEAR ENERGY/ NUCLEAR WASTES
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT/ALTERNATIVE ENERGY SOURCES/ GEOTHERMAL POWER

28

BOWEN, R.G.

1971

ELECTRICITY FROM GEOTHERMAL, NUCLEAR, COAL SOURCES: AN ENVIRONMENTAL COMPARISON.

ORE BIN 33(11):197-209.

RECOGNIZING THAT WHILE THE PRODUCTION OF ELECTRICAL ENERGY IS GROWING RAPIDLY AND THAT THE GROWTH OF HYDROELECTRIC POWER GENERATION WILL SOON CEASE WHILE OTHER METHODS OF POWER GENERATION ARE UNDESIRABLE OR TOO FAR IN THE FUTURE, IT IS FELT THAT NUCLEAR (FISSION) REACTORS, COAL-FIRED GENERATORS, AND GEOTHERMAL PLANTS ARE THE LIKELY SOURCES OF ELECTRICAL POWER IN THE NEAR FUTURE. THE PROBABLE OR ACTUAL ENVIRONMENTAL IMPACT OF EACH OF THESE THERMAL SOURCES IS EVALUATED AND COMPARED WITH THE OTHERS FOR LAND, AIR, AND WATER. A DRY STEAM GEOTHERMAL PLANT IS THE ONLY TYPE OF THERMAL POWER PLANT THAT DOES NOT COMPETE WITH OTHER USES OF WATER. NOR DOES GEOTHERMAL POWER HAVE THE CYCLE OF MINING, MILLING, REFINING, ENRICHMENT, FABRICATION, REPROCESSING, AND WASTE STORAGE INVOLVED IN THE PRODUCTION OF BOTH FOSSIL AND NUCLEAR FUELS. THIS SELF-CONTAINED ASPECT SEEMS TO CONVEY AN ECONOMIC ADVANTAGE TO DRY STEAM GEOTHERMAL POWER PRODUCTION WHICH IS BORNE OUT BY THE EXPERIENCE OF TWO PLANTS IN OPERATION.

ELECTRIC POWER/GEOTHERMAL STUDIES/ENVIRONMENTAL EFFECTS/STEAM/THERMAL POWERPLANTS/NUCLEAR POWERPLANTS/COALS/POWERPLANTS/COMPARATIVE BENEFITS/ COMPARATIVE COSTS/HYDROELECTRIC POWER/FOSSIL FUELS
/IDENTIFIERS: /DRY STEAM FIELDS/GEOTHERMAL POWER/ALTERNATIVE ENERGY SOURCES

29

BOWEN, R.G.

1972

GEOTHERMAL OVERVIEW OF OREGON. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER J, 9 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03429.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/OREGON/THERMAL WATER/ WATER TEMPERATURE/THERMAL PROPERTIES/HYDROGEOLOGY/EXPLORATION/THERMAL SPRINGS/ VOLCANOES/SPATIAL DISTRIBUTION
/IDENTIFIERS: /GEOTHERMAL RESOURCES/SPACE HEATING/KLAMATH FALLS

30

BOWEN, R.G.

1973

ENVIRONMENTAL IMPACT OF GEOTHERMAL DEVELOPMENT. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 197-215.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13224.

ENVIRONMENTAL EFFECTS/GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/ THERMAL POWERPLANTS/ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/STEAM TURBINES/ WATER RESOURCES DEVELOPMENT/WELLS/THERMAL POLLUTION/WATER POLLUTION SOURCES/ MULTIPLE PURPOSE/AIR POLLUTION EFFECTS/AIR POLLUTION/GASES/LAND USE
/IDENTIFIERS: /ALTERNATIVE ENERGY SOURCES

31

BOWEN, R.G./GROH, E.A.

1971

GEOTHERMAL--EARTH'S PRIMORDIAL ENERGY.

TECHNOLOGY REVIEW 74(1):42-48. EIA 72-00337.

A GENERAL REVIEW ON GEOTHERMAL POWER WHICH DISTINGUISHES ITSELF FROM OTHER SIMILAR REVIEWS IN ITS CONSIDERATION OF THE ECONOMICS AND ENVIRONMENTAL EFFECTS OF GEOTHERMAL POWER. EXPLORATION COSTS, AMORTIZED AT 14 PERCENT PER YEAR FOR A ONE MILLION KW FIELD, WOULD BE ONLY 0.175 MILLS/KWH. EVERY INDICATION IS THAT GEOTHERMAL POWER WILL COST LESS THAN THAT PRODUCED BY COAL, NUCLEAR, AND EVEN HYDRO METHODS. GEOTHERMAL PLANTS DO NOT NEED A SUPPLEMENTAL SOURCE OF COOLING WATER, SO, SIGNIFICANTLY, GEOTHERMAL PLANTS, UNLIKE OTHER TYPES OF THERMAL PLANTS, DO NOT COMPETE WITH OTHER USERS OF FRESH WATER. IT IS ALSO FELT THAT THE POTENTIAL QUANTITY OF GEOTHERMAL ENERGY, WORLDWIDE, HAS BEEN UNDERESTIMATED IN THE PAST.

GEOTHERMAL STUDIES/THERMAL POWER/ENVIRONMENTAL EFFECTS/COSTS/EXPLORATION/ECONOMICS/COMPARATIVE COSTS/COMPARATIVE BENEFITS/COOLING WATER
/IDENTIFIERS: /ALTERNATIVE ENERGY SOURCES/GEOTHERMAL RESOURCES

32

BRADBURY, J.J.C.

1971

THE ECONOMICS OF GEOTHERMAL POWER.

UNITED NATIONS NATURAL RESOURCES FORUM 1:46-54.

SEE: SWRA W72-13092.

GEOTHERMAL STUDIES/STEAM/VARIABLE COSTS/FIXED COSTS/OPERATING COSTS/EXPLORATION/DRILLING/ECONOMICS/COSTS/COMPARATIVE COSTS/THERMAL POWERPLANTS/WELLS
/IDENTIFIERS: /ALTERNATIVE ENERGY SOURCES/GEOTHERMAL POWER

33

BRONDI, M./DALL'AGLIO, M./VITRANI, F.

1973

LITHIUM AS A PATHFINDER ELEMENT IN THE LARGE SCALE HYDROGEOCHEMICAL EXPLORATION FOR HYDROTHERMAL SYSTEMS.

GEOTHERMICS 2(3-4):142-153.

LITHIUM CONTENT IN WATER IS HIGH ALMOST EXCLUSIVELY WHEN WATER-ROCK INTERACTION IS AT HIGH TEMPERATURES; IT IS CONTRASTINGLY VERY LOW IN NORMAL COLD METEORIC WATERS. THUS, SINCE LITHIUM (ONCE IN SOLUTION) IS EXTREMELY MOBILE IN SURFACE WATERS, IT IS AN IDEAL ELEMENT FOR REGIONAL GEOTHERMAL EXPLORATION WHEN THERE IS A WELL-DEVELOPED SURFACE DRAINAGE NETWORK. ANOMALOUS LITHIUM CONTENT OF SURFACE WATER CAN BE FOLLOWED BACK TO ITS SOURCE. (OALS)

GEOTHERMAL STUDIES/GEOCHEMISTRY/EXPLORATION/TEMPERATURE/CHEMICAL PROPERTIES/TRACE ELEMENTS/WATER CHEMISTRY/WATER TEMPERATURE
/IDENTIFIERS: /LITHIUM

34

BUDD, C.F., JR.

1973

STEAM PRODUCTION AT THE GEYSERS GEOTHERMAL FIELD. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 129-144.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13220.

GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/THERMAL POWERPLANTS/ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/INJECTION/CALIFORNIA/STEAM TURBINES/WATER RESOURCES DEVELOPMENT/WELLS/INJECTION WELLS/PRESSURE/COOLING TOWERS/STEAM
/IDENTIFIERS: /GEOTHERMAL POWER/POWER DEMAND/GEYSERS FIELD, CALIFORNIA/LARDERELLO/MATSUKAWA/VAPOR-DOMINATED SYSTEMS/WELL HEAD EQUIPMENT/DRY STEAM FIELDS

35

BULLARD, SIR E.

1973

BASIC THEORIES. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 19-29.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

SOURCE OF EARTH HEAT IS MOSTLY RADIOACTIVE DECAY, BUT SOME HEAT IS LEFT FROM EARTH FORMATION. GEOTHERMAL AREAS ARE NOT DISTRIBUTED RANDOMLY. MOST FAVORABLE AREAS ARE AT CRUSTAL PLATE BOUNDARIES, ESPECIALLY WHERE NEW CRUST IS BEING FORMED OF BASALTIC INTRUSIONS AND LAVAS (RIFT ZONES, MID-OCEANIC RIDGES), AND WHERE OLD CRUST IS BEING MELTED AND DESTROYED (SUBDUCTION ZONES, ISLAND ARCS), WITH ANDESITIC VOLCANISM AND EMPLACEMENT OF MORE FELSIC MAGMAS. IT APPEARS THAT EARTH IS A HEAT ENGINE, THAT THERMAL CONVECTION IN THE MANTLE DRIVES SEA FLOOR SPREADING AND CONTINENTAL DRIFT. MOLTEN ROCK RISING TOWARD SURFACE DRIVES HYDROTHERMAL CONVECTION SYSTEMS (MOSTLY METEORIC WATER) AND CONCENTRATES RARE ELEMENTS TO FORM MINERAL DEPOSITS. GEOTHERMAL POWER, THUS, IS A LOCAL MANIFESTATION OF THE MACROSCALE EARTH HEAT ENGINE WHICH DRIVES GEOLOGICAL CHANGE. (OALS)

GEOTHERMAL STUDIES/GEOLOGY/SPATIAL DISTRIBUTION/THERMODYNAMICS/THERMODYNAMIC BEHAVIOR/CONVECTION
/IDENTIFIERS: /GEOTHERMAL HEAT/WORLD/GEOTHERMAL BELTS/PLATE BOUNDARIES/RIFT ZONES/VOLCANISM/MAGMA/MID-OCEANIC RIDGES/ISLAND ARCS/SUBDUCTION/CONTINENTAL DRIFT/GLOBAL TECTONICS/HYDROTHERMAL CONVECTION SYSTEMS/MINERAL DEPOSITS/GLOBAL DISTRIBUTION

36

BURNHAM, J.B./STEWART, D.H.

1973

RECOVERY OF GEOTHERMAL ENERGY FROM HOT, DRY ROCK WITH NUCLEAR EXPLOSIVES. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 223-230.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13226.

NUCLEAR EXPLOSIONS/GEOTHERMAL STUDIES/ELECTRIC POWER/THERMAL POWERPLANTS/EXPLOSIVES/ECONOMICS/FRACTURE PERMEABILITY
/IDENTIFIERS: /PROJECT PLOWSHARE/GEOTHERMAL POWER/HOT-DRY ROCKS/GEOTHERMAL ENERGY

37

BURNSIDE, R.A.

1973

WORLD GEOTHERMAL FINANCING.

GEOTHERMAL WORLD DIRECTORY, 1973. P. 128-133.

UP TO 1970 TOTAL FUNDING FOR ENTIRE WORLD GEOTHERMAL EXPLORATION AND DEVELOPMENT WAS UNDER 100 MILLION DOLLARS. VAST NEW FUNDING IS NEEDED FOR RAPIDLY EXPANDING GEOTHERMAL INDUSTRY. FUNDING AGENCIES WHICH SUPPORT GEOTHERMAL PROJECTS GLOBALLY INCLUDE WORLD BANK AND UNITED NATIONS. ONE TABLE COMPARES GEOTHERMAL AND ALTERNATIVE ELECTRICITY COSTS IN EIGHT COUNTRIES, INCLUDING ETHIOPIA AND KENYA. ANOTHER TABLE SUMMARIZES POPULATION, PER CAPITA INCOME AND POWER PODUCTION, GROWTH RATES, POWER CAPACITY (HYDRO AND THERMAL), AND POWER MARKET DATA FOR 29 COUNTRIES. (OALS)

GEOTHERMAL STUDIES/FINANCING/ECONOMICS/CREDIT/CAPITAL/INVESTMENT/LOANS/UNITED NATIONS/EXPLORATION/COMPARATIVE COSTS/HUMAN POPULATION/INCOME/ELECTRIC POWER PRODUCTION/HYDROELECTRIC POWER
/IDENTIFIERS: /WORLD/DEVELOPING COUNTRIES/GEOTHERMAL RESOURCES DEVELOPMENT/ALTERNATIVE ENERGY SOURCES/ETHIOPIA/KENYA/POWER CAPACITY

38

CALAMAI, A./CERON, P.

1973

AIR CONVECTION WITHIN MONTANA DEL FUEGO (LANZAROTE ISLAND, CANARY ARCHIPELAGO). IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(1):611-614.

VOLCANIC ERUPTIONS HAVE OCCURRED ON THIS SEMIARID VOLCANIC ISLAND AS RECENTLY AS 1824, AND AS RECENTLY AS 1736 IN MONTANA DEL FUEGO AREA. THROUGHOUT THIS AREA HOT AIR WITH TRACES OF CARBON DIOXIDE AND AMMONIA ESCAPES FROM ROCK FISSURES AT TEMPERATURES WHICH CAN EXCEED 250 DEGREES C. ROCK TEMPERATURE GRADIENTS ARE HIGH: A TEMPERATURE OF 700 DEGREES C. WAS REACHED AT ONLY 27

METERS DEPTH IN ONE WELL. THE AUTHORS SUGGEST THAT THE VOLCANIC ROCKS ARE SO PERMEABLE AND METEORIC WATER IS SO SCARCE THAT HEAT TRANSFER OCCURS BY CONVECTION OF AIR (NOT WATER OR STEAM) THROUGH INTERCONNECTING FRACTURES. GEOLOGIC MAP INCLUDED. (OALS)

GEOTHERMAL STUDIES/AIR CIRCULATION/CONVECTION/AIR TEMPERATURE/MOUNTAINS/ AIR-EARTH INTERFACES/GASES/HEAT TRANSFER/HEATING/CARBON DIOXIDE/AMMONIA/ VOLCANOES/LAVA/IGNEOUS ROCKS/FRACTURES(GEOLOGIC)/FRACTURE PERMEABILITY/ PERMEABILITY/FISSURES(GEOLOGIC)/SEMIARID CLIMATES/GEOLOGY/MAPS/ISLANDS /IDENTIFIERS: /CANARY ISLANDS/VOLCANISM/TEMPERATURE GRADIENT/GEOTHERMAL FLUIDS/HOT-DRY ROCKS/GEOTHERMAL HEAT

39

CALIFORNIA DEPARTMENT OF CONSERVATION

1972

GEOTHERMAL MEETING IN IMPERIAL VALLEY.

GEOTHERMICS 1(2):90-92.

SUMMARIZES HIGHLIGHTS OF THE 1972 GEOTHERMAL RESOURCES COUNCIL MEETING IN EL CENTRO. IMPERIAL VALLEY IS EXPERIENCING A BOOM IN GEOTHERMAL ACTIVITIES. PREVIOUS WAVES OF INTEREST CRESTED IN 1927 AND 1957. FARMERS AND RANCHERS ARE ACUTELY AWARE OF POWER POTENTIAL BENEATH THEIR LANDS. A BILLBOARD AT THE AIRPORT PROCLAIMS: WELCOME TO IMPERIAL VALLEY, GEOTHERMAL CAPITAL OF THE NATION. INTENSIVE IRRIGATED AGRICULTURE IN THE VALLEY IS BASED ENTIRELY ON COLORADO RIVER WATER, WHICH IS BECOMING SALTIER AND YET MORE IN DEMAND. GEOTHERMAL RESOURCES DEVELOPMENT MIGHT SAVE THIS AGRICULTURAL SYSTEM FROM RUIN. (OALS)

GEOTHERMAL STUDIES/CALIFORNIA/CONFERENCES/AGRICULTURE/COLORADO RIVER/ IRRIGATION/SALINE WATER/WATER DEMAND/DESALINATION /IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL RESOURCES DEVELOPMENT

40

CATALDI, R./DIMARIO, P./LEARDINI, T.

1973

APPLICATION OF GEOTHERMAL ENERGY TO THE SUPPLY OF ELECTRICITY IN RURAL AREAS.

GEOTHERMICS 2(1):3-16.

SMALL (0.5 TO 15 MW) DIRECT-INTAKE EXHAUSTING-TO-ATMOSPHERE TURBOGENERATOR UNITS ARE IDEAL FOR RURAL POWER PRODUCTION WHEN GEOTHERMAL FLUIDS ARE AVAILABLE. COOLING WATER IS NOT NEEDED, AND HOT EXHAUST FLUIDS CAN BE USED FOR MULTIPLE-PURPOSE HEATING AND DESALTING OPERATIONS. COSTS AND TECHNICAL ASPECTS OF SEVERAL ITALIAN EXAMPLES ARE REVIEWED. FOR LOAD FACTOR GREATER THAN 35 PERCENT, GEOTHERMAL OUTCOMPETES DIESEL POWER IN THIS OUTPUT RANGE. (OALS)

RURAL AREAS/GEOTHERMAL STUDIES/ELECTRIC POWER PRODUCTION/STEAM TURBINES/ MULTIPLE-PURPOSE PROJECTS/HEATING/DESALINATION/COST COMPARISONS/LOADS(FORCES) /IDENTIFIERS: /GEOTHERMAL ENERGY/ITALY/ALTERNATIVE ENERGY SOURCES

41

CHIOSTRI, E./BALSAMO, A.

1975

USE OF GEOTHERMAL RESOURCES IN THE MEDICAL TREATMENT OF MAN. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS VIII-3.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

NATURAL HOT WATER HAS BEEN KNOWN THROUGH THE CENTURIES TO HAVE CURATIVE PROPERTIES DUE NOT ONLY TO TEMPERATURE, BUT ALSO TO PHYSICO-CHEMICAL PROPERTIES OF SALTS AND GASES DISSOLVED IN IT. THIS WATER CAN BE USED FOR SEVERAL TREATMENTS DEPENDING UPON COMPOSITION: AS A DRINK, IN THE FORM OF BATHS (OFTEN IN CONNECTION WITH TREATMENTS WITH MUD), AND IN THE FORM OF INHALATION. USE OF THESE NATURAL TREATMENTS IS ESPECIALLY IMPORTANT FOR PREVENTIVE AND MASS MEDICINE.

THERMAL WATER/PUBLIC HEALTH/POTABLE WATER/MINERAL WATER/SALTS/GASES /IDENTIFIERS: /HOT BATHS

42

COLP, J.I./BRANDVOLD, G.E.

1975

SANDIA MAGMA ENERGY RESEARCH PROJECT. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS VI-10.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

THE OBJECTIVE OF THIS PROJECT IS TO LOCATE AND DEFINE POTENTIAL MAGMA RESOURCES, AND TO PROVIDE MATERIALS TECHNOLOGY AND ENGINEERING CONCEPTS TO PRODUCE CLEAN, HIGH QUALITY ENERGY. IT WILL BE IMPLEMENTED IN FOUR GENERAL AREAS: 1) SOURCE LOCATION AND DEFINITION; 2) SOURCE TAPPING; 3) MAGMA-MATERIAL COMPATIBILITIES; AND 4) ENERGY EXTRACTION. THERE ARE MANY POTENTIAL SITES FOR A MAGMA DEMONSTRATION IN THE WESTERN UNITED STATES. TWO WILL BE SELECTED FOR DETAILED EXPLORATION NEXT YEAR. ABILITY OF ENGINEERING MATERIALS TO SURVIVE IN A MAGMA ENVIRONMENT IS CRITICAL TO THE SUCCESS OF THIS PROJECT. MAGMA ENERGY EXTRACTION CONCEPT BEING STUDIED CONSISTS OF A CLOSED, WATER-SYSTEM HEAT EXCHANGER INSERTED DIRECTLY INTO MOLTEN ROCK. OTHER CONCEPTS FOR ELECTRICITY OR FUEL PRODUCTION WILL BE CONSIDERED.

GEOTHERMAL STUDIES/RESEARCH AND DEVELOPMENT/MATERIALS ENGINEERING/MATERIALS TESTING/HEAT EXCHANGERS
/IDENTIFIERS: /GEOTHERMAL ENERGY/WESTERN U.S./GEOTHERMAL POWER/HOT-DRY ROCKS

43

COMBE, M.

1969

LES SOURCES THERMO-MINERALES DU MAROC (THE THERMO-MINERAL SPRINGS OF MOROCCO). IN INTERNATIONAL GEOLOGICAL CONGRESS, 23D, PRAGUE, 1968, PROCEEDINGS, SYMPOSIUM 2: MINERAL AND THERMAL WATERS OF THE WORLD, [PT.] B, OVERSEAS COUNTRIES, P. 121-137.

ACADEMIA, PRAGUE.

IN MOROCCO THE TERM 'THERMOMINERAL' COVERS MEDICINAL WATERS USED FOR THERAPEUTIC PURPOSES AND HOT WATERS WHICH COULD BE USED FOR GEOTHERMAL ENERGY. THREE MODERN STATIONS EXPLOIT THE MEDICINAL WATERS--MOULAY YACOUB (HOT SULFUR WATERS, 53 DEGREES C.), SIDI HARAZEM (TEPID BICARBONATE WATERS, 35 DEGREES C.), AND OULMES (HOT GASEOUS BICARBONATE WATERS, 42.8 DEGREES C.). THE LAST HAVE BEEN BOTTLED AND SOLD SINCE 1952. IN ADDITION THERE ARE 50 LESS WELL KNOWN SPRINGS USED FOR THERAPEUTIC PURPOSES. RESEARCH AIMED AT EVENTUAL DEVELOPMENT OF GEOTHERMAL POWER IS ABOUT TO BEGIN.

GEOTHERMAL STUDIES/AFRICA/THERMAL WATER/MINERAL WATER/WATER TEMPERATURE/WATER TYPES/THERMAL SPRINGS/WATER CHEMISTRY/POTABLE WATER
/IDENTIFIERS: /MOROCCO/GEOTHERMAL RESOURCES

44

COMBS, J.

1973

FEASIBILITY STUDY FOR DEVELOPMENT OF HOT-WATER GEOTHERMAL SYSTEMS.

U.S. AIR FORCE OFFICE OF SCIENTIFIC RESEARCH, FINAL TECHNICAL REPORT 73-2070. 115 P. AVAILABLE NTIS AS AD-771 016.

SEE: SWRA W74-13213.

GEOTHERMAL STUDIES/THERMAL WATER/CALIFORNIA/GROUNDWATER/WATER TEMPERATURE/FEASIBILITY STUDIES
/IDENTIFIERS: /GEOTHERMAL ENERGY/GEOTHERMAL FLUIDS/GEOTHERMAL RESERVOIRS

45

COMBS, J./MUFFLER, L.J.P.

1973

EXPLORATION FOR GEOTHERMAL RESOURCES. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 95-128.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13219.

GEOTHERMAL STUDIES/EXPLORATION/SUBSURFACE INVESTIGATIONS/HYDROGEOLOGY/WATER RESOURCES DEVELOPMENT/SURVEYS/EVALUATION/MEASUREMENT/REMOTE SENSING/GEOLOGIC INVESTIGATIONS/HYDROGEOLOGY/GEOCHEMISTRY/GEOPHYSICS/DRILLING
/IDENTIFIERS: /GEOTHERMAL RESERVOIRS/GEOTHERMAL FLUIDS/MESA ANOMALY/IMPERIAL VALLEY/BROADLANDS FIELD, NEW ZEALAND

46

CORMY, G./D'ARCHIMBAUD, J.D.

1973

LES POSSIBILITES GEOTHERMIQUES DE L'ALGERIE (GEOTHERMAL POSSIBILITIES IN ALGERIA). IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(1):110-116.

PRELIMINARY EXPLORATION FOR GEOTHERMAL RESOURCES IN NORTHERN ALGERIA IS SUMMARIZED, AND TECTONIC, MAGMATIC, AND METALLOGENIC PATTERNS ARE REVIEWED. MAPS SHOW SEISMIC ZONES AND THERMAL SPRING DISTRIBUTION IN NORTHERN ALGERIA, AS WELL AS MORE DETAILED GEOLOGY OF THE NORTHEASTERN PART, WHERE THE BEST GEOTHERMAL PROSPECTS OCCUR. GEOCHEMICAL AND GEOPHYSICAL (DEEP RESISTIVITY AND THERMAL GRADIENT MEASUREMENT) SURVEYS WERE UNDERTAKEN, AND DEEP DRILLING IS THE NEXT STEP. THE AREA AROUND SIDI ZID, NEAR THE TUNISIAN BORDER, APPEARS MOST PROMISING FOR DETAILED EXPLORATION. (OALS)

GEOTHERMAL STUDIES/AFRICA/EXPLORATION/THERMAL SPRINGS/THERMAL WATER/GEOLOGY/HYDROGEOLOGY/GEOCHEMISTRY/GEOPHYSICS/SPATIAL DISTRIBUTION/DRILLING/SURVEYS/RESISTIVITY/MAPS
/IDENTIFIERS: /ALGERIA/GEOTHERMAL RESOURCES/TEMPERATURE GRADIENT

47

CORTECCI, G.

1974

OXYGEN ISOTOPIC RATIOS OF SULFATE ION-WATER PAIRS AS A POSSIBLE GEOTHERMOMETER.

GEOTHERMICS 3(2):60-64.

PREVIOUS GEOTHERMOMETERS (FOR DETERMINING GEOTHERMAL RESERVOIR TEMPERATURES FROM WATER ANALYSES) ARE REVIEWED. SILICA CONTENT INDICATES LAST ROCK-WATER EQUILIBRATION, BUT READJUSTMENT IS RAPID AND DILUTION BY NEAR-SURFACE WATER ALTERS RESULTS. SODIUM-POTASSIUM-CALCIUM (NA-K-CA) GEOTHERMOMETER IS BETTER THAN THE EARLIER NA-K TECHNIQUE. OTHER METHODS INCLUDE ANALYSIS OF CARBON ISOTOPES (HIGHLY UNCERTAIN) AND OXYGEN ISOTOPES IN SULFATE-ION-WATER PAIRS. EXPERIMENTS INDICATE THAT THIS LAST METHOD MAY PROVIDE USEFUL TEMPERATURE MEASUREMENTS WHEN ISOTOPIC CONTENT OF OTHER SULFATE SYSTEMS IN THE SAME REGION IS KNOWN. (OALS)

GEOTHERMAL STUDIES/OXYGEN ISOTOPES/ISOTOPE STUDIES/ANALYTICAL TECHNIQUES/SILICA/SULFATES/GEOCHEMISTRY/TEMPERATURE/TRACE ELEMENTS/WATER CHEMISTRY
/IDENTIFIERS: /GEOTHERMOMETERS/SODIUM-POTASSIUM-CALCIUM GEOTHERMOMETER

48

CROMLING, J.

1973

HOW GEOTHERMAL WELLS ARE DRILLED AND COMPLETED.

WORLD OIL 177(7):42-45.

SEE: SWRA W74-10860.

GEOTHERMAL STUDIES/GEYSERS/SUBSURFACE WATERS/STEAM/ROTARY DRILLING/DRILLING FLUIDS/DRILLING EQUIPMENT/CALIFORNIA/DRILLING/WELL CASINGS
/IDENTIFIERS: /GEOTHERMAL WELL COMPLETIONS/GEOTHERMAL WELL DRILLING/IMPERIAL VALLEY/WELL COSTS

49

CROSBY, J.W.

1971

GEOTHERMAL EXPLORATION.

NORTHWEST CONFERENCE ON GEOTHERMAL POWER, 1ST, OLYMPIA, WASHINGTON, 1971, PAPER. 20 P.

SEE: SWRA W72-00077.

GEOTHERMAL STUDIES/INFRARED RADIATION/GRAVITY STUDIES/SEISMIC STUDIES/MAGNETIC STUDIES/EXPLORATION/HEAT FLOW/RESOURCES DEVELOPMENT/THERMAL POWER/HOT SPRINGS/GEOLOGIC INVESTIGATIONS/RESISTIVITY/WASHINGTON/GEOCHEMISTRY/SUBSURFACE INVESTIGATIONS/GEOPHYSICS

50

DE ANDA, L.F./REYES, S.C./TOLIVIA, M.E.

1973

PRODUCTION OF FRESH WATER FROM THE ENDOGENOUS STEAM OF CERRO PRIETO GEOTHERMAL FIELD. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1632-1635.

SEE: SWRA W74-09037.

GEOTHERMAL STUDIES/MEXICO/WATER SUPPLY/WATER TREATMENT/SALINE WATER/ POTABLE WATER/PILOT PLANTS/DESALINATION/DESALINATION PLANTS
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL STEAM/CERRO PRIETO FIELD, MEXICO

51

DECKER, E.R.

1972

GEOTHERMAL RESOURCES, PRESENT AND FUTURE DEMAND FOR POWER, AND LEGISLATION IN THE STATE OF WYOMING. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER M, 23 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03432.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/WYOMING/THERMAL WATER/ WATER TEMPERATURE/GEOLOGY/HYDROGEOLOGY/THERMAL PROPERTIES/THERMAL SPRINGS/ WATER QUALITY/EXPLORATION/LEGISLATION/ELECTRIC POWER DEMAND/ SPATIAL DISTRIBUTION
/IDENTIFIERS: /GEOTHERMAL RESOURCES

52

DE LA FUENTE DUCH, M.F.F.

1973

AEROMAGNETIC STUDY OF THE COLORADO RIVER DELTA AREA, MEXICO.

UNIVERSITY OF ARIZONA (M.S. THESIS). 48 P.

THIS STUDY WAS UNDERTAKEN TO DETERMINE THE BASEMENT STRUCTURE UNDER RELATIVELY NONMAGNETIC SEDIMENTS AND TO COMPARE MAGNETIC VALUES WITH THE ROCK TYPES IN OUTCROP AREAS. FROM AN ECONOMIC POINT OF VIEW, THERE IS A CLOSE RELATIONSHIP BETWEEN BASEMENT STRUCTURE AND LITHOLOGY AND GEOTHERMAL HEAT SOURCES. ACADEMICALLY, THIS STUDY CAN ALSO RELATE THE BASEMENT STRUCTURE WITH SPREADING CENTERS. MAJOR RESULT OF THIS WORK IS THE DISCOVERY OF AN APPARENT SPREADING CENTER NAMED PANGA DE ABAJO, AT LATITUDE 32 DEGREES 2 MINUTES N., LONGITUDE 115 DEGREES 12 MINUTES W. THE ASSOCIATION OF THIS PROBABLE SPREADING CENTER WITH A GEOTHERMAL FIELD COULD NOT BE ESTABLISHED WITH THIS SURVEY.

GEOLOGY/COLORADO RIVER/GEOTHERMAL STUDIES/MAPS/GEOPHYSICS/PETROLOGY/MAGNETIC STUDIES/SURVEYS/STRUCTURAL GEOLOGY
/IDENTIFIERS: /BAJA CALIFORNIA/SPREADING CENTERS/COLORADO RIVER DELTA/ AEROMAGNETIC SURVEYS

53

DELLECHAIE, F.

1975

A HYDRO-CHEMICAL STUDY OF THE SOUTH SANTA CRUZ BASIN NEAR COOLIDGE, ARIZONA. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS II-9.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

THERMAL WATERS HAVE BEEN PUMPED FROM MORE THAN A DOZEN IRRIGATION WELLS NEAR COOLIDGE, ARIZONA, VARYING IN DEPTH FROM 1,200 TO 1,300 FEET IN A DEEP INTER-MONTANE BASIN. WATER TEMPERATURES BETWEEN 35 AND 65 DEGREES C. HAVE BEEN ENCOUNTERED. CHEMICAL SAMPLES WERE COLLECTED FROM BOTH HOT AND COLD IRRIGATION WELLS IN THE COOLIDGE AREA. SILICA AND ALKALI GEOTHERMOMETRY PORTRAYED MAXIMUM SUBSURFACE TEMPERATURES NEAR 100 DEGREES C. A GEOTHERMAL TEST WAS DRILLED THROUGH 2,000 METERS OF LACUSTRINE SEDIMENTS AND THEN BASEMENT TO A DEPTH OF 2,440 METERS. OPTIMUM RESERVOIR FLOW CHARACTERISTICS WERE DISPLAYED IN FRACTURED PRECAMBRIAN SCHIST BELOW 2,000 METERS. CHEMICALLY, FLUIDS CLOSELY CORRESPOND TO THE WARM IRRIGATION WELLS. SILICA GEOTHERMOMETRY CORRELATED WITH MAXIMUM BOTTOM HOLE TEMPERATURES OF 120 DEGREES C. A NORMAL GRADIENT (35 DEGREES C/KM) HEAT SOURCE IS IMPLIED. ANOMALOUSLY WARM WATER FOUND IN DEEP IRRIGATION WELLS ARISES FROM DEPTH TO REPLENISH A DOWNWARP OF THE WATER TABLE FROM PUMPING LARGE VOLUMES IN AN AREA OF LIMITED RECHARGE.

GEOTHERMAL STUDIES/ARIZONA/THERMAL WATER/GROUNDWATER/IRRIGATION WATER/TEST WELLS/SEDIMENTARY BASINS(GEOLOGIC)
/IDENTIFIERS: /NORMAL TEMPERATURE GRADIENT AREAS/GEOTHERMOMETERS

54

DEMISSIE, G./KAHSAI, G. A.

1975

DISTRIBUTION OF HYDROTHERMAL AREAS IN ETHIOPIA AND THEIR GEOTHERMAL ENERGY POTENTIAL. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS I-10.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

PRELIMINARY GEOTHERMAL EXPLORATION SINCE 1969 HAS DISCOVERED OVER SIX HUNDRED HYDROTHERMAL AREAS IN ETHIOPIA. ABOUT 15 PERCENT OF THESE ARE ON HIGHLAND AREAS WHILE 85 PERCENT ARE IN THE RIFT SYSTEM. DISTRIBUTION OF HYDROTHERMAL ACTIVITY REFLECTS DIFFERENT INTENSITIES OF TECTONISM AND MAGMATISM. HIGHLAND THERMAL SPRINGS HAVE TEMPERATURES BELOW 55 DEGREES C. RIFT ZONE THERMAL SPRINGS AND FUMAROLES HAVE HIGH TEMPERATURES, OFTEN WELL ABOVE BOILING POINT. RIFT ZONE THERMAL SPRINGS CONSIST OF THOSE WITH HIGH CHLORIDE CONCENTRATION (NORTHERN PART OF THE RIFT) AND THOSE WITH HIGH BICARBONATE CONCENTRATION (SOUTHERN PART).

GEOTHERMAL STUDIES/AFRICA/HYDROTHERMAL STUDIES/EXPLORATION/THERMAL SPRINGS/ HOT SPRINGS/SPATIAL DISTRIBUTION/CHLORIDES/BICARBONATES
/IDENTIFIERS: /RIFT ZONES/ETHIOPIA/DEVELOPING COUNTRIES

55

DENCH, N.D.

1973

WELL MEASUREMENTS. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 85-96.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

SEE: SWRA W74-11760.

GEOTHERMAL STUDIES/WELLS/MEASUREMENT/REVIEWS/INSTRUMENTATION/THERMAL WATER/ BOREHOLE GEOPHYSICS/STEAM/WELL DATA/DRILL HOLES/SUBSURFACE INVESTIGATIONS/ GEOPHYSICS/LOGGING(RECORDING)/FLOW MEASUREMENT/FLOW RATES/TEMPERATURE/PRESSURE/ HYDROTHERMAL STUDIES
/IDENTIFIERS: /GEOTHERMAL RESERVOIRS

56

DENTON, J.C./DUNLOP, D.D.

1973

GEOTHERMAL RESOURCES RESEARCH. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 335-346.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13232.

GEOTHERMAL STUDIES/ELECTRIC POWER/MODEL STUDIES/THERMAL POWERPLANTS/ ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/ENVIRONMENTAL EFFECTS/WATER RESOURCES DEVELOPMENT/STEAM TURBINES/WELLS/EXPLORATION/DRILLING/RESEARCH AND DEVELOPMENT/ DESALINATION
/IDENTIFIERS: /GEOTHERMAL POWER/POWER DEMAND/GEOTHERMAL RESOURCES DEVELOPMENT/ WELL STIMULATION/VAPOR TURBINES

57

DICKINSON, W.R.

1974

SUBDUCTION AND OIL MIGRATION.

GEOLOGY 2(9):421-424.

WHEN CONTINENTS COLLIDE, RIFTED-MARGIN SEDIMENT PRISMS ARE PARTLY SUBDUCTED AND HYDROCARBONS MAY BE DRIVEN UPDIP TO ACCUMULATE IN RESERVOIR TRAPS. THIS MECHANISM MAY BE RESPONSIBLE FOR THE VAST PETROLEUM DEPOSITS OF THE PERSIAN GULF AREA, AND MAY HAVE INFLUENCED OTHER OIL PROVINCES, ALSO.

OIL/OIL FIELDS/OIL RESERVOIRS/GEOLOGY/SEDIMENTARY ROCKS/FOSSIL FUELS
/IDENTIFIERS: /GLOBAL TECTONICS/CONTINENTAL DRIFT/PLATE BOUNDARIES/SUBSIDING SEDIMENTARY BASINS/SUBDUCTION/PERSIAN GULF/ENERGY SOURCES INTERFACES

58

DIMENT, W.H. ET AL

1975

TEMPERATURES AND HEAT CONTENTS BASED ON CONDUCTIVE TRANSPORT OF HEAT. IN D.E. WHITE AND D.L. WILLIAMS, EDS., ASSESSMENT OF GEOTHERMAL RESOURCES OF THE UNITED STATES--1975, P. 84-103.

U.S. GEOLOGICAL SURVEY, CIRCULAR 726.

U.S. TEMPERATURE GRADIENT DATA WAS COMPILED FROM WELL LOGS AND FROM HEAT FLOW DATA COMBINED WITH ROCK THERMAL PROPERTY ASSUMPTIONS. MAPS SHOW HEAT FLOW AND HEAT FLOW PROVINCES (HOT, NORMAL, AND COLD). ESTIMATES FOR HEAT CONTENT (ABOVE MEAN ANNUAL SURFACE TEMPERATURE) ARE TABULATED BY PHYSIOGRAPHIC PROVINCE. ESTIMATES FOR COTERMINOUS U.S. ARE, IN UNITS OF 10 TO 24TH POWER CALORIES, 0.7 (0 TO 3 KM DEPTH) AND 6 (3 TO 10 KM). MOST OF U.S. WEST OF 105 DEGREES WEST LONGITUDE HAS HIGH HEAT FLOW. (OALS) 52 REFERENCES.

GEOTHERMAL STUDIES/TEMPERATURE/HEAT TRANSFER/UNITED STATES/WELL DATA/HEAT FLOW/CONDUCTION/THERMAL CONDUCTIVITY/SPATIAL DISTRIBUTION/MAPS/ESTIMATING /IDENTIFIERS: /HEAT CONTENT/TEMPERATURE GRADIENT/WESTERN U.S.

59

DUTCHER, L.C./HARDT, W.F./MOYLE, W.R., JR.

1972

PRELIMINARY APPRAISAL OF GROUND WATER IN STORAGE WITH REFERENCE TO GEOTHERMAL RESOURCES IN THE IMPERIAL VALLEY AREA, CALIFORNIA.

U.S. GEOLOGICAL SURVEY, CIRCULAR 649. 57 P.

SEE: SWRA W72-11678.

GROUNDWATER RESOURCES/GEOTHERMAL STUDIES/THERMAL WATER/USABLE STORAGE/ CALIFORNIA/WATER COSTS/WATER QUALITY/SALINITY/WATER WELLS/WATER YIELD/AQUIFER CHARACTERISTICS/PUMPING/WATER UTILIZATION/GROUNDWATER RECHARGE/HEAT FLOW/ THERMAL POLLUTION
/IDENTIFIERS: /IMPERIAL VALLEY/METAMORPHISM/ENERGY COSTS

60

EINARSSON, S.S.

1973

GEOTHERMAL DISTRICT HEATING. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 123-134.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

GEOTHERMAL HEAT HAS BEEN USED FOR RECREATION AND HEALTH FOR CENTURIES. IN ICELAND IT HAS BEEN USED ON A LARGE SCALE FOR HEATING OF WATER, GREENHOUSES, BUILDINGS, AND SWIMMING POOLS, FOR INDUSTRIAL USES, AND FOR ELECTRICITY PRODUCTION. REYKJAVIK DISTRICT HEATING SYSTEM IS DESCRIBED IN DETAIL. IN HUNGARY, GEOTHERMAL HEAT SYSTEMS WERE CONVERTED TO NATURAL GAS WHEN A LARGE OIL AND GAS FIELD WAS DISCOVERED DURING HOT WATER DRILLING, BUT HOT WATER HAS SINCE BEEN USED FOR SPACE HEATING, GREENHOUSES, AND ANIMAL HUSBANDRY. OTHER DOMESTIC HEATING USES ARE IN JAPAN, NEW ZEALAND, AND USSR. DISTRICT HEATING SYSTEMS MUST BE TAILORED TO LOCAL CLIMATE AND NATURE OF GEOTHERMAL RESOURCES. WASTE HEAT FROM GEOTHERMAL POWER PRODUCTION CAN BE USED. WHETHER GEOTHERMAL HEAT CAN COMPETE ECONOMICALLY WITH OTHER ENERGY SOURCES IS DETERMINED BY COMPARATIVE TOTAL COST PER UNIT OF ENERGY DELIVERED. (OALS)

GEOTHERMAL STUDIES/HEATING/RECREATION/GREENHOUSES/HOT WATER/AGRICULTURE/ COMPARATIVE COSTS/ECONOMICS
/IDENTIFIERS: /GEOTHERMAL HEAT/SPACE HEATING/HOT BATHS/ICELAND/WATER HEATING/ INDUSTRIAL USES/GEOTHERMAL POWER/REYKJAVIK/HUNGARY/ENERGY SOURCES INTERFACES/ ALTERNATIVE ENERGY SOURCES/JAPAN/NEW ZEALAND/USSR/WASTE HEAT USES

61

EINARSSON, S.S./VIDES, A./CUELLAR, G.

1975

DISPOSAL OF GEOTHERMAL WASTE WATER BY REINJECTION. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS IV-6.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

HIGHLY MINERALIZED WATERS REPRESENTED MAJOR PROBLEM FOR EXPLOITATION OF THE AHUACHAPAN GEOTHERMAL FIELD. LARGE SCALE REINJECTION EXPERIMENTS WERE SUCCESSFULLY CARRIED OUT IN 1970-1971. GRAVITY FEED AND VAPOR PRESSURE WERE DRIVING FORCES. WATER WAS INJECTED INTO HIGH-TEMPERATURE AQUIFER AT DEPTH, AND RESULTING COOLING EFFECT WAS OBSERVED. NO TECHNICAL DIFFICULTIES FROM SCALING OR OTHER SOURCE WERE EXPERIENCED. REINJECTION OF HOT WATER PRACTICALLY ELIMINATES ANY DANGER OF INSUFFICIENT WATER FOR HEAT-EXTRACTION (EVEN WITH LIMITED NATURAL RECHARGE), AND AT THE SAME TIME MAY CONSERVE ENERGY.

LOCAL COOLING EFFECT AROUND THE POINT OF INJECTION (WHICH SHOULD BE MINIMUM 1.5 KM AWAY FROM PRODUCTION AREA) WAS ESTIMATED AND FOUND TO BE MINOR COMPARED TO EXPECTED BENEFITS. COST OF REINJECTION IS APPROXIMATELY 1 U.S. MIL/KWH.

GEOTHERMAL STUDIES/INJECTION/GROUNDWATER RECHARGE/INJECTION WELLS/ARTIFICIAL RECHARGE/RECHARGE WELLS/WASTE WATER DISPOSAL/SCALING/COOLING/COSTS /IDENTIFIERS: /HOT BRINES/EL SALVADOR/AHUACHAPAN FIELD

62

ELLIS, A.J.

1975

GEOTHERMAL SYSTEMS AND POWER DEVELOPMENT.

AMERICAN SCIENTIST 63(5):510-521.

REVIEWS THE GEOLOGY, GEOCHEMISTRY, PHYSICAL BEHAVIOR, AND DEVELOPMENT OF HYDROTHERMAL RESERVOIRS WORLD-WIDE. STEPS IN PREPRODUCTION ASSESSMENT OF A GEOTHERMAL FIELD INCLUDE: AERIAL PHOTOGRAPHY, SURFACE WATER GEOCHEMICAL SURVEY (TO ESTIMATE RESERVOIR TEMPERATURE AND TYPE), TEMPERATURE GRADIENT AND RESISTIVITY GEOPHYSICAL SURVEYS, AND DRILLING. A TABLE SUMMARIZES GEOLOGY, WELL DEPTH, RESERVOIR TEMPERATURE AND TYPE, AND GENERATING CAPACITY OF 18 GEOTHERMAL POWER INSTALLATIONS IN 11 COUNTRIES. ALSO REVIEWED ARE: GEOCHEMISTRY OF GEOTHERMAL FLUIDS AND ALTERATION MINERALS, POWER GENERATION TECHNOLOGY, OTHER USES FOR GEOTHERMAL FLUIDS AND HEAT (TIMBER AND DIATOMITE DRYING, SPACE HEATING, AND SULFUR MINING), AND ENVIRONMENTAL IMPACT AND PROBLEMS OF UTILIZATION (THERMAL, WATER, AND AIR POLLUTION, SUBSIDENCE, EARTHQUAKES, DRYING UP OF HOT SPRINGS, AND SCALING). (CALS)

GEOTHERMAL STUDIES/GEOLOGY/GEOCHEMISTRY/EXPLORATION/TEMPERATURE/RESISTIVITY/ DRILLING/WELL DATA/DRYING/SULFUR/ENVIRONMENTAL EFFECTS/SUBSIDENCE/SCALING/ EARTHQUAKES
/IDENTIFIERS: /GEOTHERMAL RESERVOIRS/WORLD/GLOBAL DISTRIBUTION/AERIAL PHOTOGRAPHY/TEMPERATURE GRADIENT/POWER CAPACITY/HYDROTHERMAL ALTERATION/ GEOTHERMAL POWER/INDUSTRIAL USES/SPACE HEATING

63

ENGINEERING AND MINING JOURNAL

1973

TECHNOLOGICAL BREAKTHROUGH PROMISES TO TAP GEOTHERMAL POWER CHEAPLY.

SAME AS AUTHOR. 174(3):26.

A REVOLUTIONARY NEW TECHNOLOGY TO TAP VAST SUPPLIES OF GEOTHERMAL ENERGY AND PROVIDE AN UNLIMITED SOURCE OF CHEAP POWER WAS REVEALED BY A LOS ANGELES INVENTOR, ALLEN T. VAN HUISEN OF GEO-ENERGY SYSTEMS, INC. THE INVENTION, PATENTED UNDER THE NAME 'DOWNHOLE HEAT EXCHANGER', CLAIMS TO ELIMINATE DAMAGE TO PIPES, VALVES, TURBINES, AND EQUIPMENT (CAUSED BY CORROSIVE BRINES) BY CIRCULATING WATER OR SOME OTHER CLEAN STABLE SCONDARY HEAT TRANSFER FLUID TO THE BOTTOM OF THE WELL IN A CLOSED SYSTEM. THE FLUID IS HEATED BY THE GEOTHERMAL BRINE, BROUGHT BACK TO THE SURFACE AS CLEAN STEAM TO POWER TURBINES, THEN RECIRCULATED TO THE DOWNHOLE HEAT EXCHANGER.

GEOTHERMAL STUDIES/TECHNOLOGY/HEAT TRANSFER/HEAT EXCHANGERS/EQUIPMENT/ CORROSION/ENERGY CONVERSION/THERMAL POWERPLANTS
/IDENTIFIERS: /GEOTHERMAL POWER/CLOSED SYSTEMS

64

ERGASHEV, S.E.

1973

A HYDROGEOTHERMAL DESCRIPTION OF GROUNDWATER IN UPPER CRETACEOUS DEPOSITS IN THE SOUTHEAST ARAL SEA AREA.

UZBEKSKIY GEOLOGICHESKIY ZHURNAL 1:76-78.

SEE: SWRA W74-02609.

GROUNDWATER/GEOTHERMAL STUDIES/TEMPERATURE/THERMOCLINE/THERMAL WATER/ BOREHOLE GEOPHYSICS/STRUCTURAL GEOLOGY/GEOLOGIC TIME/AQUIFERS/WATER QUALITY/ WATER TEMPERATURE
/IDENTIFIERS: /USSR/ARAL SEA/CRETACEOUS PERIOD/TECTONICS/SPACE HEATING/ TEMPERATURE GRADIENT

65

EVANS, K.R.

1972

AEROMAGNETIC STUDY OF THE MEXICALI-CERRO PRIETO GEOTHERMAL AREA.

UNIVERSITY OF ARIZONA (M.S. THESIS). 50 P.

AEROMAGNETIC SURVEY (ALTITUDE 1,000 FEET, FLIGHT-LINE SPACING 1 KM) CORRELATES CLOSELY WITH PREVIOUS GEOPHYSICAL DATA FOR SALTON-MEXICALI TROUGH. FUTURE

EXPLORATION SHOULD BE CONCENTRATED ALONG STRIKE-SLIP FAULTS, ESPECIALLY WHERE THEY COINCIDE WITH LINEAR MAGNETIC LOWS. THESE LOWS PROBABLY RESULT FROM HYDROTHERMAL ALTERATION BY GEOTHERMAL FLUIDS UPWELLING ALONG FAULTS.

GEOTHERMAL STUDIES/MAGNETIC STUDIES/GEOPHYSICS/SURVEYS/MAPPING/MEXICO/ EXPLORATION/FAULTS(GEOLOGIC)
/IDENTIFIERS: /CERRO PRIETO FIELD, MEXICO/AEROMAGNETIC SURVEYS/SALTON TROUGH/ HYDROTHERMAL ALTERATION/GEOTHERMAL FLUIDS

66

EWING, A.H.

1973

STIMULATION OF GEOTHERMAL SYSTEMS. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 217-222.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13225.

GEOTHERMAL STUDIES/ELECTRIC POWER/THERMAL POWERPLANTS/HYDROGEOLOGY/WELLS/ ELECTRIC POWER PRODUCTION/EXPLOSIVES/NUCLEAR EXPLOSIONS/HYDROFRACTURING
/IDENTIFIERS: /GEOTHERMAL POWER/WELL STIMULATION/GEOTHERMAL RESERVOIRS/ CHEMICAL EXPLOSIONS

67

FACCA, G.

1973

THE STRUCTURE AND BEHAVIOR OF GEOTHERMAL FIELDS. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 61-69.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

GENERAL MODELS FOR GEOLOGY AND MECHANICS OF HOT WATER, WET STEAM, AND DRY STEAM GEOTHERMAL FIELDS ARE PRESENTED. THREE EXAMPLES, THE GEYSERS (CALIFORNIA), OTAKE (JAPAN), AND LARDERELLO (ITALY), ARE SHOWN TO CONFORM TO THESE MODELS.

GEOTHERMAL STUDIES/GEOLOGY/HYDROLOGY/MODEL STUDIES
/IDENTIFIERS: /HOT WATER SYSTEMS/WET STEAM FIELDS/DRY STEAM FIELDS/LARDERELLO/ HYDROTHERMAL SYSTEMS/GEYSERS FIELD, CALIFORNIA/OTAKE

68

FAIRCHILD, W.D.

1972

EVOLVING WATER POLICY AND MANAGEMENT IN THE UNITED STATES. IN

INTERNATIONAL SYMPOSIUM ON WATER RESOURCES PLANNING, PAPERS, VOL. III. 19 P.

SEE: SWRA W74-02358.

PLANNING/WATER MANAGEMENT(APPLIED)/WATER ALLOCATION(POLICY)/MULTIPLE PURPOSE/ REGIONAL DEVELOPMENT/WATER SUPPLY DEVELOPMENT/WATER QUALITY CONTROL/GEOTHERMAL STUDIES/FLOW AUGMENTATION/COLORADO RIVER BASIN/RECLAMATION STATES/WATER LAW/ NATIONAL WATER COMMISSION/ENVIRONMENTAL EFFECTS
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT

69

FAIRCHILD, W.D.

1973

THE ROLE OF WATER IN THE ENERGY CRISIS. IN K.E. STORK, ED., THE ROLE OF WATER IN THE ENERGY CRISIS: PROCEEDINGS OF A CONFERENCE AT LINCOLN, NEBRASKA, 1973, P. 10-17.

NEBRASKA WATER RESOURCES RESEARCH INSTITUTE, LINCOLN, PUBLICATION. AVAILABLE NTIS AS PB-232 404.

SEE: SWRA W74-07962.

WATER DEMAND/ENERGY/POWERPLANTS/WATER SUPPLY/WATER UTILIZATION/GEOTHERMAL STUDIES/WATER MANAGEMENT(APPLIED)/THERMAL POWERPLANTS
/IDENTIFIERS: /ENERGY CRISIS/ENERGY-WATER RELATIONSHIPS

70

FENNER, D./ KLARMANN, J.

1971

POWER FROM THE EARTH.

ENVIRONMENT 13(10):19-26, 31-34. NSF-RANN ENERGY ABSTRACTS 1(19)2190.

THIS PAPER SURVEYS THE PRESENT CAPABILITIES OF GEOTHERMAL POWER AS A TECHNICALLY AND ECONOMICALLY VIABLE MEANS OF PRODUCING ELECTRIC POWER. THE MECHANISMS OF GENERATION AND POWER PRODUCTION ARE DIAGRAMMED AND REVIEWED IN A NON-TECHNICAL MANNER. THE ECONOMICS OF THE PROCESS ARE STILL RATHER UNCERTAIN, PARTLY DUE TO GREAT DIFFERENCES IN THE METHODS OF ESTIMATING COSTS IN EXISTING PLANTS. REVIEWED ARE COST OF EXPLORATION, WELL-DRILLING, POWER PLANTS, ENVIRONMENTAL POLLUTION, LAND, AND PIPELINES TO THE WELLHEAD. VARIOUS ESTIMATES OF WORLD GEOTHERMAL RESOURCES ARE BRIEFLY SURVEYED.

GEOTHERMAL STUDIES/ELECTRIC POWER/EXPLORATION/COSTS/WELLS/THERMAL POWERPLANTS/ENVIRONMENTAL EFFECTS/DRILLING/CONDENSATION/PIPELINES
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL RESOURCES

71

FINNEY, J.P.

1973

DESIGN AND OPERATION OF THE GEYSERS POWER PLANT. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 145-161.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13221.

GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/THERMAL POWERPLANTS/ELECTRIC POWER PRODUCTION/CALIFORNIA/COMPARATIVE COSTS/STEAM TURBINES/WELLS/ENTHALPY/PRESSURE/FLOW RATES/COOLING TOWERS
/IDENTIFIERS: /GEOTHERMAL POWER/POWER DEMAND/GEYSERS FIELD, CALIFORNIA/DRY STEAM FIELDS/PRODUCTION WELLS/POWER CAPACITY

72

FOURNIER, R.O./TRUESDELL, A.H.

1974

GEOCHEMICAL INDICATORS OF SUBSURFACE TEMPERATURE. PART 2: ESTIMATION OF TEMPERATURE AND FRACTION OF HOT WATER MIXED WITH COLD WATER.

U.S. GEOLOGICAL SURVEY/JOURNAL OF RESEARCH 2(3):263-270.

SEE: SWRA W74-09915.

GEOCHEMISTRY/WATER TEMPERATURE/GEOTHERMAL STUDIES/HOT SPRINGS/THERMAL SPRINGS/THERMAL WATER/MINERAL WATER/WATER CHEMISTRY/EQUILIBRIUM/SILICA
/IDENTIFIERS: /GEOTHERMAL FLUIDS/GEOTHERMOMETERS

73

FOURNIER, R.O./WHITE, D.E./TRUESDELL, A.H.

1974

GEOCHEMICAL INDICATORS OF SUBSURFACE TEMPERATURE. PART 1: BASIC ASSUMPTIONS.

U.S. GEOLOGICAL SURVEY/JOURNAL OF RESEARCH 2(3):259-262.

SEE: SWRA W74-09914.

GEOCHEMISTRY/WATER TEMPERATURE/GEOTHERMAL STUDIES/HOT SPRINGS/THERMAL SPRINGS/THERMAL WATER/MINERAL WATER/WATER CHEMISTRY/EQUILIBRIUM/SILICA/ISOTOPE STUDIES/GASES
/IDENTIFIERS: /GEOTHERMOMETERS/GEOTHERMAL FLUIDS

74

FRIZ, T.O.

1973

GEOTHERMAL AS A FUTURE ENERGY SOURCE--BY HYDRAULIC FRACTURING AND NUCLEAR EXPLOSIVE.

AWARE (37):13-15. EIA 73-11054.

TO GAUGE THE NATION'S GEOTHERMAL POTENTIAL THE ABILITY MUST BE DEVELOPED TO DETERMINE THE AVAILABILITY OF ROCKS AT SIGNIFICANT TEMPERATURES AT DEPTHS LESS

THAN 10,000 FEET. AT PRESENT TWO METHODS ARE FEASIBLE FOR THE RECOVERY OF GEOTHERMAL ENERGY--HYDRAULIC FRACTURING AND NUCLEAR EXPLOSIONS. SOME TECHNOLOGICAL PROBLEMS HINDER USE OF THESE METHODS. ALSO, THERE IS THE QUESTION OF WHETHER ENVIRONMENTALISTS AND PUBLIC IN GENERAL WILL ACCEPT DETONATION OF NUCLEAR BOMBS AS A LEGITIMATE PART OF THE QUEST FOR ENERGY RESERVES.

GEOTHERMAL STUDIES/WATER POLLUTION/AIR POLLUTION/LAND RESOURCES/NUCLEAR EXPLOSIONS/EXPLORATION/HYDROFRACTURING/POLITICAL ASPECTS
/IDENTIFIERS: /GEOTHERMAL ENERGY/WELL STIMULATION

75

FUCHS, R.L./WESTPHAL, W.H.

1973

ENERGY SHORTAGE STIMULATES GEOTHERMAL EXPLORATION.

WORLD OIL 177(7):37-41.

SEE: SWRA W74-10851.

GEOTHERMAL STUDIES/ENERGY/ELECTRIC POWER PRODUCTION/DRILLING/INDUSTRIES/GEOCHEMISTRY/GEYSERS/HOT SPRINGS/STEAM/SUBSURFACE WATERS/THERMAL WATER/ENVIRONMENTAL EFFECTS/EXPLORATION
/IDENTIFIERS: /ENERGY SHORTAGE/ENERGY RESERVES/GEOTHERMAL EXPLORATION/GEOTHERMAL HISTORY/GEOTHERMAL STEAM ACT, 1970/ALTERNATIVE ENERGY SOURCES/GEOTHERMAL RESOURCES

76

FURUMOTO, A.S.

1974

U.S.-JAPAN SEMINAR ON UTILIZATION OF VOLCANIC ENERGY.

EOS, AMERICAN GEOPHYSICAL UNION TRANSACTIONS 55(10):895-899.

SUMMARIZES PAPERS AND DISCUSSIONS OF A SEMINAR HELD IN HILO, HAWAII, FEBRUARY, 1974. TOPICS COVERED INCLUDED: CALDERAS, CRATERS, FUMAROLES, AND GEYSERS; GEOLOGIC STRUCTURE OF VOLCANOES; GEOLOGY OF VOLCANIC REGIONS; AND VOLCANOES IN THE FRAMEWORK OF GLOBAL TECTONICS. PROPOSALS FOR VOLCANC ENERGY USE RANGED FROM INJECTION OF WATER INTO HOT PERMEABLE LAVA LAYERS FOR STEAM PRODUCTION, TO ELECTROLYTIC HYDROGEN GENERATORS ON THE SEA FLOOR AT SUBMARINE VOLCANOES AND SPREADING CENTERS. NO STUDIES YET ABOUT EFFECTS ON NORMAL ERUPTION MECHANICS. SURFACE SURVEYS HAVE BEEN USEFUL, BUT DRILLING IS NEEDED NOW FOR BETTER UNDERSTANDING. (OALS)

UNITED STATES/VOLCANOES/GEOTHERMAL STUDIES/CRATERS/GEYSERS/STRUCTURAL GEOLOGY/GEOLOGY/INJECTION/HYDROGEN/SURVEYS/DRILLING
/IDENTIFIERS: /JAPAN/GLOBAL TECTONICS/GEOTHERMAL ENERGY/SPREADING CENTERS/VOLCANISM

77

GARRISON, L.E.

1972

GEOTHERMAL STEAM IN THE GEYSERS-CLEAR LAKE REGION, CALIFORNIA.

GEOLOGICAL SOCIETY OF AMERICA, BULLETIN 83(5):1449-1468.

SEE: SWRA W72-14351.

GEOTHERMAL STUDIES/CALIFORNIA/STEAM/THERMAL POWER/HEAT FLOW/GEYSERS/THERMAL WATER/WATER VAPOR/GEOPHYSICS/AQUIFER CHARACTERISTICS/CONVECTION/MAGMATIC WATER/METEORIC WATER
/IDENTIFIERS: /GEYSERS FIELD, CALIFORNIA/DRY STEAM FIELDS/POWER CAPACITY

78

GARSIDE, L.J./SCHILLING, J.H.

1972

GEOTHERMAL EXPLORATION AND DEVELOPMENT IN NEVADA. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER H, 7 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03427.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/NEVADA/THERMAL WATER/THERMAL SPRINGS/WATER TEMPERATURE/HYDROGEOLOGY/THERMAL PROPERTIES/GEOPHYSICS/EXPLORATION/DRILLING
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL STEAM

79

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA

1972

GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS.

SAME AS AUTHOR. PUBLICATION.

SEE: SWRA W73-03419.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/THERMAL WATER/WATER TEMPERATURE/THERMAL PROPERTIES/HYDROGEOLOGY/THERMAL SPRINGS/FAULTS(GEOLOGIC)/ VOLCANOES/EXPLORATION/LEGISLATION/DRILLING/GEOLOGIC INVESTIGATIONS/WATER QUALITY
/IDENTIFIERS: /GEOTHERMAL RESOURCES/WESTERN U.S.

80

GERAGHTY AND MILLER, PORT WASHINGTON, N.Y.

1973

GROUND WATER AND THE GEOTHERMAL RESOURCE.

SAME AS AUTHOR. SPECIAL REPORT. 14 P.

SEE: SWRA W74-04586.

GEOTHERMAL STUDIES/THERMAL WATER/THERMAL SPRINGS/HEAT FLOW/THERMAL POWER/ GROUNDWATER/METEORIC WATER
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL FLUIDS/GEOTHERMAL RESOURCES/ ENERGY-WATER RELATIONSHIPS

81

GILLILAND, M.W.

1975

ENERGY ANALYSIS AND PUBLIC POLICY.

SCIENCE 189(4208):1051-1056.

RESOURCE ALLOCATION AND ENERGY SYSTEM DESIGN ARE MORE RATIONAL WHEN ENERGY UNITS ARE USED INSTEAD OF DOLLARS TO MEASURE RESOURCE AVAILABILITY AND NEEDS, ECONOMIC COSTS, AND ENVIRONMENTAL CONSEQUENCES. BASIC PRINCIPLES OF NET ENERGY ANALYSIS (NET ENERGY IS ENERGY LEFT AFTER COST OF FINDING, PRODUCING, CONCENTRATING, AND DELIVERING IT IS PAID) AND ITS RELATIONSHIP TO ECONOMIC ANALYSIS (MONEY FLOW IS REVERSE OF ENERGY FLOW BUT BYPASSES INPUTS FROM NATURE) ARE PRESENTED. GEOTHERMAL POWER PRODUCTION IS USED AS AN EXAMPLE. TRUE GEOTHERMAL ENERGY RESERVES ARE THOSE OF HIGH ENOUGH ENERGY QUALITY (COMBINATION OF DEPTH, HEAT CONTENT, AND CHEMISTRY) TO YIELD NET ENERGY WITH CURRENT TECHNOLOGY. ECONOMIC RESERVES ARE THOSE WHICH HAVE A NET ENERGY RATIO (RATIO OF NET ENERGY TO ENERGY COSTS) COMPETITIVE WITH OTHER ENERGY SOURCES. DATA ARE NOT YET AVAILABLE TO CALCULATE TOTAL RESERVES, BUT NET ENERGY ANALYSES OF TWO 100 MW GEOTHERMAL POWER SYSTEMS (DRY STEAM RESERVOIR WITH TURBINE, AND WET STEAM RESERVOIR WITH TWO-STAGE FLASH TURBINE) ARE PRESENTED AS EXAMPLES. NET ENERGY RATIOS ARE CALCULATED TO BE 12.6:1 AND 10.7:1, RESPECTIVELY. NET ENERGY RATIO FOR OIL IS 30:1 AT 2 DOLLARS PER BARREL AND 6:1 AT 11 DOLLARS PER BARREL. ENERGY ANALYSIS SHOULD BE USEFUL FOR IMPROVING QUALITY OF PUBLIC POLICY DECISIONS. (OALS)

GEOTHERMAL STUDIES/ENERGY/FREE ENERGY/ENERGY BUDGET/ENERGY CONVERSION/ENERGY TRANSFER/THERMODYNAMICS/DECISION MAKING/ECONOMICS/COSTS/ENVIRONMENTAL EFFECTS/ DEPTH/TECHNOLOGY/OIL/POLITICAL ASPECTS/SYSTEMS ANALYSIS
/IDENTIFIERS: /NET ENERGY RATIO/DRY STEAM FIELDS/WET STEAM FIELDS/FLASHED STEAM CYCLE/ENERGY COSTS/ENERGY DIAGRAMS/ENERGY CIRCUIT MODELS/DRILLING COSTS/ ENERGY-DOLLAR RATIO/NET ENERGY/GEOTHERMAL POWER/GEOTHERMAL RESOURCES/GEOTHERMAL ENERGY/ENERGY QUALITY/HEAT CONTENT

82

GODWIN, L.H. ET AL

1971

CLASSIFICATION OF PUBLIC LANDS VALUABLE FOR GEOTHERMAL STEAM AND ASSOCIATED GEOTHERMAL RESOURCES.

U.S. GEOLOGICAL SURVEY, CIRCULAR 647. 18 P.

SEE: SWRA W72-00096.

LAND CLASSIFICATION/PUBLIC LANDS/FEDERAL JURISDICTION/GEOTHERMAL STUDIES/ STEAM/HOT SPRINGS/THERMAL SPRINGS/LEGAL ASPECTS/WATER LAW/GROUNDWATER/ DOCUMENTATION
/IDENTIFIERS: /GEOTHERMAL STEAM ACT, 1970

83

GOLDSMITH, M.

1971

GEOTHERMAL RESOURCES IN CALIFORNIA--POTENTIALS AND PROBLEMS.

CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, ENVIRONMENTAL QUALITY LABORATORY, EQL REPORT 5. 45 P. NSF GI-29726.

SEE: SWRA W72-10550.

THERMAL POWERPLANTS/COSTS/ENVIRONMENTAL EFFECTS/CALIFORNIA/DESALINATION/COOLING TOWERS/HEATED WATER/LAND SUBSIDENCE/SEISMIC WAVES/AIR POLLUTION/GEOTHERMAL STUDIES/RESOURCES DEVELOPMENT/GEYSERS/STEAM/COMPARATIVE COSTS
/IDENTIFIERS: /IMPERIAL VALLEY/DRY STEAM FIELDS/IMPURITIES/HOT WATER SYSTEMS/GEYSERS FIELD, CALIFORNIA

84

GRISCOM, A./MUFFLER, L.J.P.

1971

AEROMAGNETIC MAP AND INTERPRETATION OF THE SALTON SEA GEOTHERMAL AREA, CALIFORNIA. [MAP, SCALE 1:62,500]

U.S. GEOLOGICAL SURVEY, GEOPHYSICAL INVESTIGATIONS MAP GP 754. TEXT. 4 P.

SALTON SEA GEOTHERMAL AREA (IMPERIAL VALLEY) IS CLOSELY ASSOCIATED WITH FIVE SMALL RHYOLITIC VOLCANIC DOMES WHICH CROP OUT AT THE SOUTHEASTERN END OF THE SALTON SEA. AEROMAGNETIC SURVEY DATA SUGGEST THAT THESE DOMES ARE SMALL PROTRUSIONS OF A LONG NORTHWEST TRENDING SUBSURFACE RIDGE OF INTRUSIVE IGNEOUS ROCKS ABOUT 18 MILES LONG AND 3-5 MILES WIDE. HEAT EVOLVED FROM THIS COOLING MASS HAS METAMORPHOSED THE SEDIMENTARY VALLEY FILL AND CONTINUES TO DRIVE THE GEOTHERMAL SYSTEM. ESTIMATED DEPTH TO TOP OF THE INTRUSIVE MASS IS 6,500 TO 7,500 FEET. RECHARGE OF METEORIC WATER INTO THE SYSTEM MAY OCCUR ALONG AN INFERRED PARALLEL FAULT ABOUT 5 MILES NORTHEAST OF THE RIDGE. MAP SHOWS MAGNETIC CONTOURS AND SIMPLIFIED SURFACE GEOLOGY ON A BASE MAP OF SURFACE FEATURES (NATURAL DRAINAGE, SWAMPS, THERMAL SPRINGS, ROADS, TOWNS, AND GEOTHERMAL AND CARBON DIOXIDE WELL LOCATIONS). (OALS)

GEOTHERMAL STUDIES/MAPS/MAGNETIC STUDIES/REMOTE SENSING/CALIFORNIA/SURVEYS/GEOPHYSICS/SUBSURFACE MAPPING/IGNEOUS ROCKS/NATURAL RECHARGE/FAULTS(GEOLOGIC)/GEOLOGY/THERMAL SPRINGS/CARBON DIOXIDE
/IDENTIFIERS: /SALTON SEA FIELD/IMPERIAL VALLEY/AEROMAGNETIC SURVEYS/GEOTHERMAL WELLS/HOT WATER SYSTEMS

85

HAIGLER, L.B.

1969

GEOTHERMAL RESOURCES. IN MINERAL AND WATER RESOURCES OF ARIZONA.

ARIZONA BUREAU OF MINES, BULLETIN 180:575-580. GA 286-214.

BRIEFLY SUMMARIZES POWER PRODUCTION AND SPACE HEATING IN WESTERN U.S. AND CERRO PRIETO, MEXICO. PROBLEMS OF DISPOSAL OF SALINE WASTE WATER FROM HOT WATER SYSTEMS ARE MENTIONED. THE ONLY INDICATIONS OF POTENTIALLY VALUABLE GEOTHERMAL RESOURCES IN ARIZONA ARE A FEW THERMAL SPRINGS AND WELLS SHOWING HIGH THERMAL GRADIENTS. DATA FOR THESE ARE LISTED, AND LOCATIONS ARE PLOTTED ON AN INDEX MAP.

WASTE WATER DISPOSAL/THERMAL SPRINGS/WELLS/ARIZONA/GEOTHERMAL STUDIES
/IDENTIFIERS: /CERRO PRIETO FIELD, MEXICO/SPACE HEATING/TEMPERATURE GRADIENT/GEOTHERMAL RESOURCES

86

HAMILTON, R.M./MUFFLER, L.J.P.

1972

MICROEARTHQUAKES AT THE GEYSERS GEOTHERMAL AREA, CALIFORNIA.

JOURNAL OF GEOPHYSICAL RESEARCH 77(11):2081-2086.

SEE: SWRA W73-00326.

GEOTHERMAL STUDIES/MAPPING/SEISMIC STUDIES/SEISMOLOGY/FAULTS(GEOLOGIC)/INSTRUMENTATION/MONITORING/EPICENTERS/EARTHQUAKES/EARTHQUAKE FOCUS/PORE PRESSURE/CALIFORNIA/BIBLIOGRAPHIES/ENVIRONMENTAL EFFECTS/SEISMOGRAPHS/GEOLOGY/EXPLORATION
/IDENTIFIERS: /MICROEARTHQUAKES/GEOTHERMAL INVESTIGATIONS/GEOTHERMAL RESOURCES/GEYSERS FIELD, CALIFORNIA

87

HAMMOND, A.L.

1972

GEOTHERMAL ENERGY: AN EMERGING MAJOR RESOURCE.

SCIENCE 177(4053):978-980. EIA 73-00078.

SEE: SWRA W73-06413.

GEOTHERMAL STUDIES/ENERGY/INJECTION WELLS/STEAM/SUBSIDENCE/EXPLORATION/ENVIRONMENTAL EFFECTS/BRINE DISPOSAL/HEATED WATER/THERMAL POWERPLANTS/POWERPLANTS/SPATIAL DISTRIBUTION
/IDENTIFIERS: /GEYSERS FIELD, CALIFORNIA/CERRO PRIETO FIELD, MEXICO/ISOBUTANE/VALLES CALDERA/SALTON SEA/GEOTHERMAL RESOURCES/POWER CAPACITY

88

HAMMOND, A.L.

1975 A

EXPLORING THE CONTINENT BY DRILLING: A NEW PROPOSAL.

SCIENCE 189(4196):35.

A PROGRAM OF DRILLING TO DEPTHS AS GREAT AS 10 KM HAS BEEN PROPOSED: GOALS ARE TO INVESTIGATE EARTHQUAKE CONTROL, EXPLORE DEEP GEOTHERMAL SYSTEMS, AND STUDY GEOLOGY AND STRUCTURE OF CRYSTALLINE BASEMENT ROCKS. DRILLING INTO DEEP HYDROTHERMAL SYSTEMS AND EVENTUALLY INTO A MAGMA CHAMBER WOULD YIELD A WEALTH OF INFORMATION ABOUT PHYSICS OF GEOTHERMAL SYSTEMS, ORIGIN OF HYDROTHERMAL FLUIDS, MAGNITUDE OF GEOTHERMAL RESOURCES, AND BASIC IGNEOUS AND ORE-FORMING PROCESSES. NEW DRILLING AND INSTRUMENTATION TECHNOLOGY NEEDS TO BE DEVELOPED FIRST. HIGH COST (100 MILLION DOLLARS OVER 10 YEARS) MAY BE REPAID BY INADVERTENT ORE DEPOSIT DISCOVERIES. (OALS)

GEOTHERMAL STUDIES/HYDROTHERMAL STUDIES/EXPLORATION/ON-SITE INVESTIGATIONS/DRILLING/DEEP WELLS/EARTHQUAKES/GEOLOGY/IGNEOUS ROCKS/DRILLING EQUIPMENT/INSTRUMENTATION/COSTS
/IDENTIFIERS: /GEOTHERMAL RESERVOIRS/MAGMA/GEOTHERMAL FLUIDS/GEOTHERMAL RESOURCES/MINERAL DEPOSITS/DRILLING COSTS

89

HAMMOND, A.L.

1975 B

MINERALS AND PLATE TECTONICS: A CONCEPTUAL REVOLUTION.

SCIENCE 189(4205):779-781.

NEW PLATE TECTONICS IDEAS ARE UNIFYING THEORIES OF METAL ORE DEPOSITION. MANY ORE DEPOSITS WERE CONCENTRATED BY HYDROTHERMAL CONVECTION SYSTEMS ASSOCIATED WITH VOLCANISM AND IGNEOUS INTRUSION ALONG DIVERGENT AND CONVERGENT PLATE BOUNDARIES (MID-OCEANIC RIDGES, RIFT ZONES, ISLAND ARCS, SUBDUCTION ZONES) AND ABOVE MANTLE HOT SPOTS. PORPHYRY COPPER AND MASSIVE SULFIDE DEPOSITS (CONTAINING COPPER, MOLYBDENUM, GOLD, SILVER, LEAD, ZINC, AND OTHER METALS) MAY FORM BY DOUBLE CONCENTRATION, FIRST AT SPREADING RIDGES AND THEN IN SUBDUCTION ZONES. PLATE TECTONIC THEORY CAN BE A MINERALS EXPLORATION TOOL. AND, IN TURN, ANCIENT ORE DEPOSITS SIMILAR TO MORE RECENT ONES CAN BE CLUES TO PLATE TECTONIC ACTIVITY AS LONG AGO AS 3 BILLION YEARS. (OALS)

GEOTHERMAL STUDIES/HYDROTHERMAL STUDIES/METALS/GEOLOGY/IGNEOUS ROCKS/COPPER/MOLYBDENUM/GOLD/LEAD/ZINC/EXPLORATION
/IDENTIFIERS: /GLOBAL TECTONICS/MINERAL DEPOSITS/HYDROTHERMAL CONVECTION SYSTEMS/VOLCANISM/PLATE BOUNDARIES/RIFT ZONES/MID-OCEANIC RIDGES/SUBDUCTION/HOT SPOTS/SILVER/ISLAND ARCS

90

HAMMOND, A.L.

1975 C

MINERALS AND PLATE TECTONICS (II): SEAWATER AND ORE FORMATION.

SCIENCE 189(4206):868-869, 915, 917.

GOLD, TIN, TUNGSTEN, MOLYBDENUM, AND SILVER ARE NOW THOUGHT TO BE CONCENTRATED IN THE SUBMARINE ENVIRONMENT OF MID-OCEANIC RIDGES AND ISLAND ARCS BY DEEP (PERHAPS DOWN TO 10 KM) HYDROTHERMAL CONVECTION OF SEA WATER THROUGH NEWLY FORMED VOLCANIC ROCKS. SEAWATER ALTERS THE ROCKS, RELEASING THE METALS, AND SOLUBLE METAL-CHLORIDE COMPLEXES ARE FORMED WHICH CAN PRECIPITATE AT THE SURFACE UNDER FAVORABLE GEOCHEMICAL CONDITIONS TO FORM METAL-RICH SEDIMENTS. SUCH SUBMARINE HYDROTHERMAL SYSTEMS HAVE BEEN OBSERVED RECENTLY ALONG THE MID-ATLANTIC RIDGE AND THE GALAPAGOS RIFT. MOST SPECTACULAR IS THE METAL-RICH HOT BRINE CONVECTION SYSTEM OF THE RED SEA, WHERE SEDIMENTS ARE ENRICHED IN COPPER, LEAD, AND ZINC. SAUDI ARABIA AND SUDAN HAVE AGREED TO SHARE THESE SEA

FLOOR RESOURCES. MINING COMPANIES ARE LARGELY SKEPTICAL OF PLATE TECTONICS IDEAS RELATED TO METAL ORE DEPOSITS, BUT OIL COMPANY MINERAL EXPLORATION GROUPS AND UNIVERSITY SCIENTISTS HAVE ENTHUSIASTICALLY ADOPTED THEM. (OALS)

GEOTHERMAL STUDIES/HYDROTHERMAL STUDIES/SEA WATER/METALS/GEOLOGY/GOLD/LEAD/MOLYBDENUM/MARINE GEOLOGY/SUBMARINE SPRINGS/IGNEOUS ROCKS/SEDIMENTS/COPPER/ZINC/MINERAL INDUSTRY
/IDENTIFIERS: /MINERAL DEPOSITS/TIN/TUNGSTEN/SILVER/MID-OCEANIC RIDGES/SUDAN/ISLAND ARCS/VOLCANISM/HYDROTHERMAL CONVECTION SYSTEMS/HYDROTHERMAL ALTERATION/CHLORIDES/RIFT ZONES/HOT BRINES/RED SEA/SAUDI ARABIA/GLOBAL TECTONICS/OIL INDUSTRY/UNIVERSITIES

91

HARLOW, F.H./PRACHT, W.E.

1972

A THEORETICAL STUDY OF GEOTHERMAL ENERGY EXTRACTION.

JOURNAL OF GEOPHYSICAL RESEARCH 77(35):7038-7048.

SEE: SWRA W74-10087.

GEOTHERMAL STUDIES/THERMAL WATER/THEORETICAL ANALYSIS/HYDROFRACTURING/ENERGY
/IDENTIFIERS: /GEOTHERMAL ENERGY EXTRACTION/THERMAL POWER/GEOTHERMAL WELL LIFE/HOT-DRY ROCKS

92

HARSHBARGER, J.W.

1972 A

OVERVIEW OF GEOTHERMAL RESOURCES POTENTIAL IN ARIZONA.

ARIZONA BUREAU OF MINES, FIELD NOTES 2(2):9-12.

INTENSIVE GEOLOGICAL AND GEOPHYSICAL EXPLORATION SURVEYS AND STUDIES OF THE POTENTIAL GEOTHERMAL RESOURCES IN ARIZONA ARE ACTIVELY UNDERWAY. DATA ON 25 WELLS AND SPRINGS IN LOCALITIES WHERE THERMAL WATERS OF 100 DEGREES F. OR GREATER ARE KNOWN, ARE PRESENTED. THERE ARE NO KNOWN GEOTHERMAL RESOURCES AREAS WHICH PRODUCE GEOTHERMAL STEAM IN ARIZONA, AND NO KNOWN BOREHOLES HAVE BEEN DRILLED TO EXPLORE THE POTENTIAL OF GEOTHERMAL ENERGY. A RESUME OF CONDITIONS RELATED TO POTENTIAL GEOTHERMAL RESOURCES IS GIVEN, WITH THE CONCLUSIONS: 1) THAT THERE ARE NO KNOWN SUCH AREAS IN ARIZONA, ALTHOUGH IN SOUTHERN ARIZONA THERE ARE MANY GEOLOGIC STRUCTURAL AND ROCK CHARACTERISTICS SIMILAR TO KNOWN GEOTHERMAL RESERVOIRS, 2) THAT THERE ARE NO SURFACE INDICATIONS OF STEAM LEAKAGE, BUT THAT THE OCCURRENCE OF THERMAL WATER NEAR FAVORABLE GEOLOGIC FEATURES SUGGESTS THE POTENTIAL OCCURRENCE OF GEOTHERMAL ENERGY, 3) THAT THE APPLICATION OF STUDY, IMAGINATION, AND DATA FROM BOREHOLE DRILLING PROGRAMS COULD LEAD TO SUCCESSFUL GEOTHERMAL DEVELOPMENT.

GEOTHERMAL STUDIES/EXPLORATION/ARIZONA/THERMAL SPRINGS/WELLS/STEAM/BOREHOLE GEOPHYSICS/WELL DATA/THERMAL WATER/GEOLOGIC INVESTIGATIONS
/IDENTIFIERS: /GEOTHERMAL RESOURCES

93

HARSHBARGER, J.W.

1972 B

OVERVIEW OF GEOTHERMAL RESOURCES POTENTIAL IN ARIZONA. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER A, 13 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03420.

GEOTHERMAL STUDIES/THERMAL WATER/SUBSURFACE WATERS/ARIZONA/GEOPHYSICS/WATER TEMPERATURE/THERMAL PROPERTIES/THERMAL SPRINGS/THERMAL POWER
/IDENTIFIERS: /GEOTHERMAL RESOURCES

94

HATTON, J.W.

1973

GROUND SUBSIDENCE OF A GEOTHERMAL FIELD DURING EXPLOITATION. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1294-1296.

SEE: SWRA W74-09010.

SUBSIDENCE/WITHDRAWAL/DAMAGES/HYDROTHERMAL STUDIES/GEOTHERMAL STUDIES/THERMAL POWER/WATER LEVELS/HYDROGEOLOGY/LAND SUBSIDENCE/SURVEYS/ENVIRONMENTAL EFFECTS
/IDENTIFIERS: /NEW ZEALAND/GEOTHERMAL POWER/WAIRAKEI

95

HEAD, J.

1970

GEOTHERMAL ENERGY FOR GREENHOUSE HEATING.

ORE BIN 32(9):182-183.

ONE POSSIBLE USE OF GEOTHERMAL ENERGY IS IN GREENHOUSE AND SOIL HEATING, NOW BEING DONE IN SEVERAL NATIONS AROUND THE WORLD. THIS ARTICLE DESCRIBES THE COMMERCIAL GREENHOUSE TOMATO-GROWING OPERATION OF OREGON DESERT FARMS, INC., IN THE HIGH DESERT COUNTRY OF OREGON WHERE SUMMERS ARE HOT AND WINTERS COLD. TOMATOES ARE GROWN YEAR-ROUND BY TAPPING GEOTHERMAL HEAT AT 440 FEET BELOW THE SURFACE BY PUMPING COLD WATER INTO HEAT EXCHANGERS. THIS PROVIDES A CONSTANT 70 DEGREE TEMPERATURE WITHIN THE GREENHOUSE UNDER OUTSIDE CONDITIONS OF ZERO DEGREES WITH A 10-MILE PER HOUR WIND. THE GREENHOUSES ARE COOLED IN THE SUMMERTIME BY A SYSTEM OF EVAPORATIVE COOLING AND FANS.

GEOTHERMAL STUDIES/GREENHOUSES/OREGON/TOMATOES/HEAT EXCHANGERS/HEATING
/IDENTIFIERS: /SOIL HEATING/SPACE HEATING

96

HEALY, J./HOCHSTEIN, M.P.

1973

HORIZONTAL FLOW IN HYDROTHERMAL SYSTEMS.

JOURNAL OF HYDROLOGY (NEW ZEALAND) 12(2):71-82.

SEE: SWRA W75-02382.

HYDROTHERMAL SYSTEMS/THERMAL WATER/GEOTHERMAL STUDIES/RESISTIVITY/WELLS/ GROUNDWATER MOVEMENT/PERMEABILITY/WATER TEMPERATURE/HYDROLOGIC ASPECTS/ MODEL STUDIES/GROUNDWATER/EXPLORATION
/IDENTIFIERS: /MAGMATIC HEAT SOURCE/CHILE/NEW ZEALAND/HORIZONTAL FLOW/ GEOTHERMAL RESERVOIRS/GEOTHERMAL WATER/PRODUCTION WELLS

97

HEBB, D.H.

1972

SOME ECONOMIC FACTORS OF GEOTHERMAL ENERGY.

MINES MAGAZINE 62(7):15-19. EIA 72-08231.

WHEN COMPARED WITH OTHER TYPES OF ENERGY, GEOTHERMAL POWER HAS AN ECONOMIC ADVANTAGE. SUCH POWERPLANTS ARE EXPENSIVE TO BUILD, BUT CHEAP TO RUN. ONE LARGE PROBLEM LIES IN POSSIBLE DAMAGE TO THE ENVIRONMENT BY GEOTHERMAL WELLS AND PLANTS. SOME EXAMPLES OF POSSIBLE ADVERSE AFFECTS ARE: NOISE AND VISUAL POLLUTION, ATMOSPHERIC AND HYDROSPHERIC THERMAL POLLUTION, AND SEISMIC STIMULATION FROM THE RE-INJECTION OF WASTE WATERS.

GEOTHERMAL STUDIES/WATER POLLUTION/AIR POLLUTION/ENVIRONMENTAL EFFECTS/ ELECTRIC POWER PRODUCTION/ECONOMIC EFFICIENCY/COSTS/THERMAL POWER/THERMAL POLLUTION/OPERATING COSTS/EARTHQUAKES/INJECTION
/IDENTIFIERS: /ALTERNATIVE ENERGY SOURCES/GEOTHERMAL POWER

98

HENDERSON, F.B./PHILLIPS, S.L./TRIPPE, T.

1975

COMPILATION OF GEOTHERMAL INFORMATION. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS I-15.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

LAWRENCE BERKELEY LABORATORY IS ESTABLISHING A NATIONAL GEOTHERMAL INFORMATION RESOURCE (GRID). THIS COMPILATION IS A JOINT EFFORT WITH THE U.S. GEOLOGICAL SURVEY. GRID WILL COLLECT AND CRITICALLY EVALUATE INFORMATION AND DATA GATHERED FROM BOTH DOMESTIC AND FOREIGN SOURCES. THE FOLLOWING MAJOR CATEGORIES ARE COVERED: EXPLORATION AND EVALUATION, PHYSICAL CHEMISTRY, UTILIZATION AND ECONOMICS, AND ENVIRONMENTAL, LEGAL AND INSTITUTIONAL CONSIDERATIONS. BIBLIOGRAPHIC AND NUMERICAL DATA ARE COMPILED IN TWO FORMATS, LOOSE-LEAF HANDBOOK, AND COMPUTER-AIDED RECALL. INCLUDES ANNOTATED AND INDEXED BIBLIOGRAPHY OF GEOTHERMAL LITERATURE AND DATA, AND CRITICAL COMPARISONS AMONG ALTERNATIVE METHODS OF GEOTHERMAL DEVELOPMENT AND UTILIZATION. WHEN FULLY ESTABLISHED, GRID WILL BE A READY AND UP-TO-DATE SOURCE OF INTERPRETED AND EVALUATED GEOTHERMAL INFORMATION AND DATA COMPILED FROM BOTH PUBLISHED LITERATURE AND UNPUBLISHED DATA SOURCES OF THE WORLD, AND WILL PROVIDE A VARIETY OF SERVICES IN TRANSFER OF THIS INFORMATION FROM THE ORIGINATOR TO ULTIMATE USER.

GEOTHERMAL STUDIES/DATA COLLECTIONS/BIBLIOGRAPHIES/DATA STORAGE AND RETRIEVAL/ DATA TRANSMISSION/INFORMATION RETRIEVAL/DOCUMENTATION/EXPLORATION/ECONOMICS/ ENVIRONMENTAL EFFECTS/LEGAL ASPECTS
/IDENTIFIERS: /WORLD

99

HEWITT, W.P./STOWE C.H./STROMBERG, R.R.

1972

UTAH'S GEOTHERMAL RESOURCES, LOCATION, POTENTIAL, AND ADMINISTRATIVE AGENCIES. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER K, 12 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03430.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/UTAH/THERMAL WATER/ WATER TEMPERATURE/THERMAL PROPERTIES/GEOLOGY/HYDROGEOLOGY/THERMAL SPRINGS/ EXPLORATION/WATER QUALITY/HOT SPRINGS/SPATIAL DISTRIBUTION /IDENTIFIERS: /GEOTHERMAL RESOURCES

100

HEYLMUN, E.B.

1966

GEOTHERMAL POWER POTENTIAL IN UTAH.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY, SPECIAL STUDIES 14. 28 P.
ANAG(1966) 5298.

A BRIEF SUMMARY OF POTENTIAL FOR DEVELOPMENT OF GEOTHERMAL ENERGY. PREVIOUS WORK IN UTAH IS LISTED AND MENTION IS MADE OF EXPLORATION METHODS USED THROUGHOUT THE WORLD. THERMAL SPRING AREAS ARE GROUPED INTO WASATCH, WESTERN DESERT, SEVIER-SANPETE, PANGUITCH, HURRICANE, AND SNAKE VALLEY AREAS, ALL ROUGHLY PARALLEL OR EN ECHELON AND TRENDING IN NORTH-SOUTH OR NORTHEAST-SOUTHWEST DIRECTIONS. SHORT DESCRIPTIONS ARE GIVEN OF EACH AREA INCLUDING PRINCIPAL WARM AND HOT SPRINGS. OIL, GAS, AND WATER WELLS WHICH HAVE PENETRATED WARM OR HOT WATER AT DEPTH ARE LISTED WITH DEPTH AND TEMPERATURES RECORDED; TEMPERATURES ARE GIVEN ALSO FOR A FEW MINES. AVAILABLE CHEMICAL ANALYSES OF HOT SPRING WATERS ARE INCLUDED. THE WASATCH AND WESTERN DESERT AREAS ARE THE MOST EXTENSIVE BUT THE LATTER OFFERS THE GREATER POSSIBILITY FOR DEVELOPMENT OF STEAM WELLS.

GEOTHERMAL STUDIES/UTAH/THERMAL POWER/STEAM/WELLS/EXPLORATION/THERMAL SPRINGS/ TEMPERATURE/HOT SPRINGS/CHEMICAL ANALYSIS/WELLS /IDENTIFIERS: /GEOTHERMAL RESOURCES

101

HICKEL, W.J.

1973

GEOTHERMAL ENERGY, A NATIONAL PROPOSAL FOR GEOTHERMAL RESOURCES RESEARCH. FINAL REPORT OF THE GEOTHERMAL RESOURCES RESEARCH CONFERENCE, BATTELLE SEATTLE RESEARCH CENTER, SEATTLE, WASHINGTON, 1972.

UNIVERSITY OF ALASKA. 95 P. AVAILABLE NTIS AS PB-216 423.

SEE: SWRA W74-04917.

GEOTHERMAL STUDIES/CONFERENCES/THERMAL POWER/RESEARCH AND DEVELOPMENT/ WATER RESOURCES DEVELOPMENT/TECHNOLOGY/MODEL STUDIES /IDENTIFIERS: /GEOTHERMAL ENERGY/GEOTHERMAL RESOURCES DEVELOPMENT

102

HILL, D.P./MOWINCKEL, P./PEAKE, L.G.

1975

EARTHQUAKES, ACTIVE FAULTS, AND GEOTHERMAL AREAS IN THE IMPERIAL VALLEY, CALIFORNIA.

SCIENCE 188(4195):1306-1308.

A NETWORK OF 20 SEISMOGRAPH STATIONS HAS YIELDED DETAILED EARTHQUAKE DATA. EARTHQUAKE SWARM EPICENTERS (CLOSELY ASSOCIATED WITH TWO KNOWN GEOTHERMAL AREAS) OCCURRED ALONG IMPERIAL AND BRAWLEY FAULTS WITH A GEOMETRY WHICH SUGGESTS THAT THE SPREADING CENTER BETWEEN THEM (BRAWLEY GEOTHERMAL ANOMALY) IS A COMPLEX OF EN ECHELON STRIKE-SLIP FAULTS RATHER THAN A SINGLE RIFT. EARTHQUAKES ALSO OCCURRED ALONG SAN JACINTO FAULT, INDICATING THAT IT, TOO, IS ACTIVE. EARTHQUAKE SWARMS (MICROEARTHQUAKE CLUSTERS) ARE COMMON IN IMPERIAL VALLEY ALONG FAULTS AND BENEATH GEOTHERMAL ANOMALIES AND ARE REGARDED AS PROMISING SIGNS IN GEOTHERMAL PROSPECTING. (OALS)

GEOTHERMAL STUDIES/EARTHQUAKES/FAULTS(GEOLOGIC)/CALIFORNIA/SEISMIC STUDIES/ GEOPHYSICS/SEISMOGRAPHS/ON-SITE DATA COLLECTIONS/GEOLOGY/MOVEMENT /IDENTIFIERS: /IMPERIAL VALLEY/SPREADING CENTERS/RIFT ZONES

103

HODDER, D.T.

1973

APPLICATION OF REMOTE SENSING TO GEOTHERMAL PROSPECTING. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(1):368-380.

FEASIBILITY OF RECONNAISSANCE GEOTHERMAL EXPLORATION WITH AIRBORNE OR SPACECRAFT REMOTE SENSORS WAS STUDIED USING KNOWN GEOTHERMAL SITES IN LONG VALLEY AND SALTON SEA AREAS, CALIFORNIA AS EXAMPLES. MULTIBAND PHOTOGRAPHY IN VISIBLE AND NEAR INFRARED DETECTS HYDROTHERMAL ALTERATION HALOES, SOIL MOISTURE ANOMALIES, AND GEOLOGICAL STRUCTURES. PASSIVE THERMAL INFRARED IMAGERY (8 TO 14 MICRON) AND PASSIVE MICROWAVE RADIOMETRY (16 AND 19 GIGAHERTZ) DETECT TEMPERATURE ANOMALIES. EFFECTS OF DIURNAL AND SEASONAL CYCLES AND FLIGHT ALTITUDE ON SPECTRAL AND THERMAL SIGNATURES WERE MEASURED. INEXPENSIVE AERIAL THERMAL MAPPING IS SUGGESTED AS THE MOST EFFECTIVE FIRST STEP IN A REGIONAL EXPLORATION PROGRAM, RAPIDLY NARROWING THE CHOICE OF AREAS FOR MORE DETAILED SURVEYS. (OALS)

GEOTHERMAL STUDIES/EXPLORATION/REMOTE SENSING/AERIAL PHOTOGRAPHY/INFRARED RADIATION/MICROWAVES/THERMAL RADIATION/INSTRUMENTATION/MAPPING/SURVEYS/ON-SITE INVESTIGATIONS/SOIL MOISTURE/STRUCTURAL GEOLOGY
/IDENTIFIERS: /IMPERIAL VALLEY/SALTON SEA/MULTIBAND PHOTOGRAPHY/INFRARED PHOTOGRAPHY/HYDROTHERMAL ALTERATION

104

HODDER, D.T.

1975

COMPARISON OF SATELLITE AND AIRBORNE INFRARED LINE SCANNING OF ETHIOPIA FOR GEOTHERMAL EXPLORATION. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS III-41.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

HIGH ALTITUDE (10,000 FEET) AIRBORNE INFRARED LINE SCANNING OF THE DANAKIL DEPRESSION REVEALED OVER 100 THERMAL ANOMALIES LATER IDENTIFIED BY HELICOPTER-SUPPORTED FIELD GEOLOGISTS AS THERMAL SPRINGS OR RELATED PHENOMENA. THESE ANOMALIES WERE GENERALLY 10 DEGREES C. ABOVE AMBIENT OVER AN AREA OF 100 M2 OR GREATER. IN SOME CASES THESE ANOMALIES OCCUR IN LINEAR BELTS TENS OF KM IN LENGTH. IT IS POSSIBLE TO SEPARATE OUT FEATURES IN SATELLITE IR IMAGERY WHICH CORRELATE WITH THESE ANOMALIES. A METHOD OF EXPLORATION FOR POORLY MAPPED AREAS IS PROPOSED: START WITH PHOTOGEOLOGY AND ISOTHERMAL MAPPING FROM AVAILABLE SATELLITE IMAGERY, RESURVEY ANOMALOUS ZONES FROM AIRCRAFT FOR HIGHER RESOLUTION, AND FINALLY FIELD CHECK A VERY LIMITED NUMBER OF SITES.

GEOTHERMAL STUDIES/AFRICA/REMOTE SENSING/AERIAL PHOTOGRAPHY/INFRARED RADIATION/SATELLITES(ARTIFICIAL)/EXPLORATION/THERMAL SPRINGS
/IDENTIFIERS: /ETHIOPIA/DANAKIL DEPRESSION/DEVELOPING COUNTRIES

105

HOLDREN, J./ HERRERA, P.

1971

ENERGY, A CRISIS IN POWER.

SIERRA CLUB, SAN FRANCISCO. 252 P.

A THOROUGH REVIEW OF THE PROBLEMS OF ENERGY, PARTICULARLY ELECTRICAL POWER, FROM THE POINT OF VIEW OF THE ENVIRONMENTALISTS. GEOTHERMAL POWER IS DISCUSSED IN A CHAPTER ON POSSIBLE IMPORTANT, NON-POLLUTING ENERGY SOURCES. SOME DOUBT IS CAST ON THE POTENTIAL IMPORTANCE OF THIS RESOURCE, BUT FUTURE RESEARCH IS URGED.

ENERGY/ELECTRIC POWER/ENVIRONMENTAL ENGINEERING/THERMAL POWER/GEOTHERMAL STUDIES
/IDENTIFIERS: /GEOTHERMAL ENERGY/ALTERNATIVE ENERGY SOURCES

106

HOUSE, P.A./JOHNSON, P.M.

1975

POTENTIAL POWER GENERATION AND GAS PRODUCTION FROM GULF COAST GEOPRESSURE RESERVOIRS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS VII-18.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

EXTENSIVE ON-SHORE AND OFF-SHORE ZONES OF GEOPRESSURED SAND RESERVOIRS ARE FOUND IN THE TEXAS AND LOUISIANA GULF COAST REGION. ENERGY IN THESE WATER RESERVOIRS EXISTS IN THE FORM OF NATURAL GAS IN SOLUTION, GEOTHERMAL, AND GEOHYDRAULIC ENERGY. CLASSES I, II, AND III OF RESERVOIRS ARE DEFINED WITH

DEPTHS OF 5,000-10,000, 10,000-15,000, AND 15,000-20,000 FEET. RESERVOIR FLUID TEMPERATURES AND PRESSURES ARE 200 DEGREES F., 250 DEGREES F., 300 DEGREES F., AND 5100 PSI, 9100 PSI, AND 12800 PSI, RESPECTIVELY. NATURAL GAS IS ASSUMED TO EXIST AT SATURATION LEVELS. ECONOMIC ANALYSIS INDICATES THAT CLASS I RESERVOIRS WOULD BE PROFITABLE FOR GAS PRODUCTION, CLASSES II AND III FOR COMBINED POWER GENERATION AND GAS PRODUCTION. CLASS III RESERVOIR WITHOUT PRESENCE OF GAS WOULD BE MARGINALLY PROFITABLE FOR ELECTRICAL GENERATION ALONE.

GEOTHERMAL STUDIES/GULF OF MEXICO/TEXAS/LOUISIANA/ECONOMICS/NATURAL GAS/GULF COASTAL PLAIN
/IDENTIFIERS: /GEOPRESSURED SYSTEMS/GEOTHERMAL RESOURCES/GEOTHERMAL RESERVOIRS/ GEOTHERMAL POWER

107

HUBBERT, M.K.

1971

THE ENERGY RESOURCES OF THE EARTH.

SCIENTIFIC AMERICAN 224(3):60-70.

FROM THIS QUANTITATIVE SURVEY AND EVALUATION OF WORLD ENERGY RESOURCES, THE AUTHOR COMES TO THE CONCLUSION THAT WHILE THE FUTURE FOR FOSSIL FUELS IS NOT BRIGHT, THE POTENTIAL OF GEOTHERMAL POWER, WHICH HE ESTIMATES AT NO MORE THAN 60,000 MW/YEAR OVER THE NEXT FIFTY YEARS, IS HARDLY MORE SO.

ENERGY/THERMAL POWER/RESOURCES DEVELOPMENT/FOSSIL FUELS/FORECASTING
/IDENTIFIERS: /GEOTHERMAL RESOURCES/WORLD

108

HUGHES, E.E./DICKSON, E.M./SCHMIDT, R.A.

1974

CONTROL OF ENVIRONMENTAL IMPACTS FROM ADVANCED ENERGY SOURCES.

U.S. ENVIRONMENTAL PROTECTION AGENCY, TECHNOLOGY SERIES, REPORT EPA-600/2-74-002. 326 P.

SEE: SWRA W75-05313.

ENVIRONMENTAL CONTROL/ENERGY TECHNOLOGY/AIR POLLUTION/GEOTHERMAL ENERGY/ ENERGY/OIL SHALES/SOLID WASTES/HYDROGEN/ENVIRONMENTAL EFFECTS/RESEARCH AND DEVELOPMENT
/IDENTIFIERS: /COAL GASIFICATION/ENVIRONMENTAL IMPACT/SOLAR ENERGY/HYDROGEN ENERGY SOURCES/ALTERNATIVE ENERGY SOURCES

109

HUTCHINSON, A.J.L.

1974

POWER GENERATION FROM HOT BRINES.

U.S. PATENT OFFICE, OFFICIAL GAZETTE 928(1):54. U.S. PATENT 3,845,627. 6 P.

SEE: SWRA W75-03737.

PATENTS/HEAT FLOW/HEAT EXCHANGERS/HEAT TRANSFER/GROUNDWATER/SPECIFIC GRAVITY/ VAPOR PRESSURE/SALTS/MINERALS/STEAM/OILY WATER
/IDENTIFIERS: /POWER GENERATION/POWER SOURCES/GEOTHERMAL WELLS/GASES/ GEOTHERMAL HEAT/GEOTHERMAL FLUIDS/HOT BRINES/HEAT TRANSFER FLUIDS/VAPOR-TURBINE CYCLE/CLOSED SYSTEMS

110

ISITA, J./MOOSER, F./SOTO, S.

1975

THE CERRO PRIETO GEOTHERMAL FIELD. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS I-17.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

INCREASING EVIDENCE SHOWS THAT CERRO PRIETO FIELD STANDS ON WESTERN EXTREME OF SPREADING RIDGE UNITING ACTIVE SAN JACINTO AND IMPERIAL FAULTS. 37 WELLS HAVE BEEN DRILLED WEST OF SAN JACINTO FAULT TO DEPTHS FROM 600 TO 2,600 M, PENETRATING BELOW A THICK SEALING CAP OF CLAYS AND SANDY CLAYS. OPTIMUM PRODUCING HORIZON (PLEISTOCENE FLUVIAL SANDSTONES AND SANDY SHALES) IS AT 900 TO 1,500 M. EAST OF SAN JACINTO FAULT NEW WELL M-53 STRUCK PRODUCING HORIZON AT 1,800 TO 2,000 M, THUS PROVING DOWNDROP OF 500 M. HIGH BOTTOM HOLE TEMPERATURE (344 DEGREES C.), AND HIGH WELLHEAD FLOW PRESSURE (1,090 PSI) OF THIS WELL PROMISE THAT MORE IMPORTANT EXTENSIONS OF THIS FIELD PROBABLY LIE EAST OF PRESENT FIELD, WITHIN THE TECTONICALLY SPREADING RIFT AREA.

GEOTHERMAL STUDIES/GEOLOGY/DEPTH/FAULTS(GEOLOGIC)/WATER TEMPERATURE/PRESSURE/MEXICO
/IDENTIFIERS: /CERRO PRIETO FIELD, MEXICO/RIFT ZONES/SPREADING CENTERS/CAP ROCK/PRODUCTION/WELLS/EXPLORATION WELLS

111

IYENGAR, B.R.R.

1973

GEOTHERMAL RESOURCES IN INDIA. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1044-1049.

SEE: SWRA W74-08980.

GEOTHERMAL STUDIES/THERMAL WATER/THERMAL SPRINGS/HOT SPRINGS/THERMAL POWER/HYDROGEOLOGY/ASIA/EXPLORATION/DRILLING
/IDENTIFIERS: /GEOTHERMAL POWER/INDIA/GEOTHERMAL RESOURCES/HOT WATER SYSTEMS/POWER CAPACITY

112

JACOBY, C.H.

1974

SALT DOMES AS A SOURCE OF GEOTHERMAL ENERGY.

MINING ENGINEERING 26(5):34-39.

SALT DOMES IN SEDIMENTARY BASINS HAVE KNOWN VALUE AS HYDROCARBON TRAPS AND CHEMICAL RESOURCES, BUT THE AUTHOR BELIEVES THEIR MAIN VALUE IN THE FUTURE WILL BE AS GEOTHERMAL ENERGY SOURCES. ROCK SALT THERMAL CONDUCTIVITY IS VERY HIGH, SO A SALT DOME CAN ACT AS A VERTICAL HEAT CONDUIT, WITH HEAT FLOW 5 TO 8 TIMES REGIONAL AVERAGE (GULF OF MEXICO COAST). SEVERAL TECHNIQUES FOR EXPLOITING SALT DOME HEAT ARE SUGGESTED: DRILLING OF TWO WELLS TO A SINGLE SOLUTION CAVITY FOR WATER CIRCULATION AND HOT BRINE OR STEAM TRANSFER TO SURFACE POWER EQUIPMENT, USE OF CAVITY AS GIANT CHEMICAL RETORT, AND DESALINATION BY CONDENSING STEAM BOILED IN CAVITY. CIRCULATION FLUID CAN ALSO BE A LIQUID IN WHICH SALT IS NOT SOLUBLE. AND ENERGY CAN BE STORED UNDERGROUND BY PUMPING HIGH PRESSURE AIR INTO SUCH A SALT DOME CAVITY. (OALS)

GEOTHERMAL STUDIES/GULF COASTAL PLAIN/SEDIMENTARY BASINS(GEOLOGIC)/SALTS/OIL RESERVOIRS/SODIUM CHLORIDE/THERMAL CONDUCTIVITY/THERMAL PROPERTIES/HEAT FLOW/HEAT TRANSFER/HEAT EXCHANGERS/DESALINATION
/IDENTIFIERS: /SALT DOMES/GEOTHERMAL ENERGY/GEOTHERMAL POWER/GEOTHERMAL HEAT/TEMPERATURE GRADIENT/HOT BRINES

113

JAMES, R.

1973

THE ECONOMICS OF THE SMALL GEOTHERMAL POWER STATION. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1697-1704.

SEE: SWRA W74-09045.

THERMAL POWER/GEOTHERMAL STUDIES/ELECTRIC POWER COSTS/ECONOMIES OF SCALE/COSTS/INCOME/PRICES/THERMAL POWERPLANTS
/IDENTIFIERS: /GEOTHERMAL POWER/NEW ZEALAND/INDUSTRIAL USES/ENERGY COSTS/HOT WATER SYSTEMS

114

JONES, P.H.

1973

GEOTHERMAL RESOURCES OF THE NORTHERN GULF OF MEXICO BASIN. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(1):14-26.

THE NORTHERN GULF OF MEXICO BASIN, FROM COASTAL PLAIN OF TEXAS AND LOUISIANA OUTWARD TOWARD THE CONTINENTAL SHELF EDGE, IS SUBSIDING WITH RAPID SEDIMENTARY INFILL. DESPITE LOW HEAT FLOW IN THE UPPER 2 KILOMETERS (KM), HIGH GEOTHERMAL GRADIENT EXISTS AT DEPTHS OF 4 TO 7 KM IN AN EXTENSIVE ZONE OF HOT (UP TO 237 DEGREES C.) GEOPRESSURED FIELD (PRESSURE GREATER THAN HYDROSTATIC). THIS FLUID IS LOW-SALINITY FREE PORE WATER DERIVED FROM THERMAL DIAGENESIS OF MONTMORILLONITE CLAY AT TEMPERATURES OF 80 TO 120 DEGREES C. SALINITY DECREASES WITH DEPTH. GEOPRESSURE RESULTS WHEN THE WATER IS TRAPPED BY FAULT AND STRATIGRAPHIC BARRIERS. HEAT IS STORED AND THERMAL GRADIENT IS HIGH AT

DEPTH BECAUSE SATURATED CLAY LAYERS ARE GOOD INSULATORS. HIGH TEMPERATURES AMPLIFY SALT DIAPIRISM, WHICH IN TURN ACCELERATES HEAT FLOW. MANY HYDROCARBON AND TEST WELLS IN THE AREA HAVE PRODUCED LARGE VOLUMES OF GEOPRESSURED FLUIDS (PUMPING IS NOT NECESSARY). RESERVOIRS ARE FINITE AND DEPLETABLE, BUT LARGE. FLUIDS COULD BE USED FOR POWER PRODUCTION, FRESH WATER SUPPLY BY SELF-DISTILLATION, OR SECONDARY RECOVERY OF OIL AND GAS. (OALS)

GULF OF MEXICO/GEOTHERMAL STUDIES/GULF COASTAL PLAIN/TEXAS/LOUISIANA/HEAT FLOW/THERMAL WATER/DIAGENESIS/SEDIMENTARY BASINS(GEOLOGIC)/MONTMORILLONITE/DEEP WELLS/OIL WELLS/TEST WELLS/SECONDARY RECOVERY(OIL)/WATER SUPPLY/DISTILLATION/WATER QUALITY/SALINITY/SEMIARID CLIMATES
/IDENTIFIERS: /SUBSIDING SEDIMENTARY BASINS/GEOPRESSURED SYSTEMS/TEMPERATURE GRADIENT/GEOTHERMAL RESOURCES/GEOTHERMAL FLUIDS/GEOTHERMAL RESERVOIRS/HOT WATER SYSTEMS/HEAT STORAGE/GEOTHERMAL POWER/ENERGY SOURCES INTERFACES

115

KAPPELMEYER, O./HAENEL, R.

1974

GEOTHERMICS, WITH SPECIAL REFERENCE TO APPLICATION.

GEBRUDER BORNTRAEGER, BERLIN. GEOEXPLORATION MONOGRAPHS, SER. 1, NO. 4. 238 P.

PHYSICAL NATURE OF HEAT AND PROCESSES OF ITS STORAGE, CONDUCTION, RADIATION, AND CONVECTION ARE REVIEWED. GEOPHYSICAL ASPECTS OF THE HEAT IN EARTH'S INTERIOR AND CRUST (INCLUDING THERMAL PROPERTIES, ENERGY SOURCES, ENERGY FLOWS, AND TEMPERATURES) ARE DISCUSSED. PRACTICAL APPLICATIONS OF GEOTHERMAL STUDIES INCLUDE EXPLORATION FOR GEOTHERMAL POWER, STUDY OF GROUNDWATER FLOW, AND PROSPECTING FOR SULFIDE AND RADIOACTIVE ORES, SALT DOMES, AND HYDROCARBONS. GEOTHERMAL INVESTIGATIONS IN DEEP WELLS HAVE MANY USES, SUCH AS EVALUATION OF HYDROFRACTURING, LOCATION OF LOST DRILLING FLUID CIRCULATION, AND CORRELATION OF TEMPERATURE GRADIENT WITH ROCK TYPES. 22 PAGES OF BASIC TABLES, AND EXTENSIVE BIBLIOGRAPHY (ABOUT 250 REFERENCES) COMPLETE THE BOOK. (OALS)

GEOTHERMAL STUDIES/HEAT/HEAT FLOW/HEAT TRANSFER/TEMPERATURE/BIBLIOGRAPHIES/THERMAL PROPERTIES/THERMAL RADIATION/CONDUCTION/CONVECTION/GEOPHYSICS/ENERGY CONVERSION/ENERGY GRADIENT/EXPLORATION/GROUNDWATER FLOW/FOSSIL FUELS/DEEP WELLS/HYDROFRACTURING/SUBSURFACE INVESTIGATIONS/WELL DATA/WATER CIRCULATION
/IDENTIFIERS: /HEAT STORAGE/GEOTHERMAL HEAT/GEOTHERMAL POWER/SALT DOMES/MINERAL DEPOSITS/TEMPERATURE GRADIENT

116

KAUFMAN, A.

1971

AN ECONOMIC APPRAISAL OF GEOTHERMAL ENERGY.

PUBLIC UTILITIES FORTNIGHTLY 88(7):19-24.

BECAUSE AMERICA'S ENERGY DEMANDS ARE OUTSTRIPPING CURRENT POWER PRODUCTION, NEW RESOURCES SUCH AS GEOTHERMAL ENERGY SHOULD BE EXPLORED. AT PRESENT THE PACIFIC GAS AND ELECTRIC CO. GEOTHERMAL PLANT AT THE GEYSERS IN CALIFORNIA IS THE ONLY OPERATING FACILITY USING THIS SOURCE. BASICALLY IT HAS BEEN LEGAL AND NOT ECONOMIC PROBLEMS THAT HAVE HINDERED DEVELOPMENT IN THIS FIELD. MOST GEOTHERMAL RESOURCES ARE ON FEDERAL LAND AND ONLY RECENTLY HAS THE DEPARTMENT OF THE INTERIOR ESTABLISHED A LEASING PROGRAM. THERE IS A VAST POTENTIAL TO BE TAPPED, ABOUT 500 TIMES THE NATION'S COAL RESERVES. THE PLANTS APPEAR TO BE ECONOMICALLY COMPETITIVE WITH OTHER METHODS OF POWER PRODUCTION. HOWEVER, CERTAIN POLLUTION PROBLEMS WILL HAVE TO BE SOLVED. DISCHARGES FROM THE PLANTS ARE BRINY AND CAN CONTAIN SODIUM AND POTASSIUM COMPOUNDS. THE INSTALLATIONS THEMSELVES MAY BLIGHT MANY AREAS PRESENTLY USED FOR RECREATION.

GEOTHERMAL STUDIES/THERMAL POWER/WATER POLLUTION/ENERGY CONVERSION/ELECTRIC POWER PRODUCTION/ENVIRONMENTAL EFFECTS/LAND RESOURCES/ECONOMIC EFFICIENCY/ELECTRIC POWER DEMAND/LEGAL ASPECTS/LEASES/UNITED STATES/SALINE WATER
/IDENTIFIERS: /ALTERNATIVE ENERGY SOURCES/GEYSERS FIELD, CALIFORNIA/GEOTHERMAL POWER/GEOTHERMAL RESOURCES

117

KEENE, J./ARDEN, T.

1971

GEOTHERMAL STATIONS HAVE POLLUTION PROBLEMS, TOO.

POWER 115(5):96-97. EIA 71-03720.

PACIFIC GAS AND ELECTRIC'S GEOTHERMAL PLANT IN CALIFORNIA HAS DAMAGED THE ENVIRONMENT BY DISCHARGING STEAM. BEGINNING IN 1960 (WITH THREE UNITS ON LINE BY 1968) THE PLANT HAS BEEN RELEASING STEAM. THIS IN TURN HAS LED TO A BUILD UP IN BORON, HYDROGEN SULFIDE, AND AMMONIA SALT LEVELS IN THE LOCAL WATER AND ENDANGERED STEELHEADS AND SALMON. A SOLUTION NOW BEING TRIED INVOLVES REINJECTING THE CONDENSATE INTO DEEP STEAM WELLS.

THERMAL POWER/CALIFORNIA/ENVIRONMENTAL EFFECTS/WATER POLLUTION/SALMON/POLLUTION ABATEMENT/EQUIPMENT/INJECTION WELLS/STEAM/DEEP WELLS/BORON/HYDROGEN SULFIDE/AMMONIUM COMPOUNDS
/IDENTIFIERS: /GEYSERS FIELD, CALIFORNIA/GEOTHERMAL POLLUTION/GEOTHERMAL STEAM

118

KLEMME, H.D.

1975

GEOTHERMAL GRADIENTS, HEAT FLOW, AND HYDROCARBON RECOVERY. IN A.G. FISCHER AND S. JUDSON, EDS., PETROLEUM AND GLOBAL TECTONICS, P. 251-304.

PRINCETON UNIVERSITY PRESS.

MUCH EVIDENCE SUGGESTS THAT HIGH GEOTHERMAL GRADIENTS IN SEDIMENTARY ROCK SEQUENCES ENHANCE PROCESSES OF FORMATION, MIGRATION, AND ENTRAPMENT OF OIL AND NATURAL GAS. DEPTH OF HYDROCARBON OCCURRENCE APPEARS TO BE RELATED TO BASIN TEMPERATURE HISTORY. BASINS ASSOCIATED WITH HIGH HEAT FLOW ALONG PLATE MARGINS AND IN RIFT ZONES TEND TO YIELD MORE HYDROCARBONS THAN BASINS WITH LOW HEAT FLOW IF REQUISITE GEOLOGIC FACTORS ARE ALL PRESENT. MAPS SHOW WORLDWIDE COINCIDENCE OF GIANT OIL FIELDS AND HIGH HEAT FLOWS.

GEOTHERMAL STUDIES/HEAT FLOW/OIL/FOSSIL FUELS/NATURAL GAS/OIL RESERVOIRS/OIL FIELDS/SEDIMENTARY BASINS(GEOLOGIC)/DEPTH/MAPS
/IDENTIFIERS: /TEMPERATURE GRADIENT/PLATE BOUNDARIES/GEOTHERMAL BELTS/GLOBAL TECTONICS/RIFT ZONES

119

KOELZER, V.A.

1972

DESALTING.

NATIONAL WATER COMMISSION REPORT NWC-EES 72-045. 134 P. AVAILABLE NTIS AS PB-209 942.

SEE: SWRA W72-13354.

DESALINATION/DESALINATION PROCESSES/COST ANALYSIS/WATER COSTS/WATER SUPPLY/ WATER PURIFICATION/ECONOMIC FEASIBILITY/ENVIRONMENTAL EFFECTS/ECONOMIES OF SCALE/MAINTENANCE COSTS/TECHNICAL FEASIBILITY/BRINE DISPOSAL/DISTILLATION/ CRYSTALLIZATION/MEMBRANE PROCESSES/GEOTHERMAL STUDIES/ENERGY/FORECASTING/ OSMOSIS
/IDENTIFIERS: /ENERGY COSTS/WATER MARKETS/ENERGY-WATER RELATIONSHIPS

120

KOENIG, J.B.

1967

THE SALTON-MEXICALI GEOTHERMAL PROVINCE.

CALIFORNIA, DIVISION OF MINES AND GEOLOGY, MINERAL INFORMATION SERVICE 20(7):75-81.

DEVELOPMENT OF TWO REGIONS IN THE SALTON-MEXICALI GEOTHERMAL PROVINCE HAS BROUGHT RENEWED INTEREST TO THE AREA. AT NILAND, IMPERIAL COUNTY, SODIUM AND CALCIUM CHLORIDES WILL BE PRODUCED BY MORTON, INTERNATIONAL, INC., WHILE THE MEXICAN FEDERAL ELECTRICITY COMMISSION (CFE) WILL PRODUCE ELECTRICAL POWER. EACH WILL BE A SINGLE-PURPOSE OPERATION. MORTON WILL RECOVER THE SALTS BY A SOLAR EVAPORATION PROCESS. STEAM PRODUCED FROM THE WELLS WILL BE USED IN THE FINAL EVAPORATION PROCESS FOR NACL. POST-FLASH BRINE RUNS AS HIGH AS 330,000 PPM, SO A REINJECTION WELL HAS BEEN CONSTRUCTED, ALTHOUGH THE POSSIBILITY OF CONTAMINATION OF GROUNDWATER SUPPLIES CANNOT BE RULED OUT. RESULTS OF PUMPING TESTS IN THE WELLS AT CERRO PRIETO ARE DESCRIBED IN SOME DETAIL. THE RESIDUAL BRINES, SIMILAR IN COMPOSITION TO SEA WATER, WILL BE PIPED TO THE GULF OF CALIFORNIA. A REVIEW OF THE GEOLOGY OF THE REGION INDICATES THAT BOTH FIELDS WERE CREATED BY CRUSTAL THINNING AND ESTABLISHMENT OF CONVECTION CELLS FOR HEAT TRANSFER THROUGH WATER-SATURATED SEDIMENTS. IT IS CONCLUDED THAT FUTURE PROSPECTING FOR HEAT FIELDS IN THE PROVINCE MIGHT CONCENTRATE ON: HIGH GRAVITY ZONES, THICK IMPERMEABLE BEDS IN THE SHALLOW SUBSURFACE, HIGH PRESSURES AND HEAT FLUXES IN SHALLOW WELLS, AND SURFACE HEAT MANIFESTATIONS.

GEOTHERMAL STUDIES/CALIFORNIA/ELECTRIC POWER/BRINES/BRINE DISPOSAL/INJECTION WELLS/HEAT TRANSFER/HEAT/SOLAR DISTILLATION/EVAPORATION/EXPLORATION/GEOLOGIC INVESTIGATIONS/CONVECTION
/IDENTIFIERS: /SALTON SEA/BAJA CALIFORNIA/CERRO PRIETO FIELD, MEXICO/CHEMICAL RECOVERY

121

KOENIG, J.B.

1971

GEOTHERMAL DEVELOPMENT.

GEOTIMES 16(3):10-12.

AN ACCOUNT OF THE 1970 U.N. SYMPOSIUM ON DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, HELD IN PISA, ITALY. HOW THE SPECIALIZED TECHNICAL KNOWLEDGE OF THE SYMPOSIUM PARTICIPANTS CAN BE TRANSLATED INTO THE DEVELOPMENT OF GEOTHERMAL RESOURCES (ESPECIALLY IN UNDERDEVELOPED COUNTRIES) AND THE ECONOMIC FEASIBILITY OF A MULTIPLE-USE GEOTHERMAL PROJECT WERE

DISCUSSED. IT WAS NOTED THAT TWO UNCERTAIN TECHNOLOGIES, DESALINATION AND GEOTHERMAL POWER GENERATION, WOULD BE COMBINED IN A HIGH-RISK VENTURE THAT WOULD TEND TO DOUBLE THE POSSIBILITY FOR FAILURE AND INCREASE INVESTOR HESITANCY. IT WAS APPARENT THAT GEOTHERMAL POWER GENERATION TO DATE DEPENDS ON THE USE OF STEAM, AND EXPLORATION HAS CENTERED ON DISCOVERY OF DRY-STEAM RESERVOIRS. A NEWLY-DESIGNED SYSTEM, USING ISOBUTANE AS THE HEAT EXCHANGING MEDIUM WAS DESCRIBED WHICH, IF SUCCESSFUL, COULD RADICALLY CHANGE THE COURSE OF GEOTHERMAL EXPLORATION AND SPUR DEVELOPMENT OF LOWER-ENTHALPY HOT-WATER SYSTEMS FOR POWER GENERATION. THE PAPER CONCLUDES WITH A TABLE OF EXISTING AND PROPOSED GEOTHERMAL POWER STATIONS SHOWING 23 OPERATING, PLANNED, OR UNDER CONSTRUCTION IN 13 COUNTRIES, AND THEIR PROJECTED KW CAPACITY.

GEOTHERMAL STUDIES/RESOURCES DEVELOPMENT/THERMAL POWER/STEAM/EXPLORATION/ HEAT EXCHANGERS/COSTS/ENTHALPY/MULTIPLE-PURPOSE PROJECTS/DESALINATION /IDENTIFIERS: /DRY STEAM FIELDS/ISOBUTANE/GEOTHERMAL RESOURCES DEVELOPMENT/ GLOBAL DISTRIBUTION/GEOTHERMAL POWER/DEVELOPING COUNTRIES/HOT WATER SYSTEMS/ POWER CAPACITY

122

KOENIG, J.B.

1973 A

GEOTHERMAL EXPLORATION IN THE WESTERN UNITED STATES. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(1):1-13.

SEE: SWRA W71-11812.

GEOTHERMAL STUDIES/GEOLOGIC INVESTIGATIONS/TEMPERATURE/WARM SPRINGS/THERMAL POWER/WELLS/STEAM/BRINES/DRILLING/HOT SPRINGS/EXPLORATION/WASTE WATER DISPOSAL/ CALIFORNIA/NEVADA/WYOMING/OREGON/WASHINGTON/NEW MEXICO/ALASKA/HAWAII/SCALING /IDENTIFIERS: /GEYSERS FIELD, CALIFORNIA/YELLOWSTONE NATIONAL PARK/SALTON SEA/ DRY STEAM FIELDS/VALLES CALDERA/WESTERN U.S.

123

KOENIG, J.B.

1973 B

WORLDWIDE STATUS OF GEOTHERMAL RESOURCES DEVELOPMENT. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 15-58.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13216.

GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/THERMAL POWERPLANTS/ ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/WATER RESOURCES DEVELOPMENT/ENERGY/ STEAM TURBINES/WELLS/SPATIAL DISTRIBUTION/GEOLOGY /IDENTIFIERS: /GEOTHERMAL POWER/GLOBAL DISTRIBUTION/GEOTHERMAL RESOURCES DEVELOPMENT/POWER CAPACITY/VOLCANISM/SUBSIDING SEDIMENTARY BASINS/RIFT ZONES/ PLATE BOUNDARIES/WORLD

124

KOENIG, J.B./HUTTRER, G.W.

1975

GEOTHERMAL PROSPECTING ALONG ALIGNED FEATURES IN THE WESTERN UNITED STATES. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS II-24.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

GEOTHERMAL PROSPECTING OPPORTUNITIES EXIST ALONG SEVERAL GEOGRAPHICALLY PERSISTENT FEATURES IN WESTERN U.S. MOST OF THESE FEATURES ARE CHARACTERIZED BY PARALLEL FAULT ZONES, SERVE AS SIGNIFICANT GEOLOGIC BOUNDARIES, AND ARE EXPRESSED AS TOPOGRAPHIC ALIGNMENTS VISIBLE IN HIGH-ALTITUDE PHOTOGRAPHS. SUBTLE ALIGNMENTS CAN BE SEEN IN SELECTED GEOPHYSICAL AND HYDROTHERMAL DATA. THESE ALIGNMENTS OFTEN ARE DISCONTINUOUS, EN ECHELON OR CURVILINEAR, AND ARE TENS TO HUNDREDS OF MILES LONG. THEY ARE TYPICALLY INTERSECTED BY TRANSVERSE FEATURES SUCH AS FAULTS AND FOLDS OR PROVINCE BOUNDARIES. INTERSECTIONS TEND TO LOCALIZE INTRUSIVE, EXTRUSIVE AND HYDROTHERMAL ACTIVITY. ALIGNMENTS COMMONLY REPRESENT INTRA-PLATE RIFTS, HINGE LINES, AND OTHER BOUNDARIES BETWEEN REGIONS OF DIVERSE DEPOSITIONAL OR TECTONIC HISTORY. EXAMPLES ARE TENSIONAL FRACTURE SYSTEMS ALONG WEST SIDE OF RIO GRANDE RIFT (NEW MEXICO AND COLORADO), AND IN WESTERN SNAKE RIVER PLAIN (IDAHO AND OREGON), ORTHOGONAL FRACTURE SETS IN LAVA PLATEAUS OF NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON, A BELT TRENDING NORTHEAST ACROSS BASIN AND RANGE OF NORTHERN NEVADA, ZONE OF LARAMIDE THRUSTING FROM BRITISH COLUMBIA AND MONTANA TO ARIZONA AND NEW MEXICO (AND PERHAPS BEYOND); AND ZONE NEARLY ENCIRCLING THE COLORADO PLATEAU. EXPLORATION ALONG SUCH FEATURES MAY PROVE MORE FRUITFUL THAN PREVIOUS RANDOM EVALUATION OF HYDROTHERMAL AND GEOPHYSICAL ANOMALIES. EXPLORATION SHOULD CONCENTRATE UPON SUBTLE INTERSECTIONS, EXTRAPOLATION OF LINEAR FEATURES, AND THE SEARCH FOR NON-LEAKING SYSTEMS.

GEOTHERMAL STUDIES/STRUCTURAL GEOLOGY/FAULTS (GEOLOGIC)/FOLDS (GEOLOGIC)/ GEOMORPHOLOGY/TOPOGRAPHY/NEW MEXICO/COLORADO/IDAHO/OREGON/CALIFORNIA/ FRACTURES (GEOLOGIC)/NEVADA/ARIZONA/EXPLORATION

125

KREMNJOV, O.A./ZHURAVLENKO, V.J./SHURTSHKOV, A.V.

1973

TECHNICAL-ECONOMIC ESTIMATION OF GEOTHERMAL RESOURCES. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1688-1696.

SEE: SWRA W74-09044.

GEOTHERMAL STUDIES/HYDROGEOLOGY/AQUIFER TESTING/DRILLING/EXPLORATION/HYDROTHERMAL STUDIES/BOREHOLE GEOPHYSICS/THERMAL WATER/THERMAL POWER/COSTS/DATA COLLECTIONS/HYDROLOGIC DATA
/IDENTIFIERS: /GEOTHERMAL POWER/USSR/ALTERNATIVE ENERGY SOURCES

126

KRIKORIAN, O.H.

1973

CORROSION AND SCALING IN NUCLEAR-STIMULATED GEOTHERMAL POWER PLANTS. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 315-334.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13231.

ENVIRONMENTAL EFFECTS/NUCLEAR EXPLOSIONS/WELLS/GEOTHERMAL STUDIES/CORROSION/MATERIALS/SCALING/THERMAL POWERPLANTS/WATER POLLUTION SOURCES/TURBINES/RADIOACTIVE WASTES/SEISMIC STUDIES/MATERIALS TESTING
/IDENTIFIERS: /WELL STIMULATION/GEOTHERMAL POWER

127

KRUGER, P.

1975

DEVELOPMENT OF THE NATION'S GEOTHERMAL ENERGY RESOURCES.

GEOTHERMAL ENERGY 3(8):25-37.

FEDERAL ENERGY ADMINISTRATION ESTABLISHED A GOAL (IN NOVEMBER, 1974) FOR 1985 OF 20,000 TO 30,000 MW OF GEOTHERMAL ELECTRIC POWER CAPACITY, 40 TO 60 TIMES CURRENT CAPACITY (500 MW AT THE GEYSERS, CALIFORNIA), MEANING 5 TRILLION KWH PRODUCED OVER THE 30 YEAR AMORIZATION PERIOD. THIS WILL REQUIRE AT LEAST 6,000 PRODUCTION WELLS ON AN AREA OF 600 SQUARE KILOMETERS (KM) AND RESERVOIR VOLUME 400 CUBIC KM. SUCH DEVELOPMENT WILL NECESSITATE HIGH PRIORITY FOR EXPLORATION, UTILIZATION TECHNOLOGY RESEARCH AND DEVELOPMENT, AND SOLUTION OF INSTITUTIONAL AND LEGAL PROBLEMS. MAJOR GOALS OF THE NATIONAL GEOTHERMAL PROGRAM ARE REVIEWED: ESTABLISH ADEQUATE RESERVES FOR 20,000 TO 30,000 MW, DEVELOP AND DEMONSTRATE NEAR-TERM AND ADVANCED PRODUCTION TECHNOLOGIES, AND ENCOURAGE RAPID GROWTH OF GEOTHERMAL INDUSTRY BY LOAN INCENTIVES, REDUCTION OF INSTITUTIONAL BOTTLENECKS, AND DIRECT TECHNICAL ASSISTANCE. (OALS)

GEOTHERMAL STUDIES/UNITED STATES/RESEARCH AND DEVELOPMENT/EXPLORATION/INSTITUTIONAL CONSTRAINTS/LEGAL ASPECTS/FEDERAL GOVERNMENT/TECHNOLOGY/LOANS/INDUSTRIES
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL POWER/POWER CAPACITY/PRODUCTION WELLS

128

KRUGER, P./OTTE, C. EDS.

1973

GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA. 360 P.

SEE: SWRA W73-13214.

GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/THERMAL POWERPLANTS/ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/WATER RESOURCES DEVELOPMENT/ENERGY/STEAM TURBINES/WELLS/STIMULATED RECOVERY/EXPLOSIVES/EXPLOSIONS/EXPLORATION/DEEP WELLS/ENVIRONMENTAL EFFECTS/ECONOMICS
/IDENTIFIERS: /GEOTHERMAL POWER/GEYSERS FIELD, CALIFORNIA/WELL STIMULATION/GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT/ALTERNATIVE ENERGY SOURCES

129

KUNZE, J.P.

1975

WHAT IF THE WATER ISN'T HOT ENOUGH?

GEOTHERMAL ENERGY 3(5):60-64.

DISCUSSES HYPOTHETICAL CURVES FOR AMOUNT OF GEOTHERMAL WATER AND ENERGY AVAILABLE VERSUS TEMPERATURE. TECHNOLOGIC IMPROVEMENTS CAN VASTLY INCREASE THE ENERGY AVAILABLE BY LOWERING THE TEMPERATURE (PRESENTLY 180 DEGREES C.) AT WHICH RESOURCES ARE MARGINAL (COSTS JUST COMPETE WITH OTHER SOURCES OF ENERGY). ALSO, DRILLING SUCCESS RATIO WILL IMPROVE BECAUSE LOWER TEMPERATURES ARE MORE COMMON THAN HIGH ONES. WHETHER WE CAN UTILIZE A CERTAIN AMOUNT OF GEOTHERMAL ENERGY IS NOT AS IMPORTANT AS HOW MUCH IT WILL COST AT A GIVEN TEMPERATURE. GEOTHERMAL ENERGY COSTS, EVEN FOR VAPOR-DOMINATED RESERVOIRS, ARE NOT WELL KNOWN. TECHNOLOGICAL IMPROVEMENTS, LOWERING COSTS OF LIQUID-DOMINATED RESERVOIR EXPLOITATION, MAY BE EXPECTED SOON. A TEST WELL (4650 FEET, 146 DEGREES C.) HAS BEEN DRILLED IN THE RAFT RIVER VALLEY, SOUTHERN IDAHO. (OALS)

GEOTHERMAL STUDIES/IDAHO/TECHNOLOGY/HOT WATER SYSTEMS/COSTS/DRILLING/TEST WELLS/TEMPERATURE
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL WATER/GEOTHERMAL ENERGY/HOT WATER SYSTEMS

130

LAHSEN, A./TRUJILLO, P.

1975

THE GEOTHERMAL FIELD OF EL TATIO, CHILE. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS I-22.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

EL TATIO IS LOCATED IN HIGH ANDES (68 DEGREES 1'S, 22 DEGREES 20'W). GEOELECTRICAL STUDIES HAVE DEFINED A RESISTIVITY ANOMALY WITH AN AREA OF APPROXIMATELY 30 KM2, ELONGATED IN THE DIRECTION OF THE MAIN GRABEN STRUCTURE. GEOCHEMICAL STUDIES SHOW THAT THE AQUIFER RECHARGING THE FIELD IS BETWEEN 800 AND 900 METERS BELOW SURFACE, AT 265 DEGREES C. STEAM EQUIVALENT TO 18 MW IS CURRENTLY OBTAINED FROM THREE PILOT WELLS. FUTURE DEVELOPMENT PROGRAMS ARE EXPECTED TO YIELD UP TO 50 MW, ONLY A SMALL PART OF THE REAL POTENTIAL.

GEOTHERMAL STUDIES/SOUTH AMERICA/ELECTRICAL STUDIES/RESISTIVITY/GEOPHYSICS/GEOCHEMISTRY/TEMPERATURE
/IDENTIFIERS: /CHILE/EL TATIO FIELD/GEOTHERMAL RESOURCES DEVELOPMENT/POWER CAPACITY/ANDES

131

LAIRD, A.D.K.

1971

RANKING RESEARCH PROBLEMS IN GEOTHERMAL DEVELOPMENT.

U.S. OFFICE OF SALINE WATER RESEARCH AND DEVELOPMENT, PROGRESS REPORT 711. 33 P. OSW GRANT 14-30-2635.

SEE: SWRA W72-03777.

DESALINATION/DISTILLATION/GEOTHERMAL STUDIES/BRINE DISPOSAL/CALIFORNIA/WATER POLLUTION SOURCES/BENEFITS/WATER SUPPLY/ENVIRONMENTAL EFFECTS/PLANNING/STEAM/RESOURCES DEVELOPMENT/RESEARCH AND DEVELOPMENT
/IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL RESOURCES

132

LAIRD, A.D.K.

1973

WATER FROM GEOTHERMAL RESOURCES. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 177-196.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA. DESALINATION ABSTRACTS 74-727.

SEE: SWRA W73-13223.

DESALINATION/GEOTHERMAL STUDIES/ELECTRIC POWER/THERMAL POWERPLANTS/ECONOMICS/DISTILLATION/WATER RESOURCES DEVELOPMENT/ENERGY/WATER SOURCES
/IDENTIFIERS: /GEOTHERMAL POWER

133

LAIRD, A.D.K. ET AL

1972

GEOTHERMAL DESALINATION AND POWER PRODUCTION.

UNIVERSITY OF CALIFORNIA, RICHMOND, SEA WATER CONVERSION LABORATORY, REPORT 73-1:35-43. DESALINATION ABSTRACTS 74-725.

ECONOMIC DUAL-PURPOSE POWER AND FRESH WATER PLANTS COULD BE BUILT NOW, BUT SEVERAL MECHANICAL COMPONENTS NEED IMPROVEMENT: TURBINES, BRINE AND HEAT REJECTION SYSTEMS, NOXIOUS GAS ELIMINATION SYSTEMS, AND SILICA PRECIPITATION CONTROLS. WATER AND POWER COSTS AND INCOME ARE STRONGLY INTERDEPENDENT, AND KNOWLEDGE OF CAPITAL, OPERATING, AND MAINTENANCE COSTS IS NEEDED.

GEOTHERMAL STUDIES/DESALINATION/MULTIPLE-PURPOSE PROJECTS/TURBINES/BRINE DISPOSAL/GASES/SILICA/ELECTRIC POWER COSTS/CAPITAL COSTS/OPERATING COSTS/ MAINTENANCE COSTS/WATER COSTS
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL WATER

134

LAWVER, L.A.

1975

HEAT FLOW IN THE GULF OF CALIFORNIA. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2C, SAN FRANCISCO, 1975, ABSTRACTS III-54.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE, BERKELEY LABORATORY.

SPREADING ON EAST PACIFIC RISE CAN BE TRACED TO THE MOUTH OF GULF OF CALIFORNIA. MAJORITY OF MOVEMENT IN THE GULF IS TRANSFORM BUT IT IS ASSUMED THAT SEAFLOOR SPREADING IS ALSO OCCURRING. IT IS A UNIQUE PLACE TO TAKE HEAT FLOW MEASUREMENTS SINCE IT IS ONE OF THE FEW PLACES SEAFLOOR SPREADING IS OCCURRING UNDERNEATH A LARGE SEDIMENT BLANKET. 140 HEAT FLOW MEASUREMENTS WERE TAKEN IN CENTRAL AND SOUTHERN GULF. THESE VARIED FROM 1.3 HFU (55 MW/M2) TO 30.3 HFU (1250 MW/M2). NEAR PRESUMED SPREADING CENTERS VALUES AVERAGED GREATER THAN 200 MW/M2. WITHIN 5 TO 10 KILOMETERS OF SPREADING CENTERS HEAT FLOW VALUES DROPPED TO 100-150 MW/M2. THERE ARE THREE AREAS OF VERY HIGH HEAT FLOW: BALLENAS CHANNEL (TRANSFORM FAULT AREA), SOUTHWEST GUAYMAS DEEP NEAR MULEGE, AND NEAR FARALLON DEPRESSION (BOTH PRESUMED AREAS OF SPREADING). THERMAL GRADIENT OF >2.0 DEGREES C./METER WAS OBSERVED IN BALLENAS CHANNEL. MEASUREMENTS IN GUAYMAS DEEP WERE 0.75 TO 1.78 DEGREES C./METER. FARALLON HAS GREATER THAN 0.60 DEGREES C./METER IN A 20 SQUARE KILOMETER AREA. ALL HIGH THERMAL GRADIENTS WERE IN AREAS ROUGHLY 2000 METERS DEEP. CONDUCTIVITY WAS FAIRLY UNIFORM. IF IT IS ASSUMED THAT SEDIMENT BLANKET INHIBITS HYDROTHERMAL CIRCULATION THEN IT MAY BE POSSIBLE TO USE THE HEAT FLOW DATA IN THE GULF TO ESTIMATE TOTAL HEAT BUDGET IN SALTON TROUGH AND CERRO PRIETO AREAS.

GEOTHERMAL STUDIES/MEXICO/HEAT FLOW/ON-SITE INVESTIGATIONS/THERMAL CONDUCTIVITY/HEAT BUDGET
/IDENTIFIERS: /GULF OF CALIFORNIA/TEMPERATURE GRADIENT/SPREADING CENTERS/ MID-OCEANIC RIDGES/HYDROTHERMAL CONVECTION SYSTEMS

135

LEAR, J.

1970

CLEAN POWER FROM INSIDE THE EARTH.

SATURDAY REVIEW 53(49):53-61.

SEE: SWRA W71-08643.

GEOTHERMAL STUDIES/RESOURCES DEVELOPMENT/DESALINATION/COLORADO RIVER/ENERGY/ UNITED STATES
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT/WORLD

136

LINDAL, B.

1973 A

INDUSTRIAL AND OTHER APPLICATIONS OF GEOTHERMAL ENERGY. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 135-148.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

DESCRIBES DIVERSE APPLICATIONS (OTHER THAN ELECTRICITY PRODUCTION AND DISTRICT HEATING) OF GEOTHERMAL RESOURCES, INCLUDING: NUMEROUS INDUSTRIAL PROCESSES WHICH REQUIRE HEATING, DRYING, DISTILLATION, OR REFRIGERATION (WOOD AND PAPER PROCESSING, CHEMICAL PROCESSING, SUGAR REFINING, HEAVY WATER PRODUCTION, MINING, DIATOMITE PROCESSING, AND CHEMICAL AND GAS RECOVERY FROM GEOTHERMAL FLUIDS); AGRICULTURE (GREENHOUSE HEATING, SOIL WARMING AND STERILIZATION, ANIMAL HUSBANDRY, WOOL PROCESSING, DAIRY SYSTEMS, AND FISH, ALLIGATOR, AND CROCODILE BREEDING); AND RECREATION AND HEALTH (HOT BATHS). SOME OF THESE

POSSIBILITIES HAVE BEEN APPLIED, OTHERS ONLY DISCUSSED. INDUSTRIAL PROCESSES GENERALLY REQUIRE HIGH TEMPERATURE; AGRICULTURE REQUIRES MOSTLY LOW TEMPERATURE. VERSATILITY OF GEOTHERMAL ENERGY MAKES MULTIPLE-PURPOSE PROJECTS ATTRACTIVE, BUT TRANSPORTATION DIFFICULTY NECESSITATES UTILIZATION IN PLACE. (OALS)

GEOTHERMAL STUDIES/INDUSTRIAL PRODUCTION/CHEMICAL INDUSTRY/DAIRY INDUSTRY/ FOOD PROCESSING INDUSTRY/LUMBERING/MINERAL INDUSTRY/PULP AND PAPER INDUSTRY/ HEATING/DRYING/DISTILLATION/REFRIGERATION/DIATOMACEOUS EARTH/HEAVY WATER/ TEMPERATURE/MINING/AGRICULTURE/GREENHOUSES/RECREATION/MULTIPLE-PURPOSE PROJECTS
/IDENTIFIERS: /INDUSTRIAL USES/GEOTHERMAL ENERGY/CHEMICAL RECOVERY/ENERGY SOURCES INTERFACES/WASTE HEAT USES

137

LINDAL, B.

1973 B

THE PRODUCTION OF CHEMICALS FROM BRINE AND SEAWATER USING GEOTHERMAL ENERGY. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(1):910-917.

GEOTHERMAL BRINES AND STEAM CAN BE THE FOUNDATION OF AN ELABORATE CHEMICAL INDUSTRY USING SEA WATER AND OTHER FEEDSTOCKS. METHODS FOR EXTRACTING SODIUM CHLORIDE, POTASSIUM CHLORIDE, CALCIUM CHLORIDE, AND BROMINE FROM A GEOTHERMAL BRINE (DERIVED FROM SEA WATER) IN ICELAND ARE DESCRIBED. ALSO OUTLINED ARE NEW PROCEDURES FOR EXTRACTING MAGNESIUM AND CHLORINE FROM SEA WATER WITH THE AID OF SALT, FRESH WATER, ELECTRIC POWER, AND GEOTHERMAL STEAM. HIGH PRESSURE STEAM CAN BE USED FOR POWER PRODUCTION, DIATOMITE DRYING, HEAVY WATER PRODUCTION, OR OTHER INDUSTRIAL PROCESSES BEFORE IT ENTERS THESE CHEMICAL SYSTEMS. HOT WATER REMAINING AFTER STEAM FLASH CAN BE USED FOR SPACE HEATING. WITH ADDITIONAL INPUT OF CRUDE OIL AND MORE ELECTRICITY, A CHLORINATED HYDROCARBON INDUSTRIAL COMPLEX COULD BE ADDED TO THE CHEMICAL PLANTS. (OALS)

GEOTHERMAL STUDIES/INDUSTRIAL PRODUCTION/INDUSTRIAL PLANTS/CHEMICAL INDUSTRY/ CHEMICAL ENGINEERING/SEA WATER/BRINES/SALTS/SODIUM CHLORIDE/POTASSIUM COMPOUNDS/CALCIUM CHLORIDE/BROMINE/CHLORINE/MAGNESIUM/DIATOMACEOUS EARTH/ HEAVY WATER/ORGANIC COMPOUNDS
/IDENTIFIERS: /ICELAND/GEOTHERMAL STEAM/GEOTHERMAL FLUIDS/GEOTHERMAL POWER/ SPACE HEATING/INDUSTRIAL USES/CHEMICAL RECOVERY

138

LISTER, C.R.B.

1974

MAJOR GEOTHERMAL AREAS AND GLOBAL TECTONIC RIFTING. PAPER PRESENTED AT 21ST ANNUAL MEETING, PACIFIC NORTHWEST REGION, AMERICAN GEOPHYSICAL UNION, 1974.

EOS, AMERICAN GEOPHYSICAL UNION, TRANSACTIONS 56(8):533.

THERE IS A DIRECT CONNECTION BETWEEN LARGE GEOTHERMAL AREAS AND HIGH LEVELS OF VOLCANIC ACTIVITY. THIS MAY BE DUE DIRECTLY TO RAPID PENETRATION OF WATER INTO HOT ROCK, CAUSING ACTIVITY IN AREAS OF EPISODIC VOLCANISM TO BE SHORT-LIVED. THE LARGEST AND DEEPEST SUPPLY OF MAGMA/HOT ROCK OCCURS WHEREVER PLATE TECTONIC RIFTING CAUSES CREATION OF A COMPLETE NEW CRUST BY EMPLACEMENT FROM BELOW. THE ICELAND GEOTHERMAL REGION IS ON A KNOWN SEA-FLOOR SPREADING CENTER, THE NEW ZEALAND GEOTHERMAL AREA IS NOW SUSPECTED TO BE CAUSED BY CONTINENTAL RIFTING, AND THE ITALIAN AREAS ARE INTIMATELY ASSOCIATED WITH THE COMPLEX TECTONICS OF THE MEDITERRANEAN BASIN. THE MOST PROMISING AREAS FOR GEOTHERMAL SEARCH ARE THOSE WHERE LITHOSPHERE EXTENSION IS TAKING PLACE, WHETHER THESE ARE PRIMARY RIFTS OR SECONDARY SPREADING ASSOCIATED WITH THE TECTONICS OF TRENCHES. FLOOD BASALT AREAS ARE LESS PROMISING BECAUSE OF SURFACE EMPLACEMENT OF THE HOT MATERIAL.

GEOTHERMAL STUDIES/EXPLORATION/STRUCTURAL GEOLOGY/GEOLOGY/SPATIAL DISTRIBUTION
/IDENTIFIERS: /CONTINENTAL DRIFT/GLOBAL TECTONICS/WORLD/RIFT ZONES/VOLCANISM/ PLATE BOUNDARIES/ICELAND/NEW ZEALAND/ITALY/GLOBAL DISTRIBUTION/SPREADING CENTERS

139

LITTLETON, R.T.

1973

GEOTHERMAL DEVELOPMENT AND SOUTHWEST STORAGE BASINS.

UNIVERSITY OF CALIFORNIA, BERKELEY, WATER RESOURCES CENTER, REPORT 26:46-48.

SEE: SWRA W74-06945.

GEOTHERMAL STUDIES/GROUNDWATER BASINS/SOUTHWEST U.S./CALIFORNIA/DESALINATION/ WATER RESOURCES DEVELOPMENT/GROUNDWATER RESOURCES
/IDENTIFIERS: /GEOTHERMAL ENERGY/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL POWER

140

LIVINGSTON, V.E., JR.

1972

GEOTHERMAL ENERGY IN WASHINGTON. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER L, 17 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03431.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/WASHINGTON/THERMAL WATER/WATER TEMPERATURE/HYDROGEOLOGY/THERMAL PROPERTIES/THERMAL SPRINGS/VOLCANOES/FAULTS(GEOLOGIC)/WATER QUALITY/EXPLORATION/HOT SPRINGS/ELECTRIC POWER DEMAND/SPATIAL DISTRIBUTION
/IDENTIFIERS: /GEOTHERMAL RESOURCES

141

LUNDBERG, E.A.

1974

UTILIZATION OF THE EARTH'S NATURAL HEATING SYSTEM TO DESALT GEOTHERMAL BRINES FOR AUGMENTATION OF THE COLORADO RIVER SYSTEM.

NATIONAL WATER SUPPLY IMPROVEMENT ASSOCIATION JOURNAL 1(1):39-51.

SEE: SWRA W75-04430.

GEOTHERMAL STUDIES/DESALINATION/EXPLORATION/GEOLOGY/TEST WELLS/THERMAL WATER/FLASH DISTILLATION/BRINES/POTABLE WATER/GEOPHYSICS/GEOCHEMISTRY/WATER SUPPLY/WATER RESOURCES DEVELOPMENT/WATER QUALITY CONTROL/CALIFORNIA/COLORADO RIVER BASIN/WATER DEMAND/SALINE SOILS/RESEARCH AND DEVELOPMENT
/IDENTIFIERS: /IMPERIAL VALLEY/HOT BRINES/GEOTHERMAL RESOURCES DEVELOPMENT/CHEMICAL RECOVERY/GEOTHERMAL POWER

142

LUSBY, W.S./SOMERS, E.V.

1972

POWER PLANT EFFLUENT - THERMAL POLLUTION OR ENERGY AT A BARGAIN PRICE.

MECHANICAL ENGINEERING 94(6):12-15.

SEE: SWRA W74-02888.

ELECTRIC POWER PRODUCTION/THERMAL POLLUTION/HEATING/AIR CONDITIONING/THERMAL POWERPLANTS/DESIGN/COOLING/COST ANALYSIS/ECONOMICS/FOSSIL FUELS/SEASONAL/GEOTHERMAL STUDIES/MODEL STUDIES/PEAK LOADS
/IDENTIFIERS: /MODEL TOWNS/REYKJAVIK/LITHIUM BROMIDE/ICELAND/WASTE HEAT

143

MAHON, W.A.J.

1973

CHEMISTRY IN THE EXPLORATION AND EXPLOITATION OF HYDROTHERMAL SYSTEMS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1310-1322.

SEE: SWRA W74-09013.

GEOTHERMAL STUDIES/HYDROTHERMAL STUDIES/GEOCHEMISTRY/WATER CHEMISTRY/SCALING/EXPLORATION/HEAT FLOW/THERMAL WATER/MINERAL WATER/BOREHOLES/THERMAL SPRINGS/SAMPLING/GROUNDWATER MOVEMENT/SOLUBILITY/PERMEABILITY/THERMODYNAMICS/HYDROGEOLOGY/WATER TEMPERATURE
/IDENTIFIERS: /BOREHOLE GEOCHEMISTRY/NEW ZEALAND/GEOTHERMAL POWER/GEOTHERMAL FLUIDS/GEOTHERMAL RESERVOIRS/GEOTHERMOMETERS

144

MAHON, W.A.J./FINLAYSON, J.E.

1972

THE CHEMISTRY OF THE BROADLANDS GEOTHERMAL AREA NEW ZEALAND.

AMERICAN JOURNAL OF SCIENCE 272(1):48-68.

SEE: SWRA W72-03842.

GEOTHERMAL STUDIES/HEAT FLOW/WATER CHEMISTRY/WATER TEMPERATURE/STEAM/VOLCANOES/HOT SPRINGS/THERMAL SPRINGS/METEORIC WATER
/IDENTIFIERS: /NEW ZEALAND/BROADLANDS FIELD, NEW ZEALAND/HOT WATER SYSTEMS

145

MARINELLI, G.

1973

DEEP DOWN POWER.

DEVELOPMENT FORUM 1(3):5-10.

A PROPERLY OPERATED GEOTHERMAL FIELD CAN PRODUCE AN ENDLESS SUPPLY OF STEAM. AIR POLLUTION HAS AROUSED KEEN INTEREST IN THIS RESOURCE IN RECENT YEARS. BECAUSE GEOTHERMAL ENERGY IS CHEAP AND CLEAN, RESEARCH FUNDS SHOULD BE POURED INTO THIS FIELD, REGARDLESS OF ANY NATION'S CURRENT ENERGY SUPPLY. PERHAPS THIS SOURCE OF POWER CAN SPUR INDUSTRIALIZATION IN POOR COUNTRIES.

GEOTHERMAL STUDIES/AIR POLLUTION/COSTS/COST EFFICIENCY/ENVIRONMENTAL EFFECTS/ ELECTRIC POWER PRODUCTION/EUROPE/THERMAL POWER
/IDENTIFIERS: /GEOTHERMAL STEAM/GEOTHERMAL POWER/DEVELOPING COUNTRIES

146

MARKARENKO, F.A. ET AL

1973

GEOTHERMAL RESOURCES OF THE USSR AND PROSPECTS FOR THEIR PRATICAL USE. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1086-1091.

SEE: SWRA W74-08986.

GEOTHERMAL STUDIES/HYDROGEOLOGY/EXPLORATION/HYDROTHERMAL STUDIES/ THERMAL WATER/THERMAL POWER/COSTS/DATA COLLECTIONS/HYDROLOGIC DATA/ SPATIAL DISTRIBUTION
/IDENTIFIERS: /USSR/GEOTHERMAL RESOURCES/HOT WATER SYSTEMS

147

MARSHALL, T./BRAITHWAITE, W.R.

1973

CORROSION CONTROL IN GEOTHERMAL SYSTEMS. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 151-160.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

GEOTHERMAL FLUIDS ARE FAR FROM BEING PURE WATER; THEY CAN CONTAIN NUMEROUS DISSOLVED SOLIDS AND GASES WHICH CAN CAUSE CORROSION, THE MIXTURE VARYING GREATLY WITH LOCATION. DURING RESOURCE EXPLOITATION, GASES ARE CONCENTRATED IN STEAM, CONDENSATE, AND ATMOSPHERIC EFFLUENTS, WHILE NON-GASEOUS IMPURITIES ARE CONCENTRATED IN WATER PHASE. THESE IMPURITIES CAN CORRODE METALS AND CONCRETE (USED IN GEOTHERMAL PLANT STRUCTURES) UNDER VARIOUS CONDITIONS OF TEMPERATURE, PRESSURE, AND STRESS. CORROSION IS CONTROLLED BY USE OF SPECIAL MATERIALS (SPECIAL ALLOYS IN PIPELINES AND TURBINES, PLASTICS, WOOD, AND GLASS IN CONDENSERS AND COOLING TOWERS, ALUMINUM WIRES INSTEAD OF COPPER TO AVOID HYDROGEN SULFIDE CORROSION), SPECIAL COATINGS (EPOXY, COAL TAR, PLASTICS, GOLD AND CHROME PLATING), ENCLOSURE AND ISOLATION OF SUSCEPTIBLE MATERIALS, AND PREVENTIVE MAINTENANCE. (OALS)

GEOTHERMAL STUDIES/CORROSION/DISSOLVED SOLIDS/GASES/CORROSION CONTROL/ CHEMICAL PROPERTIES/COAL TAR COATINGS/COATINGS/ALLOYS/EFFLUENTS/METALS/GOLD/ PLASTICS/EPOXY RESINS/PROTECTIVE COATINGS/HYDROGEN SULFIDE/ALUMINUM/CONCRETES/ CHROMIUM/MAINTENANCE/TECHNOLOGY/WATER CHEMISTRY
/IDENTIFIERS: /GEOTHERMAL FLUIDS

148

MATHUR, S.P./STEWART, R. EDS.

1970

CONFERENCE ON BENEFICIAL USES OF THERMAL DISCHARGES, ALBANY, NEW YORK, 1970, PROCEEDINGS.

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, ALBANY, NEW YORK. 227 P.

SEE: SWRA W73-04337.

HEAT/THERMAL POLLUTION/FISH FARMING/AGRICULTURE/THERMAL POWERPLANTS/HEATED WATER/MULTIPLE-PURPOSE PROJECTS/ENVIRONMENTAL EFFECTS/WATER POLLUTION/HEATING/ POWERPLANTS/GREENHOUSES/COOLING/MARINE FISHERIES/FISHERIES/FISH HATCHERIES/ GEOTHERMAL STUDIES/AGRICULTURE/BENEFICIAL USE/ENVIRONMENTAL ENGINEERING
/IDENTIFIERS: /WASTE HEAT/THERMAL DISCHARGES/MARICULTURE/CARRYING CAPACITY/ WASTE HEAT USES/SPACE HEATING

149

MATLICK, S./BUSECK, P.R.

1975

A NEW EXPLORTION METHOD FOR GEOTHERMAL SOURCES USING MERCURY. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS III-61.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

MERCURY (HG) MINERALS OCCUR NEAR MANY GEOTHERMAL AREAS, AND HG ORE DEPOSITS COMMONLY HAVE ASSOCIATED HOT SPRINGS. BECAUSE OF THIS CORRELATION, USE OF HG AS AN EXPLORATION TOOL TO LOCATE GEOTHERMAL AREAS WAS TESTED. OVER 400 ANALYSES WERE MADE IN THE FIELD AT LONG VALLEY CALDERA, CALIFORNIA. SIX ANOMALOUS AREAS RANGE FROM LESS THAN 0.5 TO GREATER THAN 3 SQUARE MILES AND DO NOT APPEAR TO CORRELATE WITH ROCK TYPE. TWO CENTERS OF HOT SPRING ACTIVITY AND TWO BOUGUER GRAVITY ANOMALIES COINCIDE WITH HG HIGHS. SEVERAL HG ANOMALIES ALSO FALL OUTSIDE THESE REGIONS. KLAMATH FALLS, OREGON, ALSO SHOWS HG ANOMALIES OVER GEOTHERMALLY ACTIVE REGIONS. HG MEASUREMENTS, IF OF SUFFICIENTLY HIGH SENSITIVITY, CAN BE USED TO LOCATE AREAS OF GEOTHERMAL ACTIVITY, EVEN IN AREAS FREE OF HOT SPRING ACTIVITY.

GEOTHERMAL STUDIES/CALIFORNIA/OREGON/MERCURY/EXPLORATION/GEOCHEMISTRY/TRACE ELEMENTS/ANALYTICAL TECHNIQUES/ON-SITE INVESTIGATIONS
/IDENTIFIERS: /MINERAL DEPOSITS/LONG VALLEY CALDERA/KLAMATH FALLS

150

MATSUO, K.

1973 A

DRILLING FOR GEOTHERMAL STEAM AND HOT WATER. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 73-83.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

SURVEYS EQUIPMENT AND PROCEDURES OF FIRST-GENERATION GEOTHERMAL DRILLING TECHNOLOGY, WHICH IS BORROWED DIRECTLY FROM THE OIL INDUSTRY (BUT WITH CERTAIN NECESSARY MODIFICATIONS). STANDARD ROTARY RIGS WITH MUD CIRCULATION ARE MOST COMMONLY USED. SPECIAL CASING, DRILLING MUD, AND WELLHEAD EQUIPMENT ARE REQUIRED, AND MUD COOLING TOWER MAY BE NEEDED FOR HIGH TEMPERATURES AND PRESSURES. SEVERAL SPECIAL PROBLEMS CAN ARISE DURING DRILLING AND AFTER WELL COMPLETION, AND PROCEDURES FOR SOLVING OR PREVENTING THEM ARE OUTLINED. USING AIR FOR CIRCULATION IS FASTER AND CHEAPER IN DRY STEAM FIELDS THAN STANDARD DRILLING WITH MUD. SAFETY PRECAUTIONS, WELL SURVEYS, AND WELL REPAIRS ARE BRIEFLY DISCUSSED. (OALS)

GEOTHERMAL STUDIES/DRILLING/ROTARY DRILLING/WELL DRILLING/DRILLING EQUIPMENT/DRILLING FLUIDS/OIL INDUSTRY/MUD/AIR CIRCULATION/CASINGS/COOLING TOWERS/SAFETY/TECHNOLOGY
/IDENTIFIERS: /GEOTHERMAL STEAM/DRY STEAM FIELDS

151

MATSUO, K.

1973 B

PRESENT STATE OF DRILLING AND REPAIRING OF GEOTHERMAL PRODUCTION WELLS IN JAPAN. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1467-1479.

SEE: SWRA W74-09030.

DRILLING/WELL CASINGS/HOT SPRINGS/GEOTHERMAL STUDIES/WELLS/WATER TEMPERATURE/EXPLORATION/STEAM/ROTARY DRILLING/DRILLING EQUIPMENT/WELL SCREENS
/IDENTIFIERS: /GEOTHERMAL POWER/JAPAN/MATSUKAWA/OTAKE

152

MCMILLAN, D.A., JR.

1970

ECONOMICS OF THE GEYSERS GEOTHERMAL FIELD, CALIFORNIA. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1705-1714.

SEE: SWRA W71-11650; W74-09046.

GEOTHERMAL STUDIES/THERMAL POWERPLANTS/COMPARATIVE COSTS/PIPELINES/WELLS/STEAM/COSTS/WASTE WATER DISPOSAL/ECONOMICS/CALIFORNIA/CORROSION/THERMAL POWER/ELECTRIC POWER COSTS/CALIFORNIA/ECONOMIES OF SCALE/INCOME/PRICES
/IDENTIFIERS: /TURBOGENERATORS/GEYSERS FIELD, CALIFORNIA/GEOTHERMAL POWER

153

MCNITT, J.R.

1973

THE ROLE OF GEOLOGY AND HYDROLOGY IN GEOTHERMAL EXPLORATION. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 33-40.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

SEE: SWRA W74-11761.

HYDROLOGY/GEOLOGY/HYDROGEOLOGY/GEOTHERMAL STUDIES/REVIEWS/THERMAL WATER/ EXPLORATION/SURVEYS/INVESTIGATIONS/GEOPHYSICS/GEOCHEMISTRY/RESISTIVITY/ DRILLING
/IDENTIFIERS: /EXPLORATION WELLS

154

MCNITT, J.R.

1975

ORGANIZATION OF UNITED NATIONS GEOTHERMAL EXPLORATION PROJECTS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS III-67.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

IN THE PERIOD 1965-1975 THE U.N. WILL HAVE COMPLETED GEOTHERMAL EXPLORATION PROJECTS AT AN AVERAGE COST OF 3 MILLION DOLLARS EACH. DURATION OF A PROJECT IS FROM 4-7 YEARS. PROJECT WORK PROGRESSES THROUGH FIVE CONSECUTIVE PHASES: 1) RECONNAISSANCE SURVEY TO IDENTIFY SPECIFIC PROSPECT AREAS (HYDROGEOCHEMISTRY, REGIONAL GEOLOGY, HYDROGEOLOGY, AND AERIAL INFRA-RED IMAGERY SURVEYS). 2) RESISTIVITY, MICROEARTHQUAKE, AND TEMPERATURE GRADIENT SURVEYS, TO LOCATE SITES FOR EXPLORATION DRILLING. 3) EXPLORATION DRILLING (160 TO 450 THOUSAND DOLLARS PER HOLE). 4) DRILLING OFFSET WELLS (TO PROVE SUFFICIENT PRODUCTION FOR THE FIRST GENERATING PLANT AND STUDY RESERVOIR CONDITIONS). 5) FEASIBILITY STUDY TO DETERMINE CAPITAL AND OPERATING COST OF A GEOTHERMAL POWERPLANT.

GEOTHERMAL STUDIES/UNITED NATIONS/EXPLORATION/COSTS/SURVEYS/GEOLOGY/DRILLING/ HYDROGEOLOGY/GEOCHEMISTRY/REMOTE SENSING/INFRARED RADIATION
/IDENTIFIERS: /DRILLING COSTS

155

MEADOWS, K.F. ED.

1972 - TO DATE.

GEOTHERMAL WORLD DIRECTORY.

SAME AS AUTHOR. GLENDORA, CALIFORNIA. 1972, 190 P.; 1973, 242 P.; 1974, 302 P.

AN ANNUALLY UPDATED COMPILATION OF ADDRESSES AND OTHER INFORMATION USEFUL TO GEOTHERMAL INDUSTRY. PART ONE LISTS INDIVIDUALS (280, 450, 600--NUMBER LISTED IN 1972, 1973, AND 1974 DIRECTORIES, RESPECTIVELY) AND COMMERCIAL FIRMS (116, 300, 400) ACTIVE IN GEOTHERMAL RESEARCH, EXPLORATION, AND UTILIZATION. ALSO LISTED ARE UNIVERSITIES AND COLLEGES WHO SUBSCRIBE, U.S. PUBLIC UTILITIES COMMISSIONS, PUBLIC UTILITIES, POWER POOLS, AND SELECTED GEOTHERMAL-RELATED PUBLICATIONS. QUESTIONNAIRE ANSWERS FROM U.S. CONGRESSMEN, STATE GOVERNMENTS, AND FOREIGN COUNTRIES, AND ADVERTISEMENTS FOR PRODUCTS, SERVICES, AND PUBLICATIONS ARE INCLUDED, AS WELL. PART TWO (TWO-THIRDS OF THE DIRECTORY) CONSISTS OF ORIGINAL AND REPRINTED TECHNICAL AND SUMMARY ARTICLES ON GEOTHERMAL TOPICS. (OALS)

GEOTHERMAL STUDIES/DATA COLLECTIONS/RESEARCH AND DEVELOPMENT/EXPLORATION/ EXPLOITATION/PUBLIC UTILITIES/MANUALS
/IDENTIFIERS: /DIRECTORIES/WORLD/GEOTHERMAL RESOURCES DEVELOPMENT

156

MEIDAV, T.

1975 A

CRITIQUE OF GEOTHERMAL EXPLORATION TECHNOLOGY. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS III-68.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

INDIVIDUAL EXPLORATION TECHNIQUES HAVE DISPLAYED THEIR VALUE IN SOME CASES, AND HAVE FAILED IN OTHERS. TEMPERATURE GRADIENT, ELECTRICAL RESISTIVITY, SELF-POTENTIAL, GROUND-NOISE SURVEYS, MICROEARTHQUAKE SEISMOLOGY, GRAVIMETRY, GEOCHEMICAL THERMOMETRY, AND ISOTOPE GEOCHEMISTRY HAVE PROVEN

DIAGNOSTIC IN SOME CASES, BUT HAVE BEEN TOTALLY MISLEADING WHERE MISAPPLIED. EVALUATIONS BASED ON ANY ONE PARAMETER MAY RESULT IN ERRONEOUS CONCLUSIONS ABOUT LOCATION OF POTENTIAL GEOTHERMAL RESERVOIRS, THEIR STATE AND THEIR TEMPERATURE. GEOCHEMICAL EXPLORATION PROVIDES SIGNIFICANT INFORMATION REGARDING GEOTHERMAL RESERVOIR CHARACTERISTICS IF REGIONAL GEOCHEMICAL TRENDS, EFFECTS OF MIXING OF DIFFERENT WATER TYPES, AND ROCK-WATER INTERACTIONS ARE QUANTITATIVELY EVALUATED. GEOTHERMAL EXPLORATION SUCCESS CAN BE IMPROVED BY COMBINING DATA FROM CERTAIN GEOPHYSICAL AND GEOCHEMICAL METHODS WHICH COMPLEMENT EACH OTHER. EXAMPLES ARE GIVEN.

GEOTHERMAL STUDIES/EXPLORATION/TECHNOLOGY/GEOPHYSICS/GEOCHEMISTRY/SURVEYS/ ELECTRICAL STUDIES/RESISTIVITY/SEISMIC STUDIES/GRAVITY STUDIES /IDENTIFIERS: /TEMPERATURE GRADIENT/GEOTHERMOMETERS/GEOTHERMAL RESERVOIRS

157

MEIDAV, T.

1975 B

GEOTHERMAL EXPLORATION DEVELOPMENTS IN ISRAEL.

GEOTHERMAL ENERGY 3(5):20-22.

GEOLOGICAL AND GEOPHYSICAL EXPLORATION FOR GEOTHERMAL RESOURCES IS AT AN EARLY STAGE. PROMISING AREAS INCLUDE THE EILAT-JORDAN RIFT VALLEY (A TRANSFORM FAULT), DEAD SEA REGION (2 PROMISING RESISTIVITY ANOMALIES), SEA OF GALILEE AREA, AND YARMUK VALLEY (JORDAN-SYRIA BOUNDARY, SITE OF RECENT VOLCANISM). REGIONAL GEOLOGY IS BRIEFLY REVIEWED. THERMAL SPRINGS NEAR DEAD SEA AND SEA OF GALILEE (TIBERIAS AND EL HAMMA HOT SPRINGS) HAVE HAD BALNEOLOGICAL USE SINCE BIBLICAL TIMES. NEW HOT WATER SOURCES ARE BEING SOUGHT FOR BATHS AT NEW DEAD SEA HOTELS AND FOR POSSIBLE POWER GENERATION. GEOTHERMAL EXPLOITATION MIGHT FRESHEN SEA OF GALILEE WATER BY SLOWING FLOW FROM UNDERWATER SALINE HOT SPRINGS. EXPERIMENTAL GEOTHERMAL HEATING OF GREENHOUSES HAS JUST BEGUN IN NORTHERN NEGEV DESERT. (OALS)

GEOTHERMAL STUDIES/EXPLORATION/GEOLOGY/GEOPHYSICS/RESISTIVITY/THERMAL SPRINGS/ SALINE WATER/GREENHOUSES/LAKE BOTTOM SPRINGS/HISTORY /IDENTIFIERS: /ISRAEL/RIFT ZONES/VOLCANISM/JORDAN/SYRIA/HOT BATHS/GEOTHERMAL POWER/NEGEV/DEAD SEA/SEA OF GALILEE/GEOTHERMAL RESOURCES

158

MEIDAV, T./FURGERSON, R.

1972

RESISTIVITY STUDIES OF THE IMPERIAL VALLEY GEOTHERMAL AREA, CALIFORNIA.

GEOTHERMICS 1(2):47-62.

KNOWN GEOTHERMAL ANOMALIES APPEAR AS RESIDUAL RESISTIVITY LOWS SUPERIMPOSED ON REGIONAL GRADIENT DECREASING NORTHWESTWARD. GROUNDWATER SALINITY INCREASES NORTHWESTWARD, FROM VERY LOW NEAR YUMA TO VERY HIGH AT SALTON SEA. SALINITY INCREASES BY AN ORDER OF MAGNITUDE WESTWARD ACROSS IMPERIAL FAULT. MAXIMUM SALINITY CAN BE ESTIMATED FROM RESISTIVITY SURVEY AND WELL-LOG DATA. (OALS)

GEOTHERMAL STUDIES/RESISTIVITY/ELECTRICAL STUDIES/GEOPHYSICS/CALIFORNIA/ SALINITY/SALINE WATER SYSTEMS/GROUNDWATER/WELL DATA/SURVEYS/EXPLORATION /IDENTIFIERS: /IMPERIAL VALLEY/SALTON SEA

159

MERCADO, S.

1974

THE GEOTHERMAL PLANT OF CERRO PRIETO, B.C., MEXICO, AND PROBLEMS ENCOUNTERED DURING ITS DEVELOPMENT.

GEOTHERMICS 3(3):125-126.

FLASHED STEAM FROM CENTRIFUGAL SEPARATORS IS PIPED TO TWO 37.5 MW TURBOGENERATORS WITH SPECIAL ALLOY BLADES. WASTE WATER, HIGH IN SILICA AND SODIUM AND POTASSIUM CHLORIDES, IS SENT TO AN EVAPORATION POND FOR EVENTUAL REINJECTION. CERRO PRIETO IS A WATER DOMINATED FIELD TAPPED BY 28 PRODUCTION WELLS UP TO 1600 METERS DEEP. PRODUCTION LIMITS AND LIFE OF THE RESERVOIR ARE NOT KNOWN, BUT 400 MW IS THOUGHT POSSIBLE FROM THE PRESENT EXPLOITATION AREA. EXPERIENCE-TESTED REMEDIES FOR DIVERSE PROBLEMS ARE REVIEWED. PROBLEM AREAS INCLUDE EXPLORATION (RESISTIVITY SURVEY IS BEST), DRILLING (SPECIAL FLUIDS, CEMENT MIXTURES, AND PROCEDURES), WELL DEVELOPMENT (HORIZONTAL DISCHARGE TO AVOID SALT DAMAGE TO CROPS), STEAM SEPARATION, SCALING AND CORROSION, AIR POLLUTION (HYDROGEN SULFIDE), AND POWER PRODUCTION (CONTINUOUS WELL DISCHARGE, EVEN WHEN GENERATORS ARE DOWN). (OALS)

GEOTHERMAL STUDIES/POWERPLANTS/ENGINEERING STRUCTURES/THERMAL POWERPLANTS/ WASTE WATER DISPOSAL/EXPLORATION/ELECTRICAL STUDIES/DRILLING/SCALING/SILICA/ CORROSION/CHLORIDES/HYDROGEN SULFIDE/AIR POLLUTION /IDENTIFIERS: /GEOTHERMAL POWER/CERRO PRIETO FIELD, MEXICO/BAJA CALIFORNIA/ POWER CAPACITY/WATER-DOMINATED SYSTEMS/PRODUCTION WELLS/GEOTHERMAL RESERVOIRS/ MEXICO

160

MEYER, C.F./TODD, D.K.

1973

CONSERVING ENERGY WITH HEAT STORAGE WELLS.

ENVIRONMENTAL SCIENCE AND TECHNOLOGY 7(6):512-516. EIA 73-08063.

LARGE QUANTITIES OF USEFUL HEAT MAY BE STORED UNDERGROUND IN SPECIAL WATER WELLS, WITH MORE THAN 75 PERCENT OF THE HEAT RECOVERABLE AFTER 90 DAYS. HOT WELLS ARE ENVIRONMENTALLY ACCEPTABLE IF THEY ARE NOT LOCATED TOO CLOSE TO WATER PRODUCING WELLS. TOTAL ENERGY SYSTEM CONSIDERATIONS INCORPORATING HOT WATER STORAGE IN WELLS ARE DISCUSSED.

GEOTHERMAL STUDIES/HEAT TRANSFER/INJECTION WELLS/THERMAL WATER/HEATED WATER/THERMAL POLLUTION/WASTE HEAT/UNDERGROUND STORAGE
/IDENTIFIERS: /HEAT STORAGE/THERMAL ENERGY

161

MILLER, E.M.

1974

GEOTHERMAL AND GEOPRESSURE RELATIONS AS TOOL FOR PETROLEUM EXPLORATION. ABSTRACT OF PAPER PRESENTED AT 5TH ANNUAL MEETING OF SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS, ROCKY MOUNTAIN SECTION, CASPER, WYOMING, 1974.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, BULLETIN 58(5):916.

HIGH GEOTEMPERATURE, ABNORMALLY HIGH PRESSURE, AND PRESENCE OF ORGANIC-RICH SHALE FACIES ALL COEXIST WITH PRODUCTIVE HYDROCARBONS IN WASATCH FORMATION OF UINTA BASIN. MAPPING OF SUBSURFACE TEMPERATURE AND PRESSURE MAY BE A VERY USEFUL TOOL FOR PETROLEUM EXPLORATION IN TERTIARY BASINS WITH FRESH- AND BRACKISH-WATER LACUSTRINE SEDIMENTARY DEPOSITS.

GEOTHERMAL STUDIES/TEMPERATURE/PRESSURE/OIL RESERVOIRS/ORGANIC MATTER/OIL SHALES/EXPLORATION/SUBSURFACE INVESTIGATIONS/LAKE BEDS/BRACKISH WATER/FRESHWATER
/IDENTIFIERS: /GEOPRESSURED SYSTEMS/ENERGY SOURCES INTERFACES

162

MOYLE, W.R., JR.

1974

TEMPERATURE AND CHEMICAL DATA FOR SELECTED THERMAL WELLS AND SPRINGS IN SOUTHEASTERN CALIFORNIA.

WATER-RESOURCES INVESTIGATIONS 33-73. 12 P.

SEE: SWRA W75-01814.

THERMAL WATER/THERMAL SPRINGS/CALIFORNIA/WATER CHEMISTRY/DATA COLLECTIONS/HYDROLOGIC DATA/HYDROGEOLOGY/GEOTHERMAL STUDIES/HYDROTHERMAL STUDIES/WATER TEMPERATURE/WATER QUALITY/SPATIAL DISTRIBUTION/FAULTS(GEOLOGIC)
/IDENTIFIERS: /IMPERIAL VALLEY

163

MUFFLER, L.J.P.

1973

GEOTHERMAL RESOURCES. IN D.A. BROBST AND E.P. PRATT, EDS., UNITED STATES MINERAL RESOURCES, P. 251-261.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 820. NSF-RANN ENERGY ABSTRACTS 1(10)2343.

GEOTHERMAL RESOURCES BASE IS DEFINED AS ALL THE HEAT ABOVE 15 DEGREES C. IN THE EARTH'S CRUST, BUT ONLY A SMALL PART OF THIS BASE CAN PROPERLY BE CONSIDERED AS A RESOURCE. THE MAGNITUDE OF THE GEOTHERMAL RESOURCE DEPENDS ON THE EVALUATION OF MANY PHYSICAL, TECHNOLOGICAL, ECONOMIC, ENVIRONMENTAL, AND GOVERNMENTAL FACTORS. PHYSICAL FACTORS THAT CONTROL THE DISTRIBUTION OF HEAT AT DEPTH CAN BE EVALUATED, AT LEAST RUDELY. MORE TENUOUS ARE THE ASSUMPTIONS OF TECHNOLOGY, ECONOMICS, AND GOVERNMENTAL POLICY. THESE ASSUMPTIONS ARE CRITICAL TO GEOTHERMAL RESOURCE ESTIMATION, AND DIFFERENCES AMONG THEM ARE IN GREAT PART RESPONSIBLE FOR THE VAST RANGE IN MAGNITUDE AMONG DIFFERENT GEOTHERMAL RESOURCE ESTIMATES. UTILIZATION OF A GREATER PROPORTION OF THE GEOTHERMAL RESOURCE BASE DEPENDS ON ACHIEVING ONE OR MORE OF THE FOLLOWING ITEMS: 1) TECHNOLOGICAL ADVANCES THAT WOULD ALLOW ELECTRICAL GENERATION FROM LOW-TEMPERATURE RESERVOIRS 2) BREAKTHROUGHS IN DRILLING TECHNOLOGY THAT WOULD PERMIT LOW-COST DRILLING OF HOLES TO DEPTHS GREATER THAN 3 KILOMETERS; 3) DEVELOPMENT OF TECHNIQUES OF ARTIFICIAL STIMULATION THAT WOULD INCREASE THE PRODUCTIVITY OF GEOTHERMAL RESERVOIRS; AND 4) EXPANSION OF THE USE OF LOW-GRADE GEOTHERMAL RESOURCES FOR SUCH PURPOSES AS SPACE HEATING, PRODUCT PROCESSING, AGRICULTURE, AND DESALINATION. (AUTHOR)

GEOTHERMAL STUDIES/ENERGY CONVERSION/EVALUATION/RESOURCE INVENTORY/
GOVERNMENTS/DRILLING/DESALINATION
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT/
GEOTHERMAL POWER/WELL STIMULATION/GEOTHERMAL RESERVOIRS/SPACE HEATING/
INDUSTRIAL USES/GEOTHERMAL HEAT

164

MUNDORFF, J.C.

1970

MAJOR THERMAL SPRINGS OF UTAH.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY, WATER RESOURCES BULLETIN 13. 60 P.

SEE: SWRA W71-11779.

THERMAL SPRINGS/UTAH/HOT SPRINGS/WATER YIELD/WATER QUALITY/WATER TEMPERATURE/
THERMAL WATER/WATER CHEMISTRY/DISCHARGE(WATER)/WATER RESOURCES/GROUNDWATER/
WARM SPRINGS/DATA COLLECTIONS/HYDROLOGIC DATA/FAULTS(GEOLOGIC)
/IDENTIFIERS: /GEOTHERMAL RESOURCES

165

MURRAY, W.B.

1972

PRODUCING FRESH WATER FROM BRINE.

WATER AND SEWAGE WORKS 119(1-2):40-43, 54-57.

SEE: SWRA W72-12661.

FRESHWATER/BRINES/DEMINERALIZATION/NUCLEAR POWERPLANTS/FOG/EVAPORATION/
GEOTHERMAL STUDIES/WATER SOURCES/WATER RESOURCES DEVELOPMENT/COSTS/STEAM/
PRECIPITATION(ATMOSPHERIC)/CALIFORNIA/THERMOCLINE/CONDENSATION/COASTAL
STRUCTURES/SEA WATER/NUCLEAR POWERPLANTS/THERMAL WATER/MULTIPLE-PURPOSE
PROJECTS
/IDENTIFIERS: /GEOTHERMAL FLUIDS

166

NARATH, A.

1975

ADVANCED DRILLING TECHNOLOGY.

GEOTHERMAL ENERGY 3(6):8-17.

DRILLING COSTS ARE DETERMINED MAINLY BY DRILLING TIME, WHICH DEPENDS ON DRILLING RATE, WHICH IN TURN DEPENDS ON BIT LIFE AND CUTTING RATE. AT PRESENT, USING MODIFIED OIL DRILLING TECHNOLOGY, GEOTHERMAL DRILLING COSTS 2 TO 4 TIMES AS MUCH AS OIL DRILLING. NEW DRILLING TECHNOLOGIES, CURRENTLY IN RESEARCH STAGE, INCLUDE: SPARK DRILL (DOWN-HOLE ELECTRICAL PULSE GENERATOR SPARKS CAUSE SHOCK WAVES, CAVITATION, AND ROCK SPALLING; FLUID REMOVES ROCK CHIPS), TERRA DRILL (COMBINES STANDARD ROTARY ROCK BIT WITH TERRADYNAMIC TECHNOLOGY--PROJECTILES PENETRATE AND WEAKEN ROCKS), DOWN-HOLE CHANGEABLE BIT (LESS FREQUENT PULLING OF ENTIRE DRILL STRING OUT OF HOLE TO REPLACE BITS), CONTINUOUS CHAIN BIT (REPLACES CUTTING SURFACE MANY TIMES WITHOUT PULLING DRILL STRING), SUBTERRENE (ROCK MELTING BY ELECTRICALLY HEATED BIT, RESULTS IN GLASS-LINED HOLE, AND WORKS BETTER THE HOTTER THE ROCK IS), AND STANDARD ROTARY BIT WITH VERY HIGH PRESSURE DRILLING MUD. FIRST 4 ARE BEING DEVELOPED AT SANDIA LAB, THE 5TH AT LOS ALAMOS LAB, AND THE LAST BY EXXON. (OALS)

GEOTHERMAL STUDIES/DRILLING/ROTARY DRILLING/DRILLING EQUIPMENT/RESEARCH AND
DEVELOPMENT/TECHNOLOGY
/IDENTIFIERS: /DRILLING COSTS/SPARK DRILL/TERRA DRILL/SUBTERRENE/DRILL BITS

167

NATHENSON, M.

1974

FLASHING FLOW IN HOT-WATER GEOTHERMAL WELLS.

U.S. GEOLOGICAL SURVEY/JOURNAL OF RESEARCH 2(6):743-751.

SEE: SWRA W75-02138.

HYDROTHERMAL STUDIES/GEOTHERMAL STUDIES/WATER WELLS/THERMODYNAMICS/BOILING/
GROUNDWATER MOVEMENT/HEATED WATER/FLOW RATES/STEAM/WATER YIELD/WATER
TEMPERATURE/FLOW CHARACTERISTICS
/IDENTIFIERS: /GEOTHERMAL WELLS/HOT WATER SYSTEMS/PRODUCTION WELLS

168

NATHENSON, M./MUFFLER, L.J.P.

1975

GEOTHERMAL RESOURCES IN HYDROTHERMAL CONVECTION SYSTEMS AND CONDUCTION-DOMINATED AREAS. IN D.E. WHITE AND D.L. WILLIAMS, EDS., ASSESSMENT OF GEOTHERMAL RESOURCES OF THE UNITED STATES--1975, P. 104-121.

U.S. GEOLOGICAL SURVEY, CIRCULAR 726.

ESTIMATED POTENTIAL ELECTRICAL ENERGY OBTAINABLE IS TABULATED FOR 38 LARGE IDENTIFIED HIGH TEMPERATURE (150 DEGREES C. PLUS) HYDROTHERMAL CONVECTION SYSTEMS IN ALASKA, CALIFORNIA, IDAHO, NEVADA, NEW MEXICO, OREGON, AND UTAH. TOTAL IS 8,000 MEGAWATT-CENTURIES (MW-C), OR 27,000 MW FOR 30 YEARS. A SIMPLE MODEL OF ECONOMICS AND WELL BEHAVIOR WAS USED TO DETERMINE THAT OF THIS AMOUNT, 3,500 MW-C ARE RESERVES (RECOVERABLE AT COST THAT IS COMPETITIVE NOW), 3,500 MW-C ARE PARAMARGINAL RESERVES (COST 1 TO 2 TIMES CURRENT ENERGY PRICE), AND 1,000 PLUS MW-C ARE SUBMARGINAL RESERVES (COST MORE THAN 2 TIMES CURRENT ENERGY PRICE). UNDISCOVERED RESOURCE ESTIMATE IS 38,000 MW-C. POTENTIAL ECONOMIC RECOVERY OF PROCESS HEAT FROM 28 LARGE IDENTIFIED INTERMEDIATE TEMPERATURE (90-150 DEGREES C.) HYDROTHERMAL CONVECTION SYSTEMS IS TENTATIVELY ESTIMATED TO BE 20 TIMES 10 TO 18TH POWER CALORIES, AND UNDISCOVERED RESOURCES MAY BE 3 TIMES AS MUCH. (OALS)

GEOTHERMAL STUDIES/HYDROTHERMAL STUDIES/ELECTRIC POWER/UNITED STATES/ALASKA/CALIFORNIA/IDAHO/NEVADA/NEW MEXICO/OREGON/UTAH/ECONOMICS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/HYDROTHERMAL CONVECTION SYSTEMS/POWER CAPACITY/HOT WATER SYSTEMS/VAPOR-DOMINATED SYSTEMS/HYDROTHERMAL SYSTEMS/WESTERN U.S./GEOTHERMAL POWER/GEOTHERMAL HEAT/HEAT STORAGE

169

NATIONAL PETROLEUM COUNCIL, COMMITTEE ON THE U.S. ENERGY OUTLOOK

1972

U.S. ENERGY OUTLOOK, AN INTERIM REPORT: AN INITIAL APPRAISAL BY THE NEW ENERGY FORMS TASK GROUP, 1971-1985.

SAME AS AUTHOR, OTHER ENERGY RESOURCES SUBCOMMITTEE, WASHINGTON, D.C. 91 P.

ONE OF EIGHT VOLUMES IN A SERIES OF REPORTS, THIS STUDY REVIEWS THE POSSIBLE DEVELOPMENT OF ALTERNATIVE POWER SOURCES BETWEEN 1971-1985. AS A QUICK OVERVIEW OF THESE RESOURCES (HYDROELECTRIC, GEOTHERMAL, ENERGY FROM AGRICULTURE, SOLAR, TIDAL, FUEL CELLS, THERMIONICS, MAGNETOHYDRODYNAMICS) THE REPORT IS THIN IN SPOTS BUT SUCCEEDS AS AN INDICATION OF THE ENERGY INDUSTRIES APPRAISAL OF NOVEL METHODS OF PRODUCING ENERGY. GENERALLY, THE INDUSTRY TAKES A DIM VIEW OF THESE RESOURCES. FOR EXAMPLE, SOLAR ENERGY IS SEEN AS A SUPPLEMENTARY SOURCE TO BE TAPPED SOMETIME IN THE NEXT CENTURY.

ENERGY CONVERSION/HYDROELECTRIC POWER/AGRICULTURE
/IDENTIFIERS: /GEOTHERMAL RESOURCES/ALTERNATIVE ENERGY SOURCES/SOLAR ENERGY/TIDAL ENERGY/GEOTHERMAL POWER

170

NEPRIMEROF, N.N.

1975

THERMAL WATERS AS A SOURCE OF WATER-FLOODING OF OIL RESERVOIRS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS IX-9.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

MOST USSR OIL FIELDS ARE EVENTUALLY SUBJECTED TO SECONDARY RECOVERY TECHNIQUES. COLD WATER FLOODING APPEARS TO DECREASE PRODUCTIVITY, BUT AN EXAMPLE OF NATURAL FLOODING BY THERMAL WATER SHOWED PRODUCTIVITY INCREASE BY TENS OF PERCENT. THERMAL WATERS AND BRINES, COMMON IN OIL FIELDS, ARE A NATURAL SOURCE OF WATER FOR EFFICIENT SECONDARY RECOVERY FLOODING.

GEOTHERMAL STUDIES/OIL FIELDS/OIL RESERVOIRS/OIL-WATER INTERFACES/THERMAL WATER/SECONDARY RECOVERY(OIL)/FLOODING
/IDENTIFIERS: /USSR/ENERGY SOURCES INTERFACES/ENERGY-WATER RELATIONSHIPS/HOT BRINES

171

NETSCHERT, B.C.

1971

THE ENERGY COMPANY: A MONOPOLY TREND IN THE ENERGY MARKETS.

BULLETIN OF THE ATOMIC SCIENTISTS 27(8):13-17.

THIS IS PART OF A STATEMENT BEFORE THE U.S. SENATE SUBCOMMITTEE ON ANTITRUST AND MONOPOLY OF THE SENATE COMMITTEE ON THE JUDICIARY. IT ASSERTS THAT HORIZONTAL ACQUISITIONS IN THE POWER INDUSTRY THREATEN COMPETITION. THERE IS A

STRONG UPWARD PRICE PRESSURE IN ALL OF THE FUELS MARKETS, AND HORIZONTAL EXPANSION ELIMINATES THE COUNTERVAILING POWER OF INTERFUEL COMPETITION. THIS COULD MEAN THAT EMERGENCE OF NEW INDUSTRIES BASED ON NEW POWER SOURCES COULD BE CONSIDERABLY DELAYED.

FUELS/ENERGY/INDUSTRIES/ELECTRIC POWER INDUSTRY/UTILITIES/COMPETITION/PRICES/COMPETITIVE PRICES/OIL INDUSTRY/NUCLEAR ENERGY/POWER MARKETING/MONOPOLY/REGULATION
/IDENTIFIERS: /ALTERNATIVE ENERGY SOURCES

172

NICHOLS, C.R.

1970

THE GEOLOGY AND GEOCHEMISTRY OF THE PATHE GECTHERMAL ZONE, HIDALGO, MEXICO.

UNIVERSITY OF OKLAHOMA (PH.D. DISSERTATION). 206 P. DISSERTATION ABSTRACTS 31(7):4139-B.

THE MEXICAN GOVERNMENT'S COMISION FEDERAL DE ELECTRICIDAD HAS OPERATED A 3500 KW TURBOGENERATOR PLANT AT THE PATHE GEOTHERMAL FIELD IN NORTHWEST HIDALGO, MEXICO SINCE 1958. THE PRESENT INVESTIGATION EXAMINES VARIABLES WHICH CONTROL ALTERATION PRODUCT MINERALOGY DEVELOPED IN AN ACTIVE HYDROTHERMAL AREA. EXPLORATORY DRILLING HAS REACHED A DEPTH OF 1286 M WITHOUT DRILLING THROUGH TERTIARY VOLCANIC SEQUENCE OF INTERBEDDED RHYOLITE, PUMICE, TUFFS, FLOW BRECCIA, ANDESITE, AND OLIVINE BASALT. THE VERTICAL CHEMICAL VARIATION AS DETERMINED BY QUANTITATIVE CHEMICAL ANALYSES BY X-RAY FLUORESCENCE DOES NOT INDICATE AN OBVIOUS OVERALL DIFFERENTIATION TREND. LOW PRESSURE STEAM AT TEMPERATURES OF 100 TO 150 DEGREES C. IS PRODUCED FROM A 1200 M LONG PORTION OF A NORTH-SOUTH TRENDING HIGH-ANGLE FAULT. A SECOND SET OF EAST-WEST TRENDING NORMAL FAULTS HAS PRODUCED A SERIES OF GRABENS AND HORSTS PARALLEL TO AN AREA OF SUBSIDENCE THROUGH THE PATHE FIELD. STEAM IS PRESENT AT SHALLOW DEPTH AND CONSTITUTES A HAZARD IN CLAY MINES WHICH ARE PRESENT ALONG THE THERMALLY ACTIVE PORTION OF THE FISSURE. THE MINES WORK A ONE-METER WIDE VERTICAL SEAM OF HYDROTHERMAL MONTMORILLONITE, ZEOLITE AND QUARTZ, THUS ALLOWING A FIRST-HAND INSPECTION OF THE PLUMBING OF A GEOTHERMAL SYSTEM.

GEOTHERMAL STUDIES/MEXICO/TEST WELLS/DRILLING/GEOLOGIC INVESTIGATIONS/FAULTS(GEOLOGIC)/STEAM/THERMAL PROPERTIES/EXPLORATICN/GEOCHEMISTRY
/IDENTIFIERS: /PATHE HIDALGO FIELD, MEXICO

173

NICHOLS, C.R./BROCKWAY, C.E./WARNICK, C.C.

1972

GEOTHERMAL WATER AND POWER RESOURCE EXPLORATION AND DEVELOPMENT FOR IDAHO.

UNIVERSITY OF IDAHO, WATER RESOURCES RESEARCH INSTITUTE, RESEARCH TECHNICAL COMPLETION REPORT, PROJECT NSF-GEOTHERMAL 47-514. 48 P.

SEE: SWRA W73-10217.

GEOTHERMAL STUDIES/THERMAL SPRINGS/IDAHO/EXPLORATION/STEAM/GEOLOGY/THERMAL POWERPLANTS/BIBLIOGRAPHIES/NATURAL RESOURCES/HOT SPRINGS/GEOCHEMISTRY/SURVEYS/GREENHOUSES
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT/HOT WATER SYSTEMS/GEOTHERMAL POWER/HOT BRINES/SPACE HEATING

174

NOBLE, J.W./OJIAMBO, S.B.

1975

GEOTHERMAL EXPLORATICN IN KENYA. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS I-27.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

THERE ARE THREE GEOTHERMAL AREAS IN KENYA, ALL LOCATED IN THE RIFT VALLEY. TWO EXPLORATION HOLES WERE DRILLED (1957-1958) IN OLKARIA AREA SOUTH OF LAKE NAIVASHA BUT FAILED TO PRODUCE. IN LATE 1960'S INTEREST REVIVED, AND IN 1970 A NEW EXPLORATION PROJECT WAS STARTED WITH EXTENSIVE GEOLOGICAL, HYDROLOGICAL, GEOPHYSICAL, AND GEOCHEMICAL SURVEYS. IN ADDITION, CONSIDERABLE EFFORT WAS DIRECTED TOWARDS BRINGING INTO PRODUCTION CNE OF THE ORIGINAL HOLES IN CLKARIA. THIS WAS EVENTUALLY ACHIEVED THOUGH THE OUTPUT WAS SMALL AND CYCLIC. FOUR MORE EXPLORATION HOLES AT OLKARIA, EACH DRILLED TO 1350 M, HAVE DEMONSTRATED THAT CONSIDERABLE GECTHERMAL RESOURCES EXIST IN A RESERVOIR BELOW 700 M. EARLY TEST RESULTS SUGGEST THE PRESENCE OF DRY STEAM, BUT OUTPUT IS RESTRICTED BY POOR PERMEABILITY. FURTHER WELL TESTING AND EXPLORATICN DRILLING IS PLANNED BEFORE THE INSTALLATION OF A TURBINE GENERATOR PLANT.

GEOTHERMAL STUDIES/AFRICA/EXPLORATION/DRILLING/GEOLOGY/HYDROLOGY/GEOPHYSICS/GEOCHEMISTRY/SURVEYS/TEST WELLS
/IDENTIFIERS: /KENYA/DEVELOPING COUNTRIES/EXPLORATION WELLS/GEOTHERMAL RESOURCES DEVELOPMENT

175

NORTON, D./GERLACH, T.

1975

A PRELIMINARY ANALYSIS OF THE ENERGY AND WATER REQUIREMENTS FOR DEVELOPING GEOTHERMAL ENERGY IN ARIZONA. IN CONFERENCE ON WATER REQUIREMENTS FOR LOWER COLORADO RIVER BASIN ENERGY NEEDS, TUCSON, ARIZONA, 1975, PROCEEDINGS, P. 106-121.

UNIVERSITY OF ARIZONA, TUCSON, ARIZONA.

VERY LITTLE IS KNOWN ABOUT LOCATION AND MAGNITUDE OF GEOTHERMAL RESOURCES IN ARIZONA. MAP SHOWS AREAS OF HOT SPRINGS AND WELLS AND AN EAST-WEST CORRIDOR OF POSSIBLE GEOTHERMAL LOCATIONS. ENERGY EFFICIENCY OF A 2000 MW GEOTHERMAL POWER SYSTEM IS ESTIMATED ON THE BASIS OF ASSUMED EXPLORATION AND DEVELOPMENT COSTS AND ASSUMED ENERGY-MONEY EQUIVALENT RATIO. FOR RATIO 0.5 MILLION KILOCALORIES PER DOLLAR (KCAL/DOLLAR), ENERGY EFFICIENCY IS 40 PERCENT (NET ENERGY RATIO 1.6), AND FOR RATIO 15,600 KCAL/DOLLAR, ENERGY EFFICIENCY IS 98 PERCENT (NET ENERGY RATIO 50). GEOTHERMAL WATER MINED FOR POWER PRODUCTION WOULD BE VERY SMALL COMPARED TO PRESENT AGRO-INDUSTRIAL WITHDRAWALS. GEOTHERMAL DESALINATION COULD PROVIDE 50 PERCENT OF POTABLE WATER NEEDS. SALTS CAN BE REINJECTED (TO HELP SLOW SUBSIDENCE) OR DEPOSITED ON SURFACE. (OALS)

ARIZONA/WATER REQUIREMENTS/GEOTHERMAL STUDIES/SPATIAL DISTRIBUTION/ENERGY CONVERSION/ECONOMICS/COSTS/EFFICIENCIES/HOT SPRINGS/EXPLORATION/DESALINATION/ POTABLE WATER/BRINE DISPOSAL/INJECTION/SALTS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL POWER/ENERGY-DOLLAR RATIO/ ENERGY-WATER RELATIONSHIPS

176

NORTON, D. ET AL

1975

GEOTHERMAL WATER RESOURCES IN ARIZONA: FEASIBILITY STUDY.

UNIVERSITY OF ARIZONA, TUCSON, WATER RESOURCES RESEARCH CENTER, PROJECT COMPLETION REPORT, OWRT PROJECT A-054-ARIZ. (IN PRESS)

GEOTHERMAL WATER RESOURCES SEEM TO BE LIMITED TO AN EAST-WEST BELT 100 MILES WIDE CLOSELY FOLLOWING GILA RIVER. MAGMA AND HOT-DRY ROCK RESOURCES MAY OCCUR IN THIS ZONE AND ELSEWHERE (E.G., FLAGSTAFF AREA). NUMEROUS WELLS AND SPRINGS OVER 32 DEGREES C. OCCUR WITHIN THE ZONE, OFTEN ON LINEAR FEATURES IN LANDSAT IMAGES. GEOTHERMOMETRY PREDICTS RESERVOIR TEMPERATURES UP TO 150 DEGREES C., ALTHOUGH TELLIER (1973) REPORTS 300 DEGREES. VERY RECENT IGNEOUS ROCKS WITHIN THE ZONE ARE THE PROBABLE THERMAL ENERGY SOURCE, ALTHOUGH SAFFORD BASIN HEAT MAY COME FROM EXOTHERMIC ANHYDRITE HYDRATION IN LACUSTRINE EVAPORITES. SAFFORD BASIN THERMAL WATER PROBABLY OCCURS IN COARSE SAND AND CONGLOMERATE BASIN FILL AND POSSIBLY IN DEEPER LAVA FLOWS AND TUFF. SHALLOW LACUSTRINE EVAPORITES AND CLAYS PROBABLY ACT AS CAP ROCKS TO SEPARATE WARM DEEP WATER FROM COOL SURFACE WATER.

GEOTHERMAL STUDIES/ARIZONA/THERMAL SPRINGS/WATER TEMPERATURE/IGNEOUS ROCKS/ LAKE BEDS/HYDRATION/ANHYDRITE/THERMAL WATER/SEDIMENTARY BASINS(GEOLOGIC)/ GEOLOGY
/IDENTIFIERS: /SAFFORD VALLEY, ARIZONA/GEOTHERMAL WATER/GILA RIVER/GEOTHERMAL RESOURCES/MAGMA/HOT-DRY ROCKS/GEOTHERMOMETERS/CAP ROCK

177

NUCLEAR NEWS

1971

REPORT ON A PLOWSHARE GEOTHERMAL POWER PLANT.

SAME AS AUTHOR 14(7):33-34. EIA 71-03963.

NUCLEAR EXPLOSIVES CAN BE USED TO FRACTURE LARGE QUANTITIES OF HOT ROCKS. THEN BY PIPING WATER TO THERMAL ZONE, STEAM WOULD BE GENERATED CAPABLE OF RUNNING A TURBINE GENERATOR AND PRODUCING ELECTRICITY. A CLOSED SYSTEM IS ENVISIONED WITH THE STEAM BEING CONDENSED AND RECYCLED BACK TO THE THERMAL REGION. SEVERAL PRIMARY PROBLEMS REMAIN TO BE SOLVED: 1) IMPROVED TECHNOLOGY IS NEEDED IN FINDING HOT ROCK BEDS, 2) SUITABLE NUCLEAR BOMBS MUST BE DEVELOPED, 3) SCIENTISTS MUST BECOME MORE KNOWLEDGEABLE IN FLUID FLOW METHODS IN HOT ROCK ZONES, AND 4) NEW WAYS MUST BE FOUND TO CONTROL CORROSION OF THE TURBINE BLADES BY MINERAL DEPOSITS FROM THE STEAM. THIS SCHEME IS YET ANOTHER POSSIBLE BUT UNDEMONSTRATED OUTLET FOR THE PEACEFUL USE OF NUCLEAR BOMBS.

GEOTHERMAL STUDIES/NUCLEAR EXPLOSIONS/UNDERGROUND/NUCLEAR ENGINEERING/WATER POLLUTION SOURCES/ADMINISTRATIVE AGENCIES/ELECTRIC POWERPLANTS/ENERGY CONVERSION/LAND RESOURCES/EXPLORATION/RECIRCULATED WATER/CORROSION
/IDENTIFIERS: /ALTERNATIVE ENERGY SOURCES/U.S. ATOMIC ENERGY COMMISSION/ PROJECT PLOWSHARE/WELL STIMULATION/GEOTHERMAL POWER/HOT-DRY ROCKS

178

NZAFO, M.A.

1973

GEOTHERMAL RESOURCES IN TANZANIA. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1039-1043.

SEE: SWRA W74-08979.

GEOTHERMAL STUDIES/THERMAL WATER/THERMAL SPRINGS/HOT SPRINGS/HYDROGEOLOGY/AFRICA/SPATIAL DISTRIBUTION
/IDENTIFIERS: /TANZANIA/GEOTHERMAL RESOURCES/RIFT ZONES/DEVELOPING COUNTRIES

179

OAK RIDGE NATIONAL LABORATORIES

1972

AN INVENTORY OF ENERGY RESEARCH. 2 VOLS.

U.S. GOVERNMENT PRINTING OFFICE. 1724 P.

THIS REPORT PREPARED FOR THE TASK FORCE ON ENERGY OF THE SUBCOMMITTEE ON SCIENCE, RESEARCH AND DEVELOPMENT, U.S. HOUSE OF REPRESENTATIVES, CONTAINS ALL THE DATA COLLECTED ON FEDERAL ENERGY RESEARCH AS WELL AS THE INFORMATION OF AN EARLIER INVENTORY BY BOOZ, ALLEN, AND HAMILTON, INC. EACH OF THE 4400 RESEARCH PROJECTS IS LISTED BY TITLE UNDER ONE OF 14 CATAGORIES: FOSSIL FUELS (GENERAL); COAL; PETROLEUM; NATURAL GAS; NUCLEAR (GENERAL); NUCLEAR FISSION; NUCLEAR FUSION AND PLASMAS; HYDRAULIC; SOLAR; GEOTHERMAL; WIND; WOOD; AND OTHER BIOLOGICAL, CHEMICAL, UNSPECIFIED ENERGY SOURCES.

BIBLIOGRAPHIES/ENERGY CONVERSION/NUCLEAR ENERGY/FUELS/GEOTHERMAL STUDIES/COALS/NATURAL GAS/FOSSIL FUELS/OIL
/IDENTIFIERS: /SOLAR ENERGY/WIND POWER/ALTERNATIVE ENERGY SOURCES/GEOTHERMAL ENERGY

180

O'BRIEN, J.J.

1972

GEOTHERMAL RESOURCES AS A SOURCE OF WATER SUPPLY.

AMERICAN WATER WORKS ASSOCIATION, JOURNAL 64(11):694-700.

SEE: SWRA W73-12333.

GEOTHERMAL STUDIES/WATER SUPPLY/DESALINATION/SUBSIDENCE/ECONOMIC FEASIBILITY/COSTS/COLORADO RIVER/CHEMICAL ENGINEERING/SALINITY/POWERPLANTS/WATER RESOURCES DEVELOPMENT/WATER COSTS/DESALINATION PROCESSES/WATER TEMPERATURE/HOT SPRINGS/BRINES/PLANNING/WATER UTILIZATION/SALINE WATER/CALIFORNIA/TEST WELLS/INJECTION/MULTIPLE-PURPOSE PROJECTS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/IMPERIAL VALLEY/MESA ANOMALY/PRODUCTION WELLS/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL POWER/CHEMICAL RECOVERY

181

ODUM, H.T.

1972

CHEMICAL CYCLES WITH ENERGY CIRCUIT MODELS. IN D. DYRSSEN AND D. JAGNER, EDS., THE CHANGING CHEMISTRY OF THE OCEANS, TWENTIETH NOBEL SYMPOSIUM, GOTEBORG, SWEDEN, 1971, PROCEEDINGS, P. 223-259.

JOHN WILEY AND SONS, INC., NEW YORK.

ENERGY CIRCUIT MODELS, DIAGRAMS, AND LANGUAGE ARE BRIEFLY INTRODUCED AND THEN APPLIED TO NUMEROUS GEOCHEMICAL, GEOLOGICAL, HYDROLOGICAL, AND BIOLOGICAL SYSTEMS. AUTHOR SUGGESTS THAT AT LEAST PART OF THE ENERGY WHICH DRIVES VOLCANIC AND SEDIMENTARY CYCLES IS DERIVED FROM PHOTOSYNTHETICALLY CAPTURED SOLAR ENERGY IN THE FORM OF OXIDIZED AND REDUCED SUBSTANCES LAID DOWN TOGETHER AND RECOMBINED UNDER HIGH PRESSURE AND TEMPERATURE AT DEPTH. CONTINENTS, OCEANS, VOLCANOES, AND MINERAL DEPOSITS ARE SEEN AS EDDIES IN A GLOBAL SYSTEM WHICH SEEKS TO MAXIMIZE POWER FLOW. THESE CYCLES ARE NOW BEING CONTROLLED AND PREEMPTED (PERHAPS TEMPORARILY) ON A LARGE SCALE BY MAN AND HIS MACHINES. (OALS)

CHEMISTRY/GEOCHEMISTRY/SYSTEMS ANALYSIS/HYDROLOGIC SYSTEMS/MODEL STUDIES/CYCLES/HYDROLOGIC CYCLE/FOOD CHAINS/BIOLOGY/ECOLOGY/SEDIMENTATION/VOLCANOES/PHOTOSYNTHESIS/TECHNOLOGY/ENERGY/ENERGY CONVERSION/ENERGY TRANSFER/FREE ENERGY/ENVIRONMENTAL EFFECTS/THERMODYNAMICS
/IDENTIFIERS: /ENERGY CIRCUIT MODELS/ENERGY DIAGRAMS/VOLCANISM/NET ENERGY/MINERAL DEPOSITS/GLOBAL TECTONICS/ENERGY QUALITY

182

ODUM, H.T.

1975

ENERGY QUALITY INTERACTIONS OF SUNLIGHT, WATER, FOSSIL FUEL, AND LAND. IN CONFERENCE ON WATER REQUIREMENTS FOR LOWER COLORADO RIVER BASIN ENERGY NEEDS, TUCSON, ARIZONA, 1975, PROCEEDINGS, P. 165-194.

UNIVERSITY OF ARIZONA, TUCSON, ARIZONA.

PRINCIPLES OF ENERGY QUALITY (FREE ENERGY, ABILITY TO DO WORK) ARE REVIEWED AND APPLIED (WITH ENERGY CIRCUIT DIAGRAMS AND LANGUAGE) TO ENERGY AND MONEY FLOWS IN ARID LANDS. ELECTRICITY, WATER, AND ESPECIALLY UPLIFTED LAND HAVE HIGH ENERGY QUALITY COMPARED TO COAL. WATER IS A PARTICULARLY IMPORTANT ENERGY AMPLIFIER IN ARID LANDS. WATER AMPLIFICATION OF SOLAR ENERGY (AGRICULTURE) IS A PRIME ATTRACTION FOR IMPORTED FOSSIL FUELS. DESALTING WATER WITH FOSSIL FUEL FOR AGRICULTURAL USE DOES NOT AMPLIFY SOLAR ENERGY IMPOUNDMENT ENOUGH TO COMPETE WITH OTHER POSSIBLE FUEL USES. SOLAR ENERGY CONVERSION TO ELECTRICITY IS NOT A GOOD INVESTMENT OF FOSSIL FUEL, EITHER. A SIMPLIFIED ENERGY CIRCUIT DIAGRAM FOR ARIZONA SHOWS MANY NATURAL AND INDUSTRIAL SECTORS, BUT DOES NOT (ALTHOUGH IT COULD) INCLUDE GEOTHERMAL ENERGY RESOURCES AND DEVELOPMENT TECHNOLOGY. (OALS)

ENVIRONMENTAL EFFECTS/COMPETING USES/ALTERNATIVE WATER USE/ARIZONA/SOLAR RADIATION/FOSSIL FUELS/ENERGY/LAND/AGRICULTURE/WATER/COLORADO RIVER/ECONOMICS/ THERMODYNAMICS/FREE ENERGY/DESALINATION/COMPARATIVE PRODUCTIVITY/COALS/ENERGY CONVERSION/SYSTEMS ANALYSIS/HYDROLOGIC SYSTEMS/MODEL STUDIES/ELECTRIC POWER/ CYCLES/HYDROLOGIC CYCLE/ECOLOGY/TECHNOLOGY/ENERGY TRANSFER
/IDENTIFIERS: /ENERGY QUALITY/ENERGY-WATER RELATIONSHIPS/NET ENERGY/ENERGY CIRCUIT MODELS/ENERGY DIAGRAMS/SOLAR ENERGY/ENERGY-DOLLAR RATIO/ALTERNATIVE ENERGY SOURCES

183

O'KEEFE, W.

1973

GEOTHERMAL POWER: SLEEPING GIANT STIRS, BUT WILL REQUIRE YEARS TO WAKEN FULLY.

POWER 117(4):32-35. EIA 73-08046.

GEOTHERMAL ENERGY HAS POTENTIAL TO TAKE CARE OF AMERICAN ENERGY DEMANDS FOR A LONG TIME. BUT MOST OF THIS POTENTIAL CANNOT BE EXPLOITED WITH OUR CURRENT TECHNOLOGY. TODAY, GEOTHERMAL POWER IS RESTRICTED TO HIGH HEAT FLUX REGIONS WHICH ARE GENERALLY REMOTE FROM POPULATION CENTERS. IN HIGHLIGHTING FINDINGS FOR THE GEOTHERMAL RESOURCES RESEARCH CONFERENCE OF SEPTEMBER 1972, GEOLOGICAL, THERMODYNAMIC, ENGINEERING, ECONOMIC, AND POLITICAL ASPECTS OF GEOTHERMAL ENERGY DEVELOPMENT ARE REVIEWED.

GEOTHERMAL STUDIES/COST EFFICIENCY/ELECTRIC POWER PRODUCTION/ECONOMICS/ EXPLOITATION/ENVIRONMENTAL EFFECTS/GEOLOGY/THERMODYNAMICS/ECONOMICS/POLITICAL ASPECTS
/IDENTIFIERS: /GEOTHERMAL ENERGY

184

OLMSTED, F.H. ET AL

1973

SOURCES OF DATA FOR EVALUATION OF SELECTED GEOTHERMAL AREAS IN NORTHERN AND CENTRAL NEVADA.

U.S. GEOLOGICAL SURVEY, MENLO PARK, CALIFORNIA, OPEN-FILE REPORT. 78 P.

SEE: SWRA W73-12947.

GEOTHERMAL STUDIES/NEVADA/INFORMATION RETRIEVAL/PUBLICATIONS/HEAT FLOW/ GEOPHYSICS/GEOCHEMISTRY/GEOLOGY/THERMAL WATER/THERMAL PROPERTIES/THERMAL SPRINGS/NATURAL RESOURCES/WATER TEMPERATURE/CHEMICAL ANALYSIS/MINERALOGY/ BIBLIOGRAPHIES/DATA COLLECTIONS
/IDENTIFIERS: /GEOTHERMAL RESOURCES

185

O'ROURKE, J.T.

1972

CLEAN STEAM. LETTER TO THE EDITOR.

ENVIRONMENT 14(2):48.

MANY ESTIMATES OF GEOTHERMAL POWER COSTS FAIL TO INCLUDE TAX BREAKS AND ARE THEREFORE INVALID. GEOTHERMAL DEVELOPMENT REQUIRES AT LEAST 20-40 ACRES OF LAND PER MEGAWATT, EXCLUSIVE OF ROADS, PIPELINES, POWERPLANTS, AND RELATED FACILITIES. THE GEYSERS PLANT IN SONOMA, CALIFORNIA, VENTS 1,000 POUNDS OF HYDROGEN SULFIDE GAS INTO THE AIR EACH DAY, DEMONSTRATING THE AUTHOR'S FEELING THAT THE CONCEPT OF GEOTHERMAL DEVELOPMENT AS SYNONYMOUS WITH NONPOLLUTION IS

A MISCONCEPTION, THAT IT CAN BE MADE COMPATIBLE WITH THE ENVIRONMENT ONLY WHEN UNIFORM MINIMUM STANDARDS AND CONTROLS ARE ESTABLISHED, LACKING AT THE PRESENT TIME IN THE U.S. HE POINTS OUT THE COST DIFFERENTIAL IN THE U.S. WHERE TAX BREAKS ARE FIGURED INTO THE RELATIVELY LOW COST, WORLDWIDE, OF 55 DOLLARS PER METER, WITH THOSE OF 98 DOLLARS IN JAPAN, AND OF 172 DOLLARS REPORTED DURING FIRST PHASES OF DRILLING IN A NEW GEOTHERMAL FIELD.

GEOTHERMAL STUDIES/AIR POLLUTION/THERMAL POWERPLANTS/STEAM/RESOURCES DEVELOPMENT/ENVIRONMENTAL EFFECTS/THERMAL POLLUTICN/COSTS/TAX RATES
/IDENTIFIERS: /GEYSERS FIELD, CALIFORNIA

186

OTTE, C./KRUGER, P.

1973

INTRODUCTION: THE ENERGY OUTLOOK. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 1-13.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13215.

GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/THERMAL POWERPLANTS/ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/WATER RESOURCES DEVELOPMENT/ENERGY/STEAM TURBINES/WELLS/FOSSIL FUELS
/IDENTIFIERS: /GEOTHERMAL POWER/POWER DEMAND/ALTERNATIVE ENERGY SOURCES/GEOTHERMAL ENERGY/GEOTHERMAL RESOURCES

187

PALMER, H.D./GREEN, J./FORNS, J.M.

1975

EXPLOITATION OF SEAFLOOR GEOTHERMAL RESOURCES: MULTIPLE USE CONCEPT. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS IX-10.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

CONTINENTAL SHELVES OF THE WORLD ARE LARGELY DROWNED EXTENSIONS OF COASTAL GEOLOGIC STRUCTURE, AND THERE EXIST MANY OFFSHORE SITES ALONG PROJECTICNS OF KNOWN GEOTHERMAL ACTIVITY WHICH COULD BE EXPLOITED BY EXISTING MARINE TECHNOLOGY. A GEOTHERMAL POWER STATION COULD BE PLACED ON THE SEAFLOOR AT CONTINENTIAL SHELF DEPTHS (LESS THAN 200 M). POWER WOULD BE TRANSMITTED VIA CABLE TO SHORE. OR HEAT COULD BE EMPLOYED TO THERMALLY DISSOCIATE WATER TO HYDROGEN AND OXYGEN, WITH HYDROGEN STORED AS COMPRESSED GAS FUEL. HEAT NORMALLY DISCARDED TO ENVIRONMENT FROM TURBINES COULD BE BENEFICIALLY EMPLOYED BY CIRCULATING STEAM THROUGH A RADIATOR EMBEDDED IN SHELF SEDIMENTS. CONDENSATE WOULD BE RETURNED TO DEPTH AS LIQUID TC COMPLETE A CLOSED CYCLE. HEATED SEAFLOOR WOULD BE PREFERRED SITE FOR COMMERCIALLY VALUABLE FISH AND CRUSTACEA. CURRENT EXPERIMENTS IN EXPLOITATION OF HEATED EFFLUENT SUGGESTS THAT YIELD OF FOOD CAN BE INCREASED FOUR TO FIVE TIMES NORMAL ANNUAL PRODUCTION. THREE PRIME AREAS FOR SEAFLOOR ELECTRIC PLANT AND MARICULTURE STATION ARE SOUFRIERE BAY (ST. LUCIA, WEST INDIES), SOUTHERN KAGOSHIMA BAY (KYUSHU, JAPAN), AND BAY OF PLENTY (NORTH ISLAND, NEW ZEALAND).

GEOTHERMAL STUDIES/SEA WATER/CONTINENTAL SHELF/MARINE ANIMALS/COMMERCIAL FISH/MARINE FISHERIES/MULTIPLE-PURPOSE PROJECTS/ENGINEERING STRUCTURES/TECHNOLOGY/HYDROGEN
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL HEAT/INDUSTRIAL USES/WASTE HEAT USES/MARICULTURE/JAPAN/NEW ZEALAND/WEST INDIES

188

PALMER, T.D./HOWARD, J.H./LANDE, D.P.

1975

GEOTHERMAL DEVELOPMENT OF THE SALTON TROUGH, CALIFORNIA AND MEXICO.

UNIVERSITY OF CALIFORNIA, LIVERMORE, LAWRENCE LIVERMORE LABORATORY, REPORT UCRL-51775. 45 P. AVAILABLE NTIS AS TID-4500, UC-13.

REVIEWS GEOLOGY AND GEOTHERMAL RESOURCES OF THE SALTON TROUGH (MEXICALI AND IMPERIAL VALLEYS). HISTORY OF ATTEMPTS TO EXPLOIT THESE RESOURCES IS SUMMARIZED. AND ALL PRESENTLY ONGOING GEOTHERMAL PROJECTS IN THE AREA ARE DESCRIBED IN DETAIL. 69 REFERENCES.

GEOTHERMAL STUDIES/CALIFORNIA/MEXICO/GEOLOGY/EXPLOITATION/BIBLIOGRAPHIES/HISTORY
/IDENTIFIERS: /SALTON TROUGH/IMPERIAL VALLEY/MEXICALI VALLEY/CERRO PRIETO FIELD, MEXICO/GEOTHERMAL RESOURCES

189

PAPADOPULOS, S.S. ET AL

1975

ASSESSMENT OF ONSHORE GEOPRESSURED-GEOTHERMAL RESOURCES IN THE NORTHERN GULF OF MEXICO BASIN. IN D.E. WHITE AND D. L. WILLIAMS, EDS., ASSESSMENT OF GEOTHERMAL RESOURCES OF THE UNITED STATES--1975, P. 125-146.

U.S. GEOLOGICAL SURVEY, CIRCULAR 726.

ESTIMATED FLUID RESOURCE BASE OF GEOPRESSURED RESERVOIRS TO 6 AND 7 KM DEPTH IN TERTIARY SEDIMENTS OF TEXAS AND LOUISIANA ONSHORE COASTAL AREA IS (IN UNITS OF 10 TO 18TH POWER CALORIES): HEAT CONTENT 10,920, METHANE CONTENT 6,030, AND MECHANICAL ENERGY 50, OR TOTAL 17,000 UNITS. FLUID RESOURCE BASE IN CRETACEOUS SEDIMENTS AND DEEPER AND OFFSHORE ZONES IS ESTIMATED TO BE 1.5 TO 2.5 TIMES THIS TOTAL. RECOVERABILITY OF ENERGY DEPENDS ON RECOVERABILITY OF WATER, WHICH IN TURN DEPENDS ON PRODUCTION PERIOD, WELL NUMBER AND FLOW RATE, WELL HEAD PRESSURE, ECONOMICS, AND ENVIRONMENTAL FACTORS. THREE POSSIBLE DEVELOPMENT PLANS YIELD 363 AND 552 (SUBSIDENCE 5-7 METERS), AND 85 (SUBSIDENCE LESS THAN 1 METER) ENERGY UNITS THERMAL EQUIVALENT, OR 34,350 AND 38,140 AND 9,250 MEGAWATT CENTURIES (MW-C), OR 171,750 AND 190,700 AND 46,250 MW FOR 20 YEARS. TOPICS NEEDING CONSIDERATION INCLUDE SUBSIDENCE, DISPOSAL OF WASTE WATER BY INJECTION OR BY DISCHARGE INTO GULF OF MEXICO, WATER CHEMISTRY, AND POSSIBLE USE OF ABANDONED HYDROCARBON WELLS. (OALS)

GEOTHERMAL STUDIES/GULF OF MEXICO/GULF COASTAL PLAIN/TEXAS/LOUISIANA/METHANE/PRESSURE/FLOW RATES/FLOW DURATION/ECONOMICS/ENVIRONMENTAL EFFECTS/WELLS/LAND SUBSIDENCE/ELECTRIC POWER/WASTE WATER DISPOSAL/INJECTION/WATER CHEMISTRY/OIL WELLS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOPRESSURED SYSTEMS/GEOTHERMAL WATER/GEOTHERMAL RESERVOIRS/SUBSIDING SEDIMENTARY BASINS/HEAT CONTENT

190

PARODI, A.

1975

POSSIBILITIES OF UTILIZING GEOTHERMAL ENERGY IN PERU, 1975. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS I-30.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

IN NORTHERN CHILE UP TO FOUR FAVORABLE AREAS HAVE BEEN LOCATED AND EL TATIO WILL SOON BE EXPLOITED. SOUTHERN PERU IS GEOLOGICAL CONTINUATION OF THE CHILEAN TERRITORY: STRATIGRAPHY, PLUTONISM, TECTONICS AND VOLCANISM ARE ALMOST IDENTICAL. FOR THIS REASON, IT IS EXPECTED THAT POTENTIALLY FAVORABLE AREAS MAY LIKEWISE BE FOUND IN SOUTHERN PERU. THE AREA NEAR UBINAS VOLCANO MAY BE ONE OF THEM. UBINAS VOLCANO HAS SEVERAL FUMAROLES, TWO OF EXTRA-ORDINARY INTENSITY. OTHER AREAS IN PERU HAVE GEYSERS AND HIGH TEMPERATURE THERMO-MINERAL SPRINGS AND MAY HAVE ENERGY POTENTIAL.

GEOTHERMAL STUDIES/SOUTH AMERICA/GEOLOGY/VOLCANOES/GEYSERS/THERMAL SPRINGS
/IDENTIFIERS: /PERU/CHILE/VOLCANISM/FUMAROLES/GEOTHERMAL RESOURCES/ANDES

191

PEARL, R.H.

1972

GEOTHERMAL RESOURCES OF COLORADO, A SUMMARY. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER D, 7 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03423.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/COLORADO/EVALUATION/THERMAL WATER/WATER TEMPERATURE/THERMAL PROPERTIES/HYDROGEOLOGY/HOT SPRINGS/HEAT FLOW/LEASES/SPATIAL DISTRIBUTION
/IDENTIFIERS: /GEOTHERMAL RESOURCES

192

PECK, D.L.

1972

ASSESSMENT OF GEOTHERMAL ENERGY RESOURCES.

FEDERAL COUNCIL FOR SCIENCE AND TECHNOLOGY, COMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT GOALS; EXECUTIVE OFFICE OF THE PRESIDENT, OFFICE OF SCIENCE AND TECHNOLOGY. REPORT. 83 P. NSF-RANN ENERGY ABSTRACTS 1(9) 2229.

IT IS CONCLUDED THAT AN EXPANDED PROGRAM IS NEEDED TO ASSESS THE MAGNITUDE, TYPE, AND LOCATION OF U.S. GEOTHERMAL RESOURCES AND TO ENCOURAGE THE DEVELOPMENT OF IMPROVED TECHNOLOGY TO DISCOVER, EVALUATE, AND UTILIZE THE RESOURCE. RESEARCH AND DEVELOPMENT NEEDS ARE DISCUSSED, INCLUDING RESOURCES APPRAISAL, EXPLORATION METHODS, RESERVOIR DEVELOPMENT AND PRODUCTION, UTILIZATION TECHNOLOGY AND ECONOMICS, ENVIRONMENTAL EFFECTS, AND INSTITUTIONAL AND LEGAL ASPECTS.

GEOTHERMAL STUDIES/TECHNOLOGY/RESEARCH AND DEVELOPMENT/EXPLORATION/ECONOMICS/ENVIRONMENTAL EFFECTS/LEGAL ASPECTS/ADMINISTRATIVE AGENCIES/SPATIAL DISTRIBUTION
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL RESERVOIRS

193

PECK, D.L.

1975

RECOVERABILITY OF GEOTHERMAL ENERGY DIRECTLY FROM MOLTEN IGNEOUS SYSTEMS. IN D.E. WHITE AND D.L. WILLIAMS, EDS., ASSESSMENT OF GEOTHERMAL RESOURCES OF THE UNITED STATES--1975, P. 122-124.

U.S. GEOLOGICAL SURVEY, CIRCULAR 726.

THE LARGE QUANTITY OF HEAT IN MAGMA BODIES IS NOT PRESENTLY AND MAY NEVER BE RECOVERABLE. REMOTE SENSING TECHNIQUES FOR MAGMA EXPLORATION (GEOPHYSICS AND GEOLOGY) NEED TO BE IMPROVED BY STUDYING KNOWN MAGMA BODIES AND OLD, COOLED IGNEOUS ROCKS NOW EXPOSED AT THE SURFACE BY EROSION. PREREQUISITES FOR SUCCESSFUL DEVELOPMENT OF MAGMA ENERGY FLOW ARE: SPECIALIZED NEW DRILLING TECHNOLOGY, DOWN-HOLE EQUIPMENT FOR SAMPLING AND MEASUREMENT OF PHYSICAL PROPERTIES, AND HEAT RECOVERY SYSTEMS, ALL SUITED TO HIGH PRESSURE, HIGH TEMPERATURE, AND CORROSIVE CHEMICAL ENVIRONMENT. POSSIBLE HEAT EXTRACTION SYSTEMS INCLUDE LONG STEAM OR GAS HEAT EXCHANGER TUBES AND SOLID-ELECTROLYTE FUEL CELLS. ECONOMIC FEASIBILITY WILL PROBABLY HINGE ON HOW VIGOROUSLY MAGMA WILL CONVECT NEAR HEAT EXCHANGER. (OALS)

GEOTHERMAL STUDIES/GEOLOGY/GEOPHYSICS/IGNEOUS ROCKS/REMOTE SENSING/DRILLING/EXPLORATION/DRILLING EQUIPMENT/LOGGING(RECORDING)/BOREHOLE GEOPHYSICS/SAMPLING/PHYSICAL PROPERTIES/HEAT EXCHANGERS/HEAT TRANSFER/PRESSURE/CORROSION/CONVECTION
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL ENERGY/MAGMA/HEAT CONTENT/HOT-DRY ROCKS

194

PETERSON, R.E.

1975

ECONOMIC FACTORS IN THE LONGEVITY OF RESOURCES.

GEOTHERMAL ENERGY 3(3):7-14.

RESOURCE OWNERS SEEK TO MAXIMIZE PRESENT VALUE, AND WILL BE INFLUENCED TO PROLONG EXPLOITATION LIFETIME BY THESE FACTORS: INTEREST RATE FALL, EXPECTATION OF FUTURE PRICE RISE OR COST FALL, IMPORT QUOTA REMOVAL, PRORATIONING, MONOPOLIZATION, REMOVAL OF SEVERANCE TAXES AND ROYALTIES, PROPERTY TAXES, RESERVOIR UNITIZATION, EXPLORATION COST RISE, RULES OF CAPTURE ABOLITION, AND PERCENTAGE DEPLETION ALLOWANCES. AN ECONOMIC MODEL SHOWS IMPACT OF INTEREST RATES ON RESOURCE LIFE, RECOVERY RATE, AND RESERVE/OUTPUT RATIO.

ECONOMICS/VALUE/EXPLOITATION/ECONOMIC LIFE/INTEREST RATES/PRICES/COSTS/MONOPOLY/TAXES/PRORATION/FOREIGN TRADE/EXPLORATION/MODEL STUDIES/ROYALTIES
/IDENTIFIERS: /GEOTHERMAL RESOURCES

195

PIKUL, R.P./RABIN, R.

1974

PROGRAM PLAN FOR ENVIRONMENTAL EFFECTS OF ENERGY.

MITRE CORPORATION, MCLEAN, VIRGINIA, FINAL REPORT MTR-6726. NSF 74-SP-0827. 314 P. AVAILABLE NTIS AS PB-235 115.

SEE: SWRA W75-05871.

ENVIRONMENTAL EFFECTS/ENERGY/FUELS/PLANNING/COALS/OIL/SOLAR RADIATION/OIL SHALES/GEOTHERMAL STUDIES/RESEARCH AND DEVELOPMENT/DECISION MAKING/GEYSERS/FAULTS(GEOLOGIC)/HOT SPRINGS/SOCIAL ASPECTS/ECONOMIC IMPACT
/IDENTIFIERS: /ENERGY SOURCES/NATIONAL SCIENCE FOUNDATION/GEOTHERMAL ENERGY/ALTERNATIVE ENERGY SOURCES

196

PORTER, L.R.

1973

GEOTHERMAL RESOURCE INVESTIGATIONS.

AMERICAN SOCIETY OF CIVIL ENGINEERS, HYDRAULICS DIVISION, JOURNAL 99(11):2097-2111. EIA 73-30020.

SEE: SWRA W74-01273. (ALSO: SWRA W73-05943 [PREPRINT OF THIS PAPER])

GEOTHERMAL STUDIES/THERMAL POWER/WATER POLLUTION/DESALINATION/BRINES/ENVIRONMENTAL EFFECTS/COLORADO RIVER/COLORADO RIVER BASIN/WATER SUPPLY/ADMINISTRATIVE AGENCIES/ELECTRIC POWER PRODUCTION/SOUTHWEST U.S./CALIFORNIA/ARID LANDS/WATER RESOURCES DEVELOPMENT/COLORADO RIVER COMPACT/WATER DEMAND/TEST WELLS/MULTIPLE-PURPOSE PROJECTS/INJECTION/RESEARCH AND DEVELOPMENT
/IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL WATER/GEOTHERMAL POWER/GEOTHERMAL RESOURCES/HOT BRINES/CHEMICAL RECOVERY/GEOTHERMAL RESOURCES DEVELOPMENT

197

PREHN, W.L.

1973

THE FUTURE ROLE OF DESALTING IN NEVADA.

U.S. OFFICE OF SALINE WATER, REPORT INT-OSW-74-92C. 234 P. AVAILABLE NTIS AS PB-226 760/AS.

SEE: SWRA W74-08065.

DESALINATION/DESALINATION PLANTS/WATER SUPPLY/MUNICIPAL WATER/WATER COSTS/NEVADA/PLANNING/BRACKISH WATER/GEOTHERMAL STUDIES/WATER SOURCES/FEASIBILITY STUDIES/NUCLEAR POWERPLANTS
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL WATER/ALTERNATIVE ENERGY SOURCES

198

PRESSER, T.S./BARNES, I.

1974

SPECIAL TECHNIQUES FOR DETERMINING CHEMICAL PROPERTIES OF GEOTHERMAL WATER.

U.S. GEOLOGICAL SURVEY, MENLO PARK, CALIFORNIA, WATER RESOURCES INVESTIGATIONS 22-74. 11 P. AVAILABLE NTIS AS PB-235 148.

SEE: SWRA W75-03980.

WATER ANALYSIS/GEOTHERMAL STUDIES/CHEMICAL ANALYSIS/ANALYTICAL TECHNIQUES/SAMPLING/METHODOLOGY/ON-SITE INVESTIGATIONS/THERMAL WATER/LABORATORY TESTS/AQUEOUS SOLUTIONS/WATER CHEMISTRY/TRACE ELEMENTS/HEAVY METALS/HYDROGEN ION CONCENTRATION/FILTRATION/SALTS
/IDENTIFIERS: /WATER SAMPLE PRESERVATION/FIELD PREPARATION/WATER SAMPLE STABILITY/GEOTHERMAL FLUIDS

199

PURTYMAN, W.D./WEST, F.G./ADAMS, W.H.

1974

PRELIMINARY STUDY OF THE QUALITY OF WATER IN THE DRAINAGE AREA OF THE JEMEZ RIVER AND RIO GUADALUPE.

LOS ALAMOS SCIENTIFIC LABORATORY, NEW MEXICO, INFORMAL REPORT. 26 P. AVAILABLE NTIS AS LA-5595-MS.

SEE: SWRA W74-10658.

WATER QUALITY/NEW MEXICO/GEOTHERMAL STUDIES/WATER POLLUTION SOURCES/SURFACE WATERS/GROUNDWATER/TEST WELLS/BOREHOLES/WATER CHEMISTRY/DATA COLLECTIONS/HYDROLOGIC DATA/WATER QUALITY
/IDENTIFIERS: /JEMEZ RIVER(NEW MEXICO)/RIO GUADALUPE(NEW MEXICO)

200

RAMEY, H.J., JR./KRUGER, P./RAGHAVAN, R.

1973

EXPLOSIVE STIMULATION OF HYDROTHERMAL RESERVOIRS. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 231-249.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13227.

GEOTHERMAL STUDIES/ELECTRIC POWER/THERMAL POWERPLANTS/NUCLEAR EXPLOSIONS/
ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/WATER RESOURCES DEVELOPMENT/WELLS/
STEAM TURBINES/EXPLOSIVES/EXPLOSIONS/FRACTURE PERMEABILITY/ENVIRONMENTAL
EFFECTS
/IDENTIFIERS: /GEOTHERMAL POWER/WELL STIMULATION/CHEMICAL EXPLOSIONS/
GEOTHERMAL FLUIDS/HYDROTHERMAL SYSTEMS/GEOTHERMAL RESERVOIRS

201

RAMLEY, N., EL-/PETERSON, R.E./SEO, K.K.

1974

GEOTHERMAL WELLS IN IMPERIAL VALLEY, CALIFORNIA: DESALTING POTENTIALS, HISTORICAL DEVELOPMENT, AND A SELECTED BIBLIOGRAPHY.

NATIONAL WATER SUPPLY IMPROVEMENT ASSOCIATION JOURNAL 1(1):31-38.

SEE: SWRA W75-04423.

GEOTHERMAL STUDIES/DESALINATION/MULTIPLE-PURPOSE PROJECTS/BRINES/CORROSION/
BRINE DISPOSAL/SCALING/TEMPERATURE/THERMAL WATER/HEAT TRANSFER/CALIFORNIA/
POTABLE WATER/HEAT EXCHANGERS/INJECTION
/IDENTIFIERS: /IMPERIAL VALLEY/HOT BRINES/VAPOR-TURBINE CYCLE/CLOSED SYSTEMS/
GEOTHERMAL POWER

202

RAPPEPORT, P.E.

1972

A RESEARCH AND DEVELOPMENT PROGRAM--HEATING GREENHOUSES WITH GEOTHERMAL WATER.

NEGEV INSTITUTE FOR ARID ZONE RESEARCH, BEER SHEBA, ISRAEL. RESEARCH PROPOSAL. 12 P.

WARM SALINE GROUNDWATER (40 DEGREES C.) CAN BE USED TO HEAT GREENHOUSES AND THEN IRRIGATE FIELD CROPS SUCH AS WHEAT AND COTTON IN CENTRAL AND WESTERN NEGEV. HEAT CONTENT OF EACH CUBIC METER OF WATER COULD SUBSTITUTE FOR 2 KILOGRAMS OF FUEL OIL. THREE HEAT-EXCHANGE SYSTEMS AND THEIR ADVANTAGES AND DISADVANTAGES ARE DESCRIBED: OPEN WET HEATING SYSTEM (O), CLOSED RECIRCULATING WET HEATING SYSTEM (C), AND DRY HEATING SYSTEM (D). WATER USE RANKING (LOW TO HIGH) IS C, D, O. (OALS)

GEOTHERMAL STUDIES/RESEARCH AND DEVELOPMENT/GREENHOUSES/THERMAL WATER/
SALINE WATER/GROUNDWATER/IRRIGATION WATER/WHEAT/COTTON/HEAT EXCHANGERS/
WATER REQUIREMENTS
/IDENTIFIERS: /ISRAEL/NEGEV/HEAT CONTENT

203

REED, M.

1973

IMPERIAL VALLEY.

GEOTHERMAL WORLD DIRECTORY, 1973. P. 141-153.

UTILIZATION OF IMPERIAL VALLEY GEOTHERMAL RESOURCES FOR POWER, HEAT, DESALINATION, AND CHEMICAL RECOVERY HAS BEEN DELAYED BY TECHNICAL PROBLEMS IN HANDLING HIGHLY SALINE, CORROSIVE BRINES. NUMEROUS ELEMENTS IN BRINE ARE CONCENTRATED ENOUGH TO BE INCONVENIENT, BUT COST MORE THAN THEIR VALUE TO SEPARATE. PAST AND PRESENT EXPLORATION, DRILLING, AND DEVELOPMENT EFFORTS ARE BRIEFLY SUMMARIZED. HEAT EXCHANGE TECHNOLOGY MAY MAKE POWER PRODUCTION (AND POSSIBLY OTHER USES) FEASIBLE, BUT LAG TIME FOR FULL-SCALE OPERATION WILL BE 8 TO 10 YEARS. MAPS SHOW GEOTHERMAL WELL LOCATIONS IN SALTON SEA AND CERRO PRIETO (MEXICO) FIELDS, AND LOCATIONS OF TEMPERATURE GRADIENT ANOMALIES IN IMPERIAL VALLEY. EXTENSIVE REFERENCE LIST CONTAINS 115 ITEMS DATING FROM 1854 TO 1972. (OALS)

GEOTHERMAL STUDIES/CALIFORNIA/DESALINATION/CORROSION/BRINES/EXPLORATION/
DRILLING/HEAT EXCHANGERS/BIBLIOGRAPHIES
/IDENTIFIERS: /IMPERIAL VALLEY/SALTON SEA FIELD/CERRO PRIETO FIELD, MEXICO/
GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL POWER/CHEMICAL
RECOVERY/HOT BRINES/BINARY CYCLE/LEAD TIME/GEOTHERMAL WELLS/TEMPERATURE
GRADIENT

204

REINIG, L.P. ET AL

1973

ANOTHER RIO GRANDE FOR NEW MEXICO. IN STATE WATER PLAN, NEW MEXICO WATER CONFERENCE, 18TH, LAS CRUCES, 1973, PROCEEDINGS, P. 50-61.

NEW MEXICO STATE UNIVERSITY, LAS CRUCES, WATER RESOURCES RESEARCH INSTITUTE, REPORT 026:50-61. AVAILABLE NTIS AS CONF-730438-1.

SEE: SWRA W74-02461; W73-15232.

WATER RESOURCES DEVELOPMENT/NEW MEXICO/GROUNDWATER RESOURCES/DESALINATION/
NUCLEAR ENERGY/GEOTHERMAL STUDIES/METHODOLOGY/COSTS/ECONOMICS/WATER SUPPLY/
WATER DEMAND/MINERAL INDUSTRY/RECREATION FACILITIES/WATER UTILIZATION/SALINE
WATER/GROUNDWATER/WATER QUALITY/CHEMICAL ANALYSIS
/IDENTIFIERS: /TULAROSA VALLEY(NEW MEXICO)/GEOTHERMAL POWER/CHEMICAL RECOVERY/
GEOTHERMAL WATER/AQUIFERS/FEASIBILITY STUDIES

205

REISTAD, G.M.

1975

THE POTENTIAL FOR NON-ELECTRICAL APPLICATIONS OF GEOTHERMAL ENERGY AND THEIR PLACE IN THE NATIONAL ECONOMY. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS VIII-13.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

ELECTRICITY GENERATION FROM GEOTHERMAL RESOURCES PRESENTLY IS THE MAJOR U.S. RESEARCH AND DEVELOPMENT FOCUS. ALTHOUGH ELECTRICITY GENERATION HAS THE ADVANTAGE OF LOCATION INDEPENDENCE, A NUMBER OF OTHER FACTORS POINT TOWARD NON-ELECTRICAL APPLICATIONS HAVING MORE LONG-TERM POTENTIAL: 1) LOW-TO-MEDIUM TEMPERATURE RESOURCE IS MUCH LARGER THAN HIGH TEMPERATURE RESOURCES, 2) A VERY LARGE PROPORTION OF BASIC ENERGY NEEDS OF AN INDUSTRIALIZED NATION IS FOR HEATING AT LOW-TO-MEDIUM TEMPERATURES, AND 3) LOW-TO-MEDIUM TEMPERATURE HEATING NEEDS ARE NOT MET EFFICIENTLY FROM ELECTRICITY OR FOSSIL FUELS. IT IS ESTIMATED THAT GREATER THAN 40 PERCENT OF TOTAL U.S. ENERGY REQUIREMENTS COULD BE SATISFIED FROM GEOTHERMAL RESOURCES WITH HEATING AT A MAXIMUM TEMPERATURE OF 200 DEGREES C. CORRESPONDING PERCENTAGES AT 150 AND 100 DEGREES C. ARE 30 AND 20 PERCENT, RESPECTIVELY.

GEOTHERMAL STUDIES/UNITED STATES/ENERGY CONVERSION/RESEARCH AND DEVELOPMENT/
HEATING
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL HEAT/GEOTHERMAL RESOURCES/
INDUSTRIAL USES

206

RENNER, J.L./WHITE, D.E./WILLIAMS, D.L.

1975

HYDROTHERMAL CONVECTION SYSTEMS. IN D.E. WHITE AND D.L. WILLIAMS, EDS., ASSESSMENT OF GEOTHERMAL RESOURCES OF THE UNITED STATES--1975, P. 5-57.

U.S. GEOLOGICAL SURVEY, CIRCULAR 726.

REVIEWS GEOLOGY AND HYDROLOGY OF VAPOR-DOMINATED AND HOT-WATER CONVECTION SYSTEMS, AND ESTIMATES THE TOTAL HEAT CONTENT (ABOVE 15 DEGREES C., IN UNITS OF 10 TO 18TH POWER CALORIES) TO 3 KM DEPTH OF KNOWN CONVECTIVE SYSTEMS, WHICH ARE ALL IN WESTERN U.S., ALASKA, AND HAWAII. HEAT CONTENT IN 287 IDENTIFIED HOT-WATER SYSTEMS (714 UNITS) IS ABOUT 30 TIMES HEAT IN 3 VAPOR-DOMINATED SYSTEMS (26 UNITS). HEAT IN 63 HIGH-TEMPERATURE (150 DEGREES C. PLUS) HOT-WATER SYSTEMS (371 UNITS), SUITABLE FOR ELECTRICITY PRODUCTION, IS ROUGHLY EQUAL TO HEAT IN 224 INTERMEDIATE-TEMPERATURE (90 TO 150 DEGREES C.) HOT-WATER SYSTEMS (345 UNITS), SUITABLE FOR SPACE AND PROCESS HEATING. TOTAL HEAT CONTENT IN LOW-TEMPERATURE SYSTEMS (LESS THAN 90 DEGREES C.) IS NOT ESTIMATED. A SMALL MINORITY OF HOT-WATER SYSTEMS CONTAINS MAJORITY OF HEAT, SIMILAR TO LOG-NORMAL GRADE-FREQUENCY RELATIONSHIPS IN FUEL AND METALS DEPOSITS. TABLES LIST NAME, LOCATION, TEMPERATURE, AREA, DEPTH, VOLUME, AND CALCULATED HEAT CONTENT FOR EACH SYSTEM, AND MAPS SHOW LOCATIONS. (OALS) 19 REFERENCES.

GEOTHERMAL STUDIES/UNITED STATES/HYDROTHERMAL STUDIES/MAPS/ESTIMATING
/IDENTIFIERS: /GEOTHERMAL RESOURCES/VAPOR-DOMINATED SYSTEMS/HOT WATER SYSTEMS/
HYDROTHERMAL SYSTEMS/HYDROTHERMAL CONVECTION SYSTEMS/HEAT CONTENT/WESTERN U.S./
ALASKA/HAWAII

207

REX, R.W.

1970

INVESTIGATION OF GEOTHERMAL RESOURCES IN THE IMPERIAL VALLEY AND THEIR POTENTIAL VALUE FOR DESALINATION OF WATER AND ELECTRICITY PRODUCTION.

IMPERIAL VALLEY DEVELOPMENT AGENCY, REPORT 3:1-14.

REVIEWS GEOLOGY OF IMPERIAL VALLEY AND POTENTIAL EXPLOITATION OF THE HOT UNDERGROUND BRINES. IT MAY BE FEASIBLE TO ANNUALLY PRODUCE 10-15 MILLION ACRE-FEET OF BRINE YIELDING 5-7 MILLION ACRE-FEET OF DISTILLED WATER (FOR COLORADO RIVER WATER QUALITY MAINTENANCE) AND 20-30,000 MW OF ELECTRICITY. VOLUME OF WATER IN STORAGE (40 TO 70 PERCENT OF IT ABOVE 500 DEGREES F.) IS BETWEEN 1.6 AND 4.8 BILLION ACRE-FEET. HEAT IN ROCK EQUALS HEAT IN BRINE, SO INJECTED WATER FROM SALTON SEA OR GULF OF CALIFORNIA CAN RECOVER STILL MORE HEAT. DREDGING OF SHIP CANAL TO YUMA COULD BRING SEA WATER FOR INJECTION AND PROVIDE PORT FACILITIES FOR LOADING CHEMICAL BYPRODUCTS. (OALS)

GEOTHERMAL STUDIES/CALIFORNIA/DESALINATION/ELECTRIC POWER PRODUCTION/SEA WATER/GEOLOGY/EXPLOITATION/DISTILLATION/COLORADO RIVER/WATER QUALITY/GROUNDWATER RESOURCES/VOLUME/INJECTION/DREDGING
/IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL RESOURCES/HOT BRINES/GEOTHERMAL RESOURCES DEVELOPMENT/HEAT CONTENT/SALTON SEA/CHEMICAL RECOVERY

208

REX, R.W.

1971

GEOTHERMAL ENERGY, THE NEGLECTED ENERGY OPTION.

BULLETIN OF THE ATOMIC SCIENTISTS 37(8):52-56.

DRY STEAM FROM GEOTHERMAL FIELDS IS A SOURCE OF LOW-COST, NON-POLLUTING POWER. THIS IS BORNE OUT BY EXPERIENCE IN DEVELOPED FIELDS IN ITALY AND NORTHERN CALIFORNIA. TEN THOUSAND MEGAWATTS SUSTAINED PRODUCTION MAY BE POSSIBLE AT THE GEYSERS FIELD IN CALIFORNIA. ALTHOUGH ANOTHER POTENTIALLY IMPORTANT DRY STEAM FIELD HAS BEEN DISCOVERED RECENTLY AT VALLES CALDERA IN NEW MEXICO, IN GENERAL DRY STEAM FIELDS ARE RELATIVELY RARE COMPARED TO HOT WATER GEOTHERMAL AREAS. BASIC RESEARCH AND TECHNOLOGY OF HOT WATER FIELDS IS IN AN EARLY STATE OF DEVELOPMENT. SUCH FIELDS OCCUR IN THE IMPERIAL VALLEY OF CALIFORNIA AND NORTHEASTERN BAJA CALIFORNIA. SUCH FIELDS CONTAIN THE PROMISE OF NOT ONLY CHEAP POWER BUT ALSO GEOTHERMAL WATER DESALINATION. FULL DEVELOPMENT OF GEOTHERMAL WATER RESOURCES OF THE U.S. IN THE IMPERIAL VALLEY WOULD COST OVER FIVE BILLION DOLLARS, BUT NATIONAL EFFORTS IN THE DEVELOPMENT OF THIS RESOURCE HAVE BEEN LARGELY LACKING. U.S. EXPLORATION EFFORTS MIGHT YIELD UP TO ONE MILLION MW WITHIN 30 YEARS WITH SAVINGS OF OVER 100 DOLLARS PER KW COMPARED TO ALTERNATIVE ENERGY SYSTEMS.

GEOTHERMAL STUDIES/THERMAL POWER/ENERGY/RESOURCES DEVELOPMENT/CALIFORNIA/NEW MEXICO/STEAM/DESALINATION/EXPLORATION/THERMAL WATER/COSTS/HOT SPRINGS/FORECASTING/ELECTRIC POWER PRODUCTION/COMPARATIVE COSTS/UNITED STATES
/IDENTIFIERS: /VALLES CALDERA/BAJA CALIFORNIA/IMPERIAL VALLEY/GEOTHERMAL RESOURCES DEVELOPMENT/GEYSERS FIELD, CALIFORNIA/DRY STEAM FIELDS/GEOTHERMAL POWER/HOT WATER SYSTEMS/GEOTHERMAL RESOURCES/POWER CAPACITY

209

REX, R.W.

1974

HYDROGEN AS A POSSIBLE INTERMEDIATE IN DEVELOPING THE GEOTHERMAL RESOURCES OF VOLCANOES IN ISOLATED LOCATIONS.

GEOTHERMAL ENERGY 2(5):35-36.

PEAK LOAD POWER CAN BE PRODUCED BY REACTION IN FUEL CELLS OF HYDROGEN AND OXYGEN ELECTROLYZED AT THE WELL HEAD AND PIPED TO STORAGE FACILITIES. ELECTROLYSIS FACILITIES WOULD ADD ABOUT 95 DOLLARS TO THE 120 DOLLARS PER KW POWER CAPACITY FOR GENERATING EQUIPMENT. HYDROGEN ENERGY COST IS COMPARED TO NATURAL GAS, FUEL OIL, AND COAL COSTS. GEOTHERMAL HYDROGEN CYCLE PLANTS WILL PROBABLY FIND FIRST APPLICATION IN ISOLATED SMALL LOAD AREAS. (OALS)

GEOTHERMAL STUDIES/HYDROGEN/RURAL AREAS/VOLCANOES/PEAK LOADS/OXYGEN/ELECTROLYSIS/COMPARATIVE COSTS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/FUEL CELLS/ENERGY COSTS/ALTERNATIVE ENERGY SOURCES

210

REX, R.W./HOWELL, D.J.

1973

ASSESSMENT OF U.S. GEOTHERMAL RESOURCES. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 59-67.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13217.

GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/THERMAL POWERPLANTS/ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/WATER RESOURCES DEVELOPMENT/ENERGY/STEAM TURBINES/WELLS/PROFIT/ECONOMICS/COMPARATIVE COSTS
/IDENTIFIERS: /GEOTHERMAL POWER/IMPERIAL VALLEY/GEOTHERMAL RESOURCES/WESTERN U.S.

211

REYNOLDS, G.

1973

COOLING WITH GEOTHERMAL HEAT. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1658-1661.

A COMBINED SPACE HEATING-COOLING AND HOT WATER SYSTEM USING GEOTHERMAL FLUIDS AS HEAT SOURCE WAS INSTALLED IN THE ROTORUA INTERNATIONAL HOTEL, ROTORUA, NEW ZEALAND. ENGINEERING DETAILS AND DEVELOPMENT HISTORY ARE OUTLINED. HEAT IS TRANSFERRED FROM GEOTHERMAL WATER THROUGH A HEAT EXCHANGER TO A RECIRCULATING CLEAN WATER SYSTEM. A LITHIUM BROMIDE ABSORPTION REFRIGERATION UNIT PROVIDES COOL WATER WHICH CIRCULATES TO INDIVIDUAL ROOM AIR CONDITIONING UNITS. COST FOR INSTALLING THE ENTIRE SYSTEM (INCLUDING WELL DEVELOPMENT) IS ABOUT THE SAME AS FOR AN EQUIVALENT OIL-BURNING SYSTEM. BUT GEOTHERMAL OPERATING COSTS ARE ONLY 5 PERCENT OF OIL COSTS. (OALS)

COOLING/GEOTHERMAL STUDIES/AIR CONDITIONING/REFRIGERATION/TEMPERATURE CONTROL/HEAT TRANSFER/HEAT EXCHANGERS/MECHANICAL ENGINEERING/EQUIPMENT/COSTS/OPERATING COSTS/INSTALLATION COSTS
/IDENTIFIERS: /GEOTHERMAL HEAT/INDUSTRIAL USES/SPACE HEATING/ENERGY COSTS/GEOTHERMAL FLUIDS/HOT WATER SYSTEMS/NEW ZEALAND/LITHIUM BROMIDE

212

REYNOLDS, J.T./WAGNER, C.G.

1975

APPLICATION OF SATELLITE IMAGERY TO GEOTHERMAL RESOURCES EXPLORATION.

GEOTHERMAL ENERGY 3(5):45-54.

DESCRIBES TYPES OF SPACE IMAGERY AVAILABLE (LANDSAT AND SKYLAB, PHOTOGRAPHY AND MULTISPECTRAL SCANNER DATA) AND DISCUSSES ASPECTS OF GEOTHERMAL RESOURCES THAT CAN BE STUDIED WITH THE IMAGERY (REGIONAL STRUCTURES, ROCK TYPE AND ALTERATION, SOIL AND VEGETATION ANOMALIES, AND GENERAL GEOGRAPHY). ALL TYPES OF IMAGERY ARE USEFUL, EACH FOR DIFFERENT ASPECTS. PLANT MOISTURE STRESS AND RAPID SNOWMELT CAN INDICATE HIGH HEAT FLOW AREAS. 5 IMAGES FROM SOUTHWESTERN U.S. ARE ANALYZED.

REMOTE SENSING/EXPLORATION/GEOTHERMAL STUDIES/ANALYTICAL TECHNIQUES/MAPPING/PHOTOGRAPHY/PHOTOMETRY/SATELLITES(ARTIFICIAL)/SURVEYS/TERRAIN ANALYSIS/GEOLOGY/STRUCTURAL GEOLOGY/SOIL PROPERTIES/VEGETATION/SNOWMELT/SOUTHWEST U.S./MOISTURE STRESS/HEAT FLOW
/IDENTIFIERS: /GEOTHERMAL RESOURCES/HYDROTHERMAL ALTERATION

213

RINEHART, J.S.

1970

HEAT FLOW FROM NATURAL GEYSERS.

TECTONOPHYSICS 10(1-3):11-17.

SEE: SWRA W71-09118.

GEYSERS/HEAT FLOW/HEAT TRANSFER/MASS TRANSFER/HOT SPRINGS/GEOTHERMAL STUDIES/BOILING/CONVECTION/HEAT BALANCE/HEAT BUDGET/STEAM/METEORIC WATER
/IDENTIFIERS: /HOT WATER SYSTEMS

214

RINEHART, J.S.

1974

GEYSERS.

EOS, AMERICAN GEOPHYSICAL UNION TRANSACTIONS 55(12):1052-1062.

REVIEWS THE MANY TYPES OF GEYSERS AND THEIR GEOLOGY, SURFACE AND SUBSURFACE FEATURES, AND BEHAVIOR. GEYSER ACTIVITY IS STRONGLY INFLUENCED BY EARTHQUAKES, TIDAL FORCES, AND CHANGES IN BAROMETRIC PRESSURE. GEYSERS ARE RARE GEOPHYSICAL PHENOMENA BECAUSE A VERY SPECIAL SET OF CONDITIONS IS PREREQUISITE. GEOTHERMAL RESOURCES DEVELOPMENT EFFORTS ARE SPURRING RENEWED INTEREST IN GEYSERS. 63 REFERENCES.

GEOTHERMAL STUDIES/GEYSERS/GEOLOGY/EARTHQUAKES/TIDAL EFFECTS
/IDENTIFIERS: /HOT WATER SYSTEMS

215

RITTER, W.W./MASON, G.

1973

GEOTHERMAL ENERGY: PROSPECTS AND PROBLEMS.

JOURNAL OF ENVIRONMENTAL HEALTH 35(5):432-436. EIA 73-05751.

IN ADDITION TO EXAMINING THE GEOLOGICAL, ECONOMIC, ENVIRONMENTAL, AND ENGINEERING ASPECTS OF GEOTHERMAL ENERGY, THE AUTHOR POINTS OUT THAT 75 PERCENT OF THE KNOWN RESOURCES ARE ON GOVERNMENT LAND, MAINLY NATIONAL PARKS AND OTHER RECREATIONAL AREAS. ALSO, GEOTHERMAL POWERPLANTS REQUIRE A LARGE LEAD TIME. FURTHER PROBLEMS ARE CORROSION, SCALING, EFFLUENT DISPOSAL, AND POWER TRANSMISSION. ON THE PLUS SIDE, GEOTHERMAL ENERGY IS CHEAP AND RELATIVELY NON-POLLUTING.

GEOTHERMAL STUDIES/WATER POLLUTION/COST EFFICIENCY/THERMAL POWER/ELECTRIC POWER PRODUCTION/ENVIRONMENTAL EFFECTS/CORROSION/SCALING/EXPLORATION/LEGAL ASPECTS/RECREATION/WASTE WATER DISPOSAL/TRANSMISSION(ELECTRICAL)
/IDENTIFIERS: /GEOTHERMAL RESOURCES/LEAD TIME

216

ROBERTS, A.A. ET AL

1975

HELIUM SURVEY, A POSSIBLE TECHNIQUE FOR LOCATING GEOTHERMAL RESERVOIRS.

GEOPHYSICAL RESEARCH LETTERS 2(6):209-210.

HELIUM (HE) CONCENTRATION IN SOIL GASES WAS MEASURED AT INDIAN HOT SPRINGS RESORT, IDAHO SPRINGS, COLORADO, USING A NEW, HIGHLY SENSITIVE INSTRUMENT. HE CONCENTRATION GRADES SMOOTHLY FROM BACKGROUND 5.2 PARTS PER MILLION (PPM) TO A HIGH OF MORE THAN 100 PPM NEAR A WARM (26 DEGREES C.) WATER SEEP AND A HIGH OF MORE THAN 1,000 PPM NEAR A HOT (40 DEGREES C.) WATER SEEP. HE SOLUBILITY IN WATER INCREASES WITH TEMPERATURE ABOVE 30 DEGREES C. SO HOT WATER MAY SCAVENGE HE PRODUCED FROM URANIUM AND THORIUM RADIOACTIVE DECAY AND RELEASE IT AT LOWER TEMPERATURE AND PRESSURE NEAR THE SURFACE. HE SURVEY, THUS, MIGHT BE A USEFUL GEOTHERMAL EXPLORATION TOOL. (OALS)

GEOTHERMAL STUDIES/HELIUM/GEOCHEMISTRY/EXPLORATION/SURVEYS/ANALYTICAL TECHNIQUES/SOIL GASES/COLORADO/WATER CHEMISTRY/HOT SPRINGS/WATER TEMPERATURE/ SOLUBILITY/INSTRUMENTATION
/IDENTIFIERS: /GEOTHERMAL RESERVOIRS

217

ROSS, D.A.

1972

RED SEA HOT BRINE AREA: REVISITED.

SCIENCE 17(4029):1455-1457.

SEE: SWRA W72-06910.

BRINES/HOT SPRINGS/BOTTOM SEDIMENTS/DENSITY STRATIFICATIONS/GEOTHERMAL STUDIES/GEOCHEMISTRY/OCEANOGRAPHY/WATER CHEMISTRY/METALS/HEAT FLOW/SALINE WATER/EXPLORATION/COPPER/LEAD/ZINC
/IDENTIFIERS: /RED SEA/HOT BRINES/MINERAL DEPOSITS/RIFT ZONES/SPREADING CENTERS/SILVER

218

ROSS, S.H.

1973

GEOTHERMAL POTENTIAL OF IDAHO. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):975-1008.

SEE: SWRA W74-08974.

THERMAL WATER/GEOTHERMAL STUDIES/IDAHO/THERMAL SPRINGS/HOT SPRINGS/ HYDROTHERMAL STUDIES/MINERAL WATER/SPATIAL DISTRIBUTION/WATER TEMPERATURE/ WATER CHEMISTRY
/IDENTIFIERS: /GEOTHERMAL RESOURCES/HOT WATER SYSTEMS

219

SAINT, P.K.

1975

EAST AFRICAN RIFT VALLEYS, TECTONIC SETTING FOR NEW GEOTHERMAL DEVELOPMENT.

GEOTHERMAL ENERGY 3(5):71-75.

THE EAST AFRICAN RIFT SYSTEM INCLUDES DEAD SEA, RED SEA, GULF OF ADEN, AFAR TRIPLE JUNCTION, ETHIOPIAN RIFT, GREGORY RIFT IN KENYA AND TANZANIA, AND WESTERN RIFT. THESE RIFTS ARE CONTINENTAL EXTENSIONS OF MID-OCEANIC SPREADING CENTERS, EQUIVALENT TO IMPERIAL VALLEY AND ICELAND'S CENTRAL VALLEY. GEOTHERMAL AREAS ARE ASSOCIATED WITH FAULTING AND VOLCANISM. KENYA AND ETHIOPIA HAVE GREATEST POTENTIAL. NATURAL STEAM JETS IN THESE TWO COUNTRIES ARE USED FOR SPACE HEATING, DRYING OF PYRETHRUM FLOWERS, AND CONDENSATION TO POTABLE WATER. FUTURE GEOTHERMAL USES MAY ALSO INCLUDE PRODUCTION OF POWER, SALTS, HELIUM, AND MINERALS. EXPLORATION IS PROGRESSING WITH UNITED NATIONS HELP. (OALS)

GEOTHERMAL STUDIES/AFRICA/GEOLOGY/FAULTS(GEOLOGIC)/VOLCANOES/UNITED NATIONS/ EXPLORATION/STEAM/POTABLE WATER
/IDENTIFIERS: /GEOTHERMAL POWER/CHEMICAL RECOVERY/DEVELOPING COUNTRIES/DEAD SEA/SPREADING CENTERS/RIFT ZONES/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL BELTS/GLOBAL TECTONICS/RED SEA/GULF OF ADEN/AFAR TRIANGLE/ETHIOPIA/TANZANIA/ KENYA/VOLCANISM/SPACE HEATING/INDUSTRIAL USES/DISTILLATION

220

SANDQUIST, G.M./WHAN, G.A.

1973

ENVIRONMENTAL ASPECTS OF NUCLEAR STIMULATION. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 293-313.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA. EIA 73-09040.

SEE: SWRA W73-13230.

ENVIRONMENTAL EFFECTS/NUCLEAR EXPLOSIONS/WELLS/GEOTHERMAL STUDIES/THERMAL POWERPLANTS/WATER POLLUTION SOURCES/RADIOACTIVE WASTES/SEISMIC STUDIES/ RADIOACTIVITY EFFECTS/AIR POLLUTION
/IDENTIFIERS: /WELL STIMULATION/GEOTHERMAL POWER

221

SCHUSTER, R.

1972

TURNING TURBINES WITH GEOTHERMAL STEAM.

POWER ENGINEERING 76(3):36-41. EIA 72-04297.

THE AUTHOR BELIEVES THAT THE MOST REALISTIC ASSESSMENT OF THE MAXIMUM GEOTHERMAL ENERGY POTENTIAL, NATIONAL AND WORLDWIDE, IF FULLY DEVELOPED, WOULD PROVIDE ONLY A FRACTION OF TOTAL FUTURE ENERGY REQUIREMENTS. TECHNICAL FOCUS OF THE ARTICLE IS ON GEYSERS FIELD, CALIFORNIA, AND DEVELOPMENTS IN ICELAND. HE CALLS ATTENTION TO CORROSION PROBLEMS AT THE GEYSERS PLANT, AND THE STEAM-GATHERING PIPING THAT DOMINATES ITS LANDSCAPE.

GEOTHERMAL STUDIES/STEAM/EXPLORATION/TURBINES/ENTHALPY/PIPELINES/CORROSION/ ENVIRONMENTAL EFFECTS/STEAM TURBINES/UNITED STATES
/IDENTIFIERS: /GEYSERS FIELD, CALIFORNIA/ICELAND/WORLD/GEOTHERMAL RESOURCES

222

SCIENCE

1973

DRY GEOTHERMAL WELLS: PROMISING EXPERIMENTAL RESULTS.

SAME AS AUTHOR 182(4107):43-45. EIA 73-11067.

TWO QUESTIONS ABOUT TAPPING DRY GEOTHERMAL DEPOSITS IN IGNEOUS ROCKS HAVE BEEN ANSWERED BY EXPERIMENTS IN NEW MEXICO. IT HAS BEEN DEMONSTRATED THAT GRANITE CAN BE HYDROFRACTURED, AND THAT IT IS SUFFICIENTLY IMPERMEABLE TO HOLD WATER. PROJECTS IN MONTANA ARE UNDERWAY TO ASSESS DRY GEOTHERMAL RESOURCES AND TO CONFIRM SUSPECTED DEPOSITS.

GEOTHERMAL STUDIES/NEW MEXICO/MONTANA/HYDROFRACTURING/LAND RESOURCES/SOUTHWEST U.S./GRANITES/IGNEOUS ROCKS/EXPLORATION/PERMEABILITY/ON-SITE INVESTIGATIONS
/IDENTIFIERS: /HOT-DRY ROCKS

223

SCURLOCK, J.S./CONLEY, J.N.

1972

STATE OF ARIZONA SUBSURFACE TEMPERATURE MAP. [MAP,SCALE 1:1,000,000]

ARIZONA OIL AND GAS CONSERVATION COMMISSION. TABLE. 8 P.

WELL LOCATIONS ARE PLOTTED, EACH WITH DATA ON DOWN-HOLE TEMPERATURE, DEPTH, ROCK FORMATION, TEMPERATURE GRADIENT, AND TYPE OF WELL (DRY, OIL, GAS, HOT WATER, PLUGGED, ABANDONED, ETC.). A TABLE FOR WELLS IN NAVAJO AND APACHE COUNTIES (NORTHEASTERN ARIZONA) LISTS IDENTIFICATION NUMBER, LOCATION, NAME, AND TEMPERATURE DATA. (OALS)

GEOTHERMAL STUDIES/ARIZONA/MAPS/SUBSURFACE INVESTIGATIONS/WELL DATA/DRILL HOLES/TEMPERATURE
/IDENTIFIERS: /TEMPERATURE GRADIENT

224

SIGVALDASON, G.E.

1973

GEOCHEMICAL METHODS IN GEOTHERMAL EXPLORATION. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 49-59.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

SEE: SWRA W74-11786.

GEOTHERMAL STUDIES/GEOCHEMISTRY/SURVEYS/EXPLORATION/WATER CHEMISTRY/BRINES/CHLORIDES/THERMAL WATER/HYDROTHERMAL STUDIES/THERMAL POWER/CHEMICAL ANALYSIS/CHEMICAL PROPERTIES

225

SMALL, H.

1973

NATURE'S TEAKETTLE: GEOTHERMAL ENERGY FOR THE PEOPLE.

GEOTHERMAL INFORMATION SERVICES, WEST COVINA, CALIFORNIA. 213 P.

EXPLAINS THE BASIC PRINCIPLES NECESSARY FOR UNDERSTANDING GEOTHERMAL POWER, HEAT TRANSFER, AND DESALINATION. THE AUTHOR EVALUATES THE ECONOMIC DEMANDS CREATED BY ENERGY DEVELOPMENT AS WELL AS THE ENVIRONMENTAL FACTORS THAT MAKE GEOTHERMAL ENERGY AN APPEALING SOURCE OF ENERGY. NUCLEAR ENERGY AND FOSSIL FUELS ARE DISCUSSED AND COMPARED TO GEOTHERMAL ENERGY. A WORLDWIDE SURVEY OF GEOTHERMAL ENERGY DEVELOPMENT IS MADE AND A SUMMARY OF LEGISLATION PROPOSED TO AID DEVELOPMENT OF THIS RESOURCE CONCLUDES THIS PUBLICATION.

ELECTRIC POWER/FOSSIL FUELS/GEOTHERMAL STUDIES/STEAM/HEAT TRANSFER/ECONOMICS/DESALINATION/NUCLEAR ENERGY/GEOLOGY/ENVIRONMENTAL EFFECTS/LEGAL ASPECTS
/IDENTIFIERS: /DRY STEAM FIELDS/ALTERNATIVE ENERGY SOURCES/GEOTHERMAL ENERGY/GEOTHERMAL RESOURCES DEVELOPMENT/GLOBAL DISTRIBUTION/WORLD

226

SMITH, J.H.

1973

COLLECTION AND TRANSMISSION OF GEOTHERMAL FLUIDS. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 97-106.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

CHEMICAL AND PHYSICAL PROPERTIES OF GEOTHERMAL FLUIDS (WATER, STEAM, OR MIXTURE) MUST BE KNOWN BEFORE DESIGNING COLLECTION SYSTEM. WET STEAM FIELD WELLHEAD EQUIPMENT IS A SYSTEM OF SPECIALLY DESIGNED CONTROL AND SAFETY VALVES, PIPES, CYCLONE SEPARATOR (CENTRIFUGALLY SEPARATES WATER FROM STEAM), BYPASS LINES, SILENCER (BRINGS HOT WATER TO ATMOSPHERIC PRESSURE AND SUPPRESSES NOISE), AND DRAINAGE CANALS FOR WATER DISPOSAL. STEAM IS TRANSMITTED ALONG INSULATED STEEL PIPELINES (WHICH ZIG-ZAG FOR THERMAL EXPANSION-CONTRACTION) WITH SAFETY FEATURES AND WATER TRAPS. HOT WATER, IF PIPED, MUST BE KEPT AT HIGH PRESSURE TO PREVENT BOILING AND RUPTURE. TWO-PHASE (WATER AND STEAM) TRANSMISSION IS POSSIBLE, BUT THE TECHNOLOGY IS NOT PROVEN. (OALS)

GEOTHERMAL STUDIES/PIPELINES/PIPE FLOW/WELLS/VALVES/FLOW CONTROL/SEPARATION TECHNIQUES/CENTRIFUGATION/WASTE WATER DISPOSAL/TECHNOLOGY
/IDENTIFIERS: /GEOTHERMAL FLUIDS

227

SMITH, M.C. ET AL

1973

INDUCTION AND GROWTH OF FRACTURES IN HOT ROCK. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 251-268.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13228.

GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/THERMAL POWERPLANTS/ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/INJECTION/WELLS/DRILLING/PRESSURE/HYDROFRACTURING/FRACTURE PERMEABILITY
/IDENTIFIERS: /GEOTHERMAL POWER/WELL STIMULATION/HOT-DRY ROCKS

228

SMITH, M.C. ET AL

1975

MAN-MADE GEOTHERMAL RESERVOIRS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS VI-40.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

ENERGY CONTENT OF DRY GEOTHERMAL RESERVOIRS IS ENORMOUS. IF MEANS CAN BE FOUND TO EXTRACT AND USE IT ECONOMICALLY, IT CAN CONTRIBUTE SIGNIFICANTLY TO SATISFYING THE WORLD'S ENERGY NEEDS. ONE WAY TO ACCOMPLISH THIS IS TO

INJECT WATER INTO HOT ROCK THROUGH ONE HOLE, PERMIT IT TO CIRCULATE THROUGH NATURAL OR MAN-MADE FLOW PASSAGES, AND RECOVER IT AS STEAM OR HOT WATER THROUGH ANOTHER HOLE. MAJOR PROBLEMS ARE AVOIDING EXCESSIVE WATER LOSS IF NATURAL PERMEABILITY IS HIGH OR, IF IT IS LOW, CREATING OPENINGS FOR FLUID CIRCULATION AND ENOUGH SURFACE TO PERMIT EXTRACTION OF HEAT AT A USEFUL RATE FOR A USEFULLY LONG TIME. POSSIBILITIES, PROBLEMS, AND ENGINEERING REQUIREMENTS OF SUCH MAN-MADE GEOTHERMAL SYSTEMS ARE NOW BEING INVESTIGATED IN HOT GRANITES UNDERLYING JEMEZ PLATEAU, NORTHERN NEW MEXICO. HYDRAULIC FRACTURING HAS BEEN ACCOMPLISHED AT PUMPING PRESSURES LESS THAN 175 BARS BOTH AT 760 M (ROCK TEMPERATURE 100 DEGREES C.) AND AT 2040 M (ROCK TEMPERATURE 146 DEGREES C.). FRACTURES PRODUCED ARE ESSENTIALLY VERTICAL AND RATE OF WATER LOSS IS LOW. EXPERIMENTS ARE NOW IN PROGRESS AT 2920 M (ROCK TEMPERATURE 197 DEGREES C.).

GEOTHERMAL STUDIES/NEW MEXICO/INJECTION/WELL STIMULATION/HYDROFRACTURING/PERMEABILITY/FRACTURES(GEOLOGIC)/IGNEOUS ROCKS/GRANITES
/IDENTIFIERS: /HOT-DRY ROCKS/GEOTHERMAL RESERVOIRS/HEAT CONTENT/HYDROTHERMAL CONVECTION SYSTEMS/GEOTHERMAL POWER

229

SMITH, R.L./SHAW, H.R.

1975

IGNEOUS-RELATED GEOTHERMAL SYSTEMS. IN D.E. WHITE AND D.L. WILLIAMS, EDS., ASSESSMENT OF GEOTHERMAL RESOURCES OF THE UNITED STATES--1975, P. 58-83.

U.S. GEOLOGICAL SURVEY, CIRCULAR 726.

A TENTATIVE FIRST APPROACH TO ESTIMATING PRESENT HEAT CONTENT OF SUBSURFACE IGNEOUS-RELATED GEOTHERMAL SYSTEMS TO 10 KM DEPTH. ESTIMATES ARE BASED ON SURFACE MANIFESTATIONS (VOLCANIC SYSTEMS, GEOPHYSICS, FRACTURE PATTERNS) AND AGE AND COMPOSITION OF YOUNGEST ERUPTION. TABLES LIST PARAMETERS AND HEAT CONTENT FOR IDENTIFIED VOLCANIC SYSTEMS IN EACH STATE (WESTERN U.S., ALASKA, AND HAWAII), AND NAMES AND COORDINATES OF BASIC VOLCANIC FIELDS PROBABLY LESS THAN 10,000 YEARS OLD. LOCATIONS ARE PLOTTED ON MAPS. SILICIC MAGMAS ARE GENERALLY ERUPTED FROM HIGH-LEVEL STORAGE CHAMBERS WITHIN 10 KM OF SURFACE. BASIC MAGMAS, HOWEVER, FORM IN MANTLE OR DEEP CRUST AND RISE THROUGH NARROW FISSURES, FORMING NO LARGE HIGH-LEVEL STORAGE CHAMBERS (EXCEPT IN OCEANIC VOLCANOES), AND CONTRIBUTING LITTLE STORED HEAT TO UPPER CRUST. TOTAL HEAT CONTENT IN MAGMA-RELATED SYSTEMS IN WESTERN U.S. IS 23,000 TIMES 10 TO 18TH POWER CALORIES (ABOUT 30 TIMES CONTENT OF HYDROTHERMAL CONVECTION SYSTEMS), HALF AS MOLTEN MAGMA. ROOF ROCKS CONTAIN ABOUT 1/4 TO 1/3 AS MUCH HEAT. (OALS)

GEOTHERMAL STUDIES/UNITED STATES/IGNEOUS ROCKS/VOLCANIC ROCKS/ESTIMATING/GEOPHYSICS/MAPS/SPATIAL DISTRIBUTION
/IDENTIFIERS: /GEOTHERMAL RESOURCES/HOT-DRY ROCKS/HEAT CONTENT/WESTERN U.S./ALASKA/HAWAII/MAGMA

230

STANDIFORD, F.C.

1972

VTE EVAPORATORS FOR GEOTHERMAL BRINES.

U.S. OFFICE OF SALINE WATER, REPORT INT-OSW-RDPR-74-975. 150 P. AVAILABLE NTIS AS PB-233 185/AS.

SEE: SWRA W74-11829.

DESALINATION PROCESSES/CALIFORNIA/EVALUATION/DESIGN/CONSTRUCTION COSTS/HEAT TRANSFER/EVAPORATORS/EVAPORATION/BRINES/DESALINATION
/IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL BRINES/BLOWDOWN CONCENTRATIONS/GEOTHERMAL WATER

231

STEWART, R./CARRIGAN, P.H., JR.

1970 - 1971

HANDLING HOT WATER, WITH A PAYOFF.

CONSERVATIONIST 25(3):16-20.

SEE: SWRA W73-02780.

BENEFICIAL USE/HEATED WATER/ECONOMICS/HEAT/THERMAL POWERPLANTS/THERMAL POLLUTION/POWERPLANTS/WATER POLLUTION/TEMPERATURE/AGRICULTURE/FISH FARMING/CATFISHES/COOLING/DISTILLATION
/IDENTIFIERS: /WASTE HEAT USES/WASTE HEAT/GEOTHERMAL ENERGY/INDUSTRIAL USES/ICELAND

232

STIELTJES, L.

1975

RESEARCH FOR A GEOTHERMAL FIELD IN A ZONE OF OCEANIC SPREADING: EXAMPLE OF THE ASAL RIFT (FRENCH TERRITORY OF AFARS AND ISSAS - AFAR DEPRESSION - EAST AFRICA). IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS II-50.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

FOLLOWING EXPLORATION BETWEEN 1970 AND 1973 BOREHOLE SITES WERE PLANNED ON SOUTH MARGIN OF THE RIFT. ATTENTION WAS DRAWN TO THIS ZONE BY HOT SPRINGS ON BORDERS OF THE GRABEN AND BY THE RIFT STRUCTURE ITSELF. PETROLOGICAL ANALYSIS OF RIFT LAVAS REVEALS TRANSITIONAL VOLCANISM WHICH RESEMBLES VERY CLOSELY THAT FOUND ON OCEANIC RIDGES. AXIAL VALLEY HAS NUMEROUS OPEN FISSURES, SOME MAGMA-PRODUCTIVE. MORPHOLOGY AND SIZE ARE QUITE COMPARABLE TO MID-OCEANIC RIDGES. PRESENT TECTONIC EXTENSION OF THE RIFT IS ESTIMATED 2 TO 4 CM/YEAR. SEISMIC ACTIVITY IS STRONG. AVERAGE HEAT FLUX ON RIDGES IS ABOUT 3 TIMES FLUX IN THE OCEANIC BASINS. TEMPERATURE GRADIENT MEASURED AT ASAL REACHES 45 DEGREES/100 M ON THE FLANKS OF A TECTONIC SWELLING 10 KM IN DIAMETER, A MAGMATIC INTUMESCENCE IN CENTRAL PART OF RIFT. THE ACCRETION BAND, 4 TO 5 KM WIDE, IS HARDLY LIKELY TO TRAP A GEOTHERMAL FIELD. BOREHOLES WERE THEREFORE SITUATED ON THE BORDERS, WHERE STRATIGRAPHIC SERIES IS NORMAL, TECTONISATION STILL INTENSE, AND WHERE SUPERFICIAL IMPERMEABILITY AND HYDROTHERMAL INDICATIONS ALONG FAULTS OCCUR.

GEOTHERMAL STUDIES/AFRICA/EXPLORATION/GEOLOGY/HOT SPRINGS/STRUCTURAL GEOLOGY/ EARTHQUAKES/HEAT FLOW/DRILLING/FAULTS(GEOLOGIC)/EXPLORATION /IDENTIFIERS: /AFARS AND ISSAS/AFAR TRIANGLE/SPREADING CENTERS/MID-OCEANIC RIDGES/RIFT ZONES/VOLCANISM/MAGMA/TEMPERATURE GRADIENT/EXPLORATION WELLS/ CAP ROCK/GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT

233

STOREY, D.M.

1974

GEOTHERMAL DRILLING IN KALMATH FALLS, OREGON.

GEOTHERMAL ENERGY 2(11):61-63.

AIR-ROTARY, STRAIGHT-ROTARY, AND CABLE DRILLING RIGS ARE USED TO DRILL GEOTHERMAL WELLS FOR SPACE HEATING, ROAD HEATING (MELTS ICE AND SNOW), AND MILK PASTEURIZATION. COMMERCIAL WELLS ARE 400-1805 FEET DEEP AND 10-14 INCHES IN DIAMETER, ARE PUMPED 25-400 GPM, AND COST 30,000 DOLLARS OR MORE. RESIDENTIAL WELLS ARE 150-1000 FEET DEEP AND 10 INCHES IN DIAMETER AND COST 3,000 TO 10,000 DOLLARS. CASING IS PERFORATED AT TWO DEPTHS FOR THERMOSYPHON EFFECT. CITY WATER IS PUMPED THROUGH DOWN-HOLE HEAT EXCHANGERS AND BACK UP TO HOME SPACE AND WATER HEATERS. (OALS) (ALSO SEE: SWRA W75-07146).

GEOTHERMAL STUDIES/OREGON/DRILLING/ROTARY DRILLING/CASINGS/DRILLING EQUIPMENT/WELLS/DAIRY INDUSTRY/PUMPING/HEAT EXCHANGERS/WELL CASINGS/ COSTS/THERMAL WATER /IDENTIFIERS: /KLAMATH FALLS/PRODUCTION WELLS/SPACE HEATING/ROAD HEATING/DRILLING COSTS/HOT WATER SYSTEMS

234

STORK, K.E. ED.

1973

THE ROLE OF WATER IN THE ENERGY CRISIS: PROCEEDINGS OF A CONFERENCE AT LINCOLN, NEBRASKA, 1973.

NEBRASKA WATER RESOURCES RESEARCH INSTITUTE, PUBLICATION. 219 P. AVAILABLE NTIS AS PB-232 404.

SEE: SWRA W74-07961.

ENERGY/WATER MANAGEMENT(APPLIED)/WATER CONSUMPTION(EXCLUDES CONSUMPTIVE USE)/ WATER RESOURCES/WATER DEMAND/ALTERNATIVE WATER USE/WATER POLLUTION/WATER RATES/ WATER UTILIZATION/IRRIGATION EFFICIENCY/NUCLEAR ENERGY/RESEARCH AND DEVELOPMENT/TECHNOLOGY/WATER ALLOCATION(POLICY)/WATER SHORTAGE/WATER SUPPLY/ WATER CONSERVATION /IDENTIFIERS: /ENERGY CRISIS/ENERGY-WATER RELATIONSHIPS/ENERGY POOL/ WATER RESOURCES PLANNING/SOLAR ENERGY/GEOTHERMAL ENERGY

235

STRANGWAY, D.W.

1973

GEOPHYSICAL EXPLORATION THROUGH GEOLOGIC COVER. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1231-1243.

SEE: SWRA W74-09000.

GEOTHERMAL STUDIES/HYDROGEOLOGY/AQUIFER TESTING/DRILLING/EXPLORATION/COSTS/ BOREHOLE GEOPHYSICS/THERMAL WATER/DATA COLLECTIONS/HYDROLOGIC DATA/GEOPHYSICS/ MAGNETIC STUDIES/ELECTRICAL STUDIES/RESISTIVITY

236

SUKHAREV, G.M./VLASOVA, S.P./TARANUKHA, Y.K.

1973

UTILIZATION OF THERMAL WATERS FROM OIL DEPOSITS OF THE CAUCASUS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1102-1115.

SEE: SWRA W74-08988.

GEOTHERMAL STUDIES/THERMAL WATER/DRAWDOWN/THERMAL SPRINGS/HOT SPRINGS/ THERMAL POWER/HYDROGEOLOGY/OIL FIELDS/INJECTION /IDENTIFIERS: /USSR/HOT WATER SYSTEMS/INDUSTRIAL USES/SPACE HEATING

237

SUMMERS, W.K. COMP.

1971

ANNOTATED AND INDEXED BIBLIOGRAPHY OF GEOTHERMAL PHENOMENA.

NEW MEXICO, STATE BUREAU OF MINES AND MINERAL RESOURCES, SOCORRO. 665 P.

THIS MASSIVE WORK, COMPLETED IN A 3-YEAR PERIOD FROM JULY 1969 TO JULY 1971 ON NSF GRANT NO. GN-764, INCLUDES OVER 14,000 ENTRIES COVERING ALL NATURAL, PHYSICAL, AND CHEMICAL ASPECTS OF THE EARTH S HEAT. IT PURPORTS TO LIST 95 PERCENT OF REFERENCES ON GEOTHERMAL PHENOMENA APPEARING THROUGH DECEMBER 31, 1969, WITH A FEW KEY REFERENCES FOR 1970. AUTHOR, GEOGRAPHICAL, AND SUBJECT INDEXES ARE INCLUDED. A HIGH PERCENTAGE OF THE ITEMS ARE ANNOTATED.

GEOTHERMAL STUDIES/BIBLIOGRAPHIES/HEAT BUDGET/THERMAL POWER/STEAM/HOT SPRINGS/ GEOPHYSICS/GEOCHEMISTRY/GEOLOGY

238

SUMMERS, W.K.

1972 A

GEOTHERMAL PROSPECTS IN NEW MEXICO. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER I, 23 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03428.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/NEW MEXICO/THERMAL WATER/ WATER TEMPERATURE/THERMAL PROPERTIES/HYDROGEOLOGY/EXPLORATION/WATER QUALITY/ DRILLING/SPATIAL DISTRIBUTION/HOT SPRINGS/GEOLOGY /IDENTIFIERS: /GEOTHERMAL RESOURCES/RIO GRANDE TROUGH

239

SUMMERS, W.K.

1972 B

GEOTHERMAL RESOURCES OF NEW MEXICO. [MAP, SCALE 1:1,000,000]

NEW MEXICO STATE BUREAU OF MINES AND MINERAL RESOURCES.

SHOWS LOCATIONS, NAMES, AND TEMPERATURES OF THERMAL SPRINGS AND GEOTHERMAL WELLS. ALSO SHOWS LOCATIONS OF KNOWN GEOTHERMAL RESOURCE AREAS (ESTABLISHED BY U.S. DEPARTMENT OF THE INTERIOR) AND EXTENSIVE HYDROTHERMAL ANOMALIES. MOST THERMAL MANIFESTATIONS OCCUR ALONG THE RIO GRANDE AND IN SOUTHWESTERN NEW MEXICO.

GEOTHERMAL STUDIES/NEW MEXICO/MAPS/SPATIAL DISTRIBUTION/THERMAL SPRINGS /IDENTIFIERS: /RIO GRANDE RIFT/GEOTHERMAL WELLS

240

SUMMERS, W.K.

1973

GEOTHERMAL PROSPECTS IN NEW MEXICO. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1009-1014.

SEE: SWRA W74-08975.

THERMAL WATER/GEOTHERMAL STUDIES/NEW MEXICO/THERMAL SPRINGS/HOT SPRINGS/ MINERAL WATER/DISCHARGE(WATER)/FAULTS(GEOLOGIC)/WATER TEMPERATURE/WELLS/ HYDROGEOLOGY/WATER CHEMISTRY
/IDENTIFIERS: /GEOTHERMAL RESOURCES/VOLCANISM

241

SUMMERS, W.K./ROSS, S.H.

1971

GEOTHERMICS IN NORTH AMERICA: PRESENT AND FUTURE.

EARTH SCIENCE BULLETIN 4(1):7-22.

SEE: SWRA W72-01756.

GEOTHERMAL STUDIES/ELECTRIC POWER/THERMAL POWER/EXPLORATION/ENVIRONMENTAL EFFECTS/MULTIPLE-PURPOSE PROJECTS/CALIFORNIA/NEVADA/IDAHO/THERMAL SPRINGS/ RESOURCES DEVELOPMENT/COSTS/PRICES/OREGON/MEXICO/MAPS
/IDENTIFIERS: /SALTON SEA/BAJA CALIFORNIA/GEOTHERMAL STEAM ACT, 1970/ GEOTHERMAL POWER/GEOTHERMAL RESOURCES/CHEMICAL RECOVERY

242

SWANBERG, C.A.

1974

THE APPLICATION OF THE NA-K-CA GEOTHERMOMETER TO THERMAL AREAS OF UTAH AND THE IMPERIAL VALLEY, CALIFORNIA.

GEOTHERMICS 3(2):53-59.

SODIUM-POTASSIUM-CALCIUM (NA-K-CA) DATA, COMMON IN GEOLOGIC LITERATURE, CAN BE USED TO DETERMINE THE LAST TEMPERATURE AT WHICH WATER-ROCK CHEMICAL EQUILIBRIUM WAS ATTAINED. THE TECHNIQUE IS APPLIED TO THERMAL SPRING DATA TO EVALUATE THE POTENTIAL OF UTAH'S GEOTHERMAL RESOURCES. A MAP AND A TABLE SUMMARIZE THE ESTIMATED TEMPERATURES (AS HIGH AS 289 DEGREES C.). SOME ESTIMATES ARE ERRONEOUS BECAUSE HYDROGEOLOGIC CONDITIONS VIOLATE TECHNIQUE ASSUMPTIONS. ESTIMATES FOR SEVERAL SAMPLES FROM LAVERKIN HOT SPRINGS AGREE WITHIN PLUS OR MINUS 10 DEGREES C. SAMPLES FROM MESA ANOMALY, IMPERIAL VALLEY, GIVE CONSISTENT TEMPERATURE ESTIMATES DESPITE GREATLY DIFFERENT PHYSICAL SITUATIONS (DOWN-HOLE, SURFACE, FLASHING, BRINE POND), AND CLEARLY INDICATE THAT THE GEOTHERMAL SYSTEM IS CONFINED (SURFACE AQUIFER IS UNCONTAMINATED). (OAIS)

GEOTHERMAL STUDIES/ANALYTICAL TECHNIQUES/GEOCHEMISTRY/WATER TEMPERATURE/WATER CHEMISTRY/THERMAL SPRINGS/UTAH
/IDENTIFIERS: /GEOTHERMOMETERS/SODIUM-POTASSIUM-CALCIUM GEOTHERMOMETER/EAST MESA FIELD/IMPERIAL VALLEY

243

TALBOT, J.B. COMP.

1971

BIBLIOGRAPHY ON GEOTHERMAL RESEARCH.

U.S. BUREAU OF RECLAMATION, ENGINEERING AND RESEARCH CENTER, BIBLIOGRAPHY 249. 14 P.

CONTAINED ARE 150 CITATIONS FROM BIBLIOGRAPHIC SOURCES AND TECHNICAL PUBLICATIONS COVERING THE YEARS 1964 THROUGH EARLY 1971. REFERENCES ARE LISTED ALPHABETICALLY BY PERSONAL AUTHOR, AND NOTATIONS ARE INCLUDED IF THEY ARE NOT IN THE BUREAU LIBRARY IN DENVER. COVERAGE IS GENERAL AND DOES NOT INCLUDE ANY ONE SPECIFIC AREA.

BIBLIOGRAPHIES/BRINES /FUELS /GEOCHEMISTRY/GEOTHERMAL STUDIES/HEAT TRANSFER/ STEAM/THERMAL POWER/HOT SPRINGS/HEAT FLOW/GEYSERS
/IDENTIFIERS: /IMPERIAL VALLEY/NEW ZEALAND

244

TAMRAZYAN, G.P.

1973

CONTINENTAL DRIFT AND THERMAL FIELDS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1212-1225.

SEE: SWRA W74-08998.

GEOTHERMAL STUDIES/EXPLORATION/SPATIAL DISTRIBUTION/STRUCTURAL GEOLOGY
/IDENTIFIERS: /USSR/CONTINENTAL DRIFT/GLOBAL DISTRIBUTION/PLATE BOUNDARIES/ RIFT ZONES/GEOTHERMAL HEAT/GEOTHERMAL RESOURCES

245

TAZIEFF, H.

1972 A

ETHIOPIA'S GEOTHERMAL POSSIBILITIES.

COMPRESSED AIR MAGAZINE 77(1):14-17. EIA 72-04680.

THE DANAKIL DEPRESSION HOLDS AN ENORMOUS UNDERGROUND STEAM RESERVE. SINCE GEOTHERMAL POWER IS RELATIVELY CHEAP POWER THIS RESOURCE COULD BE OF SIGNIFICANCE IN DEVELOPING THIS IMPOVERISHED NATION. A COST COMPARISON IS MADE BETWEEN GEOTHERMAL POWER AND OTHER SOURCES SUCH AS COAL, HYDROELECTRIC, AND NUCLEAR.

GEOTHERMAL STUDIES/AFRICA/ENERGY CONVERSION/THERMAL POWER/LAND RESOURCES/COST COMPARISONS
/IDENTIFIERS: /ETHIOPIA/ALTERNATIVE ENERGY SOURCES/GEOTHERMAL STEAM/GEOTHERMAL RESOURCES/DEVELOPING COUNTRIES/GEOTHERMAL POWER/DANAKIL DEPRESSION

246

TAZIEFF, H.

1972 B

THE AFAR TRIANGLE.

SCIENTIFIC AMERICAN 222(2):32-40.

RIFTS IN GULF OF ADEN AND RED SEA, PERPENDICULAR TO EACH OTHER, AND NORTHERN END OF THE EAST AFRICAN RIFT ALL MEET IN THE AFAR TRIANGLE, NORTHEASTERN ETHIOPIA. GEOLOGICAL EVIDENCE INDICATES THAT THE TRIANGLE IS PART OF THE RED SEA FLOOR, AN EXAMPLE OF OCEANIC CRUST IN THE MAKING. THE AREA IS SCENE OF MUCH ACTIVE VOLCANISM, HOT SPRINGS, HIGH HEAT FLOW, AND ACTIVE GRABEN FAULTING. POROUS STRATA OF THE TRIANGLE'S FLOOR PROBABLY ABSORB MUCH WATER DURING THE RAINY SEASON. IT SEEMS LIKELY, THEREFORE, THAT THERE ARE RESERVOIRS OF GEOTHERMAL FLUIDS IN SOME AREAS. GEOTHERMAL POWER MIGHT TRANSFORM THIS BARREN DESERT REGION INTO AN INDUSTRIAL MEGALOPOLIS. (OALS)

GEOTHERMAL STUDIES/AFRICA/GEOLOGY/VOLCANOES/HOT SPRINGS/FAULTS(GEOLOGIC)/ HEAT FLOW
/IDENTIFIERS: /AFAR TRIANGLE/RIFT ZONES/GULF OF ADEN/RED SEA/ETHIOPIA/PLATE BOUNDARIES/DEVELOPING COUNTRIES/GEOTHERMAL RESOURCES/SPREADING CENTERS/GLOBAL TECTONICS/MID-OCEANIC RIDGES/GEOTHERMAL RESOURCES DEVELOPMENT

247

TELLIER, A.H.

1973

GEOTHERMAL WATERS OF ARIZONA, A PROGRESS REPORT.

GEOTHERMAL WORLD DIRECTORY, 1973. P. 163-175.

POWER PRODUCTION POTENTIAL WAS INVESTIGATED AT 34 SITES BY ANALYZING WATER SAMPLES FOR SODIUM (NA), POTASSIUM (K), SILICA, BORON, AND TOTAL DISSOLVED SOLIDS. NA/K AND SILICA GEOTHERMOMETERS INDICATE RESERVOIR TEMPERATURE OVER 200 DEGREES C. FOR 5 LOCATIONS NEAR SAFFORD AND FOR SEVERAL OTHER SITES NEAR MESA, ASH CREEK, AND WICKIEUP.

GEOTHERMAL STUDIES/ARIZONA/THERMAL WATER/WATER CHEMISTRY/SODIUM/POTASSIUM/ ON-SITE INVESTIGATIONS/SILICA/BORON/WATER ANALYSIS/WATER TEMPERATURE
/IDENTIFIERS: /GEOTHERMAL WATER/GEOTHERMAL RESOURCES/GEOTHERMAL POWER/ GEOTHERMOMETERS/GEOTHERMAL RESERVOIRS/SAFFORD VALLEY, ARIZONA

248

THOMPSON, W.E.

1972

REVIEW OF CALIFORNIA'S REGIONAL WATER SUPPLY SYSTEMS AND POSSIBLE APPLICATIONS OF DESALTING.

OAK RIDGE NATIONAL LABORATORY, TENNESSEE, NUCLEAR DESALINATION INFORMATION CENTER. PAPER. 98 P.

SEE: SWRA W72-13917.

WATER SUPPLY/DESALINATION/APPLICATION METHODS/WATER STORAGE/CALIFORNIA/WATER CONVEYANCE/CONSTRUCTION/AQUEDUCTS/COLORADO RIVER AQUEDUCT/RESERVOIRS/CENTRAL VALLEY PROJECT/IRRIGATION/WATER RATES/COSTS/WATER REQUIREMENTS/SEA WATER/ WATER DISTRIBUTION(APPLIED)/ECONOMICS/BRINES/GEOTHERMAL STUDIES/SALINITY/ COLORADO RIVER
/IDENTIFIERS: /ALL-AMERICAN CANAL/SIERRA NEVADA/IMPERIAL VALLEY/CALIFORNIA STATE WATER PROJECT/GULF OF CALIFORNIA

249

TIKHONOV, A.N./DVOROV, I.M.

1973

DEVELOPMENT OF RESEARCH AND UTILIZATION OF GEOTHERMAL RESOURCES IN THE USSR. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1072-1078.

SEE: SWRA W74-08985.

GEOTHERMAL STUDIES/HYDROGEOLOGY/EXPLORATION/THERMAL WATER/THERMAL POWER/ DATA COLLECTIONS/HYDROLOGIC DATA/REFRIGERATION/HEATING/COOLING/GREENHOUSES/ COSTS
/IDENTIFIERS: /GEOTHERMAL POWER/USSR/GEOTHERMAL RESOURCES DEVELOPMENT/ GEOTHERMAL RESOURCES/SPACE HEATING/INDUSTRIAL USES/CHEMICAL RECOVERY

250

TOMPKINS, D.C COMP.

1972

POWER FROM THE EARTH: GEOTHERMAL ENERGY.

UNIVERSITY OF CALIFORNIA, BERKELEY, INSTITUTE OF GOVERNMENTAL STUDIES, PUBLIC POLICY BIBLIOGRAPHY 3. 34 P.

THIS BIBLIOGRAPHY COVERS MATERIALS IN PUBLIC ADMINISTRATION, WATER RESOURCES, ENGINEERING, AND EARTH SCIENCES RELATING TO THE UNITED STATES SINCE 1965. INCLUDES A GENERAL BIBLIOGRAPHY, SOURCES USED, AND THEN REFERENCES LISTED UNDER STATES. THE FEDERAL PROGRAMS INVOLVED IN DEVELOPING THIS RESOURCE ARE INCLUDED WITH A SPECIAL SECTION ON THE PLOWSHARE PROGRAM.

BIBLIOGRAPHIES/GEOTHERMAL STUDIES/WATER RESOURCES/SOUTHWEST U.S./ NUCLEAR ENERGY/ENGINEERING/GEOLOGY/FEDERAL GOVERNMENT
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT/PLOWSHARE PROGRAM

251

TOWSE, D.

1975

ESTIMATING GEOTHERMAL RESOURCES: THE SALTON TROUGH, CALIFORNIA, U.S.A. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS I-39.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

ESTIMATES OF GEOTHERMAL POTENTIAL IN SALTON TROUGH HAVE RANGED FROM 4 TIMES 10 TO 18TH POWER JOULES (J), BASED ON EARLY EXPLORATORY DRILLING, TO 2 TIMES 10 TO 19TH POWER TO 6 TIMES 10 TO 19TH POWER J, BASED ON REGIONAL STUDIES. THESE ARE EQUIVALENT TO 1000 MW AND 30,000 TO 90,000 MW OF ELECTRICITY FOR 20 YEARS. PREFERRED ESTIMATES AT PRESENT ARE: 10 TO 18TH POWER J (250 MW FOR 20 YEARS) FROM IDENTIFIED (DRILLED) RESOURCE AND 2 TIMES 10 TO 19TH POWER J (5000 MW) FOR TOTAL RESOURCE. RESOURCE IS LIMITED TO WATER AT TEMPERATURES ABOVE 230 DEGREES C. AT DEPTHS OF LESS THAN 1824 M. FURTHER TECHNICAL AND ECONOMIC DEVELOPMENTS MAY MAKE AVAILABLE AS MUCH AS 4 TIMES 10 TO 19TH POWER TO 10 TO 20TH POWER J (10,000 TO 25,000 MW FOR 20 YEARS).

GEOTHERMAL STUDIES/CALIFORNIA/ESTIMATING/ANALYTICAL TECHNIQUES
/IDENTIFIERS: /SALTON TROUGH/GEOTHERMAL RESOURCES/HEAT CONTENT/GEOTHERMAL ENERGY/POWER CAPACITY

252

TRUESDELL, A.H./WHITE, D.E.

1973

PRODUCTION OF SUPERHEATED STEAM FROM VAPOR-DOMINATED GEOTHERMAL RESERVOIRS.

GEOTHERMICS 2(3-4):154-173.

MODELS FOR PHYSICAL BEHAVIOR OF DRY STEAM RESERVOIRS ARE REVIEWED, AND A SYNTHESIZED MODEL IS PRESENTED. THESE SYSTEMS INITIALLY CONSIST OF WATER- AND STEAM-FILLED RESERVOIR, WATER-SATURATED CAP ROCK, AND SATURATED DEEP RESERVOIR BELOW WATER TABLE. WITH PRODUCTION, PRESSURE IS LOWERED, WATER BOILS, AND ROCKS DRY. STEAM PASSING THROUGH DRY ROCK IS SUPERHEATED. AS EXPLOITATION CONTINUES, WATER TABLE LOWERS, BOILING EXTENDS DEEPER INTO HOTTER ROCK, AND STEAM TEMPERATURE INCREASES.

GEOTHERMAL STUDIES/STEAM/MODEL STUDIES/THERMAL WATER/PRESSURE/TEMPERATURE/ BOILING/HEAT TRANSFER
/IDENTIFIERS: /VAPOR-DOMINATED SYSTEMS/GEOTHERMAL RESERVOIRS/SUPERHEATED STEAM

253

UNITED NATIONS

1970

SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, VOL. 2. 1725 P.

SEE: SWRA W74-08973.

GEOTHERMAL STUDIES/EXPLORATION/RESOURCES DEVELOPMENT/STEAM/BRINES/COSTS/ DESALINATION/GREENHOUSES/WELLS/REMOTE SENSING/DRILLING/GEOCHEMISTRY/ MODEL STUDIES/THERMAL POWERPLANTS/THERMAL POWER/HYDROTHERMAL STUDIES/ CONFERENCES/HYDROGEOLOGY/GROUNDWATER/ECONOMICS/MINERALOGY
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL RESOURCES/GLOBAL DISTRIBUTION

254

UNITED NATIONS

1975

UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY. 213 P.

ABSTRACTS OF 358 PAPERS FOR THE SECOND U.N. GEOTHERMAL RESOURCES SYMPOSIUM (COMPARED WITH ABOUT 200 PAPERS AT THE FIRST SYMPOSIUM, IN 1970) ARE COMPILED HERE, AND AN AUTHOR INDEX IS PROVIDED. THE ABSTRACTS ARE ORGANIZED UNDER 11 HEADINGS: PRESENT STATUS OF RESOURCES DEVELOPMENT; GEOLOGY, HYDROLOGY AND GEOTHERMAL SYSTEMS; GEOCHEMICAL AND GEOPHYSICAL TECHNIQUES IN EXPLORATION; ENVIRONMENTAL FACTORS AND WASTE DISPOSAL; DRILLING TECHNOLOGY; PRODUCTION TECHNOLOGY, RESERVOIR ENGINEERING, AND FIELD MANAGEMENT; ELECTRICITY PRODUCTION; SPACE AND PROCESS HEATING; OTHER SINGLE AND MULTI-PURPOSE DEVELOPMENTS; ECONOMIC AND FINANCIAL; AND LEGAL AND INSTITUTIONAL ASPECTS. THE PROCEEDINGS, WITH COMPLETE PAPERS, WILL BE PUBLISHED IN 1976.

GEOTHERMAL STUDIES/UNITED NATIONS/CONFERENCES/GEOLOGY/HYDROLOGY/GEOCHEMISTRY/ ECONOMICS/LEGAL ASPECTS/GEOPHYSICS/EXPLORATION/ENVIRONMENTAL EFFECTS/DRILLING/ MULTIPLE-PURPOSE PROJECTS
/IDENTIFIERS: /WORLD/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL RESOURCES/ GEOTHERMAL HEAT/GEOTHERMAL POWER/SPACE HEATING

255

UNITED NATIONS, ENERGY SECTION

1972

ASPECTS OF THE DEVELOPMENT OF GEOTHERMAL RESOURCES IN LESS DEVELOPED COUNTRIES.

GEOTHERMICS 1(1):42-45.

DEVELOPMENT OF LOCAL GEOTHERMAL ENERGY SOURCES TO RAISE LIVING STANDARDS MAY LEAVE DEVELOPING COUNTRIES LESS VULNERABLE TO RISING PRICES AND SUPPLY UNCERTAINTY OF IMPORTED OIL. ECONOMIC ADVANTAGES OF GEOTHERMAL POWER (SIMPLICITY, LOW COST, SMALL UNIT SIZE, LOW POLLUTION, CONTINUOUS OUTPUT) AND MULTIPLE-PURPOSE APPLICATIONS (DESALINATION, CHEMICAL RECOVERY, SPACE AND INDUSTRIAL HEATING) ARE SUMMARIZED. U.N. GEOTHERMAL PROJECTS IN CHILE, EL SALVADOR, ETHIOPIA, KENYA, AND TURKEY ARE REVIEWED. A TABLE COMPARES GEOTHERMAL AND ALTERNATIVE POWER COSTS IN 8 DEVELOPING COUNTRIES (INCLUDING INDIA). ETHIOPIAN GEOTHERMAL RESOURCES, IF FULLY DEVELOPED, COULD SUPPLY ALL OF AFRICA'S PRESENT POWER NEEDS. (OALS)

GEOTHERMAL STUDIES/ENVIRONMENTAL EFFECTS/MULTIPLE-PURPOSE PROJECTS/ DESALINATION/COMPARATIVE COSTS
/IDENTIFIERS: /CHILE/ETHIOPIA/KENYA/INDIA/AFRICA/DEVELOPING COUNTRIES/ GEOTHERMAL RESOURCES DEVELOPMENT/ALTERNATIVE ENERGY SOURCES/GEOTHERMAL POWER/OIL/CHEMICAL RECOVERY/SPACE HEATING/INDUSTRIAL USES

256

U.S. BUREAU OF RECLAMATION, BOULDER CITY, NEVADA, REGION 3

1971

GEOTHERMAL RESOURCE INVESTIGATIONS, IMPERIAL VALLEY, CALIFORNIA. STATUS REPORT.

SAME AS AUTHOR. 47 P.

IN 1968 THE BUREAU OF RECLAMATION BEGAN FINANCING GEOTHERMAL STUDIES OF THE IMPERIAL VALLEY BY THE UNIVERSITY OF CALIFORNIA, RIVERSIDE. THIS REPORT SUMMARIZES THE RESULTS OF THE STUDIES, DEVELOPMENT FEASIBILITIES, AND FUTURE PLANS. AS MUCH AS 5 BILLION AF WATER MAY LIE IN STORAGE, TO DEPTHS OF 20,000 FEET, IN THE SALTON TROUGH. SUBSTANTIAL QUANTITIES OF THIS ARE OF LOW SALINITY WITH HIGH HEAT CONTENT, REPRESENTING ENORMOUS RESOURCE POTENTIAL FOR ELECTRIC POWER, MINERALS, FRESH WATER, AND SPACE HEATING. IT IS FELT THAT THIS RESOURCE MAY OFFER A SOLUTION TO THE PROBLEM OF WATER SALINITY IN THE LOWER COLORADO

RIVER THROUGH AUGMENTATION AND DILUTION, AND THEREBY HELP THE U.S. IN MEETING ITS MEXICAN TREATY OBLIGATIONS. THIS WIDE-RANGING REPORT COVERS GEOPHYSICAL, GEOLOGICAL, HYDROLOGICAL, AND ENGINEERING ASPECTS OF THE SUBJECT. FUTURE LINES OF RESEARCH AND DEVELOPMENT ARE DISCUSSED, AND A TENTATIVE BUDGET THROUGH 1976 IS PRESENTED. THE PROBABLE ENVIRONMENTAL IMPACTS OF GEOTHERMAL DEVELOPMENT IN THE IMPERIAL VALLEY ARE DESCRIBED. THEY APPEAR TO BE MINIMAL IF PROPER LOW-COST PRECAUTIONS ARE TAKEN. DETAILED COLORED MAPS OF THE REGION ARE INCLUDED.

GEOTHERMAL STUDIES/CALIFORNIA/RESOURCES DEVELOPMENT/EXPLORATION/COLORADO RIVER/MEXICAN WATER TREATY/WATER STORAGE/WATER QUALITY/ENVIRONMENTAL EFFECTS/THERMAL POWER/SALINE WATER/MIXING/MAPS/BUDGETING/RESEARCH AND DEVELOPMENT/GROUNDWATER RESOURCES/DESALINATION/GEOPHYSICS/GEOLOGY/HYDROLOGY/ENGINEERING STRUCTURES
/IDENTIFIERS: /IMPERIAL VALLEY/SALTON SEA/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL POWER/SPACE HEATING/CHEMICAL RECOVERY

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U.S. BUREAU OF RECLAMATION, BOULDER CITY, NEVADA, REGION 3

1972 A

DEEP GEOTHERMAL TEST WELL, GEOTHERMAL RESOURCE INVESTIGATIONS, IMPERIAL VALLEY, CALIFORNIA (DRAFT ENVIRONMENTAL IMPACT STATEMENT).

SAME AS AUTHOR. 19 P. AVAILABLE NTIS AS PB-206 161-D.

SEE: SWRA W72-11559.

ENVIRONMENTAL EFFECTS/CALIFORNIA/GEOTHERMAL STUDIES/TEST WELLS/DRILLING/MULTIPLE-PURPOSE PROJECTS/DESALINATION/DEEP WELLS/EXPLORATION/BRINES/WATER RESOURCES DEVELOPMENT/THERMAL POWER/STEAM
/IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL RESOURCES DEVELOPMENT/EAST MESA FIELD/GEOTHERMAL POWER

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U.S. BUREAU OF RECLAMATION, BOULDER CITY, NEVADA, REGION 3

1972 B

GEOTHERMAL EXPLORATION IN REGION 3 (IMPERIAL VALLEY PROJECT). IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER C, 9 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03422.

GEOTHERMAL STUDIES/THERMAL WATER/SUBSURFACE WATERS/CALIFORNIA/THERMAL POWER/WATER RESOURCES DEVELOPMENT/BOREHOLE GEOPHYSICS/GEOLOGY/WATER TEMPERATURE/THERMAL PROPERTIES/EXPLORATION/DATA COLLECTIONS/INJECTION WELLS/SEA WATER/LAND SUBSIDENCE/FAULTS(GEOLOGIC)/DESALINATION/MULTIPLE-PURPOSE PROJECTS
/IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL RESOURCES/SPREADING CENTERS

259

U.S. BUREAU OF RECLAMATION, BOULDER CITY, NEVADA, REGION 3

1972 C

PROPOSED DEEP GEOTHERMAL TEST WELL, GEOTHERMAL RESOURCES INVESTIGATIONS, IMPERIAL VALLEY, CALIFORNIA (FINAL ENVIRONMENTAL IMPACT STATEMENT).

SAME AS AUTHOR. 82 P. AVAILABLE NTIS AS PB-206 161-F.

SEE: SWRA W73-00052.

CALIFORNIA/ENVIRONMENTAL EFFECTS/TEST WELLS/GEOTHERMAL STUDIES/SUBSURFACE INVESTIGATIONS/WATER RESOURCES/SUBSURFACE WATERS/WATER SUPPLY DEVELOPMENT/BRINES/SALINE WATER/DESALINATION/ELECTRIC POWER/HYDROELECTRIC POWER/STEAM/THERMAL WATER/DEEP WELLS/SOUTHWEST U.S./ELECTRIC POWER DEMAND/DRILLING
/IDENTIFIERS: /ENVIRONMENTAL IMPACT STATEMENTS/IMPERIAL VALLEY/HOT BRINES/GEOTHERMAL TEST WELLS/GEOTHERMAL POWER

260

U.S. BUREAU OF RECLAMATION, BOULDER CITY, NEVADA, REGION 3

1974

GEOTHERMAL RESOURCE INVESTIGATIONS, EAST MESA TEST SITE, IMPERIAL VALLEY, CALIFORNIA. STATUS REPORT, NOVEMBER 1974.

SAME AS AUTHOR. 64 P.

PRIMARY GOAL IS TO DETERMINE FEASIBILITY OF GEOTHERMAL WATER SUPPLY WITH CONCURRENT POWER PRODUCTION AND CHEMICAL RECOVERY. RESULTS OF GEOPHYSICAL INVESTIGATIONS OF EAST MESA GEOTHERMAL FIELD ARE PRESENTED, AND GENERAL GEOLOGIC, GEOPHYSICAL, CHEMICAL, AND PERFORMANCE DATA FOR 5 TEST WELLS ARE SUMMARIZED. SMALL AMOUNTS OF WASTE BRINES ARE NOW DISPOSED OF IN AN EVAPORATION POND, BUT DEEP WELL INJECTION APPEARS TO BE FEASIBLE FOR LARGER

AMOUNTS. COSTS WERE ESTIMATED FOR DESALINATION AT WELLHEAD FOLLOWED IMMEDIATELY BY POWER PRODUCTION (BINARY FLUID CYCLE) AT LOWER TEMPERATURE. THIS COMBINATION OF BOTH OPERATIONS PROVIDES LOWEST WATER AND POWER COSTS. RESEARCH ON DESALINATION IS PROGRESSING WITH TWO DISTILLATICN PILCT PLANTS (MULTISTAGE FLASH AND VERTICAL TUBE EVAPORATOR) AND PLANS FOR MEMBRANE PROCESS TESTS AND FIELD TRIALS OF CROPS WITH DESALTED WATER. ENVIRONMENTAL CONSIDERATIONS ARE REVIEWED AND FUTURE RESEARCH PLANS ARE OUTLINED. (OALS)

GEOTHERMAL STUDIES/CALIFORNIA/MULTIPLE-PURPOSE PROJECTS/DESALINATION/WELL DATA/GEOPHYSICS/TEST WELLS/BRINE DISPOSAL/INJECTION/WATER COSTS/ELECTRIC POWER COSTS/FLASH DISTILLATION/MEMBRANE PROCESSES/ENVIRONMENTAL EFFECTS /IDENTIFIERS: /IMPERIAL VALLEY/EAST MESA FIELD/GEOTHERMAL WATER/GEOTHERMAL POWER/CHEMICAL RECOVERY/HOT BRINES/ENERGY-WATER RELATIONSHIPS/BINARY CYCLE

261

U.S. BUREAU OF RECLAMATION, DENVER, COLORADC, LOWER COLORADO REGION

1973

GEOTHERMAL RESOURCE INVESTIGATIONS, IMPERIAL VALLEY, CALIFORNIA: SPECIAL REPORT TEST WELL MESA 6-1.

SAME AS AUTHOR. 44 P.

SEE: SWRA W74-05139.

GEOTHERMAL STUDIES/WATER WELLS/THERMAL WATER/CALIFORNIA/THERMAL POWERPLANTS/ WATER YIELD/WELLS/EXPLORATION/DEEP WELLS /IDENTIFIERS: /GEOTHERMAL ENERGY/IMPERIAL VALLEY/EAST MESA FIELD/GEOTHERMAL TEST WELLS/HOT BRINES/HOT WATER SYSTEMS

262

U.S. BUREAU OF RECLAMATION, WASHINGTON, D.C.

1972

GEOTHERMAL RESOURCE INVESTIGATIONS, IMPERIAL VALLEY, CALIFORNIA: DEVELOPMENTAL CONCEPTS.

SAME AS AUTHOR. 58 P.

SEE: SWRA W73-09439.

DESALINATION/GEOTHERMAL STUDIES/CALIFORNIA/GRCUNDWATER/WATER SUPPLY/ WATER QUALITY/COSTS/WATER UTILIZATION/COLORADO RIVER/WATER RESOURCES DEVELOPMENT/BRINES/THERMAL POWERPLANTS/RESEARCH AND DEVELOPMENT/WATER IMPORTING/ELECTRIC POWER PRODUCTION/BRACKISH WATER/STEAM/WATER TRANSFER/ MULTIPLE-PURPOSE PROJECTS/BRINES /IDENTIFIERS: /IMPERIAL VALLEY/GEOTHERMAL WATER/HOT WATER SYSTEMS/ GEOTHERMAL POWER/CHEMICAL RECOVERY

263

U.S. BUREAU OF RECLAMATION, WASHINGTON, D.C.

1973

COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM.

SAME AS AUTHOR. 88 P.

SEE: SWRA W73-11264.

COLORADO RIVER BASIN/WATER QUALITY/SALINITY/IRRIGATION WATER/MINERAL WATER/ DESALINATION/WEATHER MODIFICATION/GEOTHERMAL STUDIES/SOUTHWEST U.S./ARIZONA/ CALIFORNIA /IDENTIFIERS: /CENTRAL ARIZONA PROJECT

264

U.S. CODE CONGRESSIONAL AND ADMINISTRATIVE NEWS

1970

GEOTHERMAL STEAM ACT OF 1970 (EXPLOITATION AND DEVELOPMENT OF GEOTHERMAL STEAM RESOURCES).

SAME AS AUTHOR. P. 6778-6788.

SEE: SWRA W71-06650.

THERMAL WATER/STEAM/MINERALOGY/ADMINISTRATIVE AGENCIES/LEGISLATION/THERMAL PROPERTIES/LEASES/PERMITS/FEDERAL GOVERNMENT/WATER TYPES/WELLS/DRILLING/ EXPLORATION/EXPLOITATION/MINING/CONSERVATION/ENERGY/HEAT/GASES/OIL/HELIUM/ RESOURCES DEVELOPMENT/BRINES/GEOTHERMAL STUDIES/ROYALTIES/REGULATION /IDENTIFIERS: /GEOTHERMAL STEAM ACT, 1970/GEOTHERMAL RESOURCES DEVELOPMENT/ GEOTHERMAL FLUIDS/GEOTHERMAL HEAT/CHEMICAL RECOVERY

265

U.S. CONGRESS, 89TH, 1ST SESSION

1965

GEOTHERMAL STEAM ACT OF 1965 (A BILL TO AUTHORIZE THE SECRETARY OF THE INTERIOR TO MAKE DISPOSITION OF GEOTHERMAL STEAM AND ASSOCIATED GEOTHERMAL RESOURCES).

SAME AS AUTHOR. SENATE BILL 1674. 11 P.

SEE: SWRA W72-06087.

STEAM/LEASES/FEDERAL RESERVATIONS/ADMINISTRATIVE AGENCIES/PUBLIC LANDS/ STATE JURISDICTION/EXPLOITATION/RENT/ROYALTIES/PAYMENT/LEGISLATION/LEGAL ASPECTS/FEDERAL GOVERNMENT/THERMAL POWER/WATER LAW/REGULATION /IDENTIFIERS: /GEOTHERMAL STEAM ACT, 1965/GEOTHERMAL FLUIDS/GEOTHERMAL RESOURCES DEVELOPMENT

266

U.S. DEPARTMENT OF THE INTERIOR, WASHINGTON, D.C.

1971

GEOTHERMAL LEASING PROGRAM (DRAFT ENVIRONMENTAL IMPACT STATEMENT).

SAME AS AUTHOR. 58 P. AVAILABLE NTIS AS PB-203 102-D.

SEE: SWRA W72-09044.

ENVIRONMENTAL EFFECTS/GEOTHERMAL STUDIES/WATER RESOURCES DEVELOPMENT/ GROUNDWATER RESOURCES/GROUNDWATER MINING/GEOLOGY/ENERGY/REGULATION/ LAND USE/WATER QUALITY/WASTE WATER(POLLUTION)/WATER POLLUTION/WATER POLLUTION CONTROL/WILDLIFE/LAND SUBSIDENCE/SALINE WATER/SILTING/ ALTERNATE PLANNING/THERMAL POWERPLANTS/TEST WELLS/FEDERAL GOVERNMENT/ LEASES/SURFACE WATERS/EXPLORATION/DRILLING/POWER SYSTEM OPERATION /IDENTIFIERS: /GEOTHERMAL STEAM ACT, 1970/VAPOR-DOMINATED SYSTEMS/ GEOTHERMAL RESOURCES DEVELOPMENT/HOT WATER SYSTEMS/GEOTHERMAL RESERVOIRS

267

U.S. DEPARTMENT OF THE INTERIOR, WASHINGTON, D.C.

1973 A

GEOTHERMAL LEASING PROGRAM. VOLUME 1: PROMULGATION OF LEASING AND OPERATING REGULATIONS (FINAL ENVIRONMENTAL IMPACT STATEMENT).

SAME AS AUTHOR. 519 P. AVAILABLE NTIS AS EIS-CA-73-1681-F-1.

SEE: SWRA W75-06166.

GEOTHERMAL STUDIES/WELLS/LAND SUBSIDENCE/ELECTRIC POWER/DRILLING/STEAM/ ELECTRIC POWER DEMAND/WATERSHED MANAGEMENT/BYPRODUCTS/EARTHQUAKES/CALIFORNIA/ RECREATION/TERRAIN ANALYSIS/GRAZING/FORESTRY/WASTE WATER DISPOSAL/FISH/WASTES/ WILDLIFE/SUBSIDENCE/ACCESS ROUTES/WASTE DISPOSAL/ENVIRONMENTAL EFFECTS/ROAD CONSTRUCTION /IDENTIFIERS: /ENVIRONMENTAL IMPACT STATEMENTS/CLEAR LAKE/GEYSERS/MONO LAKE/ LONG VALLEY/IMPERIAL VALLEY/GEOTHERMAL RESOURCES DEVELOPMENT

268

U.S. DEPARTMENT OF THE INTERIOR, WASHINGTON, D.C.

1973 B

GEOTHERMAL LEASING PROGRAM. VOLUME IV, APPENDIX I: COMMENTS ON DRAFT IMPACT STATEMENT AND PROPOSED REGULATIONS (FINAL ENVIROMENTAL IMPACT STATEMENT).

SAME AS AUTHOR. 728 P. AVAILABLE NTIS AS EIS-CA-73-1681-F-4.

SEE: SWRA W75-07781.

GEOTHERMAL STUDIES/WELLS/LEASES/DRILLING/STEAM/ELECTRIC POWER/ELECTRIC POWER PRODUCTION/ELECTRIC POWERPLANTS/ACCESS ROUTES/ENVIRONMENTAL EFFECTS/BYPRODUCTS/ GRAZING/WASTES/WASTE DISPOSAL/LAND SUBSIDENCE/WILDLIFE/RECREATION/EARTHQUAKES /IDENTIFIERS: /ENVIRONMENTAL IMPACT STATEMENTS/GEOTHERMAL POLLUTION/GEOTHERMAL RESOURCES DEVELOPMENT

269

U.S. DEPARTMENT OF THE INTERIOR, WASHINGTON, D.C., PANEL ON GEOTHERMAL ENERGY RESOURCES

1972

ASSESSMENT OF GEOTHERMAL ENERGY RESOURCES. REPORT PREPARED FOR THE COMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT GOALS, FEDERAL COUNCIL FOR SCIENCE AND TECHNOLOGY, SEPTEMBER 1972.

SAME AS AUTHOR. 84 P.

SEE: SWRA W73-10696.

GEOTHERMAL STUDIES/ENERGY/NATURAL RESOURCES/ASSESSMENTS/WATER SUPPLY/MINERAL WATER/ECONOMIC IMPACT/STEAM/HOT SPRINGS/ELECTRICAL STUDIES/EXPLORATION/GROUNDWATER RECHARGE/POWERPLANTS/DESALINATION/BRINES/MINING/MONITORING/ENVIRONMENTAL EFFECTS/HYDROGEN SULFIDE/DRILLING/MODEL STUDIES/OVERBURDEN/DISSOLVED SOLIDS/UNITED STATES/LEGAL ASPECTS/RESEARCH AND DEVELOPMENT/ELECTRIC POWER DEMAND
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL POWER/POWER CAPACITY/WELL STIMULATION/CHEMICAL RECOVERY

270

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, TECHNICAL INFORMATION CENTER

1975

A BIBLIOGRAPHY: GEOTHERMAL RESOURCES EXPLORATION AND EXPLOITATION.

SAME AS AUTHOR. 383 P. AVAILABLE NTIS AS TID-3354.

THIS COMPREHENSIVE (BUT NOT COMPLETE) COMPUTER-RETRIEVED BIBLIOGRAPHY CONTAINS 3890 SCIENTIFIC AND TECHNICAL REFERENCES ARRANGED CHRONOLOGICALLY UNDER BROAD SUBJECT CATEGORIES (GENERAL, RESOURCES-AVAILABILITY, SITE GEOLOGY-HYDROLOGY-METEOROLOGY, EXPLORATION, REGULATIONS, ECONOMICS, ENVIRONMENTAL ASPECTS, BY-PRODUCTS, POWERPLANTS, ENGINEERING, ENERGY UTILIZATION, AND SCIENTIFIC DATA). AUTHOR, SUBJECT, AND REPORT NUMBER INDEXES PROVIDE RAPID ACCESS TO RELEVANT ITEMS. REFERENCES CONTINUALLY ADDED TO THE DATA FILE ARE AVAILABLE ON ERDA'S ON-LINE COMPUTER RETRIEVAL SYSTEM, RECON. (OALS)

GEOTHERMAL STUDIES/BIBLIOGRAPHIES/INFORMATION RETRIEVAL/PUBLICATIONS/GEOLOGY/EXPLORATION/EXPLOITATION/HYDROLOGY/METEOROLOGY/ECONOMICS/ENVIRONMENTAL EFFECTS/LEGAL ASPECTS/POWERPLANTS/ENGINEERING/INDEXING/DOCUMENTATION
/IDENTIFIERS: /GEOTHERMAL RESOURCES

271

U.S. SENATE, COMMITTEE ON INTERIOR AND INSULAR AFFAIRS, 92D CONGRESS, 2D SESSION

1972 A

A SUPPLEMENTAL BIBLIOGRAPHY OF PUBLICATIONS ON ENERGY.

SAME AS AUTHOR. SERIAL 92-29. JULY 10. 35 P.

A LIST OF MAJOR REPORTS ON ENERGY PUBLISHED IN THE U.S. DURING THE LAST DECADE THAT SUPPLEMENTS 3 PREVIOUS BIBLIOGRAPHIES ISSUED AS COMMITTEE PRINTS (92-6, 92-7, AND 92-8). ENTRIES ARE NEWLY ACQUIRED REPORTS ISSUED BY CONGRESS AND THE EXECUTIVE BRANCH SINCE JULY 1972, AND MAJOR REPORTS ISSUED BY INDUSTRIAL GROUPS UNIVERSITIES, PRIVATE RESEARCH FOUNDATIONS, TRADE ASSOCIATIONS, CONSULTING FIRMS, BANKS, AND OTHER ORGANIZATIONS CONCERNED WITH ENERGY POLICY. SUBJECTS COVERED ARE NATIONAL ENERGY GOALS: COAL, OIL, URANIUM, GEOTHERMAL, SOLAR, AND OTHER RESOURCE BASES; PRODUCTION OF FUELS; ENERGY CONVERSION; ENVIRONMENTAL EFFECTS OF ENERGY PRODUCTION; RESEARCH AND DEVELOPMENT OF NEW ENERGY SOURCES; REGULATOR PRACTICES; AND FINANCING AND MANPOWER. ENTRIES ARE ALPHABETICAL BY AUTHOR AND ALSO BY SUBJECT.

BIBLIOGRAPHIES/ENERGY/FOSSIL FUELS/NATURAL RESOURCES/ENERGY CONVERSION/ENVIRONMENTAL EFFECTS/RESEARCH AND DEVELOPMENT
/IDENTIFIERS: /GEOTHERMAL ENERGY/SOLAR ENERGY/ALTERNATIVE ENERGY SOURCES

272

U.S. SENATE, COMMITTEE ON INTERIOR AND INSULAR AFFAIRS, 92D CONGRESS, 2D SESSION

1972 B

GEOTHERMAL ENERGY RESOURCES AND RESEARCH: HEARINGS.

U.S. GOVERNMENT PRINTING OFFICE. 465 P.

THESE HEARINGS HELD BETWEEN JUNE 15 AND JUNE 22, 1972 CONTAIN A MASS OF CONFLICTING TESTIMONY ON THE POTENTIAL OF UNITED STATES GEOTHERMAL RESERVES. OPINIONS VARY ON HOW MUCH GEOTHERMAL ENERGY CAN BE TAPPED, HOW FAST IT CAN BE TAPPED, AND HOW CLEAN THE ENERGY SOURCE WILL BE.

GEOTHERMAL STUDIES/THERMAL POWER/ENERGY CONVERSION/WATER POLLUTION/ENVIRONMENTAL EFFECTS/LAND RESOURCES/COST COMPARISONS/ECONOMIC IMPACT/SOUTHWEST U.S./ADMINISTRATIVE AGENCIES
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL POWER

273

U.S. SENATE, COMMITTEE ON INTERIOR AND INSULAR AFFAIRS, SUBCOMMITTEE ON WATER AND POWER RESOURCES, 93D CONGRESS, 1ST SESSION

1973

GEOTHERMAL RESOURCES: HEARINGS.

SAME AS AUTHOR. 771 P.

SEE: SWRA W75-01342.

GEOTHERMAL STUDIES/THERMAL PROPERTIES/THERMAL WATER/STEAM/POWERPLANTS/GEOLOGY/GEOPHYSICS/BOREHOLE GEOPHYSICS/HEAT FLOW/TEMPERATURE/THERMAL CONDUCTIVITY/LAND USE/THERMAL SPRINGS/GEYSERS/HOT SPRINGS/WATER RESOURCES DEVELOPMENT/PRESSURE/SUBSURFACE WATERS/HEATED WATER/ENVIRONMENTAL EFFECTS/ENERGY/ENERGY CONVERSION/WATER RESOURCES/IDAHO/PACIFIC NORTHWEST U.S.
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL HEAT/GEOTHERMAL RESOURCES/CONGRESSIONAL HEARINGS

274

UNIVERSITY OF ARIZONA, TUCSON

1975

GEOTHERMAL ENERGY AND ARIZONA.

ARIZONA EXECUTIVE OFFICE TECHNICAL BRIEFING NOTE 75-2. 3 P.

BRIEFLY REVIEWS TYPES OF GEOTHERMAL RESERVOIRS AND HOW THEY ARE EXPLOITED. MOST GEOTHERMAL POSSIBILITIES IN ARIZONA OCCUR IN AN EAST-WEST CORRIDOR IN THE SOUTHERN PART OF THE STATE. INTERESTINGLY, TWO FAVORABLE GEOTHERMAL LOCATIONS COINCIDE WITH THE PALO VERDE HILLS AND GILA BEND NUCLEAR POWERPLANT SITES. ENVIRONMENTAL IMPACT OF GEOTHERMAL POWER PRODUCTION IN ARID LANDS APPEARS TO BE SMALL COMPARED WITH ALTERNATIVE TECHNOLOGIES. EXCAVATION, MINING, REFINING, PROCESSING, MAJOR TRANSPORTATION CHANNELS, AND LARGE WORK-FORCE ARE NOT NEEDED. AIR AND NOISE POLLUTION ARE MINOR. BRINE DISPOSAL IS A PROBLEM IN ARID LANDS. U.S. GEOTHERMAL POWER DEVELOPMENT IS SLOW BECAUSE OF HIGH EXPLORATION RISK AND CONFUSED SOCIAL-POLITICAL FACTORS. ADDRESSES OF GEOTHERMAL EXPERTS IN ARIZONA ARE LISTED. (OALS)

GEOTHERMAL STUDIES/ARIZONA/NUCLEAR POWERPLANTS/ENVIRONMENTAL EFFECTS/ARID LANDS/AIR POLLUTION/BRINE DISPOSAL/EXPLORATION/RISKS
/IDENTIFIERS: /GEOTHERMAL ENERGY/GEOTHERMAL RESOURCES

275

UNIVERSITY OF ARIZONA, TUCSON, OFFICE OF ARID LANDS STUDIES

1973

EXPLORATION AND EXPLOITATION OF GEOTHERMAL RESOURCES IN ARID AND SEMIARID LANDS: A LITERATURE REVIEW AND SELECTED BIBLIOGRAPHY.

SAME AS AUTHOR. ARID LANDS RESOURCE INFORMATION PAPER 2. 119 P.

CONTEMPORARY TECHNIQUES FOR EXPLORATION OF GEOTHERMAL RESOURCES ARE OUTLINED, WITH PARTICULAR EMPHASIS ON THE WESTERN U.S. AS TYPICAL OF PROBLEMS ENCOUNTERED IN ARID AND SEMIARID LANDS. THESE INCLUDE FIELD RECONNAISSANCE, INFRARED AERIAL RECONNAISSANCE, PHOTOGEOLOGIC MAPPING, DRILLING, GEOCHEMICAL ANALYSES OF GROUNDWATER, APPLICATION OF FLUID DYNAMICS TO NATURAL STEAM SYSTEMS, ELECTRICAL PROSPECTING, SEISMIC, GRAVITY, AND MAGNETIC SURVEYS. ENVIRONMENTAL IMPACTS, INCLUDING NOISE, ODORS, SUBSIDENCE, AND LEGAL PROBLEMS INVOLVING DEVELOPMENTAL REGULATIONS, ARE REVIEWED. ADVANTAGES OF CHEAP POWER, MULTIPLE USE INCLUDING GREENHOUSE AGRICULTURAL PRODUCTION AND DILUTION OF PRESENT SALINE IRRIGATION WATER SOURCES, POWER FOR COOLING AND HEATING ARE DISCUSSED. A 102-ITEM COMPUTERIZED BIBLIOGRAPHY, MOST WITH FULL ABSTRACTS, IS INCLUDED, PLUS AUTHOR INDEX, AND A DETAILED COMPUTERIZED KEYWORD INDEX CONSTRUCTED FROM TERMINOLOGY APPLIED TO EACH CITATION FROM THE WATER RESOURCES SCIENTIFIC CENTER'S WATER RESOURCES THESAURUS, 2ND ED. REFERENCE IS MADE THROUGHOUT THE TEXT TO THESE CITATIONS.

COST-BENEFIT ANALYSIS/BIBLIOGRAPHIES/ENVIRONMENTAL EFFECTS/GEOTHERMAL STUDIES/THERMAL POWERPLANTS/BRINES/GREENHOUSES/EXPLORATION/SALINITY/COSTS/DESALINATION/DESIGN CRITERIA/EXPLOITATION/SURVEYS/GEOPHYSICS/GEOCHEMISTRY/REMOTE SENSING/LEGAL ASPECTS/MULTIPLE-PURPOSE PROJECTS
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL POWER

276

UYEDA, S./WATANABE, T.

1970

PRELIMINARY REPORT OF TERRESTRIAL HEAT FLOW IN THE SOUTH AMERICAN CONTINENT; DISTRIBUTION OF GEOTHERMAL GRADIENTS.

TECTONOPHYSICS 10(1-3):235-242.

THE CONTINENT OF SOUTH AMERICA HAS BEEN LEFT ALMOST ENTIRELY UNEXPLORED GEOTHERMALLY, ALTHOUGH THE WESTERN PART DISPLAYS MANY CHARACTERISTIC FEATURES OF ACTIVE HEAT FLOW AREAS. TERRESTRIAL HEAT FLOW MEASUREMENTS WERE MADE IN 20 MINES IN THE WESTERN PART OF THE CONTINENT, AND TEMPERATURE DATA WERE OBTAINED FROM OIL FIELDS ALL OVER THE CONTINENT. THERMAL GRADIENT VALUES WERE NORMAL OR SUBNORMAL OVER MOST OF THE CONTINENT. HIGH VALUES WERE CONCENTRATED IN ANDES AREA AND WERE OFTEN ASSOCIATED WITH GEOTHERMAL ACTIVITIES. LOWER VALUES WERE OBSERVED ON THE PACIFIC COAST AND ALONG THE AMAZON RIVER.

GEOTHERMAL STUDIES/SOUTH AMERICA/THERMAL PROPERTIES/EXPLORATION/HEAT FLOW/MEASUREMENT/SURVEYS/OIL FIELDS/GEOLOGIC INVESTIGATIONS
/IDENTIFIERS: /TEMPERATURE GRADIENT/ANDES

277

VALFELLS, A.

1973

HEAVY WATER PRODUCTION WITH GEOTHERMAL STEAM. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(1):896-900.

HEAVY WATER IS AN ESSENTIAL NEUTRON MODERATOR IN CONVERTER NUCLEAR REACTORS AND NATURAL URANIUM REACTORS. IT CAN BE PRODUCED IN ICELAND, USING GEOTHERMAL STEAM FOR PROCESS HEAT, AT 10 TO 15 PERCENT LESS COST THAN IN THE U.S. USING HEAT FROM NATURAL GAS OR STEAM FROM TURBINE EXHAUST. PLANT MODIFICATIONS NEEDED FOR CONVERSION TO GEOTHERMAL STEAM ARE OUTLINED AND DIAGRAMMED. IF HOT WATER FROM GEOTHERMAL WELLS IS ALSO USED, HEAT COST WILL BE HALVED. BUT SCALING IN HEAT EXCHANGERS MAY PREVENT SUCH USE. (OALS)

HEAVY WATER/GEOTHERMAL STUDIES/NUCLEAR POWERPLANTS/NUCLEAR ENERGY/HEATING/HEAT EXCHANGERS/SCALING/INDUSTRIAL PLANTS/THERMAL WATER
/IDENTIFIERS: /ENERGY SOURCES INTERFACES/INDUSTRIAL USES/GEOTHERMAL STEAM/GEOTHERMAL HEAT/ICELAND

278

WALLACE, R.H., JR.

1970

ABNORMAL PRESSURES AND POTENTIAL GEOTHERMAL RESOURCES IN THE RIO GRANDE EMBAYMENT OF TEXAS. IN SYMPOSIUM ON ABNORMAL SUBSURFACE PRESSURE, 2ND, BATON ROUGE, LOUISIANA, 1970, P. 87-116.

LOUISIANA STATE UNIVERSITY, SCHOOL OF GEOSCIENCE AND DEPARTMENT OF PETROLEUM ENGINEERING.

SEE: SWRA W72-12410.

HIGH PRESSURE/EARTH PRESSURE/WATER PRESSURE/ARTESIAN AQUIFERS/TEXAS/GEOTHERMAL STUDIES/DIAGENESIS/FAULTS(GEOLOGIC)/CLAY MINERALS/AQUICLUDES/AQUIFER CHARACTERISTICS/SEDIMENTATION/THERMAL PROPERTIES/SALINE WATER/GROUNDWATER RESOURCES
/IDENTIFIERS: /RIO GRANDE EMBAYMENT(TEXAS)/SUBSIDING SEDIMENTARY BASINS/TEMPERATURE GRADIENT/GEOPRESSURED SYSTEMS/GEOTHERMAL RESOURCES

279

WARD, P.L.

1972

MICROEARTHQUAKES: PROSPECTING TOOL AND POSSIBLE HAZARD IN THE DEVELOPMENT OF GEOTHERMAL RESOURCES.

GEOTHERMICS 1(1):3-12.

MICROEARTHQUAKES AND GEOTHERMAL ACTIVITY ARE OFTEN CLOSELY RELATED SPATIALLY. HOWEVER, EARTHQUAKES OF MAGNITUDE GREATER THAN 4.5 ARE RARE IN GEOTHERMAL AREAS. MICROEARTHQUAKES CAN BE USED TO LOCATE FAULTS WHICH CHANNEL HOT WATER UPWARD. EARTHQUAKE ACTIVITY CAN DAMAGE INDUSTRIAL STRUCTURES AND AFFECT FLOW FROM GEOTHERMAL WELLS. EARTHQUAKES, IN TURN, ARE AFFECTED BY GEOTHERMAL FLUID PRESSURE CHANGE: PRESSURE RISE FROM INJECTION INCREASES FREQUENCY OF SEISMIC ACTIVITY, AND PRESSURE DROP FROM FLUID REMOVAL MAY DECREASE NUMBER OF MICRO-EARTHQUAKES BUT INCREASE DANGER OF LARGE QUAKES. (OALS)

GEOTHERMAL STUDIES/EARTHQUAKES/SEISMIC STUDIES/FAULTS(GEOLOGIC)/ENVIRONMENTAL EFFECTS/EXPLORATION/WATER PRESSURE
/IDENTIFIERS: /MICROEARTHQUAKES

280

WARING, G.A.

1965

THERMAL SPRINGS OF THE UNITED STATES AND OTHER COUNTRIES OF THE WORLD. A SUMMARY.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 492. 383 P.

THERMAL SPRINGS ARE WIDELY DISTRIBUTED THROUGHOUT THE WORLD BUT ARE MOST NUMEROUS IN AREAS IN WHICH THERE HAS BEEN VOLCANIC ACTIVITY IN LATE GEOLOGIC TIME. A REVIEW OF THE AVAILABLE LITERATURE HAS REVEALED MUCH INFORMATION ON THE LOCATION OF THE SPRINGS, THE TEMPERATURE OF THE WATER, THE RATE OF FLOW, THE CHEMICAL CHARACTER OF THE WATER AND EVOLVED GASES, AND THE USES MADE OF THE WATER, TABULATED BY COUNTRY OR GEOGRAPHIC AREA AND PRESENTED IN THE FIRST PART OF THIS REPORT. ACCOMPANYING THE TABULATED DATA FOR EACH COUNTRY OR GEOGRAPHIC AREA IS A BRIEF DESCRIPTION OF THE GEOLOGY AND A MAP SHOWING THE LOCATION OF THE SPRINGS. THE SECOND PART OF THE REPORT CONSISTS OF A LIST OF SOME 3700 REFERENCES, SOME ANNOTATED BRIEFLY, TO THE LITERATURE ON THERMAL SPRINGS, GROUPED BY COUNTRY OR GEOGRAPHIC AREA AND WITHIN EACH GROUP ARRANGED IN ALPHABETICAL ORDER BY AUTHOR.

GEOTHERMAL STUDIES/THERMAL SPRINGS/REVIEWS/SURVEYS/BIBLIOGRAPHIES/UNITED STATES/SPATIAL DISTRIBUTION/FLOW RATES/WATER QUALITY/GASES/GEOLCGY/MAPS
/IDENTIFIERS: /WORLD/GLOBAL DISTRIBUTION/VOLCANISM

281

WARNER, M.M.

1972

GEOTHERMAL RESOURCES OF IDAHO. IN GEOTHERMAL RESOURCES COUNCIL, GEOTHERMAL OVERVIEWS OF THE WESTERN UNITED STATES, EL CENTRO CONFERENCE, 1972, PROCEEDINGS, PAPER F, 5 P.

GEOTHERMAL RESOURCES COUNCIL, DAVIS, CALIFORNIA, PUBLICATION.

SEE: SWRA W73-03425.

GEOTHERMAL STUDIES/SUBSURFACE WATERS/THERMAL POWER/IDAHO/THERMAL WATER/WATER TEMPERATURE/THERMAL PROPERTIES/HYDROGEOLOGY/GEOPHYSICS/EXPLORATION/SPATIAL DISTRIBUTION
/IDENTIFIERS: /GEOTHERMAL RESOURCES

282

WARNER, M.M.

1975

SPECIAL ASPECTS OF CENOZOIC HISTORY OF SOUTHERN IDAHO AND THEIR GEOTHERMAL IMPLICATIONS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS II-54.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

REGIONAL PLATE TECTONICS OF THE PACIFIC BASIN ARE DIRECTLY RELATED TO THESE FEATURES IN SOUTHERN IDAHO: BASIN DEVELOPMENT, FOUR MAJOR GEOTHERMAL BELTS, OVER 200 HOT SPRINGS AND WELLS, AND A LARGE LEFT LATERAL RIFT THAT COINCIDES GENERALLY WITH THE PRESENT SNAKE RIVER COURSE. THE REGIONAL SETTING, LOCAL RIFTING, CENOZOIC VOLCANISM, GRABEN DEVELOPMENT, THERMAL WATERS, MUCH FAULTING, GOOD RESERVOIR CONDITIONS, AND ABUNDANT SURFACE WATER AND GROUNDWATER SUPPLIES, ALL MAKE SOUTHERN IDAHO AN IDEAL REGION FOR GEOTHERMAL EXPLORATION.

GEOTHERMAL STUDIES/IDAHO/FAULTS(GEOLOGIC)/HOT SPRINGS/THERMAL WATER/GEOLOGY/STRUCTURAL GEOLOGY/GEOLOGIC HISTORY
/IDENTIFIERS: /GEOTHERMAL RESOURCES/GEOTHERMAL BELTS/RIFT ZONES/SNAKE RIVER VALLEY/VOLCANISM/GLOBAL TECTONICS

283

WEHLAGE, E.F.

1973

TESTS RUN ON NEW PRIME MOVER FOR GEOTHERMAL POWER GENERATION.

CONSULTING ENGINEER 41(2):128-129. EIA 73-09057.

FOR SOME REASON THE AMERICAN UTILITY INDUSTRY HAS PAID LITTLE ATTENTION TO A GEOTHERMAL FLUID PRIME MOVER THAT IS BEING TESTED BY THE MEXICAN GOVERNMENT. CALLED THE HELICAL ROTARY SCREW EXPANDER, IT HAS THE ABILITY TO ACCEPT DIRTY PRESSURIZED HOT WATER SUCH AS FOUND IN A GEOTHERMAL FIELD IN BAJA CALIFORNIA. LESS THAN A MILE FROM THE TEST SITE THE MEXICAN GOVERNMENT NOW OPERATES A 75,000 KW GEOTHERMAL GENERATOR.

GEOTHERMAL STUDIES/THERMAL POWER/ELECTRIC POWER PRODUCTION/WATER POLLUTION/MEXICO/EQUIPMENT/TURBINES
/IDENTIFIERS: /CERRO PRIETO FIELD, MEXICO/BAJA CALIFORNIA/HELICAL ROTARY SCREW EXPANDER

284

WEHLAGE, E.F.

1974 A

AN INTERNATIONAL GEOTHERMAL OVERVIEW: THE WORLD-WIDE SCENE IS WHERE THE ACTION IS....

GEOTHERMAL WORLD DIRECTORY, 1974. P. 95-112.

WHILE U.S. GEOTHERMAL DEVELOPMENT TAKES A CONSERVATIVE, ACADEMIC APPROACH (GOVERNMENT AND GIANT CORPORATE RESEARCH OVERKILL), OTHER NATIONS, LESS WEALTHY, CONTINUE RAPID PROGRESS WITH INNOVATIVE, PRACTICAL APPLICATIONS. GEOTHERMAL ACTIVITIES AROUND THE WORLD ARE SUMMARIZED WITH PHOTOGRAPHS AND BRIEF TEXT.

GEOTHERMAL STUDIES/RESEARCH AND DEVELOPMENT
/IDENTIFIERS: /WORLD/GEOTHERMAL RESOURCES DEVELOPMENT/DEVELOPING COUNTRIES

285

WEHLAGE, E.F.

1974 B

GEOTHERMAL ENERGY'S POTENTIAL FOR HEATING AND COOLING IN FOOD PROCESSING.

GEOTHERMAL ENERGY 2(12):7-14.

FOOD PROCESSING FOR STORAGE IS VITAL FOR AVOIDING FOOD SHORTAGES. GEO-HEAT (GEOTHERMAL HEAT FOR DIRECT APPLICATION BUT NOT POWER PRODUCTION), THROUGH STEAM HEATING AND ABSORPTION REFRIGERATION (DOWN TO MINUS 60 DEGREES C.), HAS POTENTIAL AS FOSSIL FUEL SUBSTITUTE FOR THIS INDUSTRY.

GEOTHERMAL STUDIES/HEATING/COOLING/FOOD PROCESSING INDUSTRY/REFRIGERATION
/IDENTIFIERS: /GEOTHERMAL HEAT/INDUSTRIAL USES

286

WEHLAGE, E.F.

1976

THE BASICS OF APPLIED GEOTHERMAL ENGINEERING.

GEOTHERMAL INFORMATION SERVICES, WEST COVINA, CALIFORNIA. 250 P.

SUMMARIZES GEOLOGICAL THERMAL PROCESSES, HISTORY OF GEOTHERMAL HEAT USE WORLDWIDE, AND BASIC PRINCIPLES OF ENGINEERING RELEVANT TO GEOTHERMAL TECHNOLOGY. TOPICS INCLUDE: MECHANICS, ELECTRICITY, HYDRAULICS, HEAT TRANSFER, STEAM PROPERTIES AND UTILIZATION, GEOTHERMAL GREENHOUSE (HYDROPONICS) AND AQUACULTURE SYSTEM DESIGN, DAIRY APPLICATIONS, POWER PRODUCTION MACHINERY, SPACE HEATING, AND REFRIGERATION. (ADAPTED FROM PRE-PUBLICATION PUBLICITY NOTICE)

GEOTHERMAL STUDIES/ENGINEERING/DESIGN/GEOLOGY/MECHANICAL ENGINEERING/ HYDRAULICS/HEAT TRANSFER/STEAM/GREENHOUSES/REFRIGERATION
/IDENTIFIERS: /INDUSTRIAL USES/GEOTHERMAL HEAT/GEOTHERMAL POWER/DAIRY INDUSTRY/SPACE HEATING

287

WEISMANTEL, G.

1973

GEOTHERMAL POWER STILL IFFY.

CHEMICAL ENGINEERING 80(6):40-42. EIA 73-03565.

GEOTHERMAL RESOURCES COULD HELP IN MEETING THE GROWING U.S. ENERGY DEMAND. A KEY PROBLEM REMAINING IN EXPLOITING THIS RESOURCE IS OUR LACK OF KNOWLEDGE OF BRINE-RESERVOIR CHARACTERISTICS. UNTIL WE HAVE MORE EXPERTISE IN HANDLING GEOTHERMAL FLUIDS THIS ENERGY SOURCE CANNOT BE SERIOUSLY CONSIDERED FOR POWER GENERATION.

GEOTHERMAL STUDIES/EXPLORATION/THERMAL POWER/ELECTRIC POWER PRODUCTION/ ENVIRONMENTAL EFFECTS/WATER POLLUTION/BRINES
/IDENTIFIERS: /GEOTHERMAL POWER/GEOTHERMAL RESERVOIRS

288

WERNER, H.H.

1973

CONTRIBUTION TO THE MINERAL EXTRACTION FROM SUPERSATURATED GEOTHERMAL BRINES, SALTON SEA AREA, CALIFORNIA. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(2):1651-1655.

SEE: SWRA W74-09040.

HYDROTHERMAL STUDIES/BRINES/CALIFORNIA/WATER CHEMISTRY/MINERAL WATER/SILVER/ THERMAL WATER/ZINC/LEAD/TIN/TITANIUM/COPPER/GOLD/BERYLLIUM/SCALING/ECONOMICS/ THERMAL POWER/GEOTHERMAL STUDIES/THERMAL SPRINGS
/IDENTIFIERS: /GEOTHERMAL POWER/SALTON SEA/CHEMICAL RECOVERY/IMPERIAL VALLEY/ HOT WATER SYSTEMS/MUD VOLCANOES

289

WERNER, S.L./OLSON, L.J.

1970

GEOTHERMAL WASTES AND THE WATER RESOURCES OF THE SALTON SEA AREA.

CALIFORNIA DEPARTMENT OF WATER RESOURCES, BULLETIN 143-7. 123 P.

SEE: SWRA W71-00356.

WATER RESOURCES/SURFACE WATERS/GROUNDWATER/GEOTHERMAL STUDIES/WASTE STORAGE/ WATER QUALITY/CHEMICAL ANALYSIS/SALINITY/TRACE ELEMENTS/RADIOCHEMICAL ANALYSIS/ HYDROLOGY/CLIMATIC DATA/STREAMFLOW/IRRIGATION/GEOLOGY/RECREATION FACILITIES/ BRINE DISPOSAL/WASTE WATER(POLLUTION)/INFLOW/IMPORTED WATER/MUD VOLCANOES/ WASTE WATER DISPOSAL/SALTS/CALIFORNIA/MAPS/INVESTMENT/BRINES
/IDENTIFIERS: /GEOTHERMAL RESOURCES DEVELOPMENT/GEOTHERMAL RESOURCES/SALTON SEA/GEOTHERMAL RESERVOIRS/IMPERIAL VALLEY

290

WHITE, D.E.

1965

GEOTHERMAL ENERGY.

U.S. GEOLOGICAL SURVEY, CIRCULAR 519. 17 P.

THERE ARE FOUR TYPES OF GEOTHERMAL SYSTEMS: AREAS OF NORMAL GEOTHERMAL GRADIENT, AREAS OF GREATER-THAN-NORMAL GEOTHERMAL GRADIENTS, HOT SPRINGS AREAS CHARACTERIZED BY CONVECTIVE HEAT MOVEMENT IN CIRCULATING WATER AND STEAM, AND COMPOSITE HYDROTHERMAL SYSTEMS INVOLVING BOTH CONVECTIVE AND CONDUCTIVE HEAT TRANSFER. STARTING WITH FIGURES FOR GLOBAL AVERAGE HEAT FLOW AND HEAT STORED ABOVE SURFACE TEMPERATURES IN THE TOP 100 KM OF THE EARTH S CRUST, AN EFFORT IS MADE, USING THE SCANTY AVAILABLE DATA, TO ESTIMATE THE TOTAL AMOUNT OF HEAT STORED IN EACH TYPE OF GEOTHERMAL SYSTEM AND TO LEAD FROM THIS TO TOTAL WORLD RESOURCES. VARIOUS DIFFICULTIES LIKELY TO BE ENCOUNTERED IN DEVELOPMENT OF GEOTHERMAL RESOURCES ARE CONSIDERED. THE STORED HEAT ESTIMATES LEAD TO THE CONCLUSION THAT EXISTING WORLDWIDE UTILIZATION EQUIVALENT TO ONE MILLION KW CAN PROBABLY BE INCREASED AT LEAST 10 TIMES AND MAINTAINED UNDER PRESENT ECONOMIC CONDITIONS FOR 50 YEARS.

GEOTHERMAL STUDIES/THERMAL PROPERTIES/HOT SPRINGS/HEAT FLOW/HEAT TRANSFER/ STEAM/HYDROTHERMAL STUDIES/ENERGY/CONVECTION/CONDUCTION/THERMAL POWER/ FORECASTING/ECONOMICS
/IDENTIFIERS: /TEMPERATURE GRADIENT/GEOTHERMAL RESOURCES/WORLD/HEAT STORAGE/ POWER CAPACITY/NORMAL TEMPERATURE GRADIENT AREAS/HYDROTHERMAL CONVECTION SYSTEMS

291

WHITE, D.E.

1969

RAPID HEAT-FLOW SURVEYING OF GEOTHERMAL AREAS, UTILIZING INDIVIDUAL SNOWFALLS AS CALORIMETERS.

JOURNAL OF GEOPHYSICAL RESEARCH 74(22):5191-5201.

SEE: SWRA W70-00201.

GEOTHERMAL STUDIES/HOT SPRINGS/SNOWFALL/HEAT FLOW/INFRARED RADIATION/MAPPING/ THERMAL PROPERTIES/MEASUREMENT/SNOWMELT/SNOW COVER/REMOTE SENSING/SURVEYS
/IDENTIFIERS: /YELLOWSTONE NATIONAL PARK/CALORIMETERS

292

WHITE, D.E.

1973

CHARACTERISTICS OF GEOTHERMAL RESOURCES. IN P. KRUGER AND C. OTTE, EDS., GEOTHERMAL ENERGY--RESOURCES, PRODUCTION, STIMULATION. SPECIAL SYMPOSIUM OF AMERICAN NUCLEAR SOCIETY, 1972, PROCEEDINGS, P. 69-94.

STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA.

SEE: SWRA W73-13218.

GEOTHERMAL STUDIES/ELECTRIC POWER/ELECTRIC POWER DEMAND/THERMAL POWERPLANTS/ ELECTRIC POWER PRODUCTION/HYDROGEOLOGY/WATER RESOURCES DEVELOPMENT/CONVECTION/ STEAM TURBINES/WELLS/HEAT TRANSFER /DESALINATION/MULTIPLE-PURPOSE PROJECTS
/IDENTIFIERS: /GEOTHERMAL POWER/POWER DEMAND/HOT-DRY ROCKS/POWER CAPACITY/ HYDROTHERMAL SYSTEMS/HOT WATER SYSTEMS/VAPOR-DOMINATED SYSTEMS/CHEMICAL RECOVERY/WELL STIMULATION

293

WHITE, D.E./MUFFLER, L.J.P./TRUESDELL, A.H.

1971

VAPOR-DOMINATED HYDROTHERMAL SYSTEMS COMPARED WITH HOT-WATER SYSTEMS.

ECONOMIC GEOLOGY 66(1):75-97.

SEE: SWRA W71-05059.

GEOTHERMAL STUDIES/THERMAL WATER/STEAM/WATER VAPOR/HYDROGEOLOGY/GROUNDWATER MOVEMENT/MASS TRANSFER/ION TRANSPORT/HEAT FLOW/WATER TEMPERATURE/GEYSERS/ WATER LEVELS/WATER TABLE/HYDROTHERMAL STUDIES/PERMEABILITY/CONDENSATION/ CONDUCTION/SURFACE TENSION/GYPSUM/CARBONATES/MERCURY
/IDENTIFIERS: /DRY STEAM FIELDS/VAPOR-DOMINATED SYSTEMS/HYDROTHERMAL SYSTEMS/ HOT WATER SYSTEMS/GEOTHERMAL FLUIDS/MINERAL DEPOSITS

294

WHITE, D.E./WILLIAMS, D.L. EDS.

1975

ASSESSMENT OF GEOTHERMAL RESOURCES OF THE UNITED STATES--1975.

U.S. GEOLOGICAL SURVEY, CIRCULAR 726. 155 P.

HEAT CONTENT AND RECOVERABLE ENERGY (WITHOUT CONSIDERING COST) ARE ESTIMATED FOR HIGH AND INTERMEDIATE TEMPERATURE HYDROTHERMAL CONVECTION SYSTEMS TO 3KM DEPTH, HOT IGNEOUS SYSTEMS (MOLTEN AND CRYSTALLIZED SYSTEMS, AND HOT MARGINS AND ROOF ROCKS) TO 10 KM DEPTH, REGIONS OF NORMAL TEMPERATURE GRADIENT TO 10 KM DEPTH, AND GEOPRESSURED-GEOTHERMAL RESERVOIRS OF GULF OF MEXICO COASTAL REGION. DISREGARDING COST, TOTAL MAGNITUDE OF ELECTRICAL ENERGY RECOVERABLE WITH CURRENT TECHNOLOGY FROM ASSESSED GEOPRESSURED SYSTEMS AND KNOWN HIGH-TEMPERATURE CONVECTIVE SYSTEMS IS ABOUT 42,000 MEGAWATT-CENTURIES (MW-C), OR 14,000 MW FOR 30 YEARS. UNDISCOVERED CONVECTIVE SYSTEMS AND OFFSHORE AND DEEP GEOPRESSURED SYSTEMS MAY HAVE POTENTIAL 100,000 MW-C (330,000 MW FOR 30 YEARS). PERHAPS HALF THIS TOTAL CAN BE RECOVERED WITH CURRENT TECHNOLOGY AT UP TO TWICE PRESENT ENERGY PRICE (50,000 MW-C OR 165,000 MW FOR 30 YEARS). (OALS) [OALS NOTE: PRESENT U.S. PER CAPITA ELECTRICITY USE IS APPROXIMATELY 1 KW, SO 1,000 MW WOULD SERVE 1 MILLION POPULATION.]

GEOTHERMAL STUDIES/UNITED STATES/ESTIMATING/COSTS/GULF COASTAL PLAIN/ TECHNOLOGY
/IDENTIFIERS: /GEOTHERMAL RESOURCES/HEAT CONTENT/GEOTHERMAL ENERGY/ HYDROTHERMAL SYSTEMS/HYDROTHERMAL CONVECTION SYSTEMS/HOT-DRY ROCKS/NORMAL TEMPERATURE GRADIENT AREAS/GEOPRESSURED SYSTEMS/WESTERN U.S./GEOTHERMAL POWER

295

WILLIAMS, D.L.

1975

EVALUATION OF SUBMARINE GEOTHERMAL RESOURCES. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND USE OF GEOTHERMAL RESOURCES, 2D, SAN FRANCISCO, 1975, ABSTRACTS I-40.

UNIVERSITY OF CALIFORNIA, BERKELEY, LAWRENCE BERKELEY LABORATORY.

TWENTY PERCENT OF EARTH'S HEAT LOSS (2 TIMES 10 TO 12TH POWER CAL/SEC) IS RELEASED THROUGH 1 PERCENT OF ITS SURFACE AREA (55,000 KM OF SPREADING OCEAN RIDGE) AS HEATED SEA WATER 2 TO 3 KM DEEP. THIS AMOUNT IS ROUGHLY EQUIVALENT TO MAN'S PRESENT GROSS ENERGY CONSUMPTION RATE. ALTHOUGH MOST OF THIS HEAT ESCAPES FAR FROM LAND, THERE ARE SOME NOTABLE EXCEPTIONS. IN GULF OF CALIFORNIA, RED SEA, AND ALONG REYKJANES RIDGE SOUTH OF ICELAND, THERMAL GRADIENTS IN BOTTOM SEDIMENTS EXCEED 1 DEGREE C./M, SUGGESTING HIGH-TEMPERATURE WATER AT SHALLOW DEPTHS. THERE IS GEOCHEMICAL EVIDENCE THAT RESERVOIR TEMPERATURES EXCEED 300 DEGREES C. AND GEOPHYSICAL EVIDENCE THAT RESERVOIRS MAY BE 3-5 KM THICK. IN COASTAL AREAS OF GULF OF CALIFORNIA, WHERE ELECTRICITY AND FRESH WATER ARE AT A PREMIUM, THIS POTENTIALLY ENORMOUS RESOURCE LIES WITHIN SIGHT OF LAND. BUT NONE OF THESE RESERVOIRS HAVE BEEN DRILLED AND LITTLE ELSE IS KNOWN OF THEIR PHYSICAL CHARACTERISTICS, SO THE EXISTENCE OF EXPLOITABLE RESOURCE REMAINS QUESTIONABLE.

GEOTHERMAL STUDIES/HEAT FLOW/SEA WATER/GEOPHYSICS/MEXICO/GEOCHEMISTRY
/IDENTIFIERS: /GEOTHERMAL RESOURCES/SPREADING CENTERS/GEOTHERMAL BELTS/ MID-OCEANIC RIDGES/VOLCANISM/GEOTHERMAL HEAT/SUBMARINE GEOTHERMAL RESOURCES/ GULF OF CALIFORNIA/RED SEA/ICELAND/REYKJANES RIDGE/TEMPERATURE GRADIENT

296

WITMER, F.P., JR.

1975

CHOOSE YOUR CYCLE TO SUIT YOUR WELL.

GEOTHERMAL ENERGY 3(2):27-37.

OPTIMUM POWER CYCLE FOR HOT BRINE RESERVOIRS DEPENDS ON WELL PRESSURE, AVAILABILITY OF COOLING WATER, AND MACHINERY COST. FOUR CYCLES (FLASHED STEAM (FS), TOTAL FLOW (TF), SIMPLE BINARY (SB), AND REGENERATIVE BINARY (RB) SYSTEMS) ARE ANALYZED AND COMPARED IN TERMS OF BRINE FLOW RATE, CONDENSER HEAT REJECTION, AND COOLING MAKE-UP WATER REQUIREMENTS. BRINE FLOW RATE RANKING (HIGHEST TO LOWEST) IS FS, SB, RB, TF. CONDENSER HEAT REJECTION RANKING IS SB-TF, RB, FS. MAKE-UP WATER NEED RANKING IS SB, RB, TF, FS. THUS BEST CYCLES FOR ARID LANDS (WHERE COOLING WATER IS SCARCE AND EXPENSIVE) MAY BE FLASHED STEAM (HIGHEST BRINE FLOW NEEDED) AND TOTAL FLOW (LOWEST BRINE FLOW NEEDED, BUT HEAT REJECTION IS HIGH). (OALS)

GEOTHERMAL STUDIES/WATER PRESSURE/WATER SUPPLY/ENERGY CONVERSION/MECHANICAL ENGINEERING/FLOW RATES/COOLING WATER/HEATING/ARID LANDS
/IDENTIFIERS: /POWERPLANTS/HOT BRINES/TOTAL FLOW/CLOSED SYSTEMS/BINARY CYCLE/VAPOR-TURBINE CYCLE/FLASHED STEAM CYCLE

297

WONG, C.M.

1973

GEOTHERMAL ENERGY AND DESALINATION: PARTNERS IN PROGRESS. IN UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS.

GEOTHERMICS, SPECIAL ISSUE 2, 2(1):892-895.

AGRICULTURAL PRODUCTIVITY OF FERTILE SOIL IN EXTREMELY ARID IMPERIAL VALLEY IS GREATLY AMPLIFIED BY IRRIGATION. THE VALLEY PROVIDES AN IDEAL MARKET FOR DESALTED WATER DERIVED FROM HOT SALINE GROUNDWATER. THIS PAPER OUTLINES GEOTHERMAL DESALINATION RESEARCH AND PLANS FOR IMPERIAL VALLEY, AS THEY EXISTED IN 1970. A PROJECT INCORPORATING 2000 TO 5000 WELLS (5000 TO 6000 FEET DEEP), PRODUCING A TOTAL OF 3.6 TO 10 MILLION ACRE-FEET PER YEAR OF FLUID, AND 20,000 MW OF ELECTRIC POWER WAS ENVISIONED. DESALTING OF HOT BRINES COULD MESH WELL WITH THIS POWER PRODUCTION. PROBLEMS OF SCALING, CORROSION, AND DISPOSAL OF CONCENTRATED BRINE AND NONCONDENSIBLE GASES MUST BE DEALT WITH. (OALS)

GEOTHERMAL STUDIES/DESALINATION WASTES/SALINE WATER/SCALING/WATER SUPPLY/AGRICULTURE/THERMAL WATER/SALINITY/GASES/GROUNDWATER RESOURCES/CORROSION/THERMAL POWER/BRINE DISPOSAL/DESALINATION
/IDENTIFIERS: /GEOTHERMAL ENERGY/EXTREMELY ARID CLIMATES/IRRIGATION WATER/IMPERIAL VALLEY/GEOTHERMAL POWER/HOT WATER SYSTEMS

298

WOOD, B.

1973

GEOTHERMAL POWER. IN H.C.H. ARMSTEAD, ED., GEOTHERMAL ENERGY: REVIEW OF RESEARCH AND DEVELOPMENT, P. 109-121.

UNESCO, PARIS. EARTH SCIENCES SERIES 12.

SUMMARIZES FIRST-GENERATION GEOTHERMAL POWERPLANT TECHNOLOGY (TURBINES, CONDENSERS, GAS EXTRACTION MACHINERY, AND BINARY CYCLES), AND ENGINEERING DECISIONS WHICH MUST BE MADE ABOUT PLANT DESIGN (CHOICE OF THERMODYNAMIC CYCLE, GENERATOR SIZE AND NUMBER, AND METHOD OF COOLING) ON THE BASIS OF STEAM PROPERTIES, WELL AND FIELD CHARACTERISTICS, COOLING WATER AVAILABILITY, AVAILABLE MACHINERY, AND ECONOMICS.

GEOTHERMAL STUDIES/ELECTRIC POWER PRODUCTION/THERMAL POWERPLANTS/STEAM TURBINES/TECHNOLOGY/CONDENSERS/ENGINEERING/THERMODYNAMICS/COOLING WATER/ECONOMICS
/IDENTIFIERS: /GEOTHERMAL POWER/BINARY CYCLE/GEOTHERMAL STEAM

299

WRIGHT, J.J.

1971

THE OCCURRENCE OF THERMAL GROUNDWATER IN THE BASIN AND RANGE PROVINCE OF ARIZONA. IN HYDROLOGY AND WATER RESOURCES IN ARIZONA AND THE SOUTHWEST, VOL. 1, P. 269-290.

AMERICAN WATER RESOURCES ASSOCIATION, ARIZONA SECTION/ARIZONA ACADEMY OF SCIENCE, HYDROLOGY SECTION, PROCEEDINGS OF THE 1971 MEETINGS, APRIL 22-23, TEMPE, ARIZONA.

SEE: SWRA W72-02229.

GEOTHERMAL STUDIES/THERMAL WATER/ARIZONA/METEORIC WATER/THERMAL PROPERTIES/WELLS/GROUNDWATER/STRUCTURAL GEOLOGY/GEOLOGIC INVESTIGATIONS/WATER QUALITY/SURVEYS/THERMAL SPRINGS/GEOLOGY/SPATIAL DISTRIBUTION/STRUCTURAL GEOLOGY/MAPS/IRRIGATION WATER
/IDENTIFIERS: /BASIN AND RANGE PROVINCE/TEMPERATURE GRADIENT

300

YUHARA, K.

1970

HEAT TRANSFER MEASUREMENT IN A GEOTHERMAL AREA.

TECTONOPHYSICS 10(1-3):19-30.

SEE: SWRA W71-09117.

GEYSERS/HEAT FLOW/HEAT TRANSFER/MASS TRANSFER/HOT SPRINGS/GEOTHERMAL STUDIES/BOILING/CONVECTION/COOLING/HEAT BALANCE/HEAT BUDGET/STEAM/CONDUCTION/EVAPORATION
/IDENTIFIERS: /JAPAN/FUMAROLES/STEAMING GROUND/VOLCANISM

AUTHOR INDEX

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KEYWORD INDEX

Numbers refer to numbered items in the Bibliography and not to page numbers