Arid Lands Resource Information Paper No. 12

SOLAR ENERGY, WATER, AND INDUSTRIAL SYSTEMS IN ARID LANDS: Technoecological Overview and Annotated Bibliography

Christophen Duffield

The University of Arizona
OFFICE OF ARID LANDS STUDIES
Tucson, Arizona 85721

ADDITIONAL PUBLICATIONS ON ARID LANDS

Office of Arid Lands Studies

Seventy-Five Years of Arid Lands Research at the University of Arizona, A Selective Bibliography, 1891-1965

Arid Lands Abstracts, no. 3 (1972)-no. 8 (1976)
Jojoba and Its Uses, An International Conference, 1972
Arid Lands Resource Information Papers,
no. 1 (1972)-no. 10 (1977)

An International Conference on the Utilization of Guayule, 1975

Application of Technology in Developing Countries (1977)
Desertification: A World Bibliography (1976)
Desertification: Process, Problems, Perspectives (1976)

Arid Lands Newsletter, no. 1, 1975- to date

University of Arizona Press (*=OALS authors):

- *Deserts of the World
- *Arid Lands in Perspective
- *Food, Fiber and the Arid Lands Coastal Deserts, Their Natural and Human Environments Polar Deserts and Modern Man
- *Arid Lands Research Institutions: A World Directory, Revised edition, 1977



Arid Lands Resource Information Paper No. 12

SOLAR ENERGY, WATER, AND INDUSTRIAL SYSTEMS IN ARID LANDS: Technoecological Overview and Annotated Bibliography

by Christopher Duffield

The University of Arizona
OFFICE OF ARID LANDS STUDIES
Tucson, Arizona 85721

The work upon which this publication is based was supported in part by funds provided by

The U.S. Department of the Interior/Office of Water Research and Technology as authorized under

The Water Resources Research Act of 1964, as amended

CONTENTS

		Page
	Foreword	i
	Preface	ii
	Abstract	iv
I.	INTRODUCTION	1
	Solar Energy Revolution and the Need for	
	New Perspective	1
	Technoecology for Broad, Synergetic Overview	2
	Goals of This Paper	3
II.	THEORETICAL FRAMEWORK	5
	Analogy Between Biological and Industrial	
	Systems	5
	Forms of Solar Energy	10
	Solar Energy in Technoecological Perspective .	14
III.	SOLAR ENERGY TECHNOECOSYSTEMS	25
	General Characteristics	25
	Energy Conversion, Form, and Function at	
	Organismic Level	27
	Geometry and Organization at Ecosystem Level .	33
	Evolution and Succession Environmental Interactions and Solar Energy	39
	Niche Limits	52
IV.	ARID LANDS, WATER, AND SOLAR ENERGY TECHNOECOSYSTEMS	59
	Adaptation to Aridity	59
	Water Processing	63
	Water Utilization	65
	Agricultural Technoecosystems	69
	Complex Technoecosystems	72
	Developing Countries	77
	Environmental Effects and Niche Limits	81
	Revord This Planet	84

V. CONCI	LUSION	. 88
	Importance of Technoecology	. 88 . 92
SUPPLEMEN	NTARY REFERENCES	. 96
BIBLIOGRA	АРНҮ	. 104
	Author Index	
	ILLUSTRATIONS	
Figures 1.	Solar energy revolution: steep decline of solar cell cost	. 46
2.	Solar energy revolution: invasion of U.S. buildings by solar heating systems	. 49
Tables 1.	Future solar cell costs compared to world GNP and world military spending	. 90

FOREWORD

The Arid Lands Resource Information Paper presented here, the tenth prepared for the Water Resources Scientific Information Center (WRSIC), was supported in part by the U. S. Department of the Interior, Office of Water Research and Technology Grant No. 14-34-0001-6254 (W-211), to the University of Arizona, Office of Arid Lands Studies, Patricia Paylore, Principal Investigator.

The National Science Foundation, over a period of several years, supported the early development of the computerized Arid Lands Information System (ALIS), a program that produced the 100-item bibliography accompanying this Paper. The abstracts were prepared by the author except for the few where users are referred to SWRA abstracts [Selected Water Resources Abstracts], accessible through any RECON terminal from the U. S. Department of Energy's Oak Ridge data bases.

While the University of Arizona, Office of Arid Lands Studies, is grateful to OWRT/WRSIC for their support in helping maintain the 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 University of Arizona

Tucson, Arizona

June 30, 1978

PREFACE

My intention in this paper is to present, not an introduction to solar energy technology in arid lands, or even a review of it, but rather a new conceptual framework within which the countless diverse details of this burgeoning field can be unified and easily comprehended. It is hoped that readers who are already familiar with solar technology will find this novel approach useful for reinterpreting their knowledge, and that readers who are new to the subject will find this a helpful guide to further explorations.

To save time and space, it is assumed that readers have a basic understanding of solar energy conversion technologies, as reviewed in summary articles (e.g., Von Hippel and Williams 1975, 1977) and general or popular books (e.g. Brinkworth 1972, Daniels 1964, Halacy 1973, and Meinel and Meinel 1976). In lieu of these sources, the annotated bibliography at the end of the paper may serve as a brief introduction to the scope of the field. It is also assumed that readers know a few very basic concepts of ecology, obtainable from any introductory or popular text.

The solar energy literature, a small and scattered body of information just a few years ago, is now grown to huge proportions, and is expanding ever more rapidly. Never again will an individual investigator be able to read it all. Each reader must choose his own path through this jungle of information, based on his own experiences, interests, and goals. Perhaps the bibliography and references accompanying this text will suggest new directions for such personal adventures.

The bibliography offers a small but typical selection from the solar energy literature. It includes mostly recent items (1975-1977), and a few important older ones. Major focus is on introductory and review publications, and specialized works dealing with arid lands and water.

For more recent publications and for specific detailed information searches, the reader is referred to semimonthly issues of <u>Selected Water Resources Abstracts</u> (SWRA), published by the Water Resources Scientific Information Center/Office of Water Research and Technology (WRSIC/OWRT) of the U. S. Department of the Interior, and to monthly issues of <u>Solar Energy Update</u>, which are supplements to <u>Solar Energy</u>: A Bibliography, published by the U. S. Energy Research and Development

Administration (now U. S. Department of Energy), Technical Information Center (1976). All information in both these massive data bases and in several others is instantly accessible for computerized searching on the RECON system of the U. S. Department of Energy.

An anecdote from personal experience illustrates part of the unique position of solar energy in United States society — its unequaled popularity and intense interest among inventors, and its consequent extremely rapid evolution. During a visit to the U. S. Patent Office, Washington, D. C., in June 1976, I discovered that stacks of solar energy patents were in such great demand by patent searchers that they were given special treatment. Solar patents, alone among all patent subclasses, were bound in books and chained to a table in the reading room. I see this as a herald of the future.

* * *

Parts of this work comprise much of a dissertation submitted in partial fulfillment of requirements for the doctoral degree in Arid Lands Resource Sciences at the University of Arizona (*Duffield 1978). ** For guidance and criticism, I am especially indebted to members of my doctoral committee: Dr. James H. Brown, Dr. William B. Bull, Dr. Laurence M. Gould, Dr. Paul S. Martin (Chairman), and Dr. Raymond M. Turner -- as well as to Dr. George Gaylord Simpson and Dr. Richard W. Reeves.

In addition to Miss Patricia Paylore, editor and friend, several staff members of the Office of Arid Lands Studies helped bring this paper to fruition: Mercy A. Valencia performed several RECON searches, Vicki Aragon entered the bibliography into computer storage for processing, and Twila Howell typed the camera-ready final copy of the text.

Solar energy researchers at the University of Arizona, Sandia Laboratories, and Los Alamos Scientific Laboratory provided tours of facilities and much information. Part-time office facilities were generously contributed by the Tucson law firm of Fish, Briney, Duffield, and Miller.

Many friends and relatives have assisted me in numberless ways. I especially want to thank Richard and Mary Rose Duffield, Gladys F. Carroll, Milton Frank, and Thomas H. and Margot A. Beeston.

CD 6/21/78

⁺⁺Portions of dissertation text Copyright 1978 by Christopher Duffield.

Selected Water Resources Abstracts

Input Transaction Form

4. Title

SOLAR ENERGY, WATER, AND INDUSTRIAL SYSTEMS IN ARID LANDS.

7. Author(s)

Duffield, C.

9. Organization

Arizona University, Tucson, Office of Arid Lands Studies

W

5. Report Date

3. Accession No.

Performing Organization Report No.

10. Project No.

11. Contract/Grant No.

14-34-0001-6254 (W-211)

Type of Report and Period Covered

15. Supplementary Notes

Arid Lands Resource Information Paper No 12. 151 p, 2 fig, 1 tab. 233 refs.

16. Abstract Technoecology, study of large complex industrial systems (technoecosystems) by analogy to biological ecosystems, is a new framework within which diverse solar technologies can be holistically comprehended and managed. Solar energy technoecosystems and sun-powered bioecosystems have many parallels at organismic and ecosystem levels. Evolution, succession, symbiosis, niches, competition, optical concentration, and other phenomena occur in both industrial and biological worlds. Solar collectors are analogous to plants in design, organization, and arid adaptations. Solar technologies for water processing (pumping, treatment, storage, conservation, desalination, evaporation) and use (solar energy collection, storage, and distribution; cooling; and heliohydroelectric and salinity gradient powerplants) are reviewed. Water scarcity makes large biomass systems (except those using desert plants, seawater irrigation, or greenhouses) impractical in arid lands. Complex symbiosis of solar and water technologies may be advantageous; technoecosystems in space are the ultimate extension of this. Large solar technoecosystems could counteract desertification and atmospheric CO2 increase. Solar technologies are vital to future survival of arid oil countries; other developing countries need them now, at appropriate scale. Photovoltaic solar cells, analogous to chloroplasts, but water independent (ideal for deserts), could be the new base of technoecosystem trophic pyramid, Impending self-accelerating solar cell cost plummet, already begun, may drive complete global succession from fossil fuel to solar energy niche in the next few decades. Sudden arrival of technoecosystem strategies and effects at global scale signals the start of a new geological age, the Technozoic. Its continuation may depend on switch to solar energy.

17a. Descriptors

*Solar energy, *Arid lands, *Technoecology, *Bibliographies.

*Water requirements, *Solar radiation, *Water utilization, Fossil fuels, Desalination, Engineering structures, Multiple purpose projects, Developing Countries, Diversity, Trophic pyramids, Ecosystems, Ecology, Solar cells, Electric power production, Niches, Environmental effects, Limiting factors, Adaptation, Evolution, Succession, Economics, Competition, Distribution patterns, Solar distillation, Greenhouses, Industrial

17c. COWRR Field & Group

Ø6B, Ø6A, Ø4C

systems, Hydroelectric power, Wind energy, Climate modification, Seawater irrigation, Evaporation, Pumping, Desert plants, Water conservation, Desertification.

18. Availability

Send to:
Water Resources Scientific Information Center
OFFICE OF WATER RESEARCH AND TECHNOLOGY
U.S. DEPARTMENT OF THE INTERIOR
Washington, D.C. 20240

Abstractor

Christopher Duffield

Institution University of Arizona

GPO 922-311

SOLAR ENERGY, WATER, AND INDUSTRIAL SYSTEMS IN ARID LANDS:

Technoecological Overview and Annotated Bibliography

I: INTRODUCTION

Solar Energy Revolution and the Need for New Perspective

A great fringing wave of solar energy technology is overtaking our civilization. It is about to crest, spill, and froth, tossing and tumbling us, purifying us, and driving us, even without our consent or comprehension, toward an unexpected and only dimly visible shore — a new age of great wealth based directly and consciously on the sun.

Even if, confused or misguided, we try to escape this wave by feeble attempts to swim elsewhere, it will still most probably plunge us surging, head over heel, inexorably shoreward. But if, instead, we take our bearings, assess the wave, and start paddling in the direction it will carry us, the transition will be easier, the exhilarating ride smoother and more graceful, and our sudden arrival on the warm golden sand less surprising.

The hot arid and semiarid lands, where sunlight is so abundant and water is scarce, will not avoid this wave. In fact, they are likely to experience its full force, the greatest tumult, the most profound changes. And they are likely to feel its surge first.

Solar energy technology has been undergoing a major revolution, manifested by rapidly accelerating growth, evolution, and diversification, since the 1973/1974 oil crisis awoke the world to fossil fuel mortality. The entire solar energy field is in a ferment, displaying aspects of a jungle or a multi-ring circus; solar research and development is in a state near anarchy. Companies large and small are joining solar industry in droves, and the state of the art is an exploding jumble of products, trade secrets, patents, corporate projects, and backyard inventions. Government research and development programs around the world (DeWinter and DeWinter 1976A) are fragmented, their strategies often resulting from personal bias, institutional history, and chance (Hammond and Metz 1977). And though the technical literature appears to be doubling every two or three years, the rate of technology expansion and diversification is already beyond the capacity of existing publication and information systems. So much is going on that "it appears to be impossible for any individual or even government to maintain an overview of the research 'frontier'" (Von Hippel and Williams 1977).

There is clearly an urgent need for new ways of thinking about solar energy technologies, new ways of seeing them, comprehending them, and predicting and guiding their impacts and evolution. A unifying viewpoint, a stable intellectual platform is needed from which to observe and manipulate diverse solar technologies large

and small. The purpose of this paper is to address this need, to offer such a holistic viewpoint, and to apply it to the specific case of solar energy in arid lands.

Technoecology for Broad, Synergetic Overview

In the midst of complexity, something simple but significant can be said about the whole solar energy field: all solar technologies, when manifest at macroscale, will form industrial ecosystems ("technoecosystems") which consciously or unconsciously imitate biological ecosystems.

A major thesis of this paper is that the best way to understand solar (or any) technology as a whole is by analogy to biological systems, the only other systems with comparable diversity of form and complexity of organization. Analogy between biological and industrial systems may be the new paradigm we seek. It may be the most powerful single thought framework for comprehending the complex structure and evolution of our industrial civilization, and for guiding it toward its solar energy destiny.

Many other writers have used aspects of this bio-techno analogy, but in its most generalized form it can be called "technoecology". The technoecological approach grows from the key observation that large, complex industrial systems look like biological ecosystems, especially from an airplane window. It turns out that they are alike in many aspects of their geometry, organization, and dynamics. The analogy is not just skin deep; it operates at all scales, from molecules to planets, offering comprehensive insights, research and invention ideas, and management strategy concepts.

In an earlier paper in this series (Duffield 1976) technoecological ideas were developed in great depth and were applied to geothermal energy technology. Many of those insights, and more are extended and applied to solar energy in this paper. Actually, technoecological overview is much more appropriate and applicable to solar technology than to geothermal. This is largely because solar energy, not geothermal, is the trophic base of essentially all biological systems, so there are many more bio-techno similarities. Furthermore, geothermal resources are quite limited and will drive only localized technoecosystems for just a short time. Solar resource magnitude, in contrast, is large enough to run all technoecosystems on this planet, and many beyond, for millions if not billions of years.

Technoecology is not just a useful idea framework. It is also an experience, a state of mind, an esthetically, intuitively, and intellectually satisfying way to perceive and appreciate the biological and industrial systems which surround us. Particularly satisfying are its https://doi.org/10.1001/journal.org/

Rather than examining discrete diverse details of solar technology in fragmented form, as most research does, technoecology gets us up out of the system; it pulls us back for a holistic, unified overview. Details are integrated like threads in a tapestry. Technoecology can help provide the "broadest possible perspective" which Bevan (*1977) calls for in designing successful large-scale technological systems and avoiding disastrous ones.

Equally important is the <u>synergetic</u> nature of technoecology: biological and technological concepts and facts, powerful when separate, are more potent still when they are interfaced. For the tuned-in mind, the solar technology literature seethes with biological similarities and implications, and vice versa. This synergy is so large and so powerful that all that can be done in this paper is to point out the connection between the two worlds, analyze a few important examples of bio-techno parallels, and throw the gate open for future work.

"In the history of sciences," Jacob (*1977) writes, "important advances often come from bridging the gaps" between isolated islands of scientific knowledge, and by recognizing "that two separate observations can be viewed from a new angle and seen to represent nothing but different facets of one phenomenon." Great rewards may await anyone who dares to bridge the gap and explore the full breadth and depth of the bio-techno analogy. Solar energy is a good place to start.

Goals of This Paper

The primary goals of this paper are four:

- to show that technoecology is a useful approach for understanding, designing, and managing solar energy powered industrial systems, and that technoecological concepts are applicable over the full ranges of time, size, and sophistication
- 2) to demonstrate that technoecology can help provide a basis for a coherent, comprehensive, successful solar energy research and development strategy
- 3) to explain why a solar based civilization may soon be upon us, and make projections, based on technoecological insights, about how it may arrive and what it may be like
- 4) and, within this technoecological framework, to examine past, present, and possible future interactions of sunlight, water, and technoecosystems in arid lands.

Examples dealing with water and arid lands aspects are used where possible throughout.

In the next chapter, the theoretical foundation for the paper is laid. In Chapter 3 some parallels between solar energy technocosystems and biological systems are examined in more detail. And in Chapter 4, solar technology in arid lands is reviewed in technocological perspective.

II. THEORETICAL FRAMEWORK

Analogy Between Biological and Industrial Systems

Before proceeding to solar energy specifics, it will be helpful to present briefly some general technoecological concepts. More extended discussions can be found in a previous paper (Duffield 1976).

Technoecological Terms

Several new words are quite useful for describing the special world of industrial systems seen from the air, and for solidifying the biological-industrial analogy explicitly and implicitly in our minds.

"Technoecosystem", or "industrial ecosystem", is the most important term. It refers to large, complex industrial systems which are analogous to (and which usually look like) biological ecosystems. Since men are small compared with these systems, even in primitive cultures, and are invisible from moderate altitudes, they have been excluded. Thus, an alternative definition for technoecosystem is a large, complex system, not including humans, which is under conscious human control. It can mean a local system or the aggregate of all such systems. Clearly, technoecosystem is an important subset of universe, dividing it physically into three components: men, technoecosystem, and environment. As in all systems, the boundaries of a technoecosystem (inward toward man, outward toward environment) are gradational when examined closely. But in practice they are defined where most obvious or useful.

"Technoecology" is the study and management of industrial systems by analogy to biological systems, especially at ecosystem level.

In integrated, efficient patterns, technoecosystems usually contain: large human-controlled natural systems (for example, managed bioecosystems and rivers); storages of energy and materials (water reservoirs, copper stockpiles, etc.); channels for energy, materials, and information (paths, highways, railroads, pipelines, telephone and power cables, etc.); numerous small, simple modules

(hammers, radios, etc); and many spatially discrete, mobile or stationary, complex industrial modules (cars, trains, airplanes, ships, houses, factories, powerplants, domesticated animals and plants, etc.). These latter modules maybe called "technoorganisms" or "technobes" for obvious reasons — they are either human-controlled bioorganisms or complicated machines that look like and behave like organisms.

Technoorganisms can be grouped, as needed, into loose sets called "technospecies", based on functional and morphological similarities of various degrees. Sometimes a system such as a farm can be viewed either as a technoecosystem at local scale or as a technoorganism within a still larger regional or global technoecosystem; the distinction depends on what is more useful in a specific situation. Technoorganisms tend to be more compact and three-dimensional, with centralized hierarchical control, while technoecosystems tend to be more scattered and two-dimensional (on planets), with decentralized control.

Technoecosystem can be seen as a cybernetic system of tools, a set of levers which interact synergetically with each other and environment to produce wealth and life support for men, who sit at the controls. It has its own self-maintaining, self-regulating, and self-augmenting metabolism of highly organized energy and material flows, and is many times larger and more massive than its human residents and operators. Technoecosystem, not "man", has the greatest impact on environment. In fact, environmental systems become technoecosystem components as they become known and managed or manipulated.

Technoecosystem and Evolution

Men and technoecosystem have always coexisted and coevolved. Human language, brain, culture, and even teeth (*Butzer 1977) have evolved under technoecosystem stimulus. Similarly, technoecosystem and technology strongly reflect, as well as mold the men who run them (*Bevan 1977).

Consider the history of technoecosystem evolution and expansion paralleling human population growth (*Butzer 1977): origin in bioecosystem; evolution of tools for bioecosystem exploitation; domestication of plants and animals, leading to agricultural intensification, urbanization, and colonization; and finally, industrialization. The trend is for acceleration: first stage took millions of years, second stage took thousands, and third has taken only a century or so. Industrialization itself has undergone accelerating growth and evolution, obvious in our own lifetimes.

Progressively we have seen technoecosystem discovering and entering new niches, new realms of macroscale and microscale environment for men to control. Rapidly, now, we are seeing the entire planet becoming a technoecosystem subset, as men explore and understand and start to manipulate atmosphere, biosphere, hydrosphere, and lithosphere, and even systems beyond this planet. To Calvin's (*1975) sequence of cosmic evolutionary events —formation of the elements (stellar evolution), chemical evolution, and biological evolution — we clearly need to add another item of comparable significance: Technoecosystem evolution.

Bio-techno Comparison

The bio-techno analogy is very close. Innumerable morphological, functional, and organizational features of the biological world are mirrored in the industrial world, and vice versa. A few such features are: evolution, adaptation of bio- and technoorganisms to environment and to each other, symbioses, succession, diversity, competition, multiple use of structures, hierarchical energy flow and concentration pyramids, hierarchical control networks, and allocation mechanisms for scarce resources. Examples of all of these will be given in later chapters. Both biological and industrial systems are open, organized systems which tend toward increasing complexity (evolution) and global expansion. The major distinguishing characteristic of industrial systems is that we men experience and control them from the inside.

Evolution of Industrial Systems

That there are so many similarities should not be surprising. Industrial systems exhibit biological patterns for several reasons: they originated as biological ecosystems; they engulf biological systems; they sometimes imitate biological systems through conscious human intent; they have similar complexity; they function in the same physical milieu (same planet); and they operate under the same physical, chemical, thermodynamic, and general systems principles. Furthermore, unlike stellar, geological, atmospheric, and hydrological systems, both industrial and biological systems contain information, abstractly coded (beyond mere existence, form, and organization), stored, and hierarchically implemented and adjusted. In bioecosystems this information is contained in DNA and nervous systems; in technoecosystems it is held and processed in mechanical information systems and human minds. In both systems it results in complex patterns of adaptation, learning, and evolution.

A detailed comparison between industrial and biological evolution is beyond the scope of this paper. In general, although the underlying mechanisms may differ, the results are often similar. Engineering design of industrial systems contrasts with genetic control in organisms; but both types of systems undergo selection by survival and relative competitive fitness criteria, particularly at community or ecosystem level, where different biospecies or technospecies interact. Technoecological evolution, based on human experience, science, and engineering thought, can be millions of times faster than biological evolution, where change can occur only by tiny increments. Conscious control can even greatly speed the adaptation process in biological technoorganisms, through breeding and now through direct genetic engineering. Individual mechanical technoecosystem modules, unlike bioorganisms, can be specially designed and unique without the necessity of a breeding population. Industrial systems can jump forward through invention, while biological systems are limited to slow discovery. Furthermore, industrial systems can evolve the way Lamarck thought biological systems do, by passing acquired characteristics on to the next generation (industrial Lamarckism).

Looked at externally, though, biological and industrial systems have comparable evolutionary results: convergence and divergence in various physical and competitive situations, extinctions, adaptation to new environments, coevolution, etc. Both types of systems undergo "a historical process full of contingency", analogous to tinkering (*Jacob 1977). This parallelism was explored by Rowland (*1968) in a study of the evolution of MG automobiles.

Each type of system, biological and industrial, has some physical capabilities that the other does not possess. However, it is clear that with guidance by human intellect, industrial outcompetes biological and is taking it over at all levels. Biological systems have complex organization down to molecular level, evolved over long periods of time; this is advantageous for macromolecular engineering of, for instance, sunlight-transforming chloroplasts. Industrial systems, on the other hand, can utilize new materials and geometries to produce much greater energy concentrations and colonize many new niches. Technoecosystem, an industrial exoskeleton under control of men, themselves bioorganisms, can be seen as life itself breaking away from biochemical and terrestrial limits.

Intellectual Roots of Technoecology

The idea that biological and industrial systems are analogous is nothing new; it is pervasive in our consciousness, our culture,

and our history. The analogy is ancient and well tested by many transfers of methods and ideas both ways, a true indication of its synergetic value.

Both biological and industrial worlds require from us the same thought patterns, the same logic and linguistic structures, and overlapping vocabularies. Biological words (e.g., "wing") are used to describe technological phenomena, and vice versa. In popular culture, cars are given animal names and airplanes have painted faces. This state of affairs can probably be traced back to early men, for whom bioecosystem was technoecosystem and biology was technology.

Biological and technological concepts have evolved hand in hand throughout the history of science and technology. It seems that men can really understand biological systems only when they can imitate and control them (*C. U. M. Smith 1976). In fact, today, as in the deep past, biology is ultimately a branch of technology, wherein practical applications for control, management, or even conscious conservation of biological systems follow soon after biological discoveries. Going the other direction, biological systems have been a wellspring of inspiration for many inventions.

Recent academic uses of bio-techno analogy include: H. T. Odum's comparative studies with energy flow dynamics as the common denominator (*Odum 1971, *Odum and Odum 1976); Rapport and Turner's (*1977) review of economic models applied to study of resource allocation in bioecosystems; the suggestion by Knowles (1974) that we should consciously model architectural and urban planning strategies after those of bioecosystems and bioorganisms; and the bionic adaptation of biological features to technological invention at organismic level (*Gerardin 1968).

The technoecological approach is clearly not a radical invention, but rather a modification, extension, and generalization of many previously fragmented efforts. Here the effort is merely to point out the bio-techno analogy in most generalized form, to outline it as a coherent thought system, and, perhaps most important, to give it a name and vocabulary. Just as the time has come to devote more effort to the study of higher levels of hierarchical biological organization (*E. P. Odum 1977), the time is also here to study higher levels of industrial organization. The two paths are parallel and complementary; technoecology needs to join bio-ecology (*Ibid.) as a central theme around which specialists from many disciplines can gather to work toward long-term human survival.

Technoecology in Action

When we say that industrial systems are similar to biological systems, we are not just being a poet playing with similes. We are implying that there is an intricate general systems homology between them, that many identical or analogous processes occur in both, that similar analytical techniques may be applied to both, and that related phenomena and concepts in one field may have counterparts, either known or yet to be invented, in the other.

Just as many branches of technological knowledge are applied to study of biological systems, each branch of biology offers a wealth of material which can yield valuable industrial inventions and insights. But of all branches of biology, bioecology is probably the synthesizing key to comprehensive understanding of industrial evolution and to generation of new, better adapted holistic management strategies.

Most bioecological terms translate into technoecological context directly or with minor modifications. The act of translation itself expands and articulates the bio-techno analogy, and suggests new ways of seeing, studying, and even modifying industrial systems. Bioecological hypotheses can be tested by observing technoecosystems from the inside. Also, bioecological models can be transferred directly to studies of industrial systems, or else bioecological principles can be rediscovered in the industrial context.

In this paper the option of passive observation of solar energy technoecosystems and direct transfer of concepts and models from several realms of bioecological investigation and theory has been chosen.

The truth is simple and obvious but has been missed by many —that what we have built and are building is and will continue to be an industrial ecosystem. Industrialists, policy makers, and energy planners would do well to supplement their economics and engineering background by studying ecology in the perspective of the bio-techno analogy.

Forms of solar energy

What union more fruitful Than a star and a planet?

Solar energy technoecosystems, by definition, are technoecosystems which maintain order and support human lives by channeling solar energy. But what is solar energy? With widened perspective we can define it more broadly than is customary.

Solar Energy in Cosmic Perspective

Our perceptions of solar energy are molded entirely by our cosmic setting, which engulfs us so completely that it is essentially invisible. In a vast universe we are unusual beings evolved in an uncommon setting — a planet orbiting a star. Everything we know and are hinges on the seemingly arbitrary nature of our circumstances: specific orbital and rotational parameters; star type and emission properties; planetary mass, chemical composition, and history; existence of atmosphere, three-phase hydrosphere (ice, water, vapor), and convecting lithosphere, etc. All these states are rare in universe; rarer still is their combination.

Most synergetic, perhaps, is the star-planet relationship itself. Planets create skies, up-down vectors, days and nights, seasons, and turbulent, gravitationally separated, spherical surface films of gas, liquid, and solid. And all these elements serve to warp and delay part of the flow of photons from star to space, simultaneously creating temporary ordered patterns.

Here, then, is the fundamental basis of what we call solar energy or stellar energy: star is hot and bright, space is cold and black, and planet is in between. Solar energy is not, as usually defined, energy from the sun. Instead solar energy is energy contrast and flow between sun and space, temporarily passing through planetary systems. Energy, particularly useful energy which creates ordered patterns, exists only by contrast. Thermodynamically, energy sink is as important as energy source, the only difference being the sign of energy flow direction, defined arbitarily by the inside-out-ness of energy quanta. Thus, in our definition, shade is a form of solar energy as much as sunlight is, but both are only in contrast to each other or to some other energy state.

Solar Energy Quality and Sun-powered Systems

The complex optical and cyclical geometric properties of solar radiation on Earth are summarized by many writers (e.g., *Robinson 1966, Brinkworth 1977, Meinel and Meinel 1976). It is diffuse and very low in energy quality, at Earth's orbit radius, if considered

and collected thermally at large-scale statistical level. But it is very high in energy quality if geometry and quantum-level properties, which encode the energy quality of the sun's surface itself, are considered. Direct sunlight is very directional and can be geometrically decoded by optical systems such as lenses and mirrors to produce high energy flux, with upper limit being the flux at the sun's surface. Solar spectrum reveals that individual photons have very high energy quality; collected at quantum level by Earth-temperature systems like chloroplasts and solar cells, they can be decoded and transformed into such high quality energy forms as electrical and chemical potential energy. Geometric and quantum decoding of solar radiation quality occur systematically only in biological and industrial systems. A third, less efficient but self-organizing decoding mechanism is found in these systems as well as in less organized physical systems: low-level thermal energy concentration by absorption and thermal emission balance.

Sellers (*1965) describes: the filtering of solar radiation through the atmosphere, governed geographically and temporally by geometric cycles of the Earth/sun gravitational system (diurnal rotation, annual revolution about the sun, and multi-millenia variations in orbital parameters); its reflection and absorption patterns in atmosphere and hydrosphere; and its ultimate emission as infrared radiation to space. Average planetary temperature and thermodynamic state is thus determined by atmospheric interactions and absorption/emission balance in relation to brightness contrast and relative solid viewing angles of sun and space.

Wherever this cyclically and geographically varying solar radiation flux occurs, it creates gradients of physical properties: temperature, density, salinity, humidity, chemical potential, electrical potential. And each of these fundamental gradients is a thermodynamic contrast which results from and mirrors the sun/space contrast, and is therefore also a form of solar energy. These gradients drive countless physical transformations and accompanying energy flows in atmosphere, hydrosphere, biosphere, and surficial lithosphere.

In all these realms, solar energy flows form self-organizing systems which in turn channel energy flows and are selected from random variation for maximum power and fitness. Hierarchical energy concentration pyramids tend to form ever smaller systems, which have more complex organization and higher energy concentration and quality, and which support themselves by controlling and harvesting less concentrated energies (*Odum 1972, *Odum and Odum 1976). The result is our highly ordered planet with its countless coevolved complex solar-powered systems.

Geothermal/Solar Energy Comparison

The only other natural energy form of any significance to our planet is geothermal energy, which flows along a similar thermal gradient, but from subsurface to atmosphere to space. While solar radiation is stellar emission energy, geothermal heat derives largely from gravitational collapse energy of supernovas, stored in radioactive elements which decay, like dying embers, in the Earth's crust. Geothermal energy flow is less than 0.0002 percent of solar radiation striking the atmosphere, but over millions and billions of years it slowly drives a similar hierarchy of energy concentration systems to produce subsurface geological order and uplift, and to interact with solar energy flows and systems in diverse and important ways. Landscapes and mineral deposits, and the atmosphere and oceans themselves, are among the symbiotic results (Duffield 1976).

Expanded Definition of Solar Energy

Now the definition of solar energy may be expanded still further. All the hierarchically concentrated energy forms and gradients which drive and are produced by complex systems, and which are based ultimately on sun/space energy contrast, are forms of solar energy. Each represents an energy contrast with some other part of the global system, and can therefore drive a further energy transformation, creating more order. Each is a fuel able to be tapped by natural or industrial systems.

This definition includes all the commonly recognized solar energy forms: direct solar radiation, wind, falling water, waves, biomass, ocean temperature gradients, and fossil fuels (oil, gas, coal, etc.). But it also includes other phenomena. As mentioned before, shade can be considered a form of solar energy. Fresh water, too, is a form of solar energy, hierarchically concentrated by atmospheric cycles and watersheds; furthermore, its energy potential relative to dry air, brines, and topographic depressions can drive physical systems. Water and oxygen are fuels for powerplants just as much as coal and oil are -- water as heat sink and oxygen as chemical potential complement, all formed by solar-powered earth cycles. Antarctic icebergs, formed of water chilled by radiation to space and distilled by atmospheric systems to extremely high purity, are a solar fuel; as heat sink and water source they help drive and modulate southern hemisphere atmospheric and oceanic systems, and can help power arid land technoecosystems. Any state of the atmosphere (temperature and humidity) is a solar energy form relative

to any other state; such contrasts result from and drive atmospheric phenomena like evaporation, wind, and storms. Hence, aridity itself can be seen as both a form and an artifact of solar energy.

Solar Energy Forms as Fossil Fuels

These are all not only solar energy forms, but also, to some degree, fossil fuels. They are all relics of solar radiation flow, some older than others. Even solar photons, freshly arrived, are fossils some 8.5 minutes old. Ultimately, of course, all forms of matter and energy, as well as the space between them, are identically-aged fossils of the "big bang" which is thought to have started universe. All order, from subatomic to intergalactic structure, consists of sequential layers of hierarchical fossilization. This noted, we may revert to traditional use of "fossil fuel" for concentrated geological deposits of reduced carbon compounds.

Bio-Techno Adaptations to Solar Energy

The influence of solar energy on the evolution of life is profound and supreme (*Wolken 1975). It is the energy base for biological systems and for most inorganic systems which form their environment. Solar radiation itself is a pervasive environmental determinant which has affected many aspects of biological systems: general form, behavior, spatial distribution, biochemistry, visual senses, energy collection, shelters, timing, etc. In the next section as well as in the rest of this paper, it will be shown that solar energy has had and will have a comparable deep and pervasive influence on the evolution of technoecosystems.

Solar Energy in Technoecological Perspective

Ultimately, all terrestrial technoecosystems are solar energy technoecosystems. Sunlight and solar-powered natural services like wind, rain, and ocean currents are by far the largest energy flows through large technoecosystems of all types; they maintain the environment to which technoecosystems (and men) are adapted and without which they would not survive. But these relatively gentle and uncontrolled natural flows are pervasive to the point of invisibility, except during severe environmental perturbations, and are ignored by traditional economic accounting methods. Instead, we tend to characterize and gauge the power of our technoecosystems by the origin and characteristics and magnitude of concentrated energy forms, like fuel and electricity, which are carefully controlled and channeled and paid for within the systems.

Solar Energy Niche

Just as animals are classed ecologically by their energy niche or source of concentrated biomass energy, so can technoecosystems be categorized. Thus, we can be said to inhabit and operate a fossil fuel technoecosystem exploiting the fossil fuel energy niche. A solar energy technoecosystem, in the more specific sense, would be a technoecosystem in which concentrated energy flows and storages are derived mostly from more direct, less delayed solar energy forms, from exploiting the solar energy niche. Such a technoecosystem might be subdivided into solar thermal electric energy technoecosystem, photovoltaic technoecosystems, biomass fuel technoecosystems, etc., each exploiting a different niche within the solar energy niche. Each niche involves appropriate technospecies, channels, and technoecosystem organization patterns for energy collection, distribution, and utilization.

Technoecosystem Evolution and Succession

Technoecosystem history can be seen as a scenario of evolution and ecological succession: a long period of solar energy niche exploitation, followed by a short, explosive, ongoing episode of fossil fuel energy niche, and a long future period of an unknown energy niche, probably solar. Looked at more closely, the past solar energy period can be viewed as a similar sequence of successional episodes, in which one more intensive and complex bioecosystem control technology replaced another in space and time.

Each replacement took place by one or both of two successional mechanisms: regressive or forced succession, in which degraded, exhausted resources, environmental change and damage, niche closing, or human population increase forced migration or technological evolution toward intensification and decreased energy yield ratio (ratio of energy yield to energy investment of equivalent energy quality [*Odum and Odum 1976]); and progressive or voluntary succession, in which invention (evolution) of new technologies or discovery of rich new resources opened new niches, increased energy yield ratio (and consequently improved competitive position), provided higher energy concentrations of military advantage, and permitted population and technoecosystem growth.

Probable examples of regressive succession are: change from hunting-gathering to agriculture, and most agricultural intensification (*Boserup 1965). Probable examples of progressive succession are: invention and adoption of weapons, tools, fire, animal transportation and power, metallurgy, sailing ships, and architecture. Both mechanisms probably worked together in the creation of large, integrated urban-agricultural technoecosystems.

Similar patterns are found in the origin and history of fossil fuel technoecosystems. Transfer of industrial burning from wood to coal occurred first in England due to forest exhaustion, largely by glassmaking industry (regressive succession), and subsequent cascading invention of improved coal processes, steam engines, etc. (progressive succession), according to Nef (*1977). In the U.S., the transfer was made by spontaneous, enthusiastic evolution and adoption of new and synergetically superior coal technologies (progressive succession), and was apparently not motivated at all by forest exhaustion (which never occurred) or even relative price difference (wood was sometimes cheaper than coal during the replacement period). Transfer from coal dependence to oil and gas was similarly motivated in the U.S., at least in part by social excitement and invention of qualitatively new processes (*Berg 1978). But in England, again, it was forced by exhaustion of coal resources.

Fossil Fuel Niche Closes; Succession Begins

Exploitation of the fossil fuel niche has brought us to where we are. It has made possible the explosive growth of an unprecedentedly large mechanical sector (cars, houses, factories, highways, etc.) in technoecosystems of industrial nations, together with the intensification of agriculture and other bioecosystem exploitation systems past the point of zero net energy yield to a state of sometimes extreme fossil fuel subsidy (*Heichel 1976). Despite accelerating population increase, technoecosystem growth, at least in rich nations, has more that kept pace, and now over a billion humans (total population in 1850) live in industrial technoecosystems with per capita annual energy consumption of 5 metric tons coal equivalent (*Handler 1975).

There is only one problem with all this: the fossil fuel energy niche is a finite nonrenewable stock niche which is closing just as the world is adjusting to it. We are running into another energy crisis in a long history of energy crises. Time after time in the past, as noted earlier, technoecosystem niches were limited in time by finite magnitude of nonrenewable stock resources (e.g., high-grade near-surface copper or coal) or by exploitation of a renewable, flow resource (e.g., game, soil, forests) at a nonrenewable, stock rate by an overpopulation of humans and technorganisms. Now we are in a similar situation: limits are becoming manifest, and succession, either progressive or regressive, must take place.

The symptoms are well known. Oil and gas production and energy yield ratio are declining in the U.S., Canada, and elsewhere (*Meyerhoff 1976), despite frenzied efforts to increase them by exploration and innovation (regressive succession). Spatial regressive succession is occurring, with temporary transfer of most fuel production to the rich oil fields of the arid Middle East. Monopoly

should be considered at most a temporary emergency measure until a permanent energy niche comes into play. The longer we wait to transfer energy systems, the larger the atmospheric CO₂ burden will be, and the larger the task of technoecosystem transformation will be.

Geothermal Resources are too Small

Geothermal energy resources are dwarfed by the enormous energy flows of industrial technoecosystems, and they are very unevenly distributed around the globe. Although they may successfully run small local technoecosystems or supplement large ones, high quality geothermal resources are likely to be exploited as a fossil fuel, at nonrenewable stock rate, resulting in net energy decrease and consequent regressive succession or possible extinction of geothermal powered technoorganism. Exploitation of deeper, lower-quality resources could result in significant very long term damage to geothermal powered geological systems. Obviously, geothermal energy is no long term base for global technoecosystems (Duffield 1976).

Nuclear Energy is Limited

Nuclear fission power is advocated by many, but it, too, is clearly not capable of powering all the world's technoecosystems. Fission power, born in a military setting, seems unlikely ever to leave it; its fuel cycle is inseparable from the options of nuclear weapon construction and proliferation, and resultant dangers of terrorism and global holocaust. Nuclear technology is inescapably gargantuan and intensively centralized, requiring technical expertise, institutional stability, and complex organization of the highest and most costly degree. Radioactive wastes must be controlled (must be part of technoecosystem) and kept isolated for thousands of centuries, an eternity compared with technoecosystem history and the brief pulse of fission power produced; but no satisfactory waste containment strategy has yet been found.

Furthermore, there is evidence that nuclear power technoecosystem is a net energy loser (*Odum and Odum 1976), meaning that it can exist only if it is embedded in and subsidized by a much larger net energy yielding technoecosystem. If so, nuclear power would be at least a parasite wasting valuable energy subsidies, and at most a way to transform fossil fuel into a possibly more convenient and secure form. Fission fuel, it turns out, is just another finite, nonrenewable, unevenly distributed fossil fuel, subject over a period of a few decades to depletion, decreasing energy yield ratio, cartel pricing, and supply uncertainties. Even if fission power techoecosystems were unlimited net energy yielders, able to fill concentrated

pricing is resulting in a simultaneous and parallel transfer of great technoecosystem wealth and control to these oil regions, corresponding to a steady stream of newly evolved supertanker technoorganisms, laden with petroleum, in the opposite direction. In developing regions without oil wealth (many are arid), efforts by industrial nations to introduce oil fueled technospecies and more intensive agricultural technologies are colliding with inexorable global oil price increase, energy yield ratio decrease, supply uncertainty, and consequent insecurity of the industrial technoecosystems themselves. At the same time, urgent, poorly coordinated, and often contradictory research and development efforts are underway around the world to retool industrial technoecosystems for temporary use of substitute fuels and to find a permanent new global technoecosystem energy base for the future, a new energy niche.

Looking for a New Global Energy Niche

Such a new energy niche must be found, or else the technoecosystem will face catastrophic supply uncertainty, vastly increased likelihood of military confrontations, chaotic regressive succession, and eventual extinction of fossil fuel powered technoorganisms, resulting in reduced human life support. Consider the energy niche options: all but solar energy appear to be evolutionary dead ends, and even solar has limits.

Fossil Fuels are Only Temporary

Any continued dependence on fossil fuels must be only for the short run, a few decades at most. Gas and oil, which will run out first, can be replaced by synthetic fuels derived from coal, oil shale, and tar sands. However, all these resources, too, are finite and nonrenewable; all are very unevenly distributed about the planet, requiring long distance transport and political stability; and all inevitably face downward trends of fuel quality, ease of recovery, and energy yield ratio. Furthermore, burning of fossil fuels irreversibly transforms ancient reduced carbon reservoirs into carbon dioxide which, released to the atmosphere, will cause climatic change of potentially great magnitude (*Kellogg 1978, *Woodwell 1978). Burning of coal, the largest resource, would have to be drastically reduced shortly after 2000 A.D. in order to keep the atmospheric CO, content from exceeding 433 ppm, 1.5 times its preindustrial concentration (*Siegenthaler and Oeschger 1978). Clearly, continued burning of fossil fuels is a slow form of suicide, and

power and fuel demands in highly centralized urban-industrial technoecosystems, they would probably never be able to supply the dispersed, low quality energy needs of rural and developing regions, where distribution costs would be prohibitive.

Similar arguments of probable net energy loss, radioactive waste and weapons dangers, over-centralization, inappropriate scale, and resource limits can be made for nuclear fusion power technoecosystems, whose technical feasibility is still highly speculative. A killing disadvantage of both fission and fusion technologies is that they are so huge that only large centralized government efforts can develop them, and that even then such large resources are required that only a few technoorganism and technoecosystem designs can be developed. There is little chance for optimization by mass production and competition between diverse designs, so effective in the biological world.

Solar Energy, the Only Viable Long-term Niche Option

There seems to be no way out of our quandary except solar energy. How fortunate we are that it appears to be such a promising energy niche option when considered by itself, but especially when compared with the other choices.

Solar energy is a vast (though finite) resource, by far the largest energy flux of our planet. It comes in many forms and is ubiquitous. Although all the forms are unevenly distributed over space and time, at least one is intermittently abundant at any location. Most solar energy forms are renewable energy storages which can, at least in theory, be depleted at greater than flow rate (e.g., biomass, ocean thermal gradients). However, the ultimate solar energy form, the energy gradient and flow between sun and space, is not depletable or even controllable, and promises to last without major change for billions of years, as it has in the past.

Most solar energy technologies, when manifest at macroscale within reasonable limits, are environmentally benign relative to the alternatives (Davidson, Grether, and Wilcox 1977). Radiation, arms proliferation, and waste disposal hazards of nuclear power technoecosystems are totally avoided. And carbon dioxide, in most cases, is either recycled or ignored, with only minor additions to or subtractions from the atmosphere. Perhaps even more important is the fabulous diversity of solar energy technologies, covering the full range of scale (pocket-size to global) and sophistication (clotheslines to chemical industries). This diversity results in great flexibility and adaptability, as well as the opportunity for mass production and design optimization by competition. Variable scale

and solar energy ubiquity make decentralized rural applications very practical.

All these positive features suggest that reconversion of global technoecosystem to solar energy niche is desirable, inevitable, and imminent. And stronger arguments will be made in following chapters. However, one must assume inevitability and imminence not only because it seems realistic, but also because, as Von Hippel and Williams (1977) point out, it is the only way directly to confront the many associated phenomena and issues.

Solar Energy Collection Strategies

There are three main solar energy collection strategies, each more intensive that the last:

- Harvest the energy storages concentrated by unmanaged natural biological and physical systems. Examples are ocean fishing and iceberg harvesting.
- 2) Control natural systems (which thereby become technoecosystem components) and harvest them. Examples are agriculture, aquiculture, and hydroelectric power.
- 3) Design and build artificial mechanical systems which directly capture and concentrate diffuse solar energy flows (wind and sunlight) and which often imitate natural biological and physical systems or use them as components. Examples are photovoltaic powerplants and solar stills.

Boundaries between these strategies are not sharp. For any one resource, depletion or increased exploitation tends to force succession toward increasing intensification, and toward increasing control of larger and less concentrated energy forms and systems.

Solar Energy Succession: Direct/fossil/direct

As outlined before, the global history of technoecosystem promises to be a three-phase technoecological succession: direct solar energy exploitation succeeded progressively by exploitation of concentrated solar energy storages (fossil fuels), succeeded regressively or perhaps progressively by direct solar energy exploitation.

Upright Trophic Pyramid of Early Technoecosystems

In the first, past solar energy stage, technoecosystem had the same pyramidal trophic structure as bioecosystems: a small, centralized intensive consumption sector powered by a large primary production sector, based largely on strategies 1 and 2 (see above), and carefully adapted to environment. Biomass production yielded most of the net energy to run the system. A few mechanical systems (wind and water mills) produced concentrated energy forms in scattered local settings.

Inverted Pyramid of Fossil Fuel Technoecosystems

In the second, present fossil fuel stage, however, the trophic pyramid is inverted. Only a few centralized mechanical modules (oil and gas wells, coal mines), comprising just a small fraction of "technomass" (techno-equivalent of biomass), are required to produce concentrated energy to run a vast, dispersed, often distant, largely mechanical consumption system. Careful adaptation of technoecosystem to environmental energy flows has not been crucial because fossil energies are so concentrated. Subsidiary biomass ecosystems, still upright-pyramidal in structure, are often highly subsidized net energy losers for producing food and materials rather than energy.

How can this largely inverted structure exist? It is actually the top of an immense, unseen, upright trophic pyramid. It is harvesting (strategy 1) the solar energies concentrated and stored by large ancient bioecosystems over vast timespans, and further concentrated by slow geological cycles. And this uniquely concentrated pyramid can be harvested only once. Our present technoecosystem is analogous to a system of predators and decomposers supported by a dwindling stock of preserved meat.

Future Solar Technoecosystems: New Base Needed

What about the future? Industrial technoecosystems must at least be maintained to support unprecedentedly large present human population. And they must be greatly expanded to raise per capita energy flow and technomass of the poor multitudes, and to provide even basic life support for the billions of newborn individuals inexorably scheduled to join us in the next few decades. Yet at the same time our energy foundation is crumbling and a new trophic base must be found. Other fossil fuels (geothermal, nuclear) may supplement fossil fuels for a short while, but eventually, and probably soon, a return to solar energy niche must be made.

Biomass and Physical systems Now too Small

We cannot turn back, however, to the scale and technologies of the solar energy niche we left behind. Our population and technoecosystem have grown supra-exponentially to immense proportions in the meantime, forcing us, as many times in the past, toward technoecosystems of new dimensions and configurations.

Intensified bioecosystem control and exploitation is possible only to a very limited and local extent. It is now a commonplace observation that most bioecosystems are already overexploited (*Holdren and Ehrlich 1974). Firewood use for small, simple industrial needs devastated the forests of 16th and 17th century England (*Berg 1978); imagine the effect of powering today's industrial technoecosystems with firewood. Modest fuel needs for cooking and heating have created the current severe firewood crisis in arid developing regions; clearly there is no wood left for industrialization. Biomass production can be increased in arid lands by supplying water, but water is a scarce and limited stock fuel, and pumping energy is required. It is costly even now to irrigate arid land and to increase crop production anywhere using rich fossil fuel subsidies; imagine how difficult it will be to switch these systems from net energy consumption to net energy production. Soil degradation in the U.S. (*Brink, Densmore, and Hill 1977) and the world (*Pimentel et al 1976) is likely to intensify as, through forced succession, demands on it increase and fuel subsidies decrease. Total net biomass production in the U.S. can supply only a fraction of its current technoecosystem energy use (Poole and Williams 1976, *Burwell 1978); and U.S. per capita fuel consumption is more than five times world per capita net primary biomass production (Duffield 1976). Clearing of rich tropical forests for fuel and agriculture is probably adding significantly to atmospheric CO, burden (*Adams, Mantovani, and Lundell 1977; *Woodwell et al 1978). And already ranges are being overgrazed and oceans overfished around the globe. This catalog of limits can go on and on. Clearly, technoecosystem and human population have outgrown and dwarfed the biomass solar energy niche of yesteryear.

If biomass can provide only a fraction of technoecosystem energy flow, where else in the solar energy niche can we turn? New technologies can be developed, or old ones extended, to mechanically harvest the concentrated fruits of, and perhaps to control, the large solar powered physical systems: ocean thermal gradients, salinity gradients, aridity gradients, gravitational potential gradients of rivers, Antarctic icebergs, etc. Yet these are all limited in size and flow magnitude. Though large, they are depletable, or at least their total flows can be captured. And large-scale exploitation can have severe effects on the natural systems which depend on them. Furthermore, large scale technologies are required and can be built

in only certain geographical settings. And technoecosystems of this type produce rather little concentrated energy relative to their size, environmental effects, and global technoecosystem needs. As in the case of biomass, these systems can help power large parts of global technoecosystem, but not all of it.

Sunlight and Wind Collectors Required: Mechanical Plant Analogues

To fill the gap between technoecosystem energy needs and the comparatively small potential of exploiting solar-powered biological and physical systems, only one exploitation strategy remains, the third one: to build artificial mechanical systems which directly collect and capture diffuse and intermittent but ubiquitous wind and solar radiation. Globally, these have the greatest potential for replacing fossil fuels as concentrated energy base for industrial technoecosystems. Wind is strong frequently and long enough to be attractive in only certain locations, so it will problably be somewhat less important than solar radiation.

Solar radiation and wind collectors are analogous to green plants, and installing and tapping them is the mechanical analogue of agriculture -- agriculture for machines. Similarly, harvesting of energy from large solar powered physical systems is the mechanical analogue of hunting or livestock management.

Future Solar Technoecosystems: Upright Pyramid Again

A whole technoecosystem can be based on concentrated energy from such mechanical systems and from managed bioecosystems. Unlike our present fossil fuel technoecosystem, it will have upright-pyramidal trophic structure -- a large solar energy producing base, carefully adapted to environment, added onto the largely energy-consuming technoecosystem sector which we already have. This is a structure which, like bioecosystems and pre-fossil-fuel technoecosystems, can survive indefinitely as long as certain niche limits are not exceeded.

It appears that technoecosystem (with its billions of human inhabitants), in order to survive, must not only engulf, control, and become the top consumer of essentially all hierarchical biological and physical energy concentration systems on this planet, but must also develop its own solar energy powered mechanical technoecosystems which imitate them. As before the fossil fuel era, most of technoecosystem and technomass, along with the people involved, will once again be carefully and consciously adapted to the demands of

harvesting solar energies from the environment. Von Hippel and Williams (1977) suggest that shifting to solar energy "might reshape our way of life at least as profoundly as did the introduction of the automobile or the products of the electronics industry," a very cautious understatement.

III. SOLAR ENERGY TECHNOECOSYSTEMS

General Characteristics

Beyond all details of form and history, solar energy technologies, when manifest at macroscale, will form and be embedded in technoecosystems. Whole technoecosystem sectors will develop for engineering, manufacturing, installing, maintaining, controlling, harvesting, and recycling large systems of solar energy converters. Small facets of individual converter design, when multiplied hundreds of millions or billions of times, will have major impact on environment and will to a large extent determine support system configurations. Multidimensional dynamic interactions will occur between solar energy producing technoecosystems, other energy producing technoecosystems, and energy consuming technoecosystems which support human lives. A whole host of ecological phenomena will occur in technoecological context: adaptation, evolution, succession, symbioses, and many others.

Convergent Evolution: Solar Collectors and Green Plants

Solar energy technoecosystems face the same environmental conditions and gradients that biological ecosystems do, and can tap many of the same energy sources. Thus it seems reasonable that solar powered industrial systems will converge unconsciously toward patterns and consciously toward strategies found in biological systems: similar geometries, "life" forms, energy conversion mechanisms, environmentally sensitive distribution gradients, and organizational patterns. Among bioecosystems and bioorganisms in separate but similar environments, convergent evolution is expected and found to be more fully developed as physical environmental variables become more important to the features involved; this is especially manifest in plants (*Orians and Solbrig 1977). We may thus expect to find that solar energy technoecosystems, very environmentally sensitive, and directly analogous to plants and plant communities, converge at all levels toward biological patterns more than do other kinds of technoecosystems. Convergence is also likely to occur, consciously or otherwise, between solar energy technoecosystems in similar environments separated by space or time.

Like sun-powered biological systems, solar energy technoecosystems require large collector areas for capturing and converting diffuse solar energy flows. And since these flows are cyclically and randomly variable and intermittent, sizeable storage systems, either centralized or decentralized, are needed, as in plants.

Due to these collector and storage requirements, solar energy technoecosystems are characterized by high energy and material (capital) costs. Fossil fuel technoecosystems, in contrast, tap energy that has already been collected and stored by natural systems; less mechanical technomass and less initial energy investment are required.

Diversity and Adaptation

As in the biological world, solar energy technoecosystems are evolving a great diversity of energy collection and conversion technologies to match the wide variety of solar energy forms. However, technoecosystems can transcend biological limitations of biochemistry and natural selection. Through breeding, biological modules can be rapidly improved. And new mechanical modules can use more parts of the solar spectrum, and can tap forms of solar energy which have previously powered only non-biological natural systems.

Because of this diversity, solar energy technoecosystems have great flexibility of design and adaptation. Like biological systems, and unlike globally homogeneous fossil fuel technoecosystems, solar energy technoecosystems will vary regionally and locally according to environmental conditions and technoecosystem energy needs (Von Hippel and Williams 1977). Plant geography will have many parallels in solar energy technoecosystem geography.

Complex Synergetic Organization

As in biological and physical systems (*Odum and Odum 1976, *Odum 1972), solar powered industrial systems will develop energy concentration and control hierarchies at organism and ecosystem levels. Solar collector modules will need to be more efficient than plants in order to repay large manufacturing and support costs and yield net energy. It is likely that many synergies between solar technologies, and between them and their support and utilization modules, will be discovered, as in biological systems (Von Hippel and Williams 1977). Energy quality cascading (both up and down), hybrids, symbioses, and multiple uses of structures are already found in many existing and proposed solar energy systems at various scales. Close integration of energy production and consumption sectors is favored because of solar energy's ubiquity. solar energy technoecosystems will be decentralized and will tend to appropriately match scale of technology and quality of energy to the ultimate energy use (*Lovins 1977). These are all patterns found in biological systems.

Energy Conservation Desirable

Since solar energy collection systems are so costly, energy conservation will be an important element of technoecosystem conversion to solar base (Von Hippel and Williams 1977). Combined with lifestyle change toward less intensive energy use, energy conservation is the most benign and cheapest energy alternative available in current industrialized technoecosystems (*Stein 1977, Ross and Williams 1976), and can be accomplished without significantly affecting human well-being (*Johnson, Stoltzfus, and Craumer 1977; *Boffey 1977; *Schipper and Lichtenberg 1976). And if such a policy is pursued, conversion from fossil fuel to solar energy niche promises to be much less traumatic. Energy conservation is nothing new; it is an important aspect of survival strategy in many organisms.

More detailed bio-techno comparisons are made in the rest of this chapter.

Energy Conversion, Form, and Function at Organismic Level

A whole book could be written comparing solar energy related adaptations in technoorganisms and bioorganisms; only a few high-lights can be presented here. Examples of technological adaptations are quite concentrated in the solar energy technology literature, whereas references to biological responses are scattered throughout the vast literature of biology.

Techoorganisms, like bioorganisms, are adapted to many forms of solar energy in countless ways. Some forms are to be collected, others to be resisted, still others just to be flowed with. Solar radiation is the main focus here; water adaptations will be discussed in more detail in chapter 4.

Technoorganism/Bioorganism Comparison

Technoorganisms which collect solar radiation are analogous to plants if their chief function is to collect solar radiation, to animals if solar radiation collection is indirect or only a minor function. Like bioorganisms, technooganisms consist of specialized materials and modules compactly and systematically arranged in configurations consciously or unconsciously optimized for survival and maximum fitness in a multidimensional, variable environment. Technoorganisms, like bioorganisms, manifest in their structure a long history of evolution and competition, and the sum of their relationships, past and present, with each other, with physical environment, and with surrounding ecosystems.

Technoorganisms are adapted to the same solar radiation phenomena that bioorganisms are, and are developing numerous similar configurations, behaviors, and energy conversion systems, either coincidentally or by design. The literature is filled with diverse technological designs and concepts for solar energy collection, concentration, conversion, transfer, and storage systems. Many are directly analogous to biological systems; other go far beyond biological limits but are still analogous in their organization and function. Diverse specialized materials with solar energy roles in bioorganisms appear in similar roles in technoorganisms: transparent materials, thermal transfer and insulation materials; specular and diffuse reflectors; selective absorbers, emitters and transmitters; semiconductors; photosensitive dyes; lubricants; thermal storage and transfer fluids; rigid and elastic structural materials, etc.

In bioorganisms, photosynthetic systems have the same origin and molecular basis as light sensors (*Wolken 1975). Similarly, in technoorganisms, photovoltaic cells are used for both energy collection and light sensing/information gathering.

Hybrids and Multiple Functions

Like animals and plants, which use both solar thermal and biochemical energy, hybrid technoorganisms can interface solar energy with other energy sources. Examples are natural gas/solar water heating systems (*Davis 1975), fossil fuel/solar powerplants (Zoschak and Wu 1975), and geothermal/solar powerplants (Finlayson and Kammer 1975).

Technoorganism structures often serve multiple functions, a pattern common in bioorganisms. For instance: solar thermal collectors can be used for both heating and cooling of houses (De Winter and De Winter 1976B); solar power farm panels might support both light collectors and waste heat rejection pipes (Meinel and Meinel 1975); and the collector tower of a central receiver/heliostat system could double as a smokestack in a fossil fuel/solar energy hybrid powerplant (Zoschak and Wu 1975).

Plants as Technoorganisms

Many comparisons can be drawn between solar radiation concentration and collection systems of biological and industrial organisms. The analogy is most direct, of course, when the technoorganisms being considered are also bioorganisms. Plants are self-forming, self-maintaining, highly sophisticated solar-power systems which can produce

useful chemicals, materials, and fuels. The ancient art of breeding them can be considered a form of technoorganism engineering. Complex plant engineering, now progressing to microscale cellular and molecular levels, is becoming faster and more powerful through techniques like DNA recombination, protoplast fusion, chloroplast transplantation, and cell culture selection (Calvin 1976, *Bassham 1977, *Day 1977, *Evans and Barber 1977). At macroscale, systems of canals, irrigated fields, and drains are analogous to plant leaves with cells served by dendritic veins. Similarly, greenhouse protection and nurture of plants is analogous to the relationship between plant leaves and cells, cells and chloroplasts, and atmosphere and biosphere.

Solar Cells: Industrial Chloroplasts

In biochemical structures of chloroplasts, plants capture solar radiation in the form of discrete quanta, and efficiently decode its high energy quality to produce molecules with concentrated chemical energy. In the industrial world, chloroplast counterparts are various types of artificial quantum collector modules, or solar cells. Solar cell research and development is proceeding rapidly in many directions, exploring many different chemistries, geometries, optical configurations, and fabrication methods (*Johnston 1977, *Kelly 1978, Hammond 1977B, Wolf 1976). Some basic solar cell types are: photochemical and photoelectrolytic cells (produce high quality chemical fuels, usually hydrogen and oxygen from water dissociation); photogalvanic cells (self-contained photochemical cells which generate electricity); and photovoltaic cells (solid-state cells using semiconductors to produce electric power). Of these, photovoltaic cells are the only cells yet developed to the point of practical, commercial application.

Photochemical cells are most closely analogous to biological systems. They have the advantage, exploited by plants, of producing fuel which can be stored to bridge gaps between fluctuating energy demand and sunlight supply. And in many cases, photochemical research parallels research in photosynthesis. Calvin (1976) seeks to produce artificial membranes which imitate those in chloroplasts. But successful membranes may not only mimic but also transcend the limits of photosynthetic membranes (*Tien 1976, Broda 1976).

Solar cells of all types are like chloroplasts in more ways than just structure and function; they are integrated into larger systems in the same manner. Individual cells, each consisting of numerous subcells, are assembled into panels, and the panels into still larger assemblies, much as plant cells, containing numerous multi-layered chloroplasts, form leaves and then plants. And at all

levels of integration, hierarchical dendritic channels, like vascular systems in plants, are required for distributing and collecting chemical reactants or electric charges. Like a meadow, a large field of chlorophyll-based photochemical cells would probably be green.

Both solar cells and plant cells can operate in solitary form. Solar cell powered watches or radios are analogous to algae. As in plants, solar cell assemblies can drive decentralized modules of any size larger than this minimum.

Just as photosynthesis is modified and optimized in plants (*Solbrig and Orians 1977), solar cells and modules can be complexly optimized for various applications, environments, and niche strategies (*Johnston 1977). Various photosynthetic pigments and pathways in plants are directly analogous to various semiconductor materials and configurations available in photovoltaic cells.

Optical Concentration Systems

A wide range of optical concentration is possible in technoorganism design, from simple flat plate collectors to solar furnaces using elaborate lens or mirror systems to reach very high temperatures. Concentrating collector designs in the solar energy technical and patent literature manifest an exuberance of materials, forms, and sun-tracking strategies which is reminiscent of the endless variety found in biological designs. Most solar radiation collectors in the biological world are flat-plate collectors; concentration is usually by photon conversion or thermal absorption rather than by optical means. Nevertheless, a few examples of biological optical concentrators do exist. Lenses occur most often as decoders of information, rather than energy quality, in animal visual systems. However, convex transparent cell shapes focus dim sunlight onto chloroplasts in a moss (Schistotega osmundacea) and a few other plants which are adapted to deep shade (*Schimper 1903, p. 62-63). Mirrors seem to be very rare in biological systems. The moss just mentioned uses reflectors to further concentrate lens-focused light. And two coldadapted plant species, Dryas integrifolia and Papaver radicatum, have flowers shaped like parabolic dish reflectors which accurately track the sun and serve to warm the pollinating insects which bask in them (*Kevan 1975).

Cooling and Heating; Active and Passive

Active and passive thermal energy collection and radiation systems in biological and industrial worlds have many similarities.

In both worlds, cooling is favored by high albedo selective radiators and heating by low albedo selective absorbers; biological examples are the highly reflective fur of the red kangaroo (*Dawson 1972) and the dark coloring of insects which forage early in the morning (* Mares 1977). Active heat collection, distribution, and exchange systems in technoorganisms use dendritic and counter current geometries found also in dolphin fins (*Schmidt-Nielsen 1970), rabbit ears (*Hill and Veghte 1976), dinosaur fins (*Farlow, Thompson, and Rosner 1976), and bees (*Heinrich 1977). Large but compactly packaged heat exchangers in ocean thermal gradient powerplants are energetically analogous to gills.

Thermodynamic Cycles

Thermodynamic cycles are common in non-living systems and solar-powered technoorganisms, but rare in bioorganisms. This is probably because the first unicellular bioorganisms were too small to collect thermal energy; and once photochemical conversion and trophic pyramids developed, lower-quality thermal energy was relegated to secondary, non-metabolic, thermoregulatory roles in larger bioorganisms. Evaporative cooling is the major non-biochemical thermodynamic transformation utilized in bioorganisms, and is also quite common in technoorganisms.

Solar-powered thermodynamic engines have countless design and cycle possibilities within the constraints of environmental gradients, properties of materials, and cost. In most cases they imitate non-living natural systems. Heat engines, heat pumps, and stills replicate various atmospheric phenomena in miniature. And ocean thermal powerplants and atmospheric convection towers imitate and tap the same vertical thermodynamic gradients as ocean currents and storms. Thermochemical reactions have geochemical but not biological counterparts.

Hybrid Energy Conversion

Just as a single bioorganism collects and uses several solar energy forms, each in several ways (e.g., sunlight for photochemistry and thermoregulation, wind for thermoregulation and transportation), so can technoorganisms be hybrid systems. Two or more solar energy conversion systems can coexist or substitute for one another, as in a house with passive and active solar heating with firewood or fossil fuel back-up, or an ocean thermal powerplant combined with wind generators and biomass conversion systems (Hagen 1975). Several systems can be combined into one conversion system, as in hybrid photochemical/thermoelectric electrolysis (*Ohta et al 1976). Such

combinations often involve hierarchical sequential upgrading of energy quality (upward cascading), as in central receiver-heliostat power systems (optical, thermodynamic, then electrical concentration [Hildebrandt and Vant-Hull 1977]), ocean thermal plants in which solar collectors raise temperature of warm water to increase thermodynamic conversion efficiency (Othmer 1976), and solar thermal powered biomass conversion systems (optical concentration, then thermochemical reaction [Antal 1976]). Finally, a single solar energy form can be split and used sequentially, often with downward cascading of energy quality; an example is the use of solar radiation for illumination, photovoltaic electricity, and heat (Duguay 1977).

Adaptation by Siting and Behavior

Technoorganisms, like bioorganisms, are often passively adapted, by morphology and location, to environmental energy states and flows. Plant leaf or cactus pad size, shape, orientation, and albedo variations can provide passive thermoregulation (*Solbrig and Orians 1977, *Gibbs and Patten 1970), as does orientation and shape of large termite nests. Similarly, building technoorganisms can be thermoregulated passively by varying shape, orientation, materials, and size (Bliss 1976), as in ancient Pueblo Bonito (Knowles 1974), and by adding such passive appendages as shading devices (Olgyay and Olgyay 1957) and wind towers (*Bahadori 1978). Plant zoning is extremely sensitive to microclimate, especially sunlight, shade, wind, and thermal stratification. Similar patterns are found in the siting of cliff dwellings (Knowles 1974), shelters of the Basuto (*Fuggle 1971), and energy efficient modern houses (Bliss 1976).

Complex environmentally adaptive behavior is also characteristic of both technoorganisms and bioorganisms. Complex animal thermoregulatory behaviors like basking, shade seeking, nocturnal activity, burrowing, body orientation and position changes, panting, and sweating all have parallels in technoorganisms: sun tracking solar collectors; movable, retractable solar collectors, shades, and insulators; cars parked in shade or sun; solar collection fluid drained into tanks at night to minimize heat loss (Dickinson et al 1976) -- analogous to curling up; and active evaporative cooling systems. Biological clocks for appropriate diurnal and annual sun-related behavior modulation in plants and animals are replaced in technoecosystems by sun-watching, sundials, and calendars based on alignments of the sun with architectural or landscape features (*Reyman 1976; *Stencel, Gifford, and Morón 1976).

Mobile technoorganisms require such high power density for locomotion that they are most likely to obtain concentrated energy from large-area communities of stationary solar energy collecting technoorganisms, much as animals derive their energy from plants.

Exceptions include windpowered sailboats and sailplanes, analogous to soaring birds, and proposed solar cell powered dirigibles (Solar Energy Digest, May, 1977, 8(5):7), analogous to the flagellumdriven photosynthetic protozoan *Euglena*.

Geometry and Organization at Ecosystem Level

The literature of bioecology offers a preview of the amazing diversity of systems and phenomena which can and may be found at ecosystem level of organization in solar energy technoecosystems of past, present, and future. Out of a vast field of ecological topics, the focus here is on spatial and organizational patterns and relationships which develop consciously or unconsciously among technoecosystem components. The next section covers evolutionary and successional dynamics of these patterns and relationships.

Geographic Zonation Patterns

Biogeographic patterns of plant zonation are a pervasive and obvious feature of our biosphere at regional and local scale. These patterns result largely from spatial variation of solar energy forms (sunlight, rainfall, evaporation, wind) and other environmental conditions (temperature, soil, hydrology, geology, etc.), interfaced with the narrow range of adaptability of each plant form (*Solbrig and Orians 1977). Other influences include mutualistic, competitive, and predatory interactions between plant forms, between plants and animals, and between plants and technoecosystems, as well as complex histories of evolution and succession.

Similar zonation occurs in solar energy technoecosystems for analogous reasons. Regional variations in availability and quality of solar energy forms (direct or diffuse sunlight, wind, running water, biomass, ocean thermal gradients, etc.) result in global diversity of regionally specialized solar energy technoecosystems (Von Hippel and Williams 1977). Regional and local gradations in other environmental conditions impose further constraints and pressures for system zonation. Water availability, a very important variable in this context, will be discussed in the next chapter.

At any location, however, environmental conditions allow many possible technoecosystem designs to exist or even coexist, much as very different bioecosystems can occur in similar arid environments and diverse plant life forms coexist in one desert community (*Solbrig and Orians 1977). Thus we may expect each locality to develop a unique symbiotic mix of solar energy technologies determined not only by environmental conditions, but also by complex evolutionary and

successional interactions between solar energy technoecosystems and bioecosystems, natural physical systems (environmental effects, resource depletion), other technoecosystems (including energy demands and available technologies), and other solar energy technoecosystems.

On global scale, some solar energy technoecosystem zones may be coextensive with plant zones: intensive biomass systems with tropical rainforests, and intensive solar cell and solar thermal power systems with deserts. Analogous patterns are found at local scale; influence of topographic shade on settlement patterns and distribution of forest and pasture in the Alps (*Garnett 1935) reflects similar influence on natural plant communities (*Duffield 1975).

Interactions, Mutualistic and Competitive

Competitive and mutualistic interactions are common between solar energy technoecosystems or technoorganisms and other systems, natural or industrial. Predator-prey interactions often characterize relationships between technoecosystems and natural systems, but seem to have become rarer in relationships between technoecosystems, replaced by tax redistribution and import-export flows.

Hybrid and Complex Technoecosystems

Mutualistic interactions at ecosystem level in solar energy technoecosystems reflect those found among components at organismic level. As in the biological world, they serve to lower system costs and increase fitness. Solar technoorganisms can coexist. Or they can form hybrid systems with each other or with other energy technoorganisms. Homogeneous solar hybrid technoecosystems include those with multiple solar inputs (e.g., solar thermal/hydroelectric powerplants [Pollard 1976A]), those with multiple outputs (e.g., total energy communities which run on solar power, space heating, hot water, and air conditioning [Harrigan 1975]), and those with both (e.g., ocean farms which use biomass, direct solar, wind, and wave energies to produce food, fuel, and materials [Wilcox 1976]). Heterogeneous hybrid technoecosystems (solar and other energy) include complex systems which produce power, distill water, and recover salts using geothermal/solar power cycles and solar evaporation ponds (Duffield 1976).

Hierarchical energy cascading is common in technoecosystems, as in bioecosystems, and occurs in both directions: upward to higher

energy quality (e.g., biomass harvesting and refining systems [Antal 1976]), and downward to lower quality (e.g., solar total energy communities). Upward cascading is usually found in production systems, and downward cascading in consumption systems, although they can coexist.

Symbiosis

Mutualistic interactions between technoecosystems and technoorganisms often tend to intensify to a state of symbiosis, as in lichens. And with spatial convergence, and often with miniaturization, distinct symbiotic components can become so closely intertwined that their union can be considered a single technoorganism. symbiosis turns an ecosystem into an organism. This symbiotic trend is seen throughout solar energy technology. Energy production and consumption technoecosystem sectors are drawn closer together when solar energy becomes the source (Von Hippel and Williams 1977). Separate agricultural systems for food, plant material, and biomass fuel production become more closely integrated for adaptability and increased profit (*Lipinsky 1978). Communities are drawn together to share centralized total energy systems (Meinel and Meinel 1975, Harrigan 1975). Small-scale food and energy systems are complexly interfaced, with materials recycling, in self-sufficient housing systems (Loewer et al 1977, Rosenbaum et al 1975). And, in the extreme case envisioned by Soleri (*1969), entire urban-industrialagricultural systems, usually occurring as thin two-dimensional membranes, are packed (or imploded) into "arcologies", macroscale three-dimensional solar-powered technoorganisms.

Biological symbioses show us the variety of symbiotic relation-ships which may appear in technological systems. A common mode is engulfing symbiosis (or invading symbiosis, if seen in reverse perspective), in which one bioorganism engulfs, protects, supports, and benefits from a smaller one. Examples include nitrogen-fixing bacteria in leguminous plants, cellulose-digesting bacteria in ruminants, and symbiotic algae in various animals, such as giant clams (*Yonge 1975). Gradual control and assimilation of biological and physical natural systems by technoecosystem can be considered a form of engulfing symbiosis.

Probably the most successful biological example of engulfing-invading symbiosis is the hypothesized origin of eukaryotic cells, those with distinct specialized organelles (*Schwartz and Dayhoff 1978). More than a billion years ago, free-living aerobic bacteria and then free-living blue-green algae invaded a proto-eukaryotic host, and subsequently evolved into mitochondria and chloroplasts, specialized metabolic and photosynthetic organelles which are now inseparable, even genetically, from the host. Modern animal and plant cells are the symbiotic result.

In technoecosystems today we are witnessing at all levels the industrial equivalent of this ancient phenomenon. Calculators, watches, and radios are being invaded by solar cells; buildings by solar water and space heaters; farms by solar powered water pumps; and cities by greenhouses and solar total energy systems. Origin of eukaryotic cells set the stage for a billion-year explosion of organismic and ecological evolution. We may expect analogous developments, although much faster, in technoecosystems as they become symbiotically integrated with newly evolved solar energy converters.

Concentrated Energy Forms

Relationships between producer and consumer components of a solar energy technoecosystem can be extended over long distances and time by concentrated energy forms such as electricity and chemical fuels. Rather than predation we have opposite flows of concentrated energy and money. With any concentrated energy form and availability of necessary materials, there is essentially no limit to what can be done through a suitable chain of energy conversions and materials transformations. Thus processes and products of a whole industrial technoecosystem could be based on hydrogen derived from many solar energy sources (Bockris 1975, *Bamberger and Braunstein 1975), or on fuels and chemicals derived from biomass production and wastes (Pollard 1976B, Poole and Williams 1976, *Sarkanen 1976, *Goldstein 1975, Calvin 1976). It is likely that several such systems will coexist and interface synergetically, as in technoecosystems of today which use coal, oil, gas, and electricity. Much as carnivores exploit many guilds of herbivores, some of which exploit many different plants, so can technoecosystems run on several fuels, each derived from many solar energy forms.

Concentrated energy forms and their appropriate transmission channels make possible technoecosystem exploitation of distant solar energy resources, such as persistent high velocity winds in poleward southern latitudes (Bockris 1975) or constant unfiltered solar radiation in space (Glaser 1976). They also make possible increased energy supply stability through interconnection of dispersed solar energy converters, such as windmills, all of which experience different time fluctuations of energy flow (Sørensen 1976, Von Hippel and Williams 1977). Both of these patterns are found in biological systems.

Spatial Patterns, Vertical and Horizontal

Relationships between technoecosystem components are often manifest in spatial patterns reminiscent of those in bioecosystems. When vertical zoning occurs, solar energy production systems are usually above consumption systems (e.g., solar collectors on roofs). Horizontal zoning often consists of centripetal-centrifugal patterns within larger grids, as in approximately hexagonal hunting and foraging territories of animals, or market territories in economic systems. Grids of windmills (Sørensen 1976) or ocean thermal powerplants should be spaced far enough to avoid interferences but near enough for reasonable energy collection cost. Biomass refineries are likely to be established on a grid, each in the center of its own biomass waste production territory (Antal 1976). Energy intensive industries will probably be drawn to ideal solar energy locations (Von Hippel and Williams 1977), forming centers in fields of dispersed collectors or circles around concentrated energy distribution points.

Competition

Numerous competitive phenomena, analogous to those in bioecosystems, can be found in solar energy technoecosystems. For example, solar radiation collectors can compete for light much as plants do (*Horn 1971). Rooftop solar panels compete with shade trees for a view of the sun, as do solar collectors on adjacent lots (*Eisenstadt and Utton 1976). Similarly, high-rise buildings compete with adjacent beaches for sunlight exposure (*Puerto Rico Planning Board 1969). Optimum sunlight zoning rights-of-way are a complex function of latitude and topography (which determine shadow trajectories [*Duffield 1975]), cloudiness, and collector type.

Solar energy technoecosystems also compete, on a larger scale, for space, materials, investment capital, and output markets. Thus, biomass fuel systems must compete with food, feed, and fiber industries for area and biomass residues, and with alternative fuel systems for capital and markets. Intense international competition between greenhouse and field crops (Dalrymple 1973) may be a preview of future competition between solar energy fuel systems. Already, in the field of solar heating systems for houses, hundreds of component and system designs are competing for capital, markets, and federal grants on the basis of countless petty details which improve efficiency, durability, cost, or convenience.

Competition between solar energy systems and other industrial systems is even more complicated and multidimensional, involving social, economic, and political dynamics at many scales. Much as urban

expansion and highway construction compete with agriculture for areas with good soil and climate (*Brink, Densmore, and Hill 1977), solar energy collectors may compete with agricultural and urban systems for space, water, and investment capital.

Simplistically, solar energy systems would compete with other energy systems on the basis of energy yield ratio (energy output per energy input of equal quality). However, this ratio is usually difficult to determine, and practical competition depends largely on economic criteria -- energy output per unit money cost. Energy comparisons can thus be warped by economic subsidies and taxes. Odum and Odum (*1976) claim that mechanical solar energy technologies are inherently net energy losers, although calculations by others (e.g., Hildebrandt and Vant-Hull 1977) indicate the reverse. And solar energy costs are certain to fall considerably with further innovation and mass production, becoming ever more competitive with rising fossil fuel costs. Even when switching from fossil fuel to solar energy systems involves apparent energy or money sacrifice, it may be undertaken anyway for increased fitness in the form of independence, security, and enjoyment (Shurcliff 1976). Such trading of energy cost for supply certainty is a common strategy in biological systems.

Large Centralized Versus Small Decentralized Systems

A controversy is raging over whether solar energy collection and conversion systems should be large and centralized, or small and decentralized. Most U.S. government funded research and development now focuses on large, centralized solar energy utilities for producing electricity and some fuels. This policy has been called into question on general principles (*Lovins 1977, Hammond and Metz 1977, Von Hippel and Williams 1977), and for several specific technologies: photovoltaic power (Hammond 1977B), ocean thermal power (Metz 1977A), solar thermal energy (Metz 1977B, Metz 1977C, Caputo 1977), and wind power (Metz 1977D).

Arguments against large centralized solar energy systems parallel some against nuclear energy systems: inappropriate scale (especially for rural and developing regions), high transmission and distribution costs (about 70 percent of total cost [*Lovins 1977]), unnecessarily centralized energy control, uncertain net energy yield, and very slow and costly evolution of just a few rather inflexible prototypes, with little opportunity for optimization by mass production and competition.

On the other hand, many solar energy forms seem to naturally favor dispersed, decentralized, small and medium scale solar energy systems. Such systems avoid energy transmission and distribution costs, are ideally suited for rural and developing regions, and encourage

popular involvement. They offer the advantages of: great flexibility of design, complex hybrids and symbioses, modular growth and size flexibility, mass production, fabulous diversity, and intense competition. They also result in a more reliable, less vulnerable, more redundant energy system.

All these arguments have biological counterparts. Solar powered bioecosystems have both centralized and decentralized solar energy conversion phenomena, but are in general mostly decentralized at ecosystem level. We may expect a similar pattern in mature solar energy technoecosystems.

Small Decentralized Systems More Likely to Succeed

The attempt to centralize solar power may be seen as a last-ditch effort by established interests to maintain the inverted pyramidal energy structure of present industrial technoecosystems. However, solar energy, unlike fossil fuels, is ubiquitous and easily tapped. It cannot be monopolized and distributed to energy consuming technoecosystems solely through a small, carefully controlled, inverted apex. The apex will be bypassed and short-circuited as production and consumption systems synergetically combine.

The bulk of government research and development funds may continue to be misdirected toward large-scale, centralized solar energy "dinosaurs". But regardless, very rapid spontaneous evolution, diversification, manufacture, and propagation of small dispersed solar energy modules and systems by a burgeoning new industry has already begun. And this trend promises to eventually (perhaps soon) transcend, overwhelm, and engulf the century-old centralized tradition.

Evolution and Succession

In essence, technological evolution is the invention and discovery of new niches, technologies, and possibilities, while technoecological succession is the dynamic manifestation of these possibilities as actualities in real macroscale technoecosystems. The two processes are dynamically interlinked. Forced or regressive succession closes old niches, forces technoecosystem into new niches, and thus stimulates the evolution of new technologies and forms. Evolution of new technologies and forms, on the other hand, opens new niches and paves the way for voluntary or progressive succession.

Both processes are involved in the switch of technoecosystems from fossil fuel to solar energy base. In biological systems succession takes place over much shorter periods (weeks to decades)

than evolution (thousands to millions of years). In technoecosystems, however, both processes occur in comparable time scales, and their relative rates may even be reversed. For example, solar technologies are evolving faster (months to years) than they can proliferate (years to decades).

Technoecosystems may provide a new laboratory for biologists to experimentally test their hypotheses about evolutionary and successional processes in biological systems, and even to search for new hypotheses. Many such biological phenomena have parallels in industrial systems. And industrial systems have the unique advantage that men within them can tell us what is going on, or at least what they think is going on. Biological and industrial succession rates are comparable. But industrial evolution is millions of times faster than biological evolution, and thus affords a valuable opportunity for paleontologists and paleoecologists to observe evolutionary processes in rich detail. Similarly, theories and concepts about evolution and succession which biologists have developed can be used to observe and understand analogous processes in industrial systems.

History of solar energy technoecosystems seems quite familiar if considered in the perspective of the history of life. We see diversity and populations exploding as new niches open up and are discovered, a great variety of forms developing which are adapted to different physical environments, succession of organisms over short time spans and of ecosystems over long ones, extinction of forms which can no longer survive under new physical or competitive conditions, progressive engulfment of advantageous symbiotic systems, and so on.

As in paleoecology (*Laporte 1977), assemblages of solar energy technoorganisms can be characterized by their time in history, geographic location, and environment. Technospecies lists can be made, and compared over time. Diversity can be quantified. Population dynamics can be charted. And age structure (for instance, of solar cells deployed) can be analyzed.

Convergent and Divergent Evolution

Convergent and divergent evolution at organism and ecosystem level can be observed in solar energy technoecosystems. Complex patterns of convergent evolution hypothesized in biological systems (*Orians and Solbrig 1977) may be found in detailed studies of the industrial world. Solar energy technoecosystems, widely separated in time, and composed of entirely different technospecies, may still have the same general ecosystem configurations and comparable niches,

a pattern which Laporte (*1977) observes in marine fossil assemblages of the Devonian and Ordovician. Also, we are likely to observe coevolution of solar energy producing and consuming technoorganisms, much as we do in communities of plants and herbivores or planktonic grazers and algae (*Porter 1977).

Niche Opening and Partitioning

Rapidly increasing diversity and populations of solar energy modules of a single type, exemplified by photovoltaic solar cells (*Kelly 1978) or active-type house heating systems (Shurcliff 1976), are characteristic of the opening of a new niche. Within each field, competition occurs in many dimensions, and we are likely to see a partitioning of this multidimensional niche space, as we do in biological communities. As a result, rather than a continuous spectrum of module designs, we will probably wind up with several distinct specialized types, each separated from the next by what in biological systems is called limiting similarity. Patterns of niche overlap may also occur, leading to competition and evolution when selection pressures intensify (*Weins 1977).

Multiple Centers of Evolution

As in biological systems, there are many local, partly isolated centers of intense evolutionary ferment (e.g., government and industrial laboratories, or the spontaneous subculture of solar house development in New Mexico). New solar energy technospecies developed in one center may spread and compete with those developed in others, or they may be contained by geographical or cultural barriers. Thus patterns of endemism as well as regional or global invasion may occur at organism and ecosystem level. Technoorganisms from many sources will come together, interface, coevolve, compete, and interact in creative, unpredictable ways, much as bioorganisms do in bioecosystems. As in bioecosystems, technospecies arrival history may be an important determinant of ultimate technoecosystem configuration, as early arrivals mold the environment for later ones.

Evolution by Engineering and Natural Selection

Two main evolutionary processes are at work in solar energy technoecosystems: engineering and natural selection. In the first, niches are predicted and systems are intentionally designed to fill them. In the second, niches become obvious, are discovered, through

success of the best adapted systems and failure of the others. The engineering process is careful, disciplined, intensely conscious, while natural selection is spontaneous, out of control, and often unconscious. Results of engineering are analogous to species level strategies and results of natural selection to community level patterns studied by ecologists (*Orians and Solbrig 1977). Both processes work together; each spurs the other on. Engineering dominates at small-scale, individual module, or technoorganism level, and natural selection dominates at macroscale technoecosystem level. No matter how carefully engineers design systems at any scale, their plans are inevitably modified and selected by interactions with other systems at the same scale and by phenomena of still larger natural and industrial systems which form the operating environment.

Out of infinite possibilities, solar energy technoecosystems will manifest only finite actualities. The patterns which prevail will be determined by complex history of engineering and natural selection interactions. These two processes operate hierarchically. Engineered systems are thrown to the environment, then re-engineered on the basis of their performance. And interactions between engineered systems, and between them and environment, are observed and become the basis for new engineering on the larger scale. Often, symbioses are first observed, then engineered. Unconscious patterns are perceived and progressively replaced by conscious strategies.

Invention and engineering of solar technologies are progressing extremely rapidly, though deliberately, on a proliferating profusion of specialized fronts. But at large scale, as in the biological world, solar energy technoecosystem evolution has a life of its own; it is out of control. Any current attempt by government or industry to understand, predict, control, and engineer exactly what will happen at macroscale ecosystem level is probably doomed to failure. We know that ecological patterns will form, but what exactly they may be is beyond our knowing. Each solar technology may interact at any time with any other technology in competition or symbiosis to produce new synergetic surprises. Thus, perhaps, systems engineering of macroscale solar energy technoecosystems should proceed only when large evolutionary patterns have become obvious, only when the systems are fairly well understood.

In the meantime, the most successful research and development strategy may be "to 'let a thousand flowers bloom' and then cultivate the most promising varieties" (Von Hippel and Williams 1977). That is, we should engineer for small and medium scale diversity, and let ecological phenomena select the best adapted forms and determine their optimum large-scale technoecosystem configurations. Such a process is the mechanical equivalent of horticultural selection, and is directly analogous to biological and ecological evolution.

Technoecological Succession: Fossil Fuel to Solar Energy Base

Patterns of technoecological succession will be apparent both in the conversion of technoecosystem from fossil fuel to solar energy base, and in the subsequent history of solar energy technoecosystems. Fossil fuel to solar energy conversion is likely to be more dramatic; it has already begun, and its trends are already clear.

As stated earlier, this switch of energy basis is likely to be both a forced and a voluntary succession. Fossil fuel costs are increasing as supplies diminish, resulting in supply uncertainty and general energy yield ratio decrease. Transfer to solar energy, driven by and resulting in increased costs and reduced wealth, is forced or regressive succession. On the other hand, new solar energy technologies are being evolved, efficiency is increasing, and costs are dropping with competition and mass production. In some cases, solar technologies are already more profitable than fossil fuel alternatives. Transfer to such solar energy technologies, in order to reduce costs and increase fitness and wealth, is voluntary or progressive succession.

Both forced and voluntary successional trends can be found in technoecosystems today, and their continuation in the future is easy to foresee. In many cases, fossil fuel cost increase and solar energy cost decrease coincide, and succession is a compound phenomema. Transfer from fossil fuel to solar technologies occurs, ideally, when their costs are equal. However, it can occur before equivalency is reached, when solar is more expensive, in order to attain immediate or anticipated political, esthetic, or security goals. And it can be delayed until afterward, when solar is cheaper, if social barriers or slow industry growth rates intervene.

In any case, succession from fossil fuel to solar energy base in technoecosystems is a sequential process operating at local to global scales along spatial, environmental, and economic gradients. Most costly, subsidized, marginal, peripheral fuel uses make the transfer first, followed by progressively cheaper, larger, more centrally important fuel uses; ultimately the entire technoecosystem is solar based. For instance, photovoltaic solar cells have long been favored over fuels for small remote unmanned technoecosystem installations like buoys and radio relay stations. Now they are cheaper than fuel systems for small-scale power in rural settlements, and are rapidly approaching competitive cost level for electricity in capital cities of developing regions (*Kelly 1978), and for powering remote military bases and electrochemical plants (Hammond 1977B); urban and industrial power markets would be the next step in market capture. A second example is that biomass fuels will probably be produced on a large scale in the tropics, and last in

areas where coal is available (Pollard 1976B). And a third example is that active-type solar thermal collectors, on houses of any one socio-economic group, tend to be used first for hot water heating and then for space heating, more costly per unit of benefit.

The energy transition from fossil fuel to solar will involve intermediate mixed-energy hybrid steps. Sørensen (1976) predicts such a wind power succession: windmills which supplement fossil fuel power systems are succeeded by windmill systems with energy storage which can progressively replace fossil fuel systems altogether. Any replacement of traditional power systems by centralized solar power systems would be likely to follow this same gradient of decreasing fossil system cost and increasing solar system cost: peak load, then intermediate load, and finally base load. Agricultural systems are likely to evolve from food and material production toward some fuel production. Such successional hybridization is already taking place in the motor fuel industry of Brazil; a progressively larger fraction of ethanol derived from sugarcane is being mixed into the gasoline supply (*Hammond 1977A).

Several other patterns are likely to accompany the energy transition. Decreasing energy yield ratio of fossil fuel systems, which coincides with and helps drive the switch to solar, is accompanied by: inflationary economic tendencies (*Odum and Odum 1976); shift of energy flows, technomass, and other wealth from energy consuming inward sector of technoecosystem to energy producing outward sector; lifestyle change toward lower energy intensiveness; and adaptation of housing, automotive, and other technoorganisms to conserve energy (Ross and Williams 1976). Not only are new technoecosystems and technoorganisms built to run on solar energy, but, even more important in the short run, old ones are augmented, adapted, and modified. Finally, as predicted and proposed by Lovins (*1977), the switch to solar energy basis will most likely, and most beneficially, involve successional transition from mostly centralized energy systems to mostly decentralized hybrid energy systems which match quality of energy source to that of final energy use.

Photovoltaic Solar Cells: Ideal Fossil Fuel Replacement

Photovoltaic solar cells may be the most promising of all solar technologies for ultimate replacement of fossil fuels as concentrated technoecosystem energy base. They offer high conversion efficiency and energy quality, as well as great simplicity, durability, and design flexibility. Furthermore, they are well suited to mass production, they can be adapted to many environments and uses, they operate

efficiently even with cloudy skies, and they require no water as evaporative heat sink in their flat plate configuration. The only limits to their widespread use are the currently high cost and the small size of the solar cell manufacturing industry. However, both of these barriers are progressively falling away, so solar cells present an ideal example of fossil fuel to solar energy succession.

Total Replacement of Fossil Fuels by Solar Cells: An Impending Revolution

Total replacement of fossil fuels by photovoltaic cells is no longer an idle fantasy. Nor can it be relegated to some distant decade in the next century, as many people have tried to do. The transition, already begun, but at such a small scale that it is almost invisible, could be well underway and almost cataclysmic in magnitude within only 10 to 15 years.

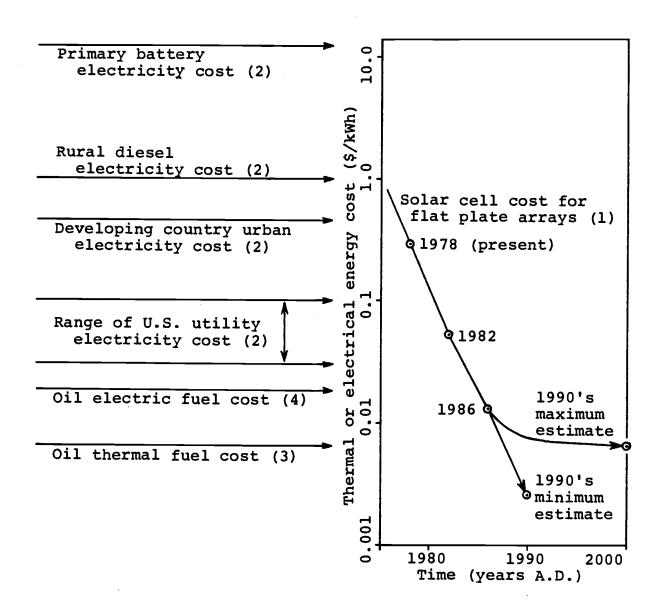
A rough comparison of fuel costs and solar cell cost goals supports this startling conclusion (Fig. 1). Present fuel cost of energy derived from oil is approximately \$0.0065 per kilowatt-hour (kWh) of thermal energy and \$0.019 per kWh of electrical energy (kWhe) [assuming \$11.00 per barrel of oil, 1.46 x 10^9 calories per barrel of oil, and 35 percent efficient thermal to electric conversion].

Correspondingly, solar cell flat plate array cost, for large orders, is now about \$11.00 per peak watt electric (Wpe), and future costs, as projected by the U.S. Department of Energy, should drop to \$2.00/Wpe by 1982, \$0.50/Wpe by 1986, and \$0.10 to \$0.30/Wpe in the 1990's (*Kelly 1978). Assuming a solar cell lifetime of 20 years, and average daily output of 5.3 kWhe from a 1000 Wpe array (*Brown and Howe 1978), these solar cell costs translate to: \$0.28/kWhe at present, \$0.052/kWhe by 1982, \$0.013/kWhe by 1986, and \$0.0026 to \$0.0077/kWhe in the 1990's.

These numbers and Fig. 1 indicate that solar cell power may become competitive with electricity from oil between 1982 and 1986, and competitive with thermal energy from oil sometime in the 1990's. Although the calculation is very crude, ignoring many important factors (e.g., oil-fired powerplant cost, solar cell installation and support system cost, probable oil price increases, and possible increased solar cell lifetime), its implications are staggering.

Consider the events implied by this projected history of solar cell cost decline. Solar cells at present are net energy losers, used in a few small-scale fossil fuel subsidized roles. Downward cost trend will decrease this subsidy, reaching the break-even point

Fig. 1. Solar energy revolution: steep decline of solar cell cost



Notes:

- (1) Data points, derived from Kelly(*1978), represent U.S. Department of Energy estimates. Curve splits to show high and low cost estimates for the 1990's. Assume 20 year solar cell lifetime, and 5.3 kWhe average daily output from a 1.0 kWe (peak) solar cell array.
- (2) Approximate present costs of electricity from various sources (*Hammond 1977B), for comparison with solar cell cost estimates.
- (3) Assume \$11.00 per barrel of oil, and 1.4×10^9 calories per barrel of oil.
- (4) Same as (3), and assume thermal to electric conversion efficiency of 35 percent.

by 1982, only four years from now; thereafter, solar cells will be self supporting, capable of yielding energy profit, of being a technoecosystem's concentrated energy base. Decreasing cost will rapidly expand the range of solar cell applications; photovoltaic power will progressively become competitively superior to rural power systems and then urban-industrial power systems fueled by fission, coal, and finally oil and gas, by 1986, only eight years hence. From then on, powerplants will be obsolete almost everywhere on the planet. Another few years, and oil itself, at 1978 prices, will be obsolete as a source of energy (actually, oil price hikes and supply disruptions are very likely before the 1990's). It will then be only a matter of time, probably not many years, for technoecosystem succession from fossil fuel to solar energy base to reach completion.

Continued decline of solar cell cost (a possibility, since the physically bounded lower limit is unknown) might fuel a technoecosystem boom equal to or surpassing the expansion we have had with cheap petroleum. However, in such a case, limits other than energy cost would eventually, and probably soon, become apparent.

Reviewers of photovoltaic technology mention this impending cost plummet with cool optimism verging on nonchalance. Yet we are dealing with the potential for a global technoecosystem energy revolution of unprecedented magnitude and speed, which could take us by storm in the next few years, and which has already been set into motion.

The storm may strike even faster than we expect. Market expansion with decreasing cost, and cost decrease with mass production are a pair of mutually reinforcing relationships which tend to form a self-enhancing feedback system. There may be a threshhold solar cell cost below which resistance to industry expansion will drop away, leading to supra-exponential growth of solar cell production, huge investments in manufacturing facilities, continued price decline and market expansion, and massively funded research for still better solar cell systems.

Other Solar Technologies: Similar Potential but Less Explosive

Solar cells are used here only as the most dramatic example; they have by far the greatest potential of any solar technology for precipitous cost decline. However, other solar technologies do appear to have possibilities for similar, though much less explosive, accelerating proliferation in the near term, once certain thresholds of production rate and cost reduction are passed. Wind power systems

in some locations are at or very near the point of competition with fossil fuel power systems (Metz 1977D, Sørensen 1976), as may be central receiver-heliostat solar thermal power systems, according to some estimates (Hildebrandt and Vant-Hull 1977).

Exponential Growth of Solar Heating and Cooling: Total U.S. Transfer by 1989?

Solar heating and cooling systems for houses may be slightly more advanced than solar cells in their invasion of technoecosystems, although the potential for cost reduction and consequent acceleration is not nearly so great. There were approximately 300 solar heated buildings in the U.S. in 1976 (Von Hippel and Williams 1977), and it has been estimated that there will be 2.5 million by 1985 (Hammond and Metz 1977). If we assume an exponential growth function, these figures imply a doubling time of only 8.3 months, somewhat faster than the 12 month doubling time actually experienced from 1973 to 1976 (Von Hippel and Williams 1977). Exponential growth has the property of being almost invisible at first and then very obvious later on, when populations are very large and yet still doubling at the same rate. The explosiveness of the predicted 8.3 month doubling time becomes apparent when it is projected beyond 1985 (Fig. 2). In less than five years, by late 1989, only seven more doublings bring the number of solar heated buildings from 2.5 million to 320 million, more than one per person. Presumably the industry would stabilize and growth would cease before that time. Yet frenzied as such a transition might be, proliferation of solar cells promises to be even swifter and more tumultuous.

Perhaps other writers are so casual about this imminent solar energy revolution because its implications are vast beyond their experience and comprehension. Only technoecological overview can give us an observation point solid and distant enough to forsee what may happen. Only examples from biological systems, and from past biological and technological revolutions viewed in fast-motion retrospect, can give us an inkling of the multitude of phenomena which may come to pass.

Solar Cell Revolution Analogous to Invention and Proliferation of Chloroplasts

Probably the best analogy to a solar cell revolution is the "invention" of chloroplasts and its aftermath. Photosynthetic mechanisms evolved and were incorporated as chlorplasts in eukaryotic cells more than a billion years ago (*Schwartz and Dayhoff 1978). The consequences for the planet have been immense -- evolution of diverse plants, animals, and ecosystems, and transformation of geo-

chemical cycles to the regime we know today, including an atmosphere with oxygen (*Cloud 1974). A billion years ago, who could have predicted the systems we have today? Similarly, it is impossible to foretell the precise consequences of the evolution of cheap solar cells, which are chloroplast analogues. We can only say that succession will happen, with solar cell-bearing systems coming into dominance, and with energy consuming technospecies evolving to harvest their energy output (animal analogues harvesting plant analogues). This new evolutionary succession of solar energy technoecosystems, like the ancient one of solar energy bioecosystems, may involve significant adjustments of planetary energy flows and geochemical cycles. But whereas the biological scenario has taken a billion years, its industrial counterpart will take place on a scale of decades.

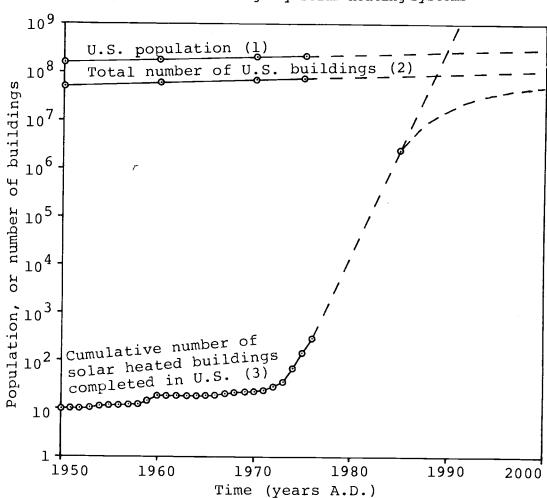


Fig 2. Solar Energy Revolution: Invasion of U.S. Buildings by Solar Heating Systems

Notes:

⁽¹⁾ Data from *U.S. Bureau of the Census (1976).
(2) Assume one building per three courses.

⁽²⁾ Assume one building per three persons.
(3) Data through 1976 from Von Hippel and Williams (1977).
Estimate for 1985 from Hammond and Metz (1977). Curved extrapolation for post-1985 period seems to be much more realistic than straight line.

Fossil Fuel/Solar Succession Analogies

The succession from fossil fuel to solar energy base is reflected in miniature by the sprouting of plants from seeds. The seed, analogous to finite fuel resources, is sufficient to drive a short period of exponential growth. But then it runs out. The seedling must by that time have subsidized the formation of solar photon collectors (green leaves) sufficient to sustain it, or else it will stagnate and die. Similarly, solar energy modules, now largely subsidized by fossil fuels, must increase in efficiency and numbers in order to support technoecosystem as the fuels give out or must be abandoned.

Finally, another apt analogy to our present situation is "the discovery of America" by Paleolithic hunters, as hypothesized by Martin (*1973) and modeled by Mosimann and Martin (*1975). Theoretically these paleo-Indians, after entering North America across the Bering land bridge around 12,000 years ago, multiplied and spread rapidly across the continent in a dense front, a successional wave of intense and wasteful slaughter of large mammals (mastodons, mammoths, etc.) which left none in its wake. This wave of extinction, after passing through the narrows of Central America, then repeated its performance in South America, reaching Tierra del Fuego by 10,500 years ago. When the large game was gone forever, the overgrown human populations suddenly faced an energy crisis. Their only choice was to turn to plants and supplemental small game for food, or to die. It appears that at least some paleo-Indians made the transition successfully.

This theory can be treated as a parable, with the elephants, exploited at stock niche rate, being analogous to fossil fuel resources. They are an easily tapped, richly concentrated solar energy storage which can be exploited only once in a successional wave of depletion, along gradients of space and energy quality. And once the brief burst of fuel hunting and often wasteful exploitation is over, newly expanded human population must turn to more direct, less concentrated solar energy forms. Technoecosystem must undergo succession from a heterotrophic predator-like state to an autotrophic solar energy collecting state which incorporates both energy producing and consuming modules.

Succession Within Solar Energy Technoecosystems

Successional patterns will continue to occur in solar energy technoecosystems after the transition from fossil fuels is complete. Progressive, voluntary succession may occur, for instance, when optimum optical concentration ratio decreases as solar cell cost

decreases (Wolf 1976), when centralized solar powerplants give way to decentralized solar energy modules as the advantages of the latter become obvious, or when newly evolved, more efficient solar technologies replace older ones.

Some concentrated solar energy forms, such as biomass resources, groundwater, or icebergs, can be tapped at stock rate, faster than they accumulate. The temptation to do so is very great; once technology is evolved for exploitation, there is no natural barrier to its proliferation beyond the flow rate threshold. As in the case of fossil fuels, exploitation usually becomes more difficult and energy yield ratio decreases as depletion progresses. Thus, regressive, forced succession (and possible extinction) of the exploiting technoecosystem may be expected. Decreased exploitation could allow the resource to grow back, except in cases of biological extinction, offering renewed exploitation opportunities. In some cases, the result could be a classical predator-prey population cycle.

Forced succession could also occur when other niche parameters become limiting. For example, large requirements of certain metals for solar collectors could cause diminishing ore grade, and consequent higher cost and lower energy yield ratio, forcing succession to take place. And in Brazil, forced succession will proceed as methanol fuel is produced first from sugarcane, then from manioc. Cane, the present source, is preferred because it is already grown, the conversion process is simple, and conversion plants are already in operation; however, cane growing land is rather limited in extent. Manioc, in contrast, can grow almost anywhere; but its conversion process is unproven, more complex, and probably more costly, and the energy yield ratio will probably be lower than that of cane (*Hammond 1977A).

In more general terms, succession of solar energy technoecosystems may reflect the classical successional patterns found in such bioecosystems as forests (*Horn 1971, *1975) and ponds (*Porter 1977). Early stages may be characterized by: low diversity; instability; incomplete cycling of materials; and pioneering technospecies and technoecosystems, generalized and low in efficiency, which are geared to rapid self-amplifying expansion and market capture. Later stages may be characterized by: high diversity; great stability, based in part on energy and material storages; complex organization patterns, with complex intermeshing behaviors, precise timing, and many symbioses and hybrids; complete and complex materials cycling; and technospecies and technoecosystems which are highly specialized and efficient, and which are geared to cooperation, complete niche filling, and maintenance of large populations at high carrying capacity. Selective advantage of fast-growing systems in early stages, and of systems with high carrying capacity in later stages (when limits are reached), is directly analogous to the bioecological concepts of r selection and K selection.

Environmental Interactions and Solar Energy Niche Limits

By their very nature, solar technologies interact with environmental systems. This relationship goes both ways. Environmental conditions determine the niche of a given technological configuration, and the industrial system in turn modifies environment, thereby affecting, to some degree, its own niche and that of other technologies. Bioorganisms and bioecosystems have evolved in this same kind of situation, and can serve as examples of what we can expect in the industrial world.

Environmental Effects

In both biological and industrial realms, seemingly negligible local environmental effects of small individual modules attain regional and even global importance when the modules exist in great numbers. Aside from agricultural systems and surface water control systems, solar energy conversion systems are still scattered and few, or else are still on the drawing board. However, local environmental effects have been studied with prototypes or by analogy with other industrial modules, and large scale effects have been predicted, or at least discussed, on a theoretical basis. Environmental effects of diverse solar technologies have been reviewed by Hughes, Dickson, and Schmidt (1974) and Davidson, Grether, and Wilcox (1977). Possible effects of various solar energy systems on global climate are reviewed in a recent volume edited by Williams, Krömer, and Weingart (*1978).

As diverse as solar technologies are, their potential environmental effects are much more numerous. Each technology has its own unique mix of environmental interactions. Only the most important and ultimate impacts, those which could involve major climatic changes, can be mentioned here.

Solar thermal and photovoltaic conversion systems change surface properties, especially albedo, and alter radiation and moisture balances of earth-atmosphere system, much as plants do. Local and global climates can be altered, depending on location and scale of installations. Large centralized power systems, covering vast areas of desert, can cause significant climatic change, according to computer models (Ibid.). However, it seems likely that such impact would be minimized or avoided if solar energy systems were decentralized, diverse, located at the point of use, and integrated into pre-existing structures, and if they were to use principles of energy cascading and hybridization.

Large scale wind energy conversion would have definite local microclimatic effects, and possible effects on global climate (Ibid., Sørensen 1976). Biomass systems would have impacts comparable to agricultural systems — surface changes of albedo, moisture content, and texture, aerosols and gaseous emissions from burning, etc. Solar heating and cooling systems for buildings are essentially benign environmentally, since they are dispersed, diverse, and integrated into existing structures. Iceberg harvesting on large scale, by changing sea surface temperature and albedo patterns, could alter climate in diverse ways (Hult and Ostrander 1973, *Holden 1977B).

The solar technology with perhaps the greatest potential for environmental damage is ocean thermal energy conversion. powerplants would lower sea surface temperature and alter thermal stratification, thus decreasing thermal stability and resulting in changes of ocean currents and climate. Specific effects are difficult to predict, due to the complexity of the ocean-atmosphere sytem, but they could be very significant if many plants were deployed. Oceanic bioecosystems could be strongly affected, as organisms are killed in heat exchangers and as artificial upwellings of nutrient-rich deep water are created. Emission of CO2 from seawater to the atmosphere would be high, about one third that of a corresponding fossil fuel powerplant (Von Hippel and Williams 1975). Volume of ocean water pumped is huge compared with the power produced, resulting in a relatively great impact per unit of energy output. For example, a single 100 megawatt electric plant would have minimum pumping rate of $2 \times 10^5 \text{ m}^3/\text{hr}$, equal to $1.8 \text{ km}^3/\text{yr}$ (Davidson, Grether, and Wilcox 1977), comparable to flow rates of major rivers like the Nile, 4.7 km³/yr (Bassler 1972), or the Colorado, 11.5 km³/yr (Duffield 1976).

Systems to control large solar-powered natural systems by weather modification, dam construction, bioecosystem management, ice dusting for increased melting, etc., can be considered solar energy technoecosystems. It is interesting to note that the desired effects of these and other solar technologies on environment are those of concern in environmental warfare, a mostly speculative and probably unimportant branch of military technology (*Barnaby 1976).

In comparing solar with other technologies, it should be remembered that environmental effects are associated not only with the energy conversion systems, but also with their manufacturing and support systems, often at a great distance (Davidson, Grether, and Wilcox 1977).

Environmental Limits: CO2 Balance

Environmental effects impose one set of limits on the solar energy niche. Ideally, each type of solar energy technoecosystem should expand only to the point where total or cumulative impacts become unacceptable or begin to close down the niche of some other technoecosystem subset. In practice, expansion might occur to the point of self inhibition or self destruction, as in some unstable simple ecosystems.

Perhaps the most important long term niche-limiting global environmental effect is the build-up of carbon dioxide in the atmosphere. The slow CO₂ equilibration process carried on by the oceans over thousands and millions of years has been overwhelmed by the present accelerating pulse of net CO₂ emission by technoecosystems. Fossil fuel burning is not the only source of excess atmospheric CO₂. Burning of wood and degradation of standing biomass by expanding human populations, especially in less developed regions, have made a comparable contribution in this century (*Adams et al 1977, *Woodwell et al 1978). If the current trend continues, global climatic changes of uncertain nature will very probably take place within a few decades. Almost any climatic change could be disastrous, causing severe dislocations in all types of technoecosystems which are closely adapted to present climate (*Baes et al 1977).

Thus it appears that atmospheric CO_2 management must be included soon in global technoecosystem survival strategy; to that extent the entire atmosphere must soon become a technoecosystem component. Unless ways can be found to increase CO_2 absorption rate in oceans, net CO_2 emissions to atmosphere must be curtailed. This means decreasing the rate of fixed carbon degradation (through greatly diminished burning of fuel and wood) and increasing production and storage of fixed carbon (through enhanced photosynthesis and bioecosystem preservation). The transition, apparently, must begin by the year 2000, or soon thereafter (*Siegenthaler and Oeschger 1978).

Photosynthesis is essentially the only way that CO₂ is reduced to fixed carbon on our planet. Technoecosystem's tendency has been to reverse this process, to degrade the products of photosynthesis (biomass and fossil fuels) in order to use their stored energy. Carbon cycle flow rate is increased, but storage is decreased. Now, suddenly, this trend must be reversed.

Can solar energy technologies accomplish the task? Some can help, but others would make the situation worse. Ocean thermal powerplants, as mentioned earlier, reverse oceanic absorption of ${\rm CO}_2$ and release the gas to atmosphere. Even worse, kelp biomass

cultivation using deep ocean water for nutrients would emit three times the ${\rm CO}_2$ of an equivalent fossil fuel powerplant (Poole and Williams 1976).

Terrestrial biomass energy systems can substitute for fossil fuel burning, but as pointed out earlier, bioecosystems do not seem to be adequate for complete fuel replacement, and are already overloaded. Furthermore, biomass systems are not necessarily $\rm CO_2$ neutral, which some authors ($\it Ibid.$, Pollard 1976B) suggest. Exploited, harvested bioecosystems tend to have lower standing biomass than natural systems. Thus, transforming tropical rainforests (e.g., in Brazil) into biomass plantations would release enormous amounts of $\rm CO_2$ into the air. Adams et al (*1977) recommend reforestation as a $\rm CO_2$ control measure, but that still represents net $\rm CO_2$ emission compared to the original state of the ecosystem. Only cultivation of biomass where little existed before, in deserts and oceans, without using deep seawater, will result in net $\rm CO_2$ decrease.

Photovoltaic, solar thermal, and wind energy systems have no effect on ${\rm CO}_2$ balance, except, of course, for the fuel which they replace and the fuel burned to produce them. These, plus biomass systems which either store ${\rm CO}_2$ or release only limited amounts, offer a global solar energy niche option with stable ${\rm CO}_2$ balance.

It is important that our ongoing, but soon to be curtailed, pulse of fixed carbon degradation and CO₂ emission be used to subsidize the establishment of such a CO₂-balancing solar energy technoecosystem. But how can this be brought about? A "tragedy of the commons" situation appears imminent. Why would anyone voluntarily stop burning cheap fuels when his neighbor continues to do so? Global restraint and cooperation of unprecedented and perhaps unlikely degree would be required. But if there were an energy option cheaper than fossil fuel, everyone would jump for it voluntarily and simultaneously. Rising fuel costs and plummeting solar cell costs may bring this about, just in time, in the next decade or so. The ecology slogan of the near future may be:

"CONSERVE FIXED CARBON - USE SOLAR CELLS"

Flow and Stock Energy Resources Limits

In addition to environmental limits, there are resource limits of the solar energy niche. As discussed in an earlier section, some solar energy forms (e.g., mammoths, mastodons, whales, forests, soils, peat, icebergs, cold deep seawater, and groundwater) can be exploited from storage faster than replenishment flow rate, resulting in a time-limited stock niche. Other solar energy forms can only be

exploited as flows: sunlight, wind, running water, and waves. The result is a rate-limited flow niche. Exploitation rate of stock niches depends on technoecosystem size and capabilities, but exploitation rate of flow niches is limited ultimately by natural energy flow rates, which can vary, often randomly, over different time scales. Even solar radiation output, which, together with black space heat sink, is the ultimate source of all solar energy forms, appears to vary on a scale of centuries (*Eddy 1977). And Earth-Sun orbital parameters vary on a scale of millenia (*Weertman 1976). These fluctuations affect all solar-powered natural systems on this planet, particularly atmospheric systems.

For the two types of solar energy niche, different optimum exploitation strategies emerge. Technoecosystems which exploit storages should do so at or below flow rate, or else face the consequences of eventual depletion. Those which exploit flow resources may do so at flow rate, but should be prepared for flow fluctuations and their environmental consequences. Wind, wave, falling water, and solar radiation systems, for instance, incorporate energy storage systems for smoothing the effects of short-term fluctuations. Flat plate solar radiation collectors (e.g., solar cells), which can operate on cloudy as well as sunny days, may be better adapted to long or short term fluctuating environments than optically concentrating collectors, which require clear skies. All systems should be adapted for survival of reasonably probable niche-limiting natural disasters -- large magnitude, low frequency energy events in atmosphere, hydrosphere, and lithosphere.

Material Resource Limits

Solar energy niches may also be limited by stocks of materials. Biomass technoecosystem niches, both terrestrial and marine, are limited by nutrients available on site or imported from elsewhere (Poole and Williams 1976). And limited crustal abundance of exploitable concentrations of metals -- "enzymes of industry" (*Skinner 1976) -- may be the ultimate limiting factor for some solar technologies. For instance, supplies of corrosion-resistant titanium are severely limited, forcing the use of less resistant aluminum for the large heat exchangers in a fleet of ocean thermal powerplants (Metz 1977A). Some solar cell technologies use geochemically scarce metals (e.g., gallium, platinum), and could result in exhaustion of resources if manifested at macroscale.

Ultimately, materials limits become net energy limits, as each additional unit obtained costs more energy, and as less efficient substitutes are introduced. Clearly it is desirable for a global solar energy technoecosystem to be based on thin, light-weight,

strong solar collectors made mostly of common elements like silicon, iron, and aluminum. Rarer elements may be used, too, as long as the amounts needed are small enough and extra cost is justified. Efficient material recycling mechanisms are highly adaptive for a long-lived technoecosystem, as for bioecosystems, in order to conserve scarce elements and save replacement energy. In addition, recycling helps prevent dispersal of toxic, harmful materials such as freons used in heat engines and air conditioners, or cadmium and arsenic used in some solar cells. "Technogeochemical" cycling, industrial analog of biogeochemical cycling, may come to dominate geochemical processes.

Silicon is by far the most abundant semiconductor element (*Johnston 1977). Therefore, should silicon solar cells become the ultimately cheapest design, solar cell proliferation and niche may be limited only by manufacturing cost, space, and other elements used in solar cell construction and installation. Should solar cell limits fall away, other limits to technoecosystem expansion will eventually become apparent.

Consider Limits and Enter Solar Energy Niche Carefully

If a new solar energy niche opens up, which appears likely, it should be entered with caution. New technologies should be deployed only after considering the macroscale technoecosystem configurations which they imply, and the other consequences of their proliferation. Rapid growth should be planned and carefully monitored; eventual limits should be kept in view. It is essential that we learn these lessons from previous technological revolutions. Time after time we have jumped into new niches and expanded our population within them until niche limits were reached or overshot, disruptions occurred, and regressive succession was forced upon us. The impending solar revolution offers us still another chance, but probably our last, to control population and attain a steady-state technoecosystem with high quality life support for everyone.

Environmental Interactions, Ancient and Modern

Technoecosystem interaction with environment is just a vastly accelerated continuation of an ancient series of global ecological evolutions and revolutions (see *Cloud 1974). Research on solar conversion technologies is analogous to biochemical "experiments" over a billion years ago. Successful designs, when multiplied, will affect environment and each other in profound and complex ways, analogous to the effects of ancient life forms on each other and on terrestrial systems. To early microbes, oxygen, a byproduct of their

photosynthesis, was a poisonous pollutant; as the gas progressively accumulated in the atmosphere, life forms were forced to adapt to its presence by converting from anaerobic to aerobic respiration. The present ${\rm CO}_2$ crisis can be seen as a modern analogue of that scenario. Industrial systems must change rapidly from net respiration to net production, from heterotrophy to autotrophy, in order to avoid global self-destruction.

Adaptation to Aridity

Aridity is an energy state, or rather a complex of interrelated energy states resulting from solar-powered cycles of atmosphere and hydrosphere and their interactions with lithosphere and solar Deserts can be defined according to many phenomena -radiation. vegetation type or coverage, evaporation/precipitation ratios, total precipitation, lack of cloudiness, etc. But water scarcity, in some form, is the basis of any such definition of aridity and arid lands. Each of the many interrelated factors which combine to characterize aridity influences adaptations of biological and industrial systems. Each factor is advantageous and is utilized for some biological or industrial functions, and disadvantageous for others, requiring avoidance or protection. The resultant adaptations to aridity in biological systems and in ancient and modern industrial systems can be quite similar. [The focus in this discussion is primarily on warm arid and semiarid lands.]

Low vegetation density, one manifestation of dry climates, is an example of such a factor with both positive and negative influence on technoecosystems. On the positive side, it causes human populations away from oases to be small and scattered. The consequent vast undeveloped spaces are ideal for building large solar collector fields and new solar-powered urban technoecosystems. On the other hand, low vegetation density also contributes to windblown dust and sand; solar collectors must thus be abrasion-resistant and easy to wash.

Skies in arid lands tend to be clearer than in other regions, resulting in a higher ratio of direct to diffuse sunlight. Focusing solar collectors, thus, are more effective in deserts than elsewhere, as are directional shading devices (Olgyay and Olgyay 1957) and building orientation, shape, and siting for passive sun/shade microclimate control (Knowles 1974). However, strong direct insolation also necessitates the use of tough, sunlight-resistant coatings and materials. Glass and sun-resistant paints and plastics used in this context are analogous to resinous or waxy leaf coatings of desert plants.

Clear skies also result in rapid cooling at night by infrared radiation to space. This can be an advantage for passive house cooling systems (*Hay 1973), simple refrigeration modules, ancient Middle Eastern techniques for making ice on nights when air temperature is above the freezing point (*Bahadori 1978), and cooling people and animals who sleep outdoors, perhaps on rooftops, on hot

nights. But it also makes shelter (e.g., tents, trees) necessary for surviving cool nights, and frost protection techniques necessary for protecting citrus farms.

Low humidity, often a characteristic of aridity, is advantageous for technologies which involve evaporative cooling (for space conditioning or heat engine heat sink) or drying. On the other hand, it necessitates water seals to protect water-conserving systems from excessive evaporation. Greenhouses may use both evaporative cooling and glass or plastic covers for water conservation (analogous to the water-resistant cuticle of succulent plants, or the water-tight exoskeleton of insects.

Low humidity, by promoting evaporation, results in the accumulation of salts in surface water and groundwater. This is useful for concentrating industrial wastes or for purifying salts in evaporation ponds, and for driving salinity engines by the energy of resulting salinity gradients. But it can be disastrous for agriculture because salts harm soil structure and kill sensitive crop plants; soil leaching systems and salt drains are thus required for long-lasting irrigation projects.

The wide daily range of temperatures characteristic of dry climates makes passive thermal storage an efficient component of arid lands architecture. Water-filled plastic bags with movable insulating shutters are a modern innovation (*Hay 1973). But earth-covered buildings (*Moreland 1975) and adobe construction (e.g., *Fathy 1973) are simple passive technologies which have been used successfully in arid lands for millenia.

Industrial systems adapt to high temperatures in many ways which are analogous to adaptations by plants and animals. Some such techniques are: heat tolerance, shade seeking or creation, going underground, evaporative cooling, "storing coolness" from the night, orientation for minimum surface area perpendicular to sun, exposing high albedo surfaces, and using natural or forced air convection. Specific embodiments of these methods are too diverse to enumerate here. For cooling of buildings, besides evaporative and night radiation cooling systems, technologists have been developing numerous other solar-powered cooling systems, including Rankine cycles, absorption systems, desiccant systems, gas-regenerative cycles, open cycles, and thermo-electric systems (DeWinter and DeWinter 1976B, Duffie and Beckman 1976).

Wind is so strong and constant in some deserts that it is the major landscape-forming agent. In some locations, wind has cut long ravines parallel to its prevailing direction; these may serve to concentrate the wind, and may thus be ideal sites for wind power modules. Constant wind direction may make simplification of wind

collector design possible, thus lowering costs. Gravity driven katabatic winds blowing off the edge of Antarctica, a polar desert, are among the strongest and most constant winds on Earth; perhaps they could be tapped by large windmill systems to generate fuel for export to warmer lands.

Adaptation to Water Scarcity

The most intensive adaptations to aridity among bioorganisms are responses to scarcity of water. Some organisms require extensive adaptation: plants to infrequent rainfall and low soil moisture content, amphibians and mammals to infrequency and scarcity of surface water for breeding and drinking, respectively. Other organisms, particularly birds and insects, need to change little for desert survival (*Orians and Solbrig 1977). Convergent evolution between species in different deserts is most striking among the first group (*Mares et al 1977).

Similarly, among industrial systems, some are sensitive to water scarcity and so require extensive adaptations (e.g., agricultural systems and solar thermal powerplants), while others, less sensitive, require little or no change (e.g., cars, airplanes, telephone systems). Convergence of arid adaptations may be expected to be more noticeable among the first group.

It should be noted that while all biological solar energy converters (plants) are water sensitive and therefore require special adaptations to aridity, this is not true of all industrial solar energy converters; although controlled plant species and solar thermal powerplants with wet cooling towers are water dependent, photovoltaic solar cells and wind generators are not. Thus, technomass of solar energy technoecosystems in arid lands is not as limited by water scarcity as biomass of vegetation is. Where no plants will grow, a field of solar cell panels could capture a tremendous amount of solar energy. This energy could be used to import and desalt the relatively small amount of water needed for support systems and associated human communities.

Plant communities in all deserts incorporate several very different, coexisting life forms (e.g., perennials, succulents of various shapes, annuals, and small trees). This indicates that there are several viable solutions to plant survival under arid conditions (*Solbrig and Orians 1977). A similar relationship may be found in solar energy technoecosystems: diverse but successful solar energy modules operating side by side. For example, several types of solar power systems of different size and type could coexist if they served different markets.

Water Niches

Water niches of arid lands solar energy technoecosystems appear to be analogous to those of desert plants. Technoecosystems which are dependent on a permanent water source (e.g., cities, irrigated agriculture systems) are analogous to phreatophytes, with wells, aqueducts, and canals corresponding to deep roots. Industrial systems which harvest intermittent runoff, store it, and conserve it (e.g., water harvesting and greenhouse systems) are comparable to succulents. And systems which are essentially independent of water supply (e.g., solar cell or wind systems) are similar to droughtenduring plants. Water-using industrial systems, like bioorganisms (*Mares 1977), often adapt to arid conditions by increasing water intake, reducing its loss, storing it, or eliminating its use altogether.

In plants there is a high energy cost for xerophytic adaptations; xerophytic leaves take longer to make energy profit than do mesophytic leaves (*Solbrig and Orians 1977). Solar thermal power-plants face a similar situation: dry cooling towers are much more costly and much less efficient than wet cooling towers.

Geographical Zonation Influenced by Water Supply

Water availability and temperature gradients often result in local and regional zonation patterns of plant species and communi-Similar ecological patterns may occur among solar energy technoecosystems and technoorganisms in arid lands. For example, ratio of direct to indirect insolation, and water availability and cost, are the gradients along which solar powerplant technologies may be distributed. Direct sunlight (clear skies) favors focusing solar collectors, while indirect sunlight (cloudy skies) favors nonfocusing systems like solar ponds and photovoltaic systems. Similarly, water abundance and low cost favor cheap, inefficient, low-temperature solar thermal systems (e.g., solar ponds), while scarcity and high cost of water favor expensive, efficient, hightemperature systems (focusing systems like central receiver-heliostat systems). And lack of water supply forces the choice of photovoltaic systems (Backus and Brown 1976). A map of a large region such as the western U.S. could conceivably be subdivided into subregions within each of which one type of solar power system would be the best, and therefore the most likely to be constructed and successfully operated. The result would be analogous to a map of potential vegetation.

Roles of Water

Water, with its many specialized properties, and its many synergetic interactions with various materials and systems in diverse settings, has countless roles in technoecosystems. It can be considered a fuel, with energy value as gravitational potential energy medium, chemical fuel for osmotic potential and chemical solution and reaction, photosynthesis amplifier, and amplifier or facilitator of other biological and industrial processes (*Odum 1970, 1975, Duffield 1976). In the next two sections we examine solar technologies which directly involve water. These technologies can be classified as those which process water, and those which utilize it.

Water Processing

Solar energy modules collect and process water for themselves and for other technoecosystem modules, much as plants do for themselves and for animals who feed on them. Much solar-powered water collection and handling technology is analogous to natural processes in biological systems and in physical systems of the hydrologic cycle.

Water Harvesting

One of the simplest and oldest technologies for collecting water (a form of solar energy) is runoff harvesting, either from natural or modified watersheds (*National Academy of Sciences 1974) or from roofs or other industrial structures. Large surface areas of solar power collectors (*Meinel and Meinel 1972) or solar stills (Eibling, Talbert, and Lof 1971) seem ideal for collecting rainfall. This would be conscious or unconscious imitation of runoff collection in natural watersheds and in some plants (e.g., agaves and aloes) whose leaves or canopies intercept rainfall and concentrate it at the center, where it can infiltrate to the roots. Plants and animals of foggy coastal deserts such as the Namib (*see, for instance, Seely and Hamilton 1976) collect moisture by condensation from the air; perhaps efficient technologies can be developed to imitate or improve on these natural techniques (Hirschmann 1975).

Pumping

Where water pumping is needed (analogous to roots and vascular systems of plants), solar-generated electric or mechanical energy can provide the necessary power. A small but growing number of

solar-powered pumping systems, of various types and levels of sophistication, are operating around the world today, mostly as irrigation demonstration projects. New designs continue to be invented and developed (e.g., Swet and Fox 1973, *Rao and Rao 1976). Very low cost solar cells might rapidly capture this market worldwide.

Iceberg Capture

Recovering Antarctic icebergs for water supply and heat sink along arid coastlines would require a complex and unique technoecosystem (*Holden 1977B, Hult and Ostrander 1973). Hunter-like satellite and search ship systems would detect and select the proper berg; it would be prepared and wrapped, and transformed into a self-propelled technoorganism for transport to its destination. Once there it would be stored and progressively "slaughtered" by specialized systems to become "food and drink" for the energy-hungry and water-thirsty urban-industrial technoecosystem which sent for it.

Storage, Treatment, and Evaporation of Water

Once water is collected, it can be stored and processed in various ways, some involving solar energy. Storage ponds can be surfaced with films or high albedo floating covers to reduce evaporation (*Cooley 1970, *National Academy of Sciences 1974), while cooling ponds can be made more efficient by surfacing with films or granules that have high albedo and high infrared emissivity (*Winiarski and Byram 1970). Conversely, evaporation of brines can be accelerated by adding green dye (*Keyes et al 1970). Active and passive water heating systems are analogous to systems in animals for blood warming by basking. As in natural aquatic ecosystems, solar radiation can help purify waste-water in sewage treatment ponds; algae oxygenate the water, and this oxygen, combined with solar ultraviolet rays, kills pathogenic organisms (*Oswald 1973).

As in the hydrologic cycle, solar energy modules can concentrate brines and purify water either separately or at the same time. Solar evaporation ponds, industrial analogues of natural closed evaporite basins in arid lands (e.g., Dead Sea, Death Valley), can be used to concentrate and dispose of wastes from factories (*Welty 1976), or brines from desalting plants (Day 1970) or geothermal powerplants (Duffield 1976). Besides disposal of liquid wastes, solar evaporation ponds can be used for separation, concentration, and production of salts and chemicals derived from seawater, geothermal brines, and closed basin brines. Producing salts from seawater is one of the

most ancient solar energy and chemical technologies.

Desalination Technologies

Solar distillation modules contain the complete hydrologic cycle in miniature. Flat-plate single- or few-effect basin-type stills are very simple but inefficient, and are the traditional technology for small-scale water supply applications. Basin-type still technology has been reviewed by Eibling, Talbert, and Lof (1971), Talbert, Eibling, and Lof (1970), and the United Nations Department of Economic and Social Affairs (1970). Efficiency goes up with the number of cascaded effects, the complexity of the design. One multiple-effect humidification technology was developed and tested by Hodges et al (1966). Thermodynamic efficiency and number of feasible effects increase still more with higher temperatures. Thus solar distillation systems which use concentrating collectors (Tleimat and Howe 1977, Weihe 1972) have very high output per unit of collector area, so high that the additional capital cost involved may be more than effset. However, concentrating collector systems require direct sunlight, while basin-type stills and other flat-plate systems work well even on cloudy days.

Open cycle ocean thermal gradient systems would be more effective for distilling seawater than for driving turbines and producing electricity (Hagen 1975). Such systems might be used for water production along the shores of coastal deserts, but the environmental impacts discussed earlier should be considered first.

Water can also be desalted by electricity from any source, including any solar power technology (e.g., very cheap solar cells), using membrane technologies like reverse osmosis and electrodialysis. Such technologies are directly analogous to kidney function in animals.

Water Utilization

Water has many roles in technoecosystem modules for solar energy conversion, corresponding to its diverse useful properties. Most of these roles of water have their counterparts in natural biological and physical systems.

Diverse Uses of Water

As in animals and hydrologic systems, water is a common heat collection, storage, transfer, and exchange fluid in solar energy

conversion modules. Proposed novel methods of heat storage include the use of groundwater as heat reservoir (Cortell 1977), and the use of a basement tank of water, together with a heat pump, to store heat in summer and cold in winter for space conditioning (*Krause 1975). Water serves as heat sink by conduction, evaporation, radiation to space, and melting (e.g., icebergs).

In solar energy technoecosystem modules, as in biological and atmospheric/hydrospheric systems, water serves as a chemical solvent and medium for chemical reaction and transport, and as a thermodynamic working fluid, by evaporation/condensation and by interactions with chemicals like ammonia or lithium bromide. As in plants, it serves as a raw material for photochemical fuels (e.g., hydrogen and oxygen), and as in animals and plants, it is a metabolic product of the consumption of such fuels.

Even optical properties of water have been used in solar energy modules. Liquid lenses constructed by Chauhan (*1976) are reminiscent of cellular lenses in plants (*Schimper 1903). Other important uses of water in solar energy technoecosystems include diverse roles in manufacturing and support systems, washing dust off solar collectors (rain does this for plants), and, of course, its amplification of plant photosynthetic capacity (discussed in the next section).

Water in our gravitational field spontaneously forms "flat" surfaces which are excellent solar energy conversion interfaces. Natural and controlled surfaces of this type can be used for solar heat collection, for evaporation, or for radiative or evaporative cooling.

Solar ponds can be very inexpensive solar collectors, useful for both absorption and storage of solar thermal energy. Cooling of solar ponds (by evaporation, conduction, radiation, and convection) is suppressed by transparent plastic film (Jensen 1977, Dickinson et al 1976), or by salinity gradients (Hirschmann 1970).

Water surfaces in arid lands are inexpensive, foolproof, maintenance-free net evaporation systems. This evaporation can be tapped as an energy source by exploiting the gradients of gravitational potential or salinity which it creates.

Heliohydroelectric Power Systems

Damming rivers on their way to the sea is one way to capture gravitational potential energy for hydroelectric power generation; deserts allow an extension of this principle. Net evaporation potential is greater in deserts than it is for the oceans, and thus, where geology and topography permit, dry basins which are substantially

below sea level can exist. Natural or artificial rivers can run, perhaps from the sea, into such a basin, and hydroelectric dams and generators can capture the resulting power. A natural example of such a flow is the Zaliv (gulf) Kara-Bogaz-Gol, where Caspian Sea overflows into Aral Sea in the Turkmen desert (Kettani and Gonsalves 1972).

Powerplants of this "heliohydroelectric" type have been proposed for the Qattara depression of Egypt (Bassler 1972) and the Dead Sea in Israel (*Finkel 1973). Numerous other arid basins around the world are also candidates for such systems. New depressions can be created by damming off narrow gulfs from the sea. Kettani and Gonsalves (1972) proposed this for Dawhat Salwah in the Arabian-Persian Gulf. A disadvantage of such a scheme is that it would take decades for the water in the new basin to evaporate to usable depth, and still longer before equilibrium depth and maximum power could be attained. In contrast, natural basins would gradually fill during the first stages of exploitation, with power potential starting out at maximum and decreasing slightly as equilibrium is approached.

Great engineering works are required for heliohydroelectric schemes: canals, dams, tunnels, penstocks, turbines, pumped storage systems, and powerlines. Vast basin areas are modified, and tremendous water flows are involved. For instance, the Qattara project would create a lake 60 meters deep and 12,000 square kilometers in area, and water flow through tunnels or canals from the Mediterranean would be at least 21 km³/yr, more than four times the flow of the Nile (Bassler 1972). Yet after all this trouble, expense, and environmental alteration, the power output of a heliohydroelectric scheme would be almost trivial: 1,000 MWe base load for the immense Qattara project, 187 MWe for the Dead Sea, and only 34 MWe for the Dawhat Salwah. [One MWe is approximately 1,000 times the average per capita power use in the United States.] The contrast of these small power magnitudes with the enormous energy needs of technoecosystems is a good illustration of how technoecosystem has outgrown the capacity of natural physical systems to support it.

Salinity Gradient Power Systems

Salinity differences, created by solar energy either naturally or through technoecosystem operation, can be tapped as a source of energy, the reverse of desalination. Mechanical power can be produced by osmosis engines (Norman 1974), and electrical power can be produced directly by electrochemical concentration cells (Clampitt and Kiviat 1976) or dialytic batteries (*Weinstein and Leitz 1976). Theoretically, any salinity difference can be exploited. Low salinity could be supplied by melted icebergs, river water, sewer outflow, or even seawater. And high salinity could be supplied by

seawater, by geothermal brines, by brines from saline seas, lakes, or evaporation ponds, or even by geologic salt deposits.

Mixing water and brine for salinity power could be a flow niche, if equilibrium flow rates were not exceeded. But exploiting salt mountains, or salt domes (*Wick and Isaacs 1978) would be a stock niche with serious consequences for subsurface geologic systems (as in the case of geothermal energy systems [Duffield 1976]) and perhaps for oceanic salinity. Salt deposits can be thought of as stored aridity. They, like oil and coal, are a depletable fossil fuel. And the analogy goes still further. Salinity build-up in the oceans due to salt exploitation would be directly analogous to the accumulation of CO₂ in the atmosphere as a result of organic fuel burning.

Water for Cooling

A major use of water in arid lands solar energy technoecosystems will be as evaporative coolant for buildings, greenhouses, and solar power technologies. Water, combined with air, is the thermodynamic working fluid of the whole planet. In this case it is acting as a refrigerant, to be recondensed to liquid form elsewhere in the hydrologic cycle. Solar thermal powerplants use as much water as fossil fuel thermal powerplants, or more, depending on thermodynamic efficiency of the power cycle. Flat plate or solar pond collectors have low efficiency and thus very high water needs, while central receiver-heliostat systems have higher efficiency and lower cooling water requirements. Even photovoltaic conversion requires cooling if much optical concentration is used. The choice of technology depends in part on relative costs of water and energy. Hybrid power and heat systems may result in higher energy efficiency and lower water needs.

Water can also cool by conduction and melting. Icebergs towed from Antarctica, or cold deep ocean water pumped to surface or shore, can be used as heat sinks for any technoecosystem process. Both are cooled, ultimately, by radiation to space at high latitudes. And the use of either has its own difficulties and environmental hazards.

When phreatophyte seedlings sprout, roots grow much sooner and faster than shoots; water supply is established before leaves can be deployed. An analogous pattern may appear when water-using solar power systems are built: wells will be drilled and water systems tested before collectors are installed.

Agricultural Technoecosystems

Agricultural technoecosystems use water and sunlight, among other factors, to produce food, fuel, and materials, based ultimately on photosynthesis in controlled plant communities. Deserts, due to clear skies and favorable latitude, have the greatest potential photosynthesis rate of any region. But due to scarcity of rainfall, their actual photosynthesis rate is among the lowest. Addition of water and appropriate technologies can push desert photosynthesis from actual toward potential values. Many different technologies are possible; agricultural systems should be carefully adapted not only to physical setting but also to the culture of human inhabitants (*Saint and Coward 1977).

Solar energy is finding application in numerous facets of agricultural enterprise: poultry and livestock production (U.S. Energy Research and Development Administration, Division of Solar Energy 1976), irrigation pumping, and crop drying (an ancient technology). Here we discuss general aspects of biomass fuel systems, crop production, and controlled environment agriculture.

Biomass Fuel Systems: Limited Practicality in Arid Lands

There is a great and growing diversity of biomass fuel ideas (Hammond 1977A), most of which require enormous amounts of water (Poole and Williams 1976). Alfalfa (Meinel and Meinel 1975) or even sugarcane could be grown for fuel in deserts, but the water needs would be prohibitive. Such crops are probably best grown for fuel in wetter climates.

Poole and Williams (1976) suggest that water use efficiency of plants may be more important than solar energy conversion efficiency for biomass fuel technoecosystems in arid lands. Drought-tolerant tumbleweeds have twice the water use efficiency of alfalfa, and might be grown as biomass fuel (A. B. Meinel, University of Arizona, personal communication, 1977). A Death Valley winter annual, Camissonia claviformis, has extremely high photosynthesis rate (*Mooney et al 1976); such plants or genetic derivatives might also be good fuel plants. Arid-adapted shrubs, Hevea and Euphorbia, could be grown as hydrocarbon sources for fuels and chemical feed-stocks (Calvin 1976).

However, the scale of a desert biomass system with more than trivial output would be immense. An area the size of Arizona would be needed to grow enough *Euphorbia* to supply current U.S. gasoline consumption (*Maugh 1976). Land and soil limits would surely be

reached before that size would be attained. Water limits would certainly intervene if irrigated crops, no matter how water-efficient, were grown as fuels. Water flow niches in southwest U.S. are already overtaxed, and groundwater stock niches are gradually being depleted, with today's urban, industrial, and agricultural systems; little growth of water consumption is feasible. Furthermore, value of energy crops is low compared with food and materials crops (*Bassham 1977), and even lower compared with water values for urban and industrial systems (*Fischer 1973). And water needs for these competing uses are sure to increase in coming years as populations grow. World food production, for example, must double in the next 25 years (*Pimentel et al 1976).

Obviously there are severe limits to the practicality of large-scale biomass fuel systems in arid lands, or at least in the dry lands of the U.S. Energy and water resources would probably be better spent in other ways. Solar thermal powerplants would use much less water, and large fields of very cheap solar cells would use little, or none at all.

Crop Production

Expanded and diversified production of crops for food and materials looks more practical. Hydrocarbon producing shrubs (Calvin 1976) may be a valuable source of chemicals. Other arid-adapted plants show similar promise (Maugh 1977), particularly jojoba, source of a sperm whale oil substitute, and guayule, source of natural rubber, resin, and wax. New technologies (or revived ancient ones) for brackish water irrigation (*Twersky 1976), more efficient irrigation, water harvesting, and reduction of evapotranspiration, may help extend agricultural capabilities in arid lands (*National Academy of Sciences 1974). Towle (1976) estimated that solar power for irrigation pumping will not be competitive until well into the next century. But rapid decline of solar energy cost would shorten that timetable considerably.

Seawater Irrigation

A momentous, but little noticed achievement reported by Epstein and Norlyn (1977) may portend tremendous future changes in arid lands agriculture. Strains of barley have been developed which can grow in dune sand with irrigation by seawater. Development of similar strains of other plants could completely alter the prospects of agriculture for coastal deserts, or for inland deserts within reach of aqueducts or canals. Food, materials, and even biomass fuels could

then be grown with no input at all of scarce and expensive fresh water. A major cost (besides fertilizer) would be for pumping seawater, but that might be done by siphons for agricultural systems in desert basins which are below sea level (e.g., Dead Sea and Salton Sea basins). Drainage, as in fresh water systems, would be essential to maintain long-term salt balance.

Seawater irrigation, beyond any other technology, appears to have the potential to transform barren deserts into highly productive controlled bioecosystems. Rapid evolution, through genetic manipulation, of seawater tolerance in crop plants, combined with evolution of seawater irrigation systems, could open up a large, new, unexplored agricultural technoecosystem niche in arid lands. Such an event, like the development of very inexpensive solar cells, could profoundly change the world.

Controlled Environment Agriculture

Since the earliest days of bioecosystem control by men, agriculture has undergone a trend toward intensification. First one factor and then another has been brought under more intensive control (*Boserup 1965). Greenhouse, or controlled environment agriculture, is the ultimate extension of this trend. Among the factors which can be controlled are atmospheric humidity and gaseous composition, light intensity and timing, soil, nutrients, water supply, and pests. Greenhouses are to crop plants what plant cells are to chloroplasts, or plant structures to photosynthesizing cells. For a review of controlled environment agriculture see Dalrymple (1973), and for more technical papers see Hodges (1975) and Jensen (1977). Papers about solar heating and cooling systems for greenhouses, and about integrated greenhouse-residence systems can be found in Jensen (1976).

Because greenhouses are so costly, they are most likely to be used for high value crops. Water, land, and nutrients are conserved at the cost of energy and dollar subsidies. It appears that greenhouses, as now developed, are unlikely to provide the total photosynthetic foundation of an arid lands technoecosystem. But they can be very useful for growing essential high value food crops locally, independent of climate, season, and long-distance transport. Advantages of supply certainty may offset the extra energy cost, a relationship commonly found among bioorganisms.

Complex Technoecosystems

A few solar energy modules or technoorganisms may operate in isolation. But most will be integrated, spontaneously or by design, with other similar and contrasting units to form complex technoecosystems. This synergetic integration will involve hybrids, symbioses, multiple functions, energy cascading, and complex cycling and recycling of materials. Production, storage, conservation, and consumption systems for energy and water are likely to be combined in various ways. Water will often be the energy and material form which connects or unifies diverse components. In each environmental setting the possibilities are infinite, limited only by niche constraints, imagination, technology, and the workings of the historic process. Such complex systems will be true technoecosystems; in this context technoecological concepts can be most applicable and fruitful.

A few complex solar energy technoecosystems have already been built in arid lands; most designs have only been proposed; and still more have yet to be envisioned. Here I survey some of these possibilities and actualities, starting with the simplest systems, those on the boundary between hybrid technoorganisms and complex technoecosystems.

Hybrid Systems

Numerous relatively simple solar hybrids have been proposed or developed for arid lands. Runoff collection built into solar collectors is one example (Dickinson et al 1976). A proposed hybrid solar thermal/hydroelectric powerplant (*Blake and Walton 1975) is another; water would serve as gravitational potential medium for pumped storage and hydropower, and as evaporative coolant for solar thermal power cycles. Agricultural systems could be integrated with biomass fuel refineries, where crop residues are reacted with steam in a solar thermal chemical process (Antal 1976). Waste heat from large solar power farms could desalt large amounts of water (Meinel and Meinel 1975), an example of energy cascading. The "hurricanado", a giant convection chimney more than a mile high, with humidification systems at the bottom, has been proposed for installation in shallow waters at the head of the Gulf of California (*Edmondson 1976); upward air convection would drive power turbines, while moisture would condense and "rain" distilled water inside.

Other hybrids which have been proposed include a greenhouse roofed with solar stills capable of producing more water than the crops below need (Selcuk and Tran 1975), and greenhouses integrated with houses for heating and food production (Jensen 1976). Solar

total energy communities (Harrigan 1975) would connect numerous discreet building technoorganisms with a single cascaded hybrid solar thermal energy system for power, heat, and cooling; water could be used as the thermal storage and circulation fluid. Dr. Brent Cluff of the Water Resources Research Center, University of Arizona, is developing a hybrid system of concentrating solar thermal collectors which float on a water reservoir like lily pads; while rotating horizontally to track the sun, these floating collectors also suppress evaporation and thus conserve water.

Solar energy shows promise for waste water treatment. Complex systems which cycle sewage through meadow and marsh/pond bioecosystems have been proposed by Woodwell (*1977); perhaps this could be done under large inflated enclosures of transparent plastic film to conserve water in arid lands. A solar-powered sewage treatment plant designed like an ecosystem has been built in Wilton, Maine (Wilke and Fuller 1976). Solar collectors heat sludge digesters, buildings, and hot water supply, while methane from the digesters generates electricity. Waste heat is recovered, and snow is used both as thermal insulator and as solar reflector.

Marine and Coastal Technoecosystems

Among more complex systems, those proposed for recovery and multiple purpose utilization of Antarctic icebergs have already been mentioned. Other complex systems, centered about ocean thermal energy conversion, have been proposed. Technoecosystems deployed at sea (Anderson 1973, Hagen 1975), perhaps near arid coastlines, could combine ocean thermal power and distillation cycles with fuel, salt, and mariculture food production systems. Hybridization with wind, solar thermal, and geothermal energy systems might be considered. Floating factories for energy-intensive industries, chemical production, and food processing could cluster about such plants, and fuel and desalted water could be carried to arid coastal cities by barge or pipeline. Othmer (1976) proposes similar complex systems, but located onshore in coastal deserts. Hybrid ocean thermal/solar thermal cycles would produce power and then distilled water (cascading), and condenser-warmed, nutrient-rich deep seawater would support a complex mariculture food web for food and materials production. Desalination waste brines could be evaporated to produce salts. Such systems could be the trophic foundation of selfcontained urban/industrial technoecosystems.

Technoecosystems Around Abandoned Open Pit Mines

Matter et al (1974) propose a complex technoecosystem which

exploits topographic opportunities left by open pit copper mines in semiarid southern Arizona. Terraced waste dumps would be sites for residential and commercial building technoorganisms, greenhouse technoorganisms, and wind power collectors. The abandoned mine pits would be used as solar power collector sites and as pumped storage water reservoirs. And the whole system would be interlaced with channels for electricity, water, and automobile technoorganisms.

Complex Technoecosystems with Agricultural Components

Large, complex, multiple purpose agricultural systems for food, fiber, wood, and biomass fuel production must coexist, and may work best when integrated (Hammond 1977A). *Lipinsky (1978) suggests that such symbiotic integration will happen spontaneously, to the benefit of all components.

Carl N. Hodges (1975) of the Environmental Research Laboratory, University of Arizona, has proposed and constructed complex technoecosystems, ideal for coastal deserts, which combine diesel power generation with water distillation and intensive controlled environment agriculture. Diesel exhaust CO₂ can be used to enrich greenhouse atmosphere and speed crop growth. Fresh water, distilled by solar energy or waste heat from generators, is used for irrigation, and poor quality brackish or ocean water can be used for greenhouse humidification to minimize fresh water needs. Support buildings and automobile technoorganisms cluster about these key greenhouse, power, and distillation modules. Electricity, fresh water, and high value food are yielded to nearby settlements. Complex systems of this type have been reviewed by Dalrymple (1973) and United Nations (1970). Ultimately, power and heat for distillation could be generated by cascaded solar thermal conversion systems.

Bassham (*1977), more ambitious still, envisions large areas of the southwestern U.S. covered with huge inflated greenhouses, one square kilometer in area and 300 meters high, within which are grown high-yield high-protein legume crops such as alfalfa. The crops, after protein extraction, would be fed to livestock or burned in powerplants. Animal wastes, and exhaust CO₂ and ash from powerplants would be recycled through the greenhouses for yield enhancement and materials conservation. Water would be conserved by the clear plastic greenhouse covers. Outputs to urban/industrial technoecosystems would be food and electricity.

Most elaborate, perhaps, are the solar power producing mixed farming communities proposed by Rosenbaum et al (1975). These would incorporate almost every solar technology in the book. The keystone of the design would be hybrid greenhouses in which linear fresnel

lenses, built into the roof, would concentrate direct sunlight for solar thermal power conversion. Wavelengths needed for plant growth would pass through spectrally selective absorber tubes to crops below. Solar distillation units could also be located in the greenhouses. Peripheral modules would include residential systems, total energy systems which use waste heat from solar power generation, livestock enclosures, fish ponds, energy forests for biomass fuels, and windmills, all suitably interconnected.

It is our opinion that technoecological concepts would be quite useful for designing and managing such a complex technoecosystem. Too many technologies are incorporated, it seems, to permit optimum design in one initial step. Two strategies for successful evolution of such a system are set. The first is to build everything all at once, together with all feasible interconnections, and then to weed out and discard the less successful components and links, and enhance the best ones. The second strategy is to start small and simple and add new technologies in an evolutionary process, as needs grow and as new synergies become apparent. This second strategy, it seems, would offer lower costs and more flexibility, permitting each community to evolve its own unique form and history in adaptation to and symbiosis with its environment.

The arcologies of Paolo Soleri (*1969) are complex urban/industrial/agricultural technoecosystems which are so closely integrated in three dimensions that they resemble bioorganisms. Arcosanti, a prototype now under construction in central Arizona, will combine several solar technologies: greenhouse architecture, the chimney effect (upward convection of warm air from greenhouses to main structure), and the apse effect (passive climate control by insolation and shading of south facing niches, as in ancient cliff dwellings).

Complex Technoecosystems in Arid Basins

Arid basins with interior drainage offer numerous possibilities for complex solar energy technoecosystems, especially if they are below sea level. Hirschmann (1970) proposed using salt flats, in high closed basins of the Andes, for solar pond thermal energy collection in complex technoecosystems which produce power, distilled water, and pure salts. Assaf (1976) made a similar proposal for the Dead Sea: Mediterranean seawater would be imported, and excess salt from existing evaporation basins and chemical industries would maintain pond salinity gradient, while thermal energy collected would drive power and desalination plants.

As long as seawater is being brought in, it might as well drive a heliohydroelectric powerplant, as envisioned by Finkel (*1973), Bassler (1972), and Kettani and Gonsalves (1972). And great salinity contrasts, between imported seawater and sunlight-concentrated salt or brine, could be used not only for solar pond density gradient maintenance, but also for salination powerplants (Norman 1974, Clampitt and Kiviat 1976, and *Weinstein and Leitz 1976).

Agricultural systems, water recreation, geothermal power and distillation plants, and salt production in evaporation ponds are all symbiotically integrated in the technoecosystem of Imperial Valley, in the Salton Sea basin of southern California (Duffield 1976). Solar energy could be integrated with geothermal energy in hybrid power systems (Finlayson and Kammer 1975) and perhaps hybrid distillation systems. The Dead Sea and some other arid basins are also geothermal regions, for similar tectonic reasons (Duffield 1976), and may thus be suited for similar complex hybrid solar/geothermal technoecosystems.

If we put these and other technologies together, we can imagine a composite complex solar energy technoecosystem of the future, in an arid sub-sea-level basin like those of Salton Sea and Dead Sea. It would include solar pond, heliohydroelectric, salination, and hybrid solar/geothermal powerplants; desalination plants; salt evaporation and chemical industries; resort facilities for water sports and hot springs; urban/industrial technoecosystems; greenhouses which are heated and cooled by solar or geothermal energy; and field crop systems irrigated by desalted water, harvested rainfall, or even seawater. All these components would be complexly and symbiotically interconnected in patterns progressively developed by evolution, succession, competition, and historical precedent.

Solar Energy Possibilities in Imperial Valley, California

An extensive geothermal-oriented analysis of the Imperial Valley technoecosystem, and its possible successional and evolutionary future, was presented in a 1976 paper (*Ibid.*). A brief solar energy supplement seems appropriate here.

Gradual closing of the Imperial Valley water niche (based over-whelmingly on Colorado River water imported via the All-American Canal) seems to be inevitable, as water demands elsewhere in the Colorado River Basin grow and as water salinity correspondingly increases. Regressive succession of crop systems seems certain to occur, either by abandonment of fields, or perhaps by replacement

of traditional crops by salt tolerant varieties. Eventually, if suitable plants are bred, seawater irrigation, using water imported from the Gulf of California via canal or aqueduct, might completely replace Colorado River water irrigation. Present and planned geothermal power and desalting modules may be supplanted by hybrid solar/geothermal systems. And this succession may continue, if geothermal resources are tapped faster than flow niche rate, by gradual replacement of hybrid systems with purely solar-powered systems. Only heroic measures can keep Salton Sea salinity from rising, especially if seawater is imported. Eventually it may become a brine-filled sea like the Dead Sea, used for salinity power, solar pond heat collection, and salt extraction and chemical industries.

Ecological interactions which may occur in arid lands solar energy technoecosystems include water competition and symbiosis between modules and between sectors. Also, energy-intensive industries and associated support technoecosystems are likely to be attracted to large centralized solar power centers, if any should be built. If there are overwhelming advantages to solar energy collection in deserts, concentrated energy forms may be exported from arid lands to other regions, much as oil and natural gas are exported from the Middle East today.

Developing Countries

We can define developing countries as those with low per capita values of technomass and concentrated energy flow. Arid and semiarid developing countries can be classified into two natural groups: those with large resources of easily recoverable fossil fuels which can be used for rapid development (chiefly Middle Eastern oil countries), and those without such resources. Optimum solar energy technoecosystem strategies for one group differ from those of the other. We shall consider oil country strategies first.

Oil Countries: Technology Could Help Organize Development

Technoecosystem growth in the Middle East is unprecedentedly rapid, and correspondingly chaotic and often wasteful. Very fast progressive succession is taking place, with no time for gradual evolution and adaptation of technoecosystem components. New technoorganisms and even whole industrial complexes, all very highly evolved, are being imported (or, alternatively, are invading) in great numbers, attracted by the huge stocks of fossil solar energy

and their attendant great foreign exchange power. Organization of these new modules is spontaneous and difficult to plan; interconnections and siting decisions are often not as effective as they might be if growth were less feverish. Sometimes modules are imported without necessary support systems, and the result can be breakdowns, inefficiency, and delay. The situation is analogous to early, pioneering, r-selection stages of bioecosystem succession; rapid growth is most important, while efficiency is secondary.

Managers and planners in these oil countries may find technoecological concepts to be very helpful in their work. The most
important, most fundamental idea for them to grasp is that they are
building an ecosystem, an industrial ecosystem, a technoecosystem,
which is directly analogous to biological ecosystems in many ways.
From this basic realization will flow numerous corollary and subsidiary ideas and strategies. These men are building an ecosystem,
consciously or unconsciously, and perhaps they can comprehensively
design and manage it like one. Countless biological analogies will
point out novel means for doing this more effectively. Alternative
organization and design strategies will become obvious, once the
limits of traditional engineering and economic thought are transcended.

Technoecological thinking will force planners and managers to consider the needs and interconnections of whole integrated systems, so bottlenecks and inefficiencies will be more easily avoided. Therefore, of the many billions of dollars and huge quantities of energy being spent on development, much will probably be saved by using technoecological thought and methods. And the final result, the technoecosystem which remains, will probably be better adapted and of higher quality than if it had been planned using traditional thought modes.

This several decade pulse of oil wealth will flow only "once in forever." Therefore, it will be advantageous to use the most powerful and comprehensive strategies available for channeling it. Technoecological thought may help in development of such strategies.

Arid Oil Countries Have Great Need for Solar Technology

With regard to solar energy, oil-rich arid developing countries are in a unique position. With temporary excesses of wealth they can well afford the luxury of developing and trying new, unproven technologies, even large-scale ones. Recent Saudi Arabian interest in iceberg recovery technologies (*Holden 1977B) may be an example of this trend. Furthermore, unlike countries which are already industrialized, these oil countries have the advantage of being

relatively uncommitted to technological alternatives; they can adopt an entire new highly evolved complex of technologies without having to adapt them to, and build them around, large established industrial systems. Thus, new solar technologies, once developed and proven, could be deployed much faster and more completely by the oil nations than by already industrialized countries.

And finally, oil countries may have a much more urgent need than industrialized nations for establishing solar energy technologies to ease the technoecosystem transition when the oil runs out. Regressive succession is likely to be much more abrupt and catastrophic in a newly evolved technoecosystem which is wholly dependent on petroleum exports and technology imports, than in a large, mature technoecosystem with broad-based intricately-developed technological and industrial foundation. And this difference will be even more pronounced if the newly evolved technoecosystem is in a very arid region, with little natural bioecosystem resilience, while the mature system has a wetter climate and thus at least some biological productivity to fall back on. Furthermore, water supplies in the arid system are highly energy-costly and energy-dependent, while at least moderate water supplies are naturally available in the more humid system.

In conclusion, oil-rich arid developing countries of the Middle East have a very great need, perhaps the greatest need, to spend a fraction of present oil wealth to prepare solar energy systems for the inevitable oil-scarce future. Fortunately, they also have the energetic and economic means to afford research and development programs for solar energy systems, and to deploy such systems on a large scale as soon as they are competitive or nearly so. And finally, in comparison with already industrialized nations, these countries have a relatively clean industrial slate, capable of rapid and complete conversion to solar energy when the time is right. Technoecological concepts could help managers and planners in these countries evaluate, choose, and organize solar energy systems, and in the near term could help them guide present technoecosystem development in such a way that the future oil-to-solar energy transition will be smooth and successful.

Small Solar Technologies Could Help Oil-Poor Developing Countries

Arid developing countries which have no oil are in a completely different situation. Biomass (as forage, crops, crop residues, dung, and wood) is the primary and often almost exclusive source of concentrated energy (Makhijani 1976). Thus solar energy, captured by plants, and severely limited by arid conditions and water scarcity,

is already (and always has been) the primary trophic base of these regions. Imported fossil fuel use is concentrated among rich urban populations, and is generally beyond the reach of the masses, except for very essential collective roles (e.g., transportation, water pumps, and auxiliary electric power). Therefore, although little fuel is used, supply and availability fluctuations can have severe effects on technoecosystem operation.

Increased demand on aridity-limited biomass production, forced by population growth, tends to overload the capacity of the bioecosystem, resulting in self-enhancing desertification pressures and firewood shortage. The firewood crisis affects more men than does the oil crisis (*Hayes 1975), and shifts fuel demands onto shrubs and dung, with increasingly dire consequences for the bioecosystem. Replacing traditional fuel-using technologies with small fossil fuel modules increases dependence on uncertain, costly fuel imports. But small, decentralized solar energy modules, already or nearly at competitive cost level, would result in decreased fuel dependence, conservation of firewood and plant biomass, and reduced desertification pressure (Moumouni 1973), assuming that populations of people and animals do not increase.

A few simple solar energy modules added at the top of the trophic pyramid can have great multiplier effect in increasing quality of life in a low-energy biomass-based developing country technoecosystem. This is a much easier task than adding a whole new solar energy trophic base to a high-energy industrialized technoecosystem. Small decentralized modules are clearly the appropriate scale of technology for developing countries, where pervasive power grids do not exist and where rural settlements are small and scattered (Moumouni 1973, Makhijani 1976, National Academy of Sciences 1972).

For general reviews of such direct and indirect solar technologies, see *Brown and Howe (1978), Makhijani (1976), National Academy of Sciences (1976), and Stoner (1974). Solar cells (Weiss and Pak, 1976), wind generators (*Merriam 1972), and flat plate solar thermal energy systems are all either competitive with diesel-generated power now, or will be in a few years (*Brown and Howe 1978). Biomass fuel systems, very favorable in tropical developing countries (*Hammond 1977A, Poole and Williams 1976, Von Hippel and Williams 1975), are less so in arid regions because of scarcity and high value of water. Although relatively small solar modules are desirable, Meinel and Meinel (1973) find that within this size range, communal units of village scale, rather than private units of family size, are more likely to succeed.

Sensitive introduction of appropriate small-scale solar technologies to developing countries by industrial countries would be advantageous to both (*Howe and Knowland 1977). Developing countries would benefit directly from new energy supplies. And industrial nations

would benefit indirectly by demonstrating new technologies, and by expanding solar energy converter markets and thus lowering unit costs through mass production (*Hammond 1977B, Weiss and Pak 1976). A substantial program to transfer solar technologies, perhaps even at subsidized cost, could be the trigger for rapid self-enhancing decline of solar energy cost, which in turn would help drive global succession from fossil fuel to solar energy basis. Furthermore, developing countries could eventually develop their own solar energy industrial base at perhaps one-tenth the cost of a nuclear energy industry and power grid, thereby also limiting potential of nuclear weapons proliferation (*Hammond 1977B).

Environmental Effects and Niche Limits

At various points in this paper we have discussed environmental interactions and niche limits of diverse solar technologies. In this section we briefly review a few of these topics which are specifically relevant to arid lands.

Carbon Dioxide and Solar Energy in Arid Lands

The future climatic effects of continued atmospheric ${\rm CO}_2$ augmentation on arid and semiarid regions are uncertain. These areas could become drier (*Woodwell 1978) or moister (Von Hippel and Williams 1977); climatic modeling provides no final conclusions. Only time will tell, in this "uncontrolled global experiment" (*Baes et al 1977).

However, the effects of various solar technologies in arid lands on CO_2 balance can be more certainly predicted. Ocean thermal systems would emit large amounts of CO_2 . Solar thermal and photovoltaic systems, once manufactured, result in CO_2 emission or absorption only to the extent that on-site vegetation cover is destroyed or augmented. And windmills have no effect on CO_2 . In terms of the whole technoecosystem, though, these solar technologies (including ocean thermal) reduce atmospheric CO_2 emission rate to the extent that they replace burning of fossil fuel and firewood. Very large mariculture, greenhouse, field crop, or range management systems which increase plant biomass density from its sparse natural state, would actually absorb CO_2 from the atmosphere, perhaps in climatically significant quantities. Clearly, solar energy systems, and especially biomass systems in deserts, should be considered as tools in a global strategy for balancing the CO_2 budget.

Albedo and Evaporation Modification Could Reverse Desertification

Desertification is an ancient and continuing process resulting from complex interactions between technoecosystem and environment. Water, soil, and biomass exploitation beyond flow niche rate are all involved at times, as is progressive salt build-up in irrigation systems with poor drainage. Random climatic fluctuations can enhance or trigger the process by permitting growth of plant and animal biomass during wet periods and placing it under severe stress in droughts (*Eckholm and Brown 1978). Bioecological concepts are already being applied to study and management of bioecosystems for attempted desertification control. Perhaps technoecological concepts can help in managing not only the biological but also the mechanical and industrial systems which are involved.

A possible self-enhancing climatic/biological feedback mechanism, which may help perpetuate drought and augment desertification pressures, has been investigated in recent years (*Otterman 1974, *Charney 1975, *Charney et al 1975). Overgrazing (e.g., in the Sahelian zone of West Africa) decreases vegetation density and bares light-colored soil, thus significantly increasing the regional albedo. Albedo increase, in turn, results in cooler surface temperatures, increased atmospheric stability, southward shift of the intertropical convergence zone, and major decrease in precipitation. Less rain means less vegetation, thus closing the feedback loop and enhancing the dry climatic conditions.

Understanding this mechanism may enable us to use it, thus expanding technoecosystem domain to include atmospheric control by albedo modulation over large areas of desert. Since albedo increase diminishes precipitation, we might expect albedo decrease to augment rainfall. Computer modeling of global climate, assuming establishment of very large low albedo solar conversion facilities in deserts of the world, indicates that this is indeed what would happen (*Potter and MacCracken 1978).

In high albedo deserts, reflectivity would be decreased by several types of solar energy conversion systems (e.g., solar thermal systems, solar ponds, heliohydroelectric basins, photovoltaic systems, and seawater irrigation crop systems). A side effect of widespread and large-scale deployment of such technologies is likely to be a permanent increase of rainfall, of obvious benefit to arid lands technoecosystems. Since these solar facilities, unlike vegetation, are essentially permanent and independent of rainfall, they would tend to damp the albedo feedback effects of climatic fluctuation, and thus might stabilize regional climate at a new, moister equilibrium.

Increased evaporation is another effect of large-scale solar energy technoecosystems deployment which may tend to increase

precipitation and make desert climates moister (*Davidson and Grether 1978). Large amounts of water might be evaporated in solar thermal powerplant cooling towers (Ibid.), but in the southwestern U.S. this is likely to be water reallocated from other uses (agriculture, cities, or perhaps shut-down fossil fuel powerplants), and thus would not represent net evaporation increase. Similarly, increased evaporation from urban and agricultural systems which support new human populations, perhaps attracted by solar energy facilities (Ibid.), might come temporarily from groundwater storage overdraft, but ultimately from reallocation of water flow resources; again no net evaporation increase in the long run. However, there are two solar technologies which definitely would increase regional evaporation: large-scale seawater irrigation systems, and heliohydroelectric systems in formerly dry basins. Possible climatic effects of these technologies need more study. Locally and regionally, effects of increased evaporation may be negligible (*McDonald 1962), dwarfed by albedo effects.

Besides albedo and evaporation changes, environmental effects of heliohydroelectric projects would include decreasing salinity in oceans, and, perhaps, slight sea level rise in the case of gulfs which are dammed. One ultimate niche limit of a heliohydroelectric system is the gradual filling of its basin with salts, as in geologic evaporite basins. Salts could be removed by mechanical means, but at the cost of much energy and much disruption at disposal site.

Limited Water Niches, Transcended by Solar Cells

For some solar technologies, as for plants, water supply is a limiting factor. Large solar energy systems which tap groundwater storages faster than they are replenished face the time limits of a stock niche, just as do irrigated agriculture systems and urban technoecosystems which depend on groundwater overdraft. Thus waterusing, water-subsidized solar thermal powerplants might "bloom" for a while, then "wither" when groundwater supplies give out. Actually, a more gradual succession is likely to take place. Falling water table would increase pumping cost and water competition with other sectors. Gradually water-using solar modules would be replaced by systems which require little or no water.

If solar cell costs should fall as fast and as far as projected, such a scenario might never take place, because water-conserving solar cells would be more favorable than solar thermal systems almost from the start of fossil fuel replacement. Human populations in deserts have been limited largely by low plant productivity and water scarcity. Water-independent very cheap solar cells, by

substantially replacing water-limited plant energy and by subsidizing high-energy water supply and conservation technologies, could remove these ancient barriers to population growth. We should prepare for the effects of such a transition.

Beyond this Planet

Now it is time to step back from the local peculiarities of our planet to a larger physical perspective. So much has been assumed in our thinking -- skies, lands, up-down vectors, earth-like atmospheres, oceans, and rains (no matter how seldom). In universe these are rare, special states. Even the difference between arid and humid lands is minute in astrophysical perspective. Space is the most arid of all environments, a four-dimensional desert drier than any on Earth.

Specially adapted technoorganisms have been developed for space, and specially adapted complex technoecosystems have been proposed for it. Whether or not these technoecosystems ever actually come into existence, they demonstrate very well numerous technoecological principles, and illustrate the ultimate extension of adaptation to aridity.

Orbiting Technoorganisms

Solar power systems, chiefly solar cells, have become routine on satellites and interplanetary space probe technoorganisms. "Space light" systems, giant mirrors in stationary Earth orbit, could direct additional sunlight to the Earth's surface, day or night, for industrial or agricultural use, urban security, or weather modification (*Von Puttkamer 1977).

Space has special advantages for solar powerplants. It is a superb radiative heat sink, and direct sunlight is not attenuated by atmosphere or blocked by day/night cycles. To exploit this niche, large satellite solar power station technoorganisms have been proposed (Glaser 1976, *Williams 1975). From geosynchronous orbits these modules would beam electrical energy as focused microwaves to large antenna fields on the surface.

Arid lands, with their sparse settlement patterns, would be likely sites for such antenna fields. These fields, as concentrated sources of high quality energy, are analogous to oil fields, and similar technoecosystem patterns might appear (e.g., attraction of energy intensive industries). Hybrid power systems, in which solar power collectors double as microwave antennas, might be considered.

Energy density would be increased and a single energy transport system could be used for both power modes.

Space power satellite systems, however, would have uncertain but possibly significant environmental impacts (*Ching 1977, Von Hippel and Williams 1977). Microwave beams could affect bioorganisms and atmospheric structure. But the greatest impacts would result from the 10 or so daily flights of space shuttle technoorganisms needed to service a satellite fleet. Exhaust products burn "holes" in ionosphere and pollute the stratosphere, thereby depleting ozone, allowing more ultraviolet radiation to reach the surface, and perhaps altering climate.

Colonies and Complex Technoecosystems in Space

Lifting materials for solar power satellites from Earth's deep gravity well imposes a large energy tax. This could be largely avoided by lifting materials from the moon, with gravity well only five percent as deep. To accomplish the task, O'Neill (1975, *1977) has proposed huge complex space technoecosystems. These would include colonies on the moon for mining and launching materials, and space colonies in high Earth orbit for manufacturing solar power satellites and still more space colonies. The orbiting space colonies would be self-contained agricultural/urban/industrial technoecosystems which are, like Soleri's arcologies, so converged and miniaturized and symbiotically interwoven that they can be considered to be technoorganisms. Unlike Earth-rooted colonies, though, these would be turned inside-out and rotated about an axis for generation of simulated gravity. Space colonies would be the ultimate in aridadapted controlled environment agriculture and dwelling systems. All materials would have to be imported and fabricated at great cost, so total recycling, especially of water and air, would be essential.

Solar energy would be the primary energy source for such a technoecosystem. It would grow plants, produce electricity, and provide process heat in the orbiting colonies. Furthermore, it would be the energy source for propulsion systems. Solar powered mass drivers would lift minerals off the moon, and could also be used as reaction engines for transporting new power satellites to geosynchronous orbit, or for retrieving metal-rich asteroids. A mass driver and solar energy can convert a mass of inert rock into the equivalent of high quality rocket fuel by throwing it at great speed. Other solar powered propulsion systems include ion accelerators, and solar sails which are driven by solar wind much like certain seeds on earth.

A complex technoecosystem of this type is analogous to biological systems in various ways. We are reminded of the colonization of a

new pond, with diverse technoorganisms interacting and multiplying at an exponential rate. Automated technoorganisms called "space spiders" have been proposed to spin light space structures; the biological analogy is quite evident in the name. Each technoorganism's design would reflect a long evolutionary past, and the careful optimization of many variables and details. Space colonies contain Earth's biosphere in miniature, much as terrestrial organisms maintain within themselves an approximation of the seawater within which they originated.

Zoning, Evolution, and Succession in Space Technoecosystems

Technoecosystems in space would face environmental gradients and resource and niche limits, just as terrestrial technoecosystems and bioorganisms do. Autotrophic solar powered technoorganisms would work well near the sun, but not very efficiently in the dimly illuminated outer solar system. In the outer reaches, perhaps only a few solar energy subsidized nuclear powered heterotrophs might venture. Asteroids are a limited resource in the solar system. A growing technoecosystem which captures and mines them might undergo regressive succession or forced evolution as the richest asteroids in the easiest orbits are used up. Certain resources like carbon, hydrogen, or water may act as limiting "nutrients" for complex space technoorganisms; large energy costs for extracting, importing, and recycling them may be worthwhile, as in biological systems.

Space technoecosystems might be imagined to undergo an eons-long evolutionary and successional history like that of life on Earth. One stage in this scenario might include technoecosystems like those that Parkinson (*1975) proposed: complex, diverse, specialized technoorganisms all over the solar system; systems for mining scarce light elements; ramjet-powered technoorganisms shooting through the atmospheres of Jupiter and Venus; and manned industrial technoorganisms supported by hot air balloons in the atmosphere of Jupiter. The geometry and details may make one disoriented and even dizzy. But objectively, they are no more weird than bioecosystems in the Namib desert, or bioecosystems in an Ordovician sea, or even the technoecosystems within which we live.

Technoecosystems on Other Planets: Martians and Men

"By the material changes in the surface of a planet wrought by the dominance of his mind over matter would the other world-worker stand confessed." So wrote the astronomer Percival Lowell (*1908, p. 107) about intelligent beings on Mars. He realized that not men, but their technoecosystem and its effects, would be most noticeable to distant observers. This same assumption underlies recent attempts to detect radio signals from civilizations in distant star systems.

Lowell thought he saw evidence of intelligent life on Mars: "Fine lines and little gossamer filaments only, cobwebbing the face of the Martian disk, but threads to draw one's mind after them across the millions of miles of intervening void." [Op. cit., p. 146] These lines he interpreted as the canals of a vast planet-wide arid lands technoecosystem. Indeed, arid lands technoecosystems on other planets might be expected to develop morphologies and adaptations similar to those in arid lands on Earth, in spite of different evolutionary histories. Such interplanetary convergent evolution would be analogous to intercontinental convergent evolution of desert plant life forms and of irrigated agricultural systems.

Sadly, though, close examination of Mars by space probe technoorganisms has shown that there are no canals, no technoecosystems there. But the entire planet could become an arid lands technoecosystem under the management of Earth men, according to a recent NASA study (*Robinson 1977). Planetary engineering might be able to change the harsh environment of Mars into one that men can inhabit. Solar energy would be the driving Force for such an endeavor. Albedo modification would warm the poles and vaporize the icecaps, liberating CO₂ and water to warm the atmosphere. And colonies of hardy microorganisms, some of them photosynthesizers, would be introduced to generate oxygen and maintain geochemical homeostasis, much as microorganisms did on the ancient Earth. Another stage would be set, then, for biological and technological adventures.

V. CONCLUSION

Importance of Technoecology

In this paper we have tried to show the usefulness and broad applicability of technoecological concepts in studying and comprehending solar energy technologies. This work is just beginning; we have barely scratched the surface of a vast field of biological analogies and their practical applications.

Technoecological overview offers us an alternative way to look at what we are doing with our industrial systems, an alternative self-concept for our civilization. Since our actions usually reflect what we think we are, such new perspective could influence the style and content of technological manifestations. Perhaps we would run the world differently, perhaps more successfully, if, rather than focusing mainly on social/political/economic phenomena, we realized that we are operating a global industrial ecosystem. Technoecosystem transition to solar energy base is probably imminent and inevitable, but this and its many ramifications are hardly obvious except through technoecological overview. Such an overview can help alert us to what is coming, and help us bring it about faster and more comfortably.

Research and Development Recommendations

Solar energy technologies seem to promise the great new permanent global energy niche which we are so desperately seeking. They deserve very much intensified research and development efforts, because time is running out fast for the present petroleum-based energy niche. Focus of U.S. research and development should probably change from large scale centralized systems to the more promising small and medium scale decentralized systems, which are capable of mass production and adaptable installation. Analogy between biological and industrial systems may be useful for evaluation, invention, design, and organization of these new technologies.

Synergies of International Cooperation

Close cooperation between industrialized nations, oil-producing developing countries, and oil-importing developing countries can help accelerate the coming solar energy transition, upon which everyone's survival appears to depend. Industrialized nations can focus their highly developed research and development capabilities on intensive

evolution of solar technologies. Oil-producing developing countries, which have a great stake in successful oil-to-solar energy transition, can help support these research and development programs, and can try promising but unproven technologies on a large scale. Finally, industrial and oil-producing countries can combine forces in subsidizing a massive transfer of solar technologies to oil-importing developing countries. In these poorer countries, energy costs and needs are great, and solar energy systems are already competitive with traditional systems, or are nearly so. Supplying this large market would help solar manufacturing industries get started, and would allow prices to fall with mass production, perhaps passing below the cost threshold where rapid spontaneous worldwide transition to solar energy will begin.

Cheap Solar Cells Could Completely Replace Fossil Fuels

Of all solar technologies, photovoltaic conversion may deserve the most intensive research and development attention. Solar cells, more than any other solar energy conversion system, have the potential to become the permanent solar energy basis for world technoecosystems, much as chloroplasts are the solar energy foundation of world bioecosystems. Solar cells are ideal because of their simplicity, durability, adaptability, economy of materials, high quality electrical energy output, high conversion efficiency, and great flexibility of size and design. They are the best solar power technology for humid climates because they work on overcast days, and the best for arid climates because they operate at quantum level and need no cooling water. Only high cost and small industry size prevent their immediate widespread deployment.

But solar cell cost is projected to plummet in the next few years, resulting in an explosion of markets, demand, and manufacturing facilities. Projected cost declines will take solar cells, now prohibitively expensive, and make them easily affordable by the global technoecosystem as a replacement for fossil fuels.

Table 1, like Fig. 1 in Chapter 3, clearly demonstrates this affordability of solar cells in the very near future. In the energy-rich United States, present per capita electricity use is about one kilowatt, and per capita consumption of high quality energy from all primary sources is about 10 kilowatts. At current prices, solar cells to provide these individual energy needs would cost \$50,000 for electricity and \$500,000 for all energy, clearly too much to be practical. But at 1986 prices, the same solar cell arrays would cost only \$2,300 for electricity, and \$23,000 (the cost of a college

Table 1. Future solar cell costs compared to world GNP and world military spending

Time (Years A.D.)	1978	1982	1986	1990's (high cost)	1990's (low cost)
Solar cell cost per peak watt (1)	\$11.00	\$2.00	\$0.50	\$0.30	\$0.10
Solar cell cost for 1 kWe power (2)	\$50,000	\$9,100	\$2,300	\$1,400	\$450
Solar cell cost for whole world population at 1 kWe per capita (3)	\$2.0 x 10 ¹⁴	\$3.6 x 10 ¹³	\$9.1 x 10 ¹²	\$5.4 x 10 ¹²	\$1.8 x 10 ¹²
Years of 1975 world military spending to pay for solar cells (4)		110	27	16	5.3
Years of 1975 world GNP to pay for solar cells (5)	35	6.4	1.6 (19 months)	0.95 (11 months)	0.32 (4 months)
Solar cell cost for 10 kWe power (6)	\$500,000	\$91,000	\$23,000	\$14,000	\$4,500
Solar cell cost for whole world population at 10 kWe per capita (7)		\$3.6 x 10 ¹⁴	\$9.1 x 10 ¹³	\$5.4 x 10 ¹³	\$1.8 x 10 ¹³
Years of 1975 world military spending to pay for solar cells (4)	5,900	1,100	270	160	53
Years of 1975 world GNP to pay for solar cells (5)	350	64	16	9.5	3.2

Notes:

- (1) U.S. Department of Energy estimates (*Kelly 1978).
- (2) One kilowatt is approximately the average electric power used per person in the U.S. Assume average daily output of 5.3 kWe for a 1 kWe (peak) solar cell array, or a 22 percent load factor (*Brown and Howe 1978).
- (3) Cost of solar cells to provide world population with electric power equal to U.S. per capita average. Total output is assumed to be 4.0 x 10⁹ kWe, or 1.0 kWe for each of 4.0 billion people.
- (4) Number of years of world military budget required to pay for all solar cells. Assume military budget of \$340 billion, the 1975 value (*U.S. Bureau of the Census 1976).
- (5) Number of years of world GNP required to pay for all solar cells. Assume world GNP is \$5.7 trillion, calculated by assuming that military budget is 6 percent of world GNP (*Ibid*.).
- (6) Ten kilowatts is approximately the average total primary energy use rate per person in U.S. (*Grether, Davidson, and Weingart 1978).
- (7) Cost of solar cells to provide world population with electric power equal to U.S. per capita total energy use.

education) for all energy. [Costs of maintenance, energy storage, and energy transmission systems are not included in this simplified analysis.]

Further cost decline through the 1990's would make photovoltaic systems affordable by most of the world's population. Solar cells capable of providing U.S. levels of electricity for 20 years would cost only \$450 to \$1400 per person, much less than present utility rates. And for the price of a new automobile, \$4,500 to \$14,000, enough solar cells could be purchased to produce all the energy an average U.S. citizen uses for 20 years.

Considered at global scale, a technoecosystem based on photo-voltaic conversion appears even more reasonable, when 1990's prices are assumed (Table 1). Supplying everyone in the world with enough solar cells to have U.S.-level electric power would require just 4 to 11 months of world GNP, or 5 to 16 years of world military spending (1975 levels). And a solar cell population capable of supporting all the world's people at U.S. energy consumption levels would cost only 3 to 9 years of world GNP.

There is no excuse for ignoring these numbers and their implications. Solar cell cost decline in the very near future will bring solar cell energy systems well within global technoecosystem affordability. It appears that solar cells could not only replace fossil fuels, but could easily go beyond fossil fuel capabilities and support the entire world population at unprecedentedly high levels of energy wealth.

Development of Cheap Solar Cells Should Have Highest Priority

The total spending necessary to bring solar cell cost down to projected 1986 levels is on the order of \$1 to \$10 billion, much less than the cost of developing breeder reactor technology (Wolf 1976), and minuscule in comparison with the ponderous world military budget, about \$350 billion per year. If national security is actually based on technoecosystem health and efficiency rather than on military power (*Holden 1977A), then a few billion dollars spent on solar cell development will be probably the greatest national security bargain available, with enormous benefits spread among all nations and all people in the world.

Why do we delay? A crash effort to develop cheap solar cells should clearly have top priority both nationally and internationally.

Promising Solar Technologies for Arid Lands

For long-term development and survival of large high energy technoecosystems in arid lands, solar cells are probably the crucial technology. Other arid lands solar technologies which deserve much development effort include: systems which collect, process, and conserve water; solar desalination systems; controlled environment agriculture systems; dry land agricultural systems based on aridadapted economic plants; and evolution of salt-tolerant crop plants for irrigated agriculture using seawater and brackish water. These technologies could form the trophic base of arid lands technoecosystems, much as desert plants support arid bioecosystems. Once this energy and water producing foundation is established, evolution of more complex arid-adapted systems, higher in the trophic pyramid, will occur spontaneously.

Solar Energy Revolution Has Begun

A solar energy revolution is brewing in technoecosystems around the world, and it appears to be on the verge of exploding into popular awareness. In many laboratories and factories, scores of solar energy inventions and technologies are being developed, each of which, if perfected and multiplied by millions, could transform desert cultures, global technoecosystems, and the lives of all humanity. In the history of technology, evolutionary spurts have involved development of ways to use energy, but never before has there been a time or technology in which so many ways to capture energy were opening up and being explored.

The only analogous situations that come to mind are the agricultural revolution, in which men tried and adopted many plants and cultivation systems, and the photosynthetic revolution, in which numerous biochemical and structural means were evolved and selected in primitive organisms. But those revolutions occurred on much longer time scales (centuries or millenia, and millions of years, respectively), while the solar energy revolution is occurring in a greatly accelerated time frame of years to decades. Technoecological overview allows us to better appreciate the momentous nature of this revolution, and gives us an early sense of what kinds of phenomena to expect and what kinds of actions might be most effective in speeding and smoothing its progress.

Pre-Solar Failure is Possible

We are at a crucial nexus of events. Oil resources are inexorably being depleted, as populations and technoecosystems

expand, international tensions rise, and military systems grow ever more destructive. And at the same time a new, large, permanent, environmentally-benevolent, global energy niche is materializing into the realm of possibility. How soon we realize this potential of solar energy and how soon we act upon that realization may have a tremendous impact on the world of the future. Technoecological concepts could help awaken people to the solar option and its importance, and could serve as the means for understanding what is happening and what we should do next.

There seems to be a finite and narrow passage which opens from our present world to a future solar civilization. This passage is lined with perils on both sides: wars, famines, environmental disasters, etc. Perhaps it is best for us to start quickly through that passage while it is still open. The solar energy revolution may be imminent, but it is inevitable only if we do not blunder away from or off the narrow path and destroy ourselves.

We are living in the same real historical time that ancient civilizations and still older fossil life forms lived in. Archae-ologists and paleontologists, respectively, study their remains and see their patterns of evolution, succession, and extinction. Our time, too, will become one of these layers of history, and our success or failure will be duly and impartially recorded. In historical symbiosis with environment, our actions will save us or destroy us. Like the ancient Egyptians, the Assyrians, the Hohokam, like the dinosaurs and trilobites, our choices are infinite in prospect, finite in retrospect. Which way will we go? A long-lasting, stable, solar-powered technoecosystem could be a very enjoyable world to live in; it would be a shame to miss it.

Civilization is now quite fluid on a scale of years to decades. New precedents are possible; nothing but the past is fixed. We are limited only by environmental conditions, physical laws, and imagination.

Solar Civilization: New Consciousness, New Limits

Transition to solar energy is likely to be accompanied by an alteration of consciousness. Rather than continuing to exploit resources blindly, heedless of consequences, we will be forced to expand our thinking to the level of whole systems and ecosystems, because that is where we will have to work to ensure our continued life support. Energy industrialists will become more like farmers, while today they are like hunters, because fossil fuels, like animals, are concentrated storages which are hunted and slaughtered,

while solar energy technologies must be selected, cultivated, and harvested like plants.

The solar energy niche may be our salvation, but it, too, has its perils. As with agricultural niches of the past, there is still the danger of technoecosystem and population growth beyond niche limits. In the past, new niches and new unpopulated lands were often available; but this time, it appears, we have nowhere else to go. No matter how large the solar energy niche looks, no matter how happy we are to find it, we must enter it with due caution. This may be our last chance to apply the lessons of history: avoid environmental disasters through awareness and planning; know technoecosystem niche limits and stay within them; and above all, stabilize population at a level which can be supported in comfort and dignity.

Dawn of the Technozoic

Earth history has been partitioned into five great divisions (*Cloud 1974). The boundaries between the last three correspond with major events in the evolution of life. The Proterophytic ended and the Proterozoic began two billion years ago, when the first eukaryotic cells (complex cells with nuclei, chloroplasts, and mitochondria) appeared. The huge success of these organisms profoundly changed geochemical cycles, resulting in an oxygen-rich atmosphere and the deposition of carbonate rocks and redbeds. Similarly, the Proterozoic ended and the Phanerozoic began about 680 million years ago, with the first appearance of metazoa (differentiated multicellular animals) and more complex plants.

The Phanerozoic continues today, according to Cloud, and "will end when multicellular plant and animal life becomes extinct." However, by analogy to the Proterophytic/Proterozoic and Proterozoic/Phanerozoic boundaries, perhaps the Phanerozoic should be considered at an end when the next higher level of life's organization becomes manifest.

But that is happening right now, we suggest. We ourselves are witnessing the end of a geologic age, the Phanerozoic, and the dawn of a new one. Technoecosystems, we maintain, are the next higher level of life's organization. Thus we can call this new division of earth history the "Technozoic", meaning age of "industrial animals" or technoorganisms.

This is indeed a new stage in earth history, directly analogous to previous ones. We men are metazoa, and have become symbiotically embedded in larger technoecosystems, much as prokaryotic cells became

embedded symbiotically in larger eukaryotes at the start of the Proterozoic, and much as eukaryotic cells became embedded symbiotically in multicellular metazoa at the start of the Phanerozoic. And the appearance of global technoecosystems, like the successive appearances of prokaryotes, eukaryotes, and metazoa, has brought about major changes, at least as profound, in geological and geochemical systems. Among the more significant changes are the mining and organization of scarce metals, the recovery and burning of fossil fuels, the modification and destruction of soils and vegetation, and the alteration of atmospheric composition.

The only difference between ancient and modern changes is that the former took place over many millions of years, while the latter have been occurring over centuries and decades, an explosion by comparison. Technoecosystem evolution can be seen as a continuation of the evolution of life, only accelerated, conscious, and free from many former biological constraints.

The Technozoic is really just getting started in this century, because only now are exponentially-growing technoecosystems, their strategies, and their effects suddenly reaching global proportions. Fossil fuel exploitation is a starter pulse, a geochemical detonation in the perspective of geologic time, and the impending conversion of technoecosystem to solar energy base will be a geological event at least as significant as the analogous evolution of chloroplasts.

We are witnessing the dawn of the Technozoic. May its sunset be far, far in the future. SUPPLEMENTARY REFERENCES

SUPPLEMENTARY REFERENCES

[indicated in text by asterisk (*) preceding author]

- Adams, J.A.S. / Mantovani, M.S.M. / Lundell, L.L. (1977) Wood versus fossil fuel as a source of excess carbon dioxide in the atmosphere: A preliminary report. Science 196(4285):54-56.
- Baes, C.F., Jr. et al (1977) Carbon dioxide and climate: The uncontrolled experiment. American Scientist 65(3):310-320.
- Bahadori, M.N. (1978) Passive cooling systems in Iranian architecture. Scientific American 238(2):144-150, 152, 154.
- Bamberger, C.E. / Braunstein, J. (1975) Hydrogen: A versatile element. American Scientist 63(4):438-447.
- Barnaby, F. (1976) Environmental warfare. Bulletin of the Atomic Scientists 32(5):36-43.
- Bassham, J.A. (1977) Increasing crop production through more controlled photosynthesis. Science 197(4304):630-638.
- Berg, C.A. (1978) Process innovation and changes in industrial energy use. Science 199(4329):608-614.
- Bevan, W. (1977) Science in the penultimate age. American Scientist 65(5):538-546.
- Blake, F.A. / Walton, J.D. (1975) Update on the solar power system and component research program. Solar Energy 17(4): 213-219.
- Boffey, P.M. (1977) How the Swedes live well while consuming less energy. Science 196(4292):856.
- Boserup, E. (1965) The conditions of agricultural growth: The economics of agrarian change under population pressure. Aldine, Chicago. 124 p.
- Brink, R.A. / Densmore, J.W. / Hill, G.A. (1977) Soil deterioration and the growing world demand for food. Science 197(4304): 625-630.
- Brown, N.L. / Howe, J.W. (1978) Solar energy for village development. Science 199(4329):651-657.
- Burwell, C.C. (1978) Solar biomass energy: An overview of U.S. potential. Science 199(4333):1041-1048.
- Butzer, K.W. (1977) Environment, culture, and human evolution. American Scientist 65(5):572-584.
- Calvin, M. (1975) Chemical evolution. American Scientist 63(2): 169-177.

- Charney, J.G. (1975) Dynamics of deserts and drought in the Sahel. Royal Meteorological Society, Quarterly Journal 101(428):193-202.
- Charney, J.G. / Stone, P.H. / Quirk, W.J. (1975) Drought in the Sahara: A biogeophysical feedback mechanism. Science 187(4175):434-435.
- Chauhan, R.S. (1976) Solar energy concentration with liquid lenses. Solar Energy 18(6):587-589.
- Ching, B.K. (1977) Space power systems: what environmental impact? Astronautics and Aeronautics 15(2):60-65.
- Cloud, P. (1974) Evolution of ecosystems. American Scientist 62(1):54-66.
- Cooley, K.R. (1970) Energy relationships in the design of floating covers for evaporation reduction. Water Resources Research 6(3):717-727. (See SWRA W70-09112)
- Davidson, M., and Grether, D. (1978) The effects of solar energy conversion on climate. In J. Williams, G. Kromer, and J. Weingart, eds. (1978), q.v., p. 91-108.
- Davis, E.S. (1975) Solar-assisted gas energy water-heating feasibility for apartments. Solar Energy 17(4):237-243.
- Dawson, T.J. (1972) Thermoregulation in Australian desert kangaroos. In G.M.O. Maloiy, ed., Comparative physiology of desert animals: Proceedings of a symposium held at the Zoological Society of London, July 15-16, 1971. Zoological Society of London, Symposia 31:133-146.
- Day, P.R. (1977) Plant genetics: increasing crop yield. Science 197(4311):1334-1339.
- Duffield, C. (1975) Solar shadow maps. University of Arizona, Tucson (M.S. thesis). 78 p.
- Duffield, C. (1978) Solar energy technoecosystems in arid lands.
 University of Arizona, Tucson (Ph.D dissertation). 176 p.
- Eckholm, E., and Brown, L.R. (1978) Spreading deserts -- the hand of man. Bulletin of the Atomic Scientists 34(1):10-16, 44-51.
- Eddy, J.A. (1977) The case of the missing sunspots. Scientific American 236(5):80-84, 85-88, 92.
- Edmondson, W.B. (1976) "Hurricanados" to supply water and power for the Southwest? Solar Energy Digest 6(5):1-4.
- Eisenstadt, M.M. / Utton, A.E. (1976) Solar rights and their effect on solar heating and cooling. Natural Resources Journal 16(2):363-414.
- Evans, H.J. / Barber, L.E. (1977) Biological nitrogen fixation for food and fiber production. Science 197(4301):332-339.

- Farlow, J.O. / Thompson, C.V. / Rosner, D.E. (1976) Plates of the dinosaur Stegosaurus: forced convection heat loss fins? Science 192(4244):1123-1125.
- Fathy, H. (1973) Architecture for the poor. University of Chicago Press. 233 p.
- Finkel, H. (1973) Hydroelectric power from the Dead Sea. Paper presented at the 3rd World Congress of Engineers and Architects in Israel, Tel Aviv, December 17-24, 1973. Faculty of Agricultural Engineering, Technion, Haifa. 12 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.
- Fuggle, R.G. (1971) Relationships between micro-climatic parameters, and Basuto dwelling sites in the Marakabei Basin, Lesotho. South African Journal of Science 67(9):443-450.
- Garnett, A. (1935) Insolation, topography, and settlement in the Alps. Geographical Review 25(4):601-617.
- Gerardin, L. (1968) Bionics. McGraw-Hill, New York. 254 p.
- Gibbs, J.G. / Patten, D.T. (1970) Plant temperatures and heat flux in a Sonoran Desert ecosystem. Oecologia 5(3):165-184.
- Goldstein, I.S. (1975) Potential for converting wood into plastics. Science 189(4206):847-852.
- Grether, D. / Davidson, M. / Weingart, J. (1978) A scenario for albedo modification due to intensive solar energy production. In J. Williams, G. Kromer, and J. Weingart, eds. (1978), q.v., p. 109-113.
- Hammond, A.L. (1977A) Alcohol: A Brazilian answer to the energy crisis. Science 195(4278):564-566.
- Hammond, A.L. (1977B) An international partnership for solar power (editorial). Science 197(4304):623.
- Handler, P. (1975) On the state of man. BioScience 25(7):425-432.
- Hay, H.R. (1973) Energy, technology, and solarchitecture. Mechanical Engineering 95(11):18-22.
- Hayes, D. (1975) Solar power in the Middle East (editorial). Science 188(4195):1261.
- Heichel, G.H. (1976) Agricultural production and energy resources.

 American Scientist 64(1):64-72.
- Heinrich, B. (1977) The physiology of exercise in the bumblebee. American Scientist 65(4):455-465.

- Hill, R.W. / Veghte, J.H. (1976) Jackrabbit ears: Surface temperatures and vascular responses. Science 194(4263):436-438.
- Holden, C. (1977A) Ecology and national security. Science 198(4318):712.
- Holden, C. (1977B) Experts ponder icebergs as relief for world water dilemma. Science 198(4314):274-276.
- Holdren, J.P. / Ehrlich, P.R. (1974) Human population and the global environment. American Scientist 62(3):282-292.
- Horn, H.S. (1971) The adaptive geometry of trees. Princeton University Press. 144 p.
- Horn, H.S. (1975) Forest succession. Scientific American 232 (5):90-98.
- Howe, J.W. / Knowland, W.E. (1977) Letter. Science 197(4308): 1034.
- Jacob, F. (1977) Evolution and tinkering. Science 196(4295): 1161-1166.
- Johnson, W.A. / Stoltzfus, V. / Craumer, P. (1977) Energy conservation in Amish agriculture. Science 198(4315):373-378.
- Johnston, W.D., Jr. (1977) The prospects for photovoltaic conversion. American Scientist 65(6):729-736.
- Kellogg, W.W. (1978) Is mankind warming the earth? Bulletin of the Atomic Scientists 34(2):10-19.
- Kelly, H. (1978) Photovoltaic power systems: A tour through the alternatives. Science 199(4329):634-643.
- Kevan, P.G. (1975) Sun-tracking solar furnaces in high arctic flowers: Significance for pollination and insects. Science 189(4204):723-726.
- Keyes, C.G. et al (1970) Disposal of brine by solar evaporation:
 Field experiments. U.S. Office of Saline Water Research and
 Development Progress Report 563. 166 p. (See SWRA W70-09150)
- Krause, C. (1975) Ice bin cometh. Oak Ridge National Laboratory Review 8(4):18-23.
- Laporte, L.F. (1977) Paleoenvironments and paleoecology. American Scientist 65(6):720-728.
- Lipinsky, E.S. (1978) Fuels from biomass: Integration with food and materials systems. Science 199(4329):644-651.
- Lovins, A.B. (1977) Soft energy paths: Toward a durable peace. Friends of the Earth-Ballinger, Cambridge, Massachusetts. 231 p.
- Lowell, P. (1908) Mars as the abode of life. Macmillan Company, New York. 288 p.

- Mares, M.A. et al (1977) The strategies and community patterns of desert animals. In G.H. Orians and O.T. Solbrig, eds., Convergent evolution in warm deserts: An examination of strategies and patterns in deserts of Argentina and the United States. US/IBP Synthesis Series 3:107-163. Dowden, Hutchinson & Ross, Stroudsburg, Pennsylvania.
- Martin, P.S. (1973) The discovery of America. Science 179(4077): 969-974.
- Maugh, T.H., II (1976) The petroleum plant: Perhaps we can grow gasoline. Science 194(4260):46.
- McDonald, J.E. (1962) The evaporation-precipitation fallacy. Weather 17(5):1-9.
- Meinel, A.B. / Meinel, M.P. (1972) A harvest of solar energy. University of Arizona, Optical Sciences Center, Newsletter 6(3):68-75. (See SWRA W73-10216)
- Merriam, M.F. (1972) Is there a place for the windmill in the less developed countries? East-West Center, Honolulu, Hawaii, Technology and Development Institute, Working Paper Series 20. 24 p.
- Meyerhoff, A.A. (1976) Economic impact and geopolitical implications of giant petroleum fields. American Scientist 64(5):536-541.
- Mooney, H.A. / Ehleringer, J. / Berry, J.A. (1976) High photosynthetic capacity of a winter annual in Death Valley. Science 194(4262):322-324.
- Moreland, F.L., ed. (1975) Alternatives in energy conservation:
 The use of earth covered buildings. Conference, Fort Worth, Texas,
 July 9-12, 1975, Proceedings. National Science Foundation
 NSF-RA-760006. 353 p.
- Mosimann, J.E. / Martin, P.S. (1975) Simulating overkill by paleoindians. American Scientist 63(3):304-313.
- National Academy of Sciences, Washington, D.C. (1974) More water for arid lands: Promising technologies and research opportunities. 153 p.
- Nef, J.U. (1977) An early energy crisis and its consequences. Scientific American 237(5):140-142, 146-149, 151.
- Odum, E.P. (1977) The emergence of ecology as a new integrative discipline. Science 195(4284):1289-1293.
- 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, New York. 331 p.

- Odum, H.T. (1972) Chemical cycles with energy circuit models. In D. Dryssen and D. Jagner, eds., The changing chemistry of the oceans, Twentieth Nobel Symposium, Gotenborg, Sweden, 1971, Proceedings p. 223-259. Wiley, New York.
- Odum, H.T. / Odum, E.C. (1976) Energy basis for man and nature. McGraw-Hill, New York. 295 p.
- Ohta, T. et al (1976) Photochemical and thermoelectric utilization of solar energy in a hybrid water-splitting system.

 International Journal of Hydrogen Energy 1(2):113-116.
- O'Neill, G.K. (1977) The high frontier: Human colonies in space. Morrow, New York. 288 p.
- Orians, G.H. / Solbrig, O.T., eds. (1977) Convergent evolution in warm deserts: An examination of strategies and patterns in deserts of Argentina and the United States. US/IBP Synthesis Series 3. Dowden, Hutchinson & Ross, Stroudsburg, Pennsylvania. 333 p.
- Oswald, W.J. (1973) Productivity of algae in sewage disposal. Solar Energy 15(1):107-117.
- Otterman, J. (1974) Baring high-albedo soils by overgrazing: A hypothesized desertification mechanism. Science 186(4163): 531-533.
- Parkinson, R.C. (1975) The resources of the solar system. Spaceflight 17(4):124-128.
- Pimentel, D. et al (1976) Land degradation: Effects on food and energy resources. Science 194(4261):149-155.
- Porter, K.G. (1977) The plant-animal interface in freshwater ecosystems. American Scientist 65(2):159-170.
- Potter, G.L., MacCracken, M.C. (1978) Possible climatic impact of large-scale solar thermal energy production. In Williams, Kromer, and Weingart, eds. (1978), q.v., p. 115-122.
- Puerto Rico Planning Board (1969) The control of building shadow. Same as author. 14 p.
- Rao, D.P., / Rao, K.S. (1976) Solar water pump for lift irrigation. Solar Energy 18(5):405-411.
- Rapport, D.J. / Turner, J.E. (1977) Economic models in ecology. Science 195(4276):367-373.
- Reyman, J.E. (1976) Astronomy, architecture, and adaptation at Pueblo Bonito. Science 193(4257):957-962.
- Robinson, A.L. (1977) Colonizing Mars: the age of planetary engineering begins. Science 195(4279):668.
- Robinson, N. (1966) Solar radiation. Elsevier, Amsterdam. 347 p.

- Rowland, R. (1968) Evolution of the MG. Nature 217(5125): 240-242.
- Saint, W.S. / Coward, F.W., Jr. (1977) Agriculture and behavioral science: Emerging orientations. Science 197(4305): 733-737.
- Sarkanen, K.V. (1976) Renewable resources for the production of fuels and chemicals. Science 191(4228):773-776.
- Schimper, A.F.W. (1903) Plant-geography upon a physical basis. Clarendon Press, Oxford. 839 p.
- Schipper, L. / Lichtenberg, A.J. (1976) Efficient energy use and well being: The Swedish example. Science 194(4269): 1001-1013.
- Schmidt-Nielsen, K. (1970) Animal physiology. 3rd ed. Prentice-Hall, Englewood Cliffs, New Jersey. 145 p.
- Schwartz, R.M. / Dayhoff, M.O. (1978) Origins of prokaryotes, eukaryotes, mitochondria, and chloroplasts. Science 199(4327): 395-403.
- Seely, M.K., / Hamilton, W.J., II (1976) Fog catchment sand trenches constructed by tenebrionid beetles, *Lepidochora*, from the Namib Desert. Science 193(4252):484-486.
- Sellers, W.D. (1965) Physical climatology. University of Chicago Press. 272 p.
- Siegenthaler, U. / Oeschger, H. (1978) Predicting future atmospheric carbon dioxide levels. Science 199(4327):388-395.
- Skinner, B.J. (1976) A second iron age ahead? American Scientist 64(3):258-269.
- Smith, C.U.M. (1976) The problem of life. Wiley, New York. 342 p.
- Solbrig, O.T. / Orians, G.H. (1977) The adaptive characteristics of desert plants. American Scientist 65(4):412-421.
- Soleri, P. (1969) Arcology: The city in the image of man. MIT Press, Cambridge, Massachusetts. 122 p.
- Stein, R.G. (1977) Architecture and energy. Anchor/Doubleday, Garden City, New York. 322 p.
- Stencel, R. / Gifford, F. / Morón, E. (1976) Astronomy and cosmology of Angkor Wat. Science 193(4250):281-286.
- Tien, H. (1976) Electronic processes and photoelectric aspects of bilayer lipid membranes. Photochemistry and Photobiology 24(2): 97-116.
- U.S. Bureau of the Census (1976) Statistical abstract of the U.S.
- Von Puttkamer, J. (1977) The next 25 years: Industrialization of space. Space World N-10-166:4-13.

- Weertman, J. (1976) Milankovitch solar radiation variations and ice age sheet sizes. Nature 261(5555):17-20.
- Weins, J.A. (1977) On competition and variable environments. American Scientist 65(5):590-597.
- Weinstein, J.N. / Leitz, F.B. (1976) Electric power from differences in salinity: The dialytic battery. Science 197(4227):557-559.
- Welty, R.K. (1976) Solar evaporation of fluoride wastes. Chemical Engineering Progress 72(3):54-57.
- Wick, G.L. / Isaacs, J.D. (1978) Salt domes: Is there more energy available from their salt than from their oil? Science 199(4336):1436-1437.
- Williams, J. / Kromer, G. / Weingart, J., eds. (1978) Climate and solar energy conversion: Proceedings of a IISA workshop, December 8-10, 1976. International Institute for Applied Systems Analysis, Laxenburg, Austria, Publication CP-77-9. 156 p.
- Williams, J.R. (1975) Geosynchronous satellite solar power. Astronautics and Aeronautics 13(11):46-52.
- Winiarski, L.D. / Byram, K.V. (1970) Reflective cooling ponds.
 American Society of Mechanical Engineers, Publication 70-WA/
 PWR-4. 8 p. (See SWRA W73-01571)
- Wolken, J.J. (1975) Photoprocesses, photoreceptors, and evolution. Academic Press, New York. 317 p.
- Woodwell, G.M. (1977) Recycling sewage through plant communities. American Scientist 65(5):556-562.
- Woodwell, G.M. (1978) The carbon dioxide question. Scientific American 238(1):34-43.
- Woodwell, G.M. et al (1978) The biota and the world carbon budget. Science 199(4325):141-146.
- Yonge, C.M. (1975) Giant clams. Scientific American 232(4): 96-105.

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

0001

ANDERSON, J.H.

1973

THE SEA PLANT: A SOURCE OF POWER, WATER, AND FOOD WITHOUT POLLUTION.

SOLAR ENERGY 14 (3):287-300.

SEA THERMAL POWERPLANT CAN PRODUCE FRESHWATER AS BYPRODUCT OR MAJOR PRODUCT. WARM WATER LEAVING POWER CYCLE IS BOILED IN VACUUM AND CONDENSED BY COLD WATER FROM POWER CONDENSERS. FRESHWATER, PERHAPS MORE THAN A BILLION GALLONS PER DAY FOR 100 MWE PLANT, MAY BE BARGED TO ARID PORTS. WARMED CONDENSER WATER PROVIDES FOOD FOR MARINE ECOSYSTEM, WITH UP TO 7 MILLION KILOGRAMS OF FISH HARVESTED YEARLY. FLOATING FACTORIES FOR ENERGY-INTENSIVE INDUSTRIES (STEEL, ALUMINUM, CHEMICALS FROM BRINE) MAY CLUSTER ABOUT THE PLANT. POTENTIAL GOOD PLANT LOCATIONS INCLUDE 18,000 MILES OF ARID TROPICAL COASTLINE.

OCEAN THERMAL ENERGY CONVERSION/DISTILLATION/ARID-SENIARID LANDS/COASTAL DESERTS/MULTIPURPOSE SYSTEMS/COMPLEX SYSTEMS/FOOD PRODUCTION/DESALINATION/ELECTRIC POWER/MARICULTURE

0002

ANTAL, M.J., JR.

1976

TOWER POWER: PRODUCING FUELS FROM SOLAR ENERGY.

BULLETIN OF THE ATOMIC SCIENTISTS 32(5):58-62.

SOLAR POWER TOWER/HELIOSTAT FURNACE CAN PRODUCE HYDROGEN OR METHANCL FUELS FROM ORGANIC MATTER. THE REACTION, USING STEAM, IS ENDOTHERMIC; ENERGY CONTENT OF PRODUCT IS ONE THIRD GREATER THAN THAT OF BIOMASS FEEDSTOCK. THUS SOLAR ENERGY COLLECTED BY HELIOSTATS IS STOPED. TOTAL CCNVERSION EFFICIENCIES EXCEEDING 70 PERCENT APPEAR REASONABLE. SOLAR WASTE GASIFICATION AMPLIFIES CROP RESIDUE RESOURCE. ENERGY IN HYDROGEN PRODUCT IS MORE THAN 3 TIMES THE ENERGY OF METHANE THAT COULD BE PRODUCED FROM THE SAME MATERIAL BY BIOGASIPICATION. HYDROGEN PRODUCED FROM ORGANIC WASTES COULD MEET ALMOST HALF OF U.S. ENERGY DEMAND. A 30-ACRE PLANT COULD COLLECT 100 TONS/DAY OF RESIDUES FROM 70 SQUARE MILES OF MIDWEST FARMS AND PRODUCE HYDROGEN AT COST COMPETITIVE WITH NATURAL GAS-DERIVED HYDROGEN. IF THE PLANT WERE PUBLICLY RATHER THAN PRIVATELY OWNED, COST COULD BE LOWER STILL, NEARLY COMPETITIVE WITH NATURAL GAS AT PRESENT PRICES. DEVELOPING COUNTRIES MAY FIND THIS TECHNOLOGY PARTICULARLY ATTRACTIVE.

SOLAR THERMAL CONVERSION/CENTRAL RECEIVER-HELIOSTAT SYSTEMS/BIGMASS FUELS/THERMOCHEMICAL CONVERSION/HYDROGEN/ENERGY STORAGE/AGRICULTURAL WASTES/HYBRID SYSTEMS/ECONOMICS/DEVELOPING COUNTRIES/HELIOSTATS

ASBURY, J.G./MUELLER, R.O.

1977

SOLAR ENERGY AND ELECTRIC UTILITIES: SHOULD THEY BE INTERFACED?

SCIENCE 195 (4277): 445-450.

INTERFACING CONVENTIONAL ELECTRIC UTILITY SYSTEMS AND MOST SOLAR ENERGY SYSTEMS IS A POOR TECHNOLOGICAL MATCH BECAUSE BOTH TECHNOLOGIES ARE VERY CAPITAL INTENSIVE. THE UTILITY IS A POOR BACKUP FOR SCLAR ENERGY SYSTEMS DUE TO ITS HIGH FIXED COSTS OF GENERATION, TRANSMISSION, AND DISTRIBUTION CAPACITY. AND THE SOLAR ENERGY SYSTEM, BECAUSE OF HIGH CAPITAL COST AND INTERMITIENT UNPREDICTABLE OPERATION, CANNOT BE CONSIDERED A RELIABLE SOURCE OF AUXILLARY ENERGY FOR THE UTILITY. VALUE OF SOLAR ENERGY IS CNLY THE VALUE OF FUEL SAVED. THUS IF UTILITY OFF-PEAK COST IS LOW, THEN SCLAR ENERGY SYSTEM HAS A VERY LOW BREAK-EVEN COST, AND COLLECTORS MUST BE CORRESPONDINGLY INEXPENSIVE.

ELECTRIC POWER/SOLAR THERMAL CONVERSION/ENERGY STORAGE/ECONOMICS/ELECTRIC UTILITIES/LIMITING FACTORS/MODEL STUDIES/COLLECTORS

0004

ASSAF, GAD

1976

THE DEAD SEA: A SCHEME FOR A SOLAR LAKE.

SOLAR ENERGY 18(4):293-299.

THE DEAD SEA COULD BE MODIFIED INTO A SOLAR LAKE FOR THERMAL POWER PRODUCTION (4000 MWE) AND DESALINATION. SOME MEDITERRANEAN SEAWATER WOULD BE IMPORTED, AND SALT FROM EXISTING CHEMICAL INDUSTRIES AT THE SOUTHERN END OF THE SEA WOULD MAINTAIN THE VERTICAL SALINITY GRADIENT. A VAST NET OF FLOATING WIND BREAKS WOULD CONTROL WIND-INDUCED TURBULENCE. BRINE FLOW RATE THROUGH POWERPLANTS WOULD BE ABOUT 1000 CUBIC METERS PER SECOND. THIS SCHEME MIGHT ALSO BE APPLIED IN THE UNITED STATES (GREAT SALT LAKE) AND IN EGYPT (GULF OF SUEZ AND QATTARA

SOLAR THERMAL CONVERSION/SOLAR PONDS/DEAD SEA/ISRAEL/ELECTRIC POWER/DESALINATION/SALT PRODUCTION/GREAT SALT LAKE/QATTARA DEPRESSION/EGYPT/MULTIPURPOSE SYSTEMS/GRINES/SALINE LAKES

0005

BACKUS, C. E. / BROWN, M. L.

1976

WATER REQUIREMENTS FOR SOLAR ENERGY.

AMERICAN WATER WORKS ASSOCIATION, JOUENAL 68 (7):366-369.

SEE: SWRA W77-02122.

WATER REQUIREMENTS/COOLING WATER/ELECTRIC POWER/SOLAR THERMAL CONVERSION/PHOTOVOLTAIC CONVERSION/ADAPTATION/GROUNDWATER/SOUTHWES1 G.S./HATER CONSERVATION/LIMITING FACTORS/HEAT SINKS

BASSLER, F.

1972

SOLAR DEPRESSION POWER PLANT OF QATTARA IN EGYPT.

SOLAR ENERGY 14(1):21-28.

GRAVITATIONAL POTENTIAL ENERGY OF MEDITERRANEAN SEAWATER CHANNELED 80 KM IN TUNNELS OR CANAL TO THE QATTARA DEPRESSION COULD DRIVE HYDROPOWER TURBINES AND PRODUCE ELECTRICITY. EVAPORATION FROM THIS EXTREMELY ARID BASIN WOULD MAINTAIN THE RESULTING SALINE LAKE AT OPTIMUM LEVEL OF MINUS 60 METERS AND AREA OF 12,000 SQUARE KILOMETERS. NET EVAPORATION OF 1.70 METERS IS ASSUMED. COMBINED WITH PUMPED STORAGE, THIS SYSTEM COULD PRODUCE 1,000 MWF PASE LOAD AND 4000 MWE PEAK LOAD POWER. WATER FLOW FOR SUCH A PROJECT WOULD PE IMMENSE, THE LARGEST IN EGYPT: AT LEAST 650 CUBIC METERS PER SECOND, COMPARED WITH ONLY 150 CUBIC METERS PER SECOND FOR THE NILE.

HYDROPOWER/QATTARA DEPRESSION/EGYPT/ELECTRIC POWER/EVAPORATION/SALINE LAKES/ARID-SEMIARID LANDS/WATER PUMPING/ENERGY STORAGE/NILE/COASTAL DESERTS/DEPRESSIONS (GEOMORPHIC)

0007

BLISS, R.W.

1976

WHY NOT JUST BUILD THE HOUSE RIGHT IN THE FIRST PLACE?

BULLETIN OF THE ATOMIC SCIENTISTS 32(3):32-40.

BUILDING NEW HOUSES BETTER AT REASONABLE EXTRA COST CAN RESULT IN LARGE HEATING FUZL SAVINGS. THIS ARTICLE DISCUSSES PRACTICAL METHODS FOR ACCOMPLISHING THAT GOAL. ENERGY LOSS CAN BE DECREASED WITH INSULATION AND CRACK SEALING, WHILE ENERGY GAIN FROM SUNLIGHT CAN BE INCREASED BY PLACING LARGE WINDOWS ON SOUTH WALLS AND MASSIVE THERMAL STORAGE MATERIALS INSIDE. PASSIVELY SOLAR-HEATED HOUSE MUST BE CUSTOM DESIGNED FOR GEOGRAPHIC LOCATION, SITE PROPERTIES, AND CLIMATE. ENERGY BUDGETS ARE CALCULATED FOR SEVERAL SPECIFIC HOUSE DESIGN EXAMPLES. IF ALL NEW HOUSES IN THE U.S. WERE BUILT A LITTLE BETTER FOR 12 YEARS, THEIR CUMULATIVE LIFETIME FUEL SAVINGS WOULD BE EQUIVALENT TO RECOVERABLE RESOURCES OF THE ALASKAN NORTH SLOPE GIANT OIL FIELD.

PASSIVE TEMPERATURE CONTROL/ADAPTATION/ECONOMICS/SPACE HEATING/SOCIAL ASPECTS/BUILDING DESIGN/MODEL STUDIES

8000

BOCKRIS, J.O'M.

1975

ENERGY: THE SOLAR HYDROGEN ALTERNATIVE.

JOHN WILEY & SONS, NEW YORK. 365 P.

A CHANGE IN TECHNOECOSYSTEM ENERGY SOURCE FROM FOSSIL FUELS TO INEXHAUSTIBLE CLEAN ONES, PROBABLY SOLAR, IS INEVITABLE AND IMMINENT. HYDROGEN CAN BE PRODUCED FROM ALMOST ANY ENERGY SOURCE AND ENERGY PRODUCTION TECHNOLOGY.

CONSEQUENTLY, HYDROGEN TECHNOLOGY COULD HAVE DIVERSE IMPORTANT ROLES IN FUTURE ENERGY SYSTEMS. IN THE CONTEXT OF A REVIEW OF MANY ENERGY PRODUCTION AND USE TECHNOLOGIES, THE AUTHOR COMPREHENSIVELY REVIEWS PRESENT AND POSSIBLE HYDROGEN PRODUCTION, TRANSPORTATION, STORAGE, AND UTILIZATION TECHNOLOGIES AND DEVELOPMENT STRATEGIES.

HYDROGEN/TECHNOLOGICAL SUCCESSION/ENERGY STORAGE/ENERGY TRANSMISSION/COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/HYBRID SYSTEMS

0009

BOS, P.B./KAMMER, W.A./BLOND, E.

1975

SOLAR THERMAL CONVERSION MISSION ANALYSIS: SOUTHWESTERN UNITED STATES. VOL. 1: SUMMARY REPORT.

AEROSPACE CORPORATION, EL SEGUNDO, CALIFORNIA, REPORT ATR-74 (7417-16) -2, VOL. 1. 227 P.

SUMMARIZES RESULTS OF A MASSIVE EVALUATION OF ALTERNATIVE SOLAR THERMAL POWER CONCEPTS, AS DETAILED IN SEPARATE VOLUMES ON SOUTHWESTERN U.S. SITING ANALYSIS, INSOLATION CLIMATOLOGY, DEMAND ANALYSIS, AND COMPARATIVE TECHNICAL AND ECONOMIC EVALUATION. THE CENTRAL RECEIVER CONCEPT, SUPPLYING INTERMEDIATE OR LOAD FOLLOWING POWER, APPEARS COMPETITIVE AND IS THE PREFERRED DESIGN. LOW-COST PARABOLIC CYLINDRICAL TROUGH COLLECTOR SYSTEM, IF ONE CAN BE FOUND, COULD BE DEVELOPED AS BACK-UP DESIGN. ASSUMING FIRST OPERATIONAL PLANT BY 1985, MARKLT CAPTURE POTENTIAL BY THE YEAR 2000 IS ESTIMATED TO BE 40,000 MWE, WITH NO SIGNIFICANT SITING CONSTRAINTS.

SOLAR THERMAL CONVERSION/SOUTHWEST U.S./ECONOMICS/CENTRAL RECEIVER-HELIOSTAT SYSTEMS/ELECTRIC POWER/MEDIUM TEMPERATURE SYSTEMS/ELECTRIC UTILITIES/CONCENTRATING COLLECTORS/HELIOSTATS/DISTRIBUTED RECEIVER SYSTEMS/MODEL STUDIES

0010

BRINKWORTH, B. J.

1972

SOLAR ENERGY FOR MAN.

JOHN WILEY & SONS, NEW YORK. 251 P.

THIS INTRODUCTION TO SOLAR ENERGY DEVELOPS THE THEORY BEHIND THE TECHNOLOGY FROM BASIC PHYSICAL PRINCIPLES, USING SIMPLE MATHEMATICS AND MANY DIAGRAMS. TOPICS COVERED INCLUDE SOLAR RADIATION PROPERTIES, REVIEW OF RELEVANT PHYSICS AND THERMODYNAMICS, SOLAR ENERGY COLLECTION, SOLAR HEATING, SOLAR HEAT ENGINES, THERMOELECTRIC AND THERMIONIC GENERATORS, PHOTOELECTRICITY, PHOTOCHEMISTRY AND PHOTOBIOLOGY, AND AN OVERVIEW OF THE PROSPECTS FOR INTRODUCING SOLAR TECHNOLOGY TO THE WORLD.

SOLAR RADIATION/SUNLIGHT GEOMETRY/OPTICAL CONCENTRATION/FLAT PLATE COLLECTORS/SPACE HEATING/HEAT ENGINES/THERMOELECTRIC CONVERSION/THERMIONIC CONVERSION/PHOTOVOLTAIC CONVERSION/PHOTOCHEMICAL CONVERSION/PHOTOSYNTHESIS/TECHNOLOGICAL SUCCESSION/SOLAR THERMAL CONVERSION/CONCENTRATING COLLECTORS

BRODA, E.

1976

SOLAR POWER, THE PHOTOCHEMICAL ALTERNATIVE.

BULLETIN OF THE ATOMIC SCIENTISTS 32(3):49-52.

PHOTOCHEMICAL ENERGY CONVERSION HAS RECEIVED LITTLE ATTENTION, ALTHOUGH ITS POTENTIAL IS INDICATED BY THE LONG-TERM SUCCESS OF PHOTOSYNTHETIC ORGANISMS. PHOTOSYNTHESIS IS CHEMICALLY EQUIVALENT TO HYDROGEN PRODUCTION FROM WATER, ALTHOUGH THE ENERGY IS CHANNELED INTO BIOSYNTHESES INSTEAD. ENERGY PLANTATIONS AND ALGAL CULTURE FOR FUEL MAY HAVE LIMITED SUCCESS BECAUSE PLANTS EVOLVED TO SURVIVE, NOT TO PRODUCE ENERGY FOR MEN. TO BYPASS THESE BIOLOGICAL LIMITS, WE SHOULD LEARN FROM PLANTS AND BE INSPIRED BY THEM IN DEVELOPING ARTIFICIAL PHOTOCHEMICAL MEMBRANESYSTEMS. A HYDROGEN ECONOMY COULD BE RUN ON PHOTOCHEMICAL PRODUCTS IMPORTED BY POPULATION CENTERS FROM VAST POWER COMPLEXES IN DESERTS OR FLOATING ON OCEANS. SOLAR ENERGY RESEARCH IS NOT REALLY EXPENSIVE COMPAGED WITH OTHER ADVANCED RESEARCH. LACK OF MILITARY INTEREST IN SOLAR ENERGY RESULTS IN LITTLE FUNDING ON ONE HAND, YET POTENTIAL FOR HELPING TO BKING ABOUT WORLD PEACE ON THE OTHER. A CENTER FOR INTERNATIONAL COOPERATION IN SOLAR ENERGY RESEARCH SHOULD BE FOUNDED.

PHOTOCHEMICAL CONVERSION/PHOTOSYNTHESIS/HYDROGEN/BIOMASS FUELS/ARID-SEMIARID LANDS/POLITICAL ASPECTS/SOCIAL ASPECTS

0012

CALVIN, M.

1976

PHOTOSYNTHESIS AS A RESOURCE FOR ENERGY AND MATERIALS.

AMERICAN SCIENTIST 64(3):270-278.

PHOTOSYNTHESIS IS A POSSIBLE RENEWABLE SOURCE OF BOTH MATERIAL AND ENERGY. FERMENTATION OF CARBOHYDRATE FROM CANE, BEETS, SEAWEED, AND OTHER PLANTS TO PRODUCE ALCOHOL AND HYDROCARBONS MAY AGAIN BECOME ECONOMIC WITH NEW TECHNOLOGY AND HIGH FOSSIL FUEL COSTS. DIRECT PRODUCTION OF HYDROCARBONS BY PLANTS SUCH AS HEVEA AND EUPHORBIA DESERVES ATTENTION. THERE ARE MANY PROMISING SPECIES, AND BREEDING CAN IMPROVE YIELDS. FINALLY, RESEARCH ON THE PHOTOCHEMISTRY OF NATURAL PHOTOSYNTHESIS SUGGESTS THAT ARTIFICIAL MEMBRANES WHICH IMITATE THOSE IN GREEN PLANT CHLOROPLASTS MAY SOMEDAY BE SYNTHESIZED TO PRODUCE FUEL, FERTILIZER, AND ELECTRICITY.

PHOTOS YNTHESIS/BIOMASS FUELS/PHOTOCHEMICAL CONVERSION/EUPFORBIA/AGRICULTURE/ECONOMIC PLANTS/HYDROGEN

0013

CAPUTO, R.S.

1977

SOLAR POWER PLANTS: DARK HORSE IN THE ENELGY STABLE.

BULLFTIN OF THE ATOMIC SCIENTISTS 33(5):46-47,50-56.

EVALUATES TECHNICAL AND ECONOMIC FEASIBILITY OF SEVERAL DESIGNS FOR LARGE SOLAR THERMAL POWERPLANTS WITH DRY COOLING TOWERS (REQUIRED DUE TO WATER SCARCITY IN SOUTHWEST U.S.) AND EFFICIENT LONG DISTANCE TRANSMISSION BY HIGH VOLTAGE OVERHEAD DIRECT CURRENT LINES. MAJOK DESIGNS CONSIDERED ARE CENTRAL RECEIVER OR POWER TOWER/HELIOSTAT SYSTEM, AND DISTRIBUTED RECEIVER SYSTEMS OF TWO TYPES (SEPARATE TRACKING COLLECTORS GENERATE EITHER ELECTRICITY OR DISSOCIATED CHEMICALS FOR COLLECTION AT A CENTRAL POINT). CENTRAL RECEIVER 1S CURRENTLY PREFERRED IN GOVERNMENT PROGRAMS, BUT DISTRIBUTED RECEIVERS MAY NOT BE MUCH MORE COSTLY. FURTHERMORE, DISTRIBUTED RECEIVERS OFFER GREATER SIZE FLEXIBILITY AND MODULAR GROWTH POTENTIAL (FROM SINGLE 20 KW MODULES TO LARGE MULTI-MEGAWATT ARRAYS), SUITABILITY FOR SMALL TOTAL ENERGY SYSTEMS, AND THE ADVANTAGES OF MASS PRODUCTION OF SMALL POWER CONVERTERS. PRESENT LARGE COST DIFFERENCE BETWEEN SOLAR AND CONVENTIONAL POWERPLANTS MAY NOT PERSIST TO THE END OF THE CENTURY. SOLAR OPTION, COMPARED TO COAL AND NUCLEAR SCHEMES, IS ENVIRONMENTALLY BENIGN: LESS HEAT REJECTION, LESS LAND REQUIRED THAN FOR COAL MINING, MINIMAL HEALTH IMPACT, NO CLIMATE-THREATENING CO2 EMISSION, AND NO NUCLEAR SABOTAGE AND WASTE DISPOSAL RISKS. SOLAR RESEARCH AND DEVELOPMENT COSTS ARE ALSO LESS THAN FOR COAL AND NUCLEAR TECHNOLOGIES.

HELIOSTATS/SIZE EFFECTS/TOTAL ENERGY SYSTEMS/MASS PRODUCTION/CLIMATIC CHANGE/SOLAR THERMAL CONVERSION/ELECTRIC POWER/ECONOMICS/DRY COOLING TOWERS/WATER CONSERVATION/SOUTHWEST U.S./HEAT ENGINES/ENERGY TRANSMISSION/DISTRIBUTED RECEIVER SYSTEMS/CENTRAL RECEIVER-HELIOSTAT SYSTEMS/THERMOCHEMICAL CONVERSION/ENVIRONMENTAL EFFECTS/CONCENTRATING COLLECTORS

0014

CHALMERS, B.

1976

THE PHOTOVOLTAIC GENERATION OF ELECTRICITY.

SCIENTIFIC AMERICAN 235(4):34-43.

BRIEFLY DESCRIBES, FOR THE GENERAL READER, SILICON SOLAR CELL PHYSICS, FABRICATION TECHNIQUES (STANDARD AND RIBBON METHODS), POTENTIAL APPLICATIONS (REMOTE REGIONS, POWER STATIONS, SATELLITE POWERPLANTS, AND HOME INSTALLATIONS), AND ECONOMICS (CAN BECOME COMPETITIVE THROUGH CAREFUL ENGINEERING AND MASS PRODUCTION).

PHOTOVOLTAIC CONVERSION/SOLAR CELLS/ECONOMICS/MASS PRODUCTION/ELECTRIC POWER

0015

CLAMPITT, p. n. / KIVIAT, F. E.

1976

ENERGY RECOVERY FROM SALINE WATER BY MEANS OF ELECTROCHEMICAL CELLS.

SCIENCE 194(4266):719-720.

SALT CONCENTRATION DIFFERENCES CAN GENERATE ELECTRICITY DIRECTLY WHEN FRESHWATER AND SEAWATER ARE MIXED IN ELECTROCHEMICAL CONCENTRATION CELLS. THEORETICALLY, WORK AVAILABLE FROM SUCH CELLS IS SOMEWHAT LESS THAN THAT AVAILABLE FROM OSMOTIC PUMPS, BUT THE CELLS ARE MUCH SIMPLER IN CONSTRUCTION AND OPERATION. FRESHWATER, OBTAINED FROM A RIVER OR PERHAPS FROM POINT ICE, MUST HAVE A SMALL AMOUNT OF SEAWATER ADDED TO IT IN ORDER TO LOWER THE COLL'S INTERNAL RESISTANCE. AN ALTERNATIVE SYSTEM WOULD BE TO EXPLOIT SALINITY

DIFFERENCE BETWEEN SEAWATER AND BRINES FROM SALINE LAKES (E.G., DEAD SEA) OK ARTIFICIAL SOLAR EVAPORATION PONDS.

SALINATION POWER/ELECTROCHEMICAL CONVERSION/ICEBERGS/OSMOSIS/DEAD SEA/EVAPORATION/ISRAEL/COASTAL DESERTS/SALINE LAKES/BRINES

0016

CORTELL, B.

1977

GROUNDWATER-SOLAR HEAT.

WATER WELL JOURNAL 31(5):73.

SEE: SWRA W77-08652.

GROUNDWATER/ENERGY STORAGE/SOLAR THERMAL CONVERSION/HEAT SINKS

0017

DALRYMPLE, D.G.

1973

CONTROLLED ENVIRONMENT AGRICULTURE: A GLOBAL REVIEW OF GREENHOUSE FOOD PRODUCTION.

U.S. DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C., ECONOMIC RESEARCH SERVICE, FOREIGN AGRICULTURAL ECONOMIC REPORT 89. 150 P.

GREENHOUSING IS THE MOST ENERGY-INTENSIVE FORM OF AGRICULTURE. MANY ENVIRONMENTAL FACTORS CAN BE CONTROLLED: IEMPERATURE, HUNIDITY, LIGHT, GAS CONCENTRATIONS, SOIL MOISTURE AND NUTRIENTS, WATER LOSS, AND PROTECTION FROM WIND, PRECIPITATION, AND PEST DAMAGE. THIS REPORT IS AN OVERVIEW AND GENERAL SYNTHESIS OF THE FIELD. TOPICS COVERED INCLUDE HISTORY OF GREENHOUSES (BACK TO THE ROMANS), STRUCTURE AND CONTROL TECHNOLOGIES (PLASTIC FILMS HAVE GREENLY REDUCED COSTS), ADVANCED FACILITIES (E.G., COASTAL DESERT FOOD-WATER-POWER COMPLEXES), AND ECONOMICS (UNSTABLE MARKET WITH INTENSE INTERNATIONAL COMPETITION). GREENHOUSE DEVELOPMENTS BY INDIVIDUAL NATIONS ON ALL CONTINENTS, INCLUDING ANTARCTICA, ARE REVIEWED.

CONTROLLED-ENVIRONMENT AGRICULTURE/GREENHOUSES/AGRICULTURE/COMPLEX SYSTEMS/ECONOMICS/ARID-SEMIARID LANDS/ANTARCTICA/COASTAL DESERTS/&OOD PRODUCTION

0018

DANIELS, F.

1964

DIRECT USE OF THE SUN'S ENERGY.

BALLANTINE BOOKS, NEW YORK. 271 P.

AN EXCELLENT INTRODUCTION TO TERRESTRIAL SOLAR ENERGY TECHNOLOGY AS IT WAS IN 1964. THESE BASICS HAVE NOT CHANGED SINCE THEN; THEY HAVE SIMPLY BEEN BUILT UPON AND ELABORATED. PRESENTATION IS MODERATELY TECHNICAL, WITH DIAGRAMS,

TABLES, SOME BASIC EQUATIONS, AND MANY REFERENCES FOR EACH CHAPTER. TOPICS COVERED INCLUDE: HISTORY, NATURE OF SOLAR RADIATION, SOLAR COLLECTORS, SOLAR COOKERS, WATER HEATERS, AGRICULTURAL AND INDUSTRIAL DRYING, HEAT STORAGE, HEATING BUILDINGS, DISTILLATION, FURNACES, SELECTIVE SURFACES, COOLING AND REFRIGERATION, HEAT ENGINES, THERMOELECTRIC AND THERMIONIC CONVERSION, PHOTOVOLTAICS, PHOTOCHEMISTRY, AND POWER STORAGE AND TRANSPORT.

OPTICAL CONCENTRATION/FLAT PLATE COLLECTORS/SOLAR RADIATION/ CONCENTRATING COLLECTORS/COOKING/WATER HEATING/CROP DRYING/PROCESS HEAT/DISTILLATION/ENERGY STORAGE/SPACE HEATING/SPACE COOLING/REFRIGERATION/HEAT ENGINES/THERMOELECTRIC CONVERSION/PHOTOVOLTAIC CONVERSION/PHOTOCHEMICAL CONVERSION/ENERGY TRANSMISSION/THERMIONIC CONVERSION/SOLAR THERMAL CONVERSION

0019

DAVIDSON, M./GRETHER, D./WILCOX, K.

1977

ECOLOGICAL CONSIDERATIONS OF THE SOLAR ALTERNATIVE.

LAWRENCE BERKELEY LABORATORY, LBL-5927. 47 P.

SEVERAL SOLAR ENERGY TECHNOLOGIES ARE REVIEWED: SOLAR THERMAL POWER (PARABOLIC TROUGH AND CENTRAL RECEIVER CONCEPTS), PHOTOVOLTAIC CELLS, OCEAN THERMAL POWERPLANTS, WIND ENERGY, SOLAR HEATING AND COOLING OF BUILDINGS, BIOCONVERSION, AND PROCESS HEAT FOR AGRICULTURE AND INDUSTRY. DIRECT AND INDIRECT ECOLOGICAL AND ENVIRONMENTAL IMPACTS OF EACH TECHNOLOGY ARE DISCUSSED AND SUMMARIZED IN TABLES. THE AUTHORS CONCLUDE THAT MOST SOLAR ENERGY TECHNOLOGIES APPEAR TO BE ENVIRONMENTALLY ACCEPTABLE COMPARED WITH CONVENTIONAL TECHNOLOGIES.

ENVIRONMENTAL EFFECTS/SOLAR THERMAL CONVERSION/PHOTOVOLTAIC CONVERSION/OCEAN THERMAL ENERGY CONVERSION/WIND ENERGY/SPACE HEATING/SPACE COOLING/BIOMASS FULLS/PROCESS HEAT/CENTRAL RECEIVER-HELIOSTAT SYSTEMS/WATER REQUIREMENTS/COOLING WATER/HELIOSTATS/LIMITING FACTORS/DISTRIBUTED RECEIVER SYSTEMS

0020

DAY, M.E.

1970

BRINE DISPOSAL POND MANUAL.

U.S. OFFICE OF SALINE WATER, RESEARCH AND DEVELOPMENT REPORT 588. 134 P.

THIS MANUAL COVERS DESIGN AND CONSTRUCTION OF PONDS FOR DISPOSING OF WASTE BRINE FROM INLAND DESALTING PLANTS. DESIGN CRITERIA BASED ON DATA FROM THE ROSWELL, NEW MEXICO AREA ARE PRESENTED. ALSO INCLUDED ARE COST ESTIMATES, OPERATION AND MAINTENANCE REQUIREMENTS, CONSTRUCTION DETAILS FOR LINING INSTALLATION, AND A SUMMARY OF THE PONDING REGULATIONS OF VARIOUS STATES.

BRINE DISPOSAL/EVAPORATION/DESALINATION/SALT PRODUCTION

DEWINTER, F./DEWINTER, J.W., EDS. 1976A

DESCRIPTION OF THE SOLAR ENERGY R&D PROGRAMS IN MANY NATIONS.

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, DIVISION OF SOLAR ENERGY, SAN/1122-76/1. 294 P.

THIS PUBLICATION, AN OUTGROWTH OF THE 1975 CONFERENCE OF THE INTERNATIONAL SOLAR ENERGY SOCIETY, IS AN ATTEMPT TO ASSIST IN COORDINATING SOLAR ENERGY RESEARCH AND DEVELOPMENT AROUND THE WORLD. DESCRIPTIONS OF SOLAR ENERGY RED PROGRAMS OF 32 COUNTRIES, THE WEST INDIES, ORGANIZATION OF AMERICAN STATES, UNESCO, AND SEVERAL PRIVATE AND GOVERNMENTAL ORGANIZATIONS IN THE US ARE INCLUDED, EACH WRITTEN BY THE MOST RELIABLE REPRESENTATIVE KNOWN FROM THE PARTICULAR NATION OR GROUP. A NUMBER OF COUNTRIES WITH ARID OR SEMIARID REGIONS ARE AMONG THOSE COVERED: ARGENTINA, AUSTRALIA, CANADA, ECUADOR, GREECE, INDIA, IRAN, IRAQ, ISRAEL, JORDAN, KUWAIT, NIGERIA, PAKISTAN, SAUDI ARABIA, SENEGAL, SOUTH AFRICA, SPAIN, SRI LANKA, TURKEY, US, AND THE WEST INDIES.

RESEARCH AND DEVELOPMENT/ARGENTINA/AUSTRALIA/ISRAEL/SAUDI ARABIA/TURKEY/GREECE/INDIA/ECUADOR/IRAN/IRAQ/JORDAN/KUWAIT/NIGERIA/PAKISTAN/SENEGAL/SOUTH AFRICA/SFAIN/WEST INDIES/CANADA/SRI LANKA

0022

DEWINTER, F./DEWINTER, J.W., EDS.

1976B

THE USE OF SOLAR ENERGY FOR THE COOLING OF BUILDINGS.

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, DIVISION OF SOLAR ENERGY, 5AN/1122-76/2. 382 P.

PROCEEDINGS OF A WORKSHOP HELD AT THE UNIVERSITY OF CALIFORNIA, LOS ANGELES, AUGUST 4-6, 1975. PEATURES 37 PAPERS PRESENTED IN 2 GENERAL SESSIONS AND SEVERAL SPECIALIZED SECTIONS. TOPICS INCLUDED HANKINE CYCLE SYSTEMS, ABSORPTION SYSTEMS, DESICCANT SYSTEMS, GAS REGENERATIVE CYCLES, OPEN CYCLES, DESICCANT CYCLES, AND THERMIC DIODES. SOLAR HEATING SYSTEMS FOR BUILDINGS CAN BE MUCH MORE ECONOMICALLY ATTRACTIVE IF SCLAR CCCLING SYSTEMS KEEP COLLECTOR WORKING IN SUMMER. COOLING SYSTEMS WILL STILL BE NEEDED EVEN WITH NEW ENERGY-CONSERVING BUILDING DESIGN AND CONSTRUCTION PRACTICES. CCCLING SYSTEMS ARE GENERALLY COMPLEX AND LESS DEVELOPED THAN HEATING SYSTEMS. MANY COOLING METHODS HAVE BEEN INVENTED IN THE LAST 200 YEARS, MAKING IT DIFFICULT TO DECIDE ON THE BEST DESIGN FOR A SPECIFIC APPLICATION. EVEN NOW, MORE CONCEPTS FOR SOLAR CCOLING ARE BEING GENERATED THAN ARE BEING ELIMINATED.

SPACE COOLING/ACTIVE TEMPERATURE CONTROL/HEAT ENGINES/ECONOMICS/SPACE HEATING/BUILDING DESIGN/CONCENTRATING COLLECTORS

0023

DICKINSON, W.C. ET AL

1976

THE SHALLOW SOLAR POND ENERGY CONVERSION SYSTEM.

SOLAR ENERGY 18 (1):3-10.

VERY INEXPENSIVE SHALLOW SOLAR PONDS, 5 CM DEEP AND COVERED WITH TRANSPARENT PLASTIC FILM PILLOWS COULD COLLECT SOLAR HEAT FOR INDUSTRIAL, COMMERCIAL, OR RESIDENTIAL USES, OR FOR LARGE-SCALE POWER GENERATION. WATER WOULD BE USED FOR HEAT COLLECTION, TRANSFER, AND STORAGE IN UNDERGROUND RESERVOIRS AT NIGHT. POWER WOULD BE PRODUCED BY A FREON-DRIVEN TURBINE, WITH WATER USED FOR COOLING. 10 NWE POWER PRODUCTION WOULD REQUIRE COLLECTOR AREA OF 2 SQUARE KILOMETERS.

SOLAR THERMAL CONVERSION/SOLAR PONDS/ELECTRIC POWER/PROCESS HEAT/ENERGY STORAGE/COOLING WATER/MULTIPURPOSE SYSTEMS

0024

DUFFIE, J.A./BECKMAN, W.A.

1976

SOLAR HEATING AND COOLING.

SCIENCE 191(4223):143-149.

REVIEWS TECHNOLOGIES FOR SOLAR HEATING AND COOLING OF BUILDINGS. SOLAR SPACE- AND WATER-HEATING TECHNOLOGY IS WELL ESTABLISHED AND COMPETITIVE WITH HIGH-COST CONVENTIONAL ENERGY SOURCES. SOLAR COOLING TECHNOLOGY IS EMBRYONIC, STILL MOSTLY EXPERIMENTAL; THERE ARE MANY THERMODYNAMIC CONFIGURATIONS TO CHOOSE FROM. SOLAR ENERGY FOR BUILDINGS CAN CONTRIBUTE SIGNIFICANTLY TO THE U.S. ENERGY ECONOMY IN THE NEXT DECADE, SPURRING GROWTH OF A WHOLE NEW INDUSTRY. THE TECHNOLOGY IS AT HAND; ITS UTILIZATION DEPENDS ON POLITICAL DECISIONS.

SPACE HEATING/SPACE COOLING/ACTIVE TEMPERATURE CONTROL/PASSIVE TEMPERATURE CONTROL/WATER HEATING/POLITICAL ASPECTS

0025

DUFFIELD, C.

1976

GEOTHERMAL TECHNOECOSYSTEMS AND WATER CYCLES IN ARID LANDS.

UNIVERSITY OF ARIZONA, TUCSON, OFFICE OF ARID LANDS STUDIES, ARID LANDS RESOURCE INFORMATION PAPER 8. 202 P.

LARGE COMPLEX INDUSTRIAL SYSTEMS ARE CLOSELY ANALOGOUS TO BIOLOGICAL ECOSYSTEMS AND CAN BE CALLED 'TECHNOECOSYSTEMS'. THIS ANALOGY CAN PROVIDE INSIGHTS USEFUL FOR DESIGN, MANAGEMENT, AND COMPREHENSION OF INDUSTRIAL CIVILIZATIONS AND THEIR COMPONENTS. CHAPTER 1 IS A GENERAL INTRODUCTION TO TECHNOECOLOGICAL VIEWPOINT AND CONCEPTS. THESE ARE APPLIED IN LATER CHAPTERS TO A REVIEW OF GEOTHERMAL RESOURCE GEOLOGY AND EXPLOITATION TECHNOLOGY, WITH ARID DEVELOPING REGIONS AND IMPERIAL VALLEY, CALIFORNIA, AS CASE STUDIES. DIVERSE ROLES OF WATER IN GEOTHERNAL AND CHER TECHNOECOSYSTEMS ARE DISCUSSED, ALONG WITH TECHNOECOSYSTEM ADAPTATION TO ARIDITY. GEOTHERMAL RESERVES ARE FINITE AND NONRENEWABLE AT PROJECTED EXPLOITATION RATES; EVER-DELPER HEAT EXTRACTION THREATENS HEAT-POWERED GEOLOGICAL SYSTEMS OF EVER-LARGER SCALE WITH IRREVERSIBLE MODIFICATION AND POSSIBLE EXTINCTION. GEOMETRIES OF SOLAR AND GEOTHERMAL TECHNOECOSYSTEMS ARE COMPARED, AND SOLAR-GEOTHERMAL HYBRID TECHNOECOSYSTEMS ARE DISCUSSED.

LIMITING FACTORS/GEOTHERMAL ENERGY/TECHNOECOSYSTEMS/TECHNOECOLOGY/BIOLOGICAL-INDUSTRIAL ANALOGY/ARID-SEMIARID LANCS/DEVELOPING COUNTRIES/IMPERIAL VALLEY/ADAPTATION/TECHNOLOGICAL SUCCESSION/ENERGY QUALITY/ROLES OF WATER/

ENVIRONMENTAL EFFECTS/HYBRID SYSTEMS/COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/
COMPETITION/BIBLIOGRAPHIES/GEOLOGY/DES ALINATION/DISTILLATION/MULTIPLE EFFECT
DISTILLATION/EVAPORATION/ECONOMICS/ELECTRIC POWER/NET ENERGY/CGLORADO RIVER/
AGRICULTURE/APPROPRIATE TECHNOLOGY/CONTROLLED-ENVIRONMENT AGRICULTURE/COOLING
WATER/GROUNDWATER/HEAT ENGINES/HEAT EXCHANGERS/HYDROGEN/IRRIGATION/ISRAEL/
MEXICO/PROCESS HEAT/REFRIGERATION/RESEARCH AND DEVELOPMENT/SIZE EFFECTS/
SOUTHWEST U.S./SPACE COOLING/SPACE HEATING/TCTAL ENERGY SYSTEMS/WASTE HEAT USE/
WATER CONSERVATION/WATER HEATING/WATER PUMPING/WATER REQUIREMENTS/WATER SUPPLY/
DIVERSITY (TECHNOLOGICAL)

0026

DUGUAY, M.A.

1977

SOLAR ELECTRICITY: THE HYBRID SYSTEM APPROACH.

AMERICAN SCIENTIST 65 (4):422-427.

SOLAR CELL ELECTRICAL GENERATION CAN BE MUCH MORE ECONOMICAL WHEN COMBINED AT POINT OF USE WITH OTHER SERVICES, SUCH AS HEATING AND LIGHTING. TWO SUCH HYBRID SYSTEMS ARE DESCRIBED. IN THE FIRST, TRACKING REFLECTORS CONCENTRATE SUNLIGHT ON HEAT COLLECTOR PIPES SURFACED WITH SOLAR CELLS. POWER GUTPUT PER CELL IS INCREASED, AND WASTE HEAT FROM COOLING THE CELLS IS PUT TO GOOD USE. THE SECOND SYSTEM USES A HELIOSTAT AND FOCUSING OPTICS TO TRANSFER SUNLIGHT INTO AN OFFICE, WHERE IT PROVIDES PLEASANT LIGHTING AS WELL AS HEAT AND ELECTRICITY. A SMALL REDUCTION IN SOLAR CELL COST WILL MAKE THE FIRST SYSTEM COMPETITIVE, WHILE THE SECOND APPEARS TO BE POTENTIALLY CHEAPER THAN CONVENTIONAL SYSTEMS ALREADY. MUCH RESEARCH AND DEVELOPMENT WORK IS NEEDED, BUT IT SEEMS THAT PRACTICAL WATER AND FUEL SAVING SOLAR ELECTRIC HYBRID SYSTEMS APE A NEAR-TERM POSSIBILITY.

HYBRID SYSTEMS/MULTIPURPOSE SYSTEMS/OPTICAL CONCENTRATION/LIGHTING/HELIOSTATS/PHOTOVOLTAIC CONVERSION/SOLAR CELLS/MEDIUM TEMPERATURE SYSTEMS/WASTE HEAT USE/ECONOMICS/CONCENTRATING COLLECTORS

0027

EIBLING, J.A./TALBERT, S.G./LOF, G.O.G.

1971

SOLAR STILLS FOR COMMUNITY USE: DIGEST OF TECHNOLOGY.

SOLAR ENERGY 13 (2):263-276.

MANY FACTORS THAT INFLUENCE PRODUCTIVITY OF SOLAR STILLS ARE DISCUSSED IN THREE CATEGORIES: ATMOSPHERIC VARIABLES, DESIGN FEATURES, AND OPERATION TECHNIQUES. DATA ON LARGE SOLAR STILLS WHICH HAVE BEEN OPERATED ARE TABULATED, AND PRODUCTIVITY CURVES ARE GIVEN FOR SEVERAL BASIN-TYPE STILLS. RESEARCH ON IMPROVED MATERIALS IS NECESSARY. SOLAR DISTILLATION CAN SUPPLY POTABLE WATER TO SMALL COMMUNITIES WERE NATURAL SUPPLY OF FRESH WATER IS INADEQUATE OR OF POOR QUALITY, AND WHERE SUNSHINE IS ABUNDANT. CAPITAL COST OF LARGE PERMANENT SOLAR STILLS CAN BE AS LOW AS 1 DOLLAR PER SQUAKE FOOT, EQUIVALENT TO 10 TO 15 DOLLARS PER DAILY GALLON OUTPUT, DEPENDING ON SOLAR RADIATION AND RAINFALL COLLECTION AMOUNTS. CORRESPONDING DISTILLED WATER COST IS 3 TO 4 DOLLARS PER 1000 GALLONS. THESE COSTS ARE GENERALLY LOWER THAN THOSE OF OTHER TYPES OF DESALINATION EQUIPMENT IN SIZES UP TO AROUND 50,000 GALLONS PER DAY.

BASIN-TYPE STILLS/ECONOMICS/ARID-SEMIARID LANDS/WATER SUPPLY/DISTILLATION/DESALINATION

EPSTEIN, E./NORLYN, J.D.

1977

SEAWATER-BASED CROP PRODUCTION: A FEASIBILITY STUDY.

SCIENCE 197 (4300):249-251.

SEVERAL SELECTIONS OF BARLEY WERE SUCCESSFULLY GROWN IN DUNE SAND WITH SEAWATEA IRRIGATION. ALL PRODUCED VIABLE GRAIN OF GOOD FEED QUALITY, WITH YIELDS APPROACHING HALF THAT OF BARLEY IRRIGATED WITH FRESH WATER. SELECTION AND BREEDING FOR SALT TOLERANCE, USING THE LARGE GLOBAL GENE POOL, IS CERTAIN TO INCREASE YIELDS OVER THOSE OF THIS PRELIMINARY EXPERIMENT. FURTHERMORE, THIS GENETIC APPROACH TO SEAWATER CROP PRODUCTION IS PROBABLY APPLICABLE TO CROPS OTHER THAN BAKLEY, INCLUDING FOOD, FIBER, FORAGE, AND BIOMASS FOR FUELS.

AGRICULTURE/SEAWATER IRRIGATION/BIOMASS FUELS/IRRIGATION/COASTAL DESEATS/ARID-SEMIARID LANDS/SALT TOLERANCE/ECONOMIC PLANTS/FOOD PRODUCTION

0029

FINLAYSON, F.C./KAMMER, W.A.

1975

INTEGRATED SOLAR/GEOTHERMAL POWER SYSTEMS: CONCEPTUAL DESIGN AND ANALYSIS.

AEROSPACE CORPORATION, EL SEGUNDO, CALIFORNIA, AEROSPACE REPORT ATR-75 (7512) -1.

PROPOSES THAT SOLAR THERMAL ENERGY BE USED TO RAISE TEMPERATURE OF MODERATE TEMPERATURE LIQUID DOMINATED GEOTHERMAL FLUIDS FOR POWER PRODUCTION IN A 10 MWE PLANT. THIS WOULD INCREASE POWER OUTPUT OVER THAT OF A PURE GEOTHERMAL SYSTEM, WOULD INCREASE 5 PERCENT THERMODYNAMIC EFFICIENCY TO 40 PERCENT, AND WOULD GREATLY REDUCE VOLUME OF GEOTHERMAL FLUID REQUIRED. GEOTHERMAL HEAT WOULD PROVIDE BASE LOAD, AND SOLAR ENERGY, WHEN AVAILABLE, WOULD SUPPLY PEAK LOAD POWER. THIS STUDY IS FOR THE RAFT RIVER VALLEY, IDAHO, BUT ITS CONCEPTS MAY BE ESPECIALLY APPLICABLE IN IMPERIAL VALLEY, CALIFORNIA, AND IN OTHER GEOTHERMAL AREAS OF SOUTHWESTERN U.S.

HYDRID SYSTEMS/SOLAR THERMAL CONVERSION/GEOTHERMAL ENERGY/LLECTRIC POWLR/SOUTHWEST U.S./IMPERIAL VALLEY/MODEL STUDIES

0030

GLASER, P. E.

1976

DEVELOPMENT OF THE SATELLITE SOLAR POWER STATION.

SPACEFLIGHT 18 (6): 198-208.

SATELLITE SOLAR POWER STATION (SSPS) MAY PROVIDE AN ECONOMICALLY VIALLE AND ENVIRONMENTALLY AND SOCIALLY ACCEPTABLE OPTION FOR POWER GENERATION TO MEET A SIGNIFICANT PORTION OF FUTURE WORLD ENERGY DEMANDS. SSPS CONCEPT IS BASED ON EXTENSION OF EXISTING TECHNOLOGY AND ON SUCCESSFUL DEVELOPMENT OF AN

EFFECTIVE SPACE SHUTTLE TRANSPORTATION SYSTEM. SOLAR CELLS WOULD CONVERT SOLAF ENERGY TO ELECTRICITY WHICH WOULD DRIVE MICROWAVE GENERATORS. MICROWAVES WOULD BE BEAMED TO A RECEIVING ANTENNA SYSTEM ON FARTH, WHERE THE ENERGY WOULD BE RECONVERTED TO ELECTRICITY SAFELY AND EFFICIENTLY. SSPS SYSTEMS COULD DELIVER POWER ALMOST ANYWHERE ON EARTH. COST OF TRANSPORTATION, ASSEMBLY, AND MAINTENANCE IS CHIEF DETERMINANT OF ECONOMIC FEASIBILITY. SEVERAL COST-LOWERING APPROACHES ARE BEING INVESTIGATED. IT IS HIGHLY LIKELY THAT A TWO-STAGE TRANSPORTATION SYSTEM WILL EVOLVE: PAYLOADS CARRIED FIRST TO LOW-EARTH ORBIT, AND THEN PARTLY ASSEMBLED COMPONENTS DELIVERED TO SYNCHRONOUS ORBIT OR INTERMEDIATE ORBIT FOR FINAL ASSEMBLY AND DEVELOPMENT.

ORBITAL POWER STATIONS/ECONOMICS/ENVIRONMENTAL EFFECTS/SOCIAL ASPECTS/ELECTRIC POWER/SOLAR CELLS/PHOTOVOLTAIC CONVERSION/ENERGY TRANSMISSION/MICROWAVE POWER TRANSMISSION

0031

HAGEN, A.W.

1975

THERMAL ENERGY FROM THE SEA.

NOYES DATA CORPORATION, PARK RIDGE, NEW JERSEY. 150 P.

A BOOK LENGTH REVIEW OF OCEAN THERMAL ENERGY CONVERSION POSSIBILITIES, INCLUDING SEVERAL SPECIFIC DESIGNS THAT HAVE BEEN PROPOSED. THERMODYNAMIC EFFICIENCY IS LOW, 2 PERCENT OR LESS, DUE TO SMALL TEMPERATURE DIFFERENCE BETWEEN SURFACE AND DEEP SEA WATER, AND FLOW REQUIREMENT IS COMPARABLE TO THAT OF HYDROELECTRIC PLANT. OPEN CYCLE SYSTEMS COULD PRODUCE DISTILLED WATER WITH OR WITHOUT POWER, AND CLOSED CYCLES MIGHT BE CHEAPER FOR POWER ALONE. GCEAN THERMAL PLANTS AND COMPLEXES COULD PRODUCE HYDROGEN, POWER, WATER, OXYGEN, BIOCHEMICALS, SALTS, AND MARICULTURE-PRODUCED FOOD. DESIGNS WILL VARY GREATLY WITH DIFFERENT ENVIRONMENTS (E.G., OFFSHORE, NEARSHORL, ONSHORE) AND PRODUCT DEMANDS. HYBRIDS WITH GEOTHERMAL ENERGY AND WITH OTHER SOLAR ENERGY FORMS ARE POSSIBLE.

OCEAN THERMAL ENERGY CONVERSION/HYDROPOWER/DISTILLATION/ELECTRIC POWER/COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/HYDROGEN/HYBRID SYSTEMS/GEOTHERMAL ENERGY/DESALINATION/SALT PRODUCTION/FOOD PRODUCTION/MARICULTURE

0032

HALACY, D.S.

1973

THE COMING AGE OF SOLAR ENERGY.

AVON BOOKS, NEW YORK. 248 P.

THIS BOOK IS A GOOD DESCRIPTIVE AND PICTORIAL INTRODUCTION TO SOLAR ENERGY TECHNOLOGY AND DEVELOPMENT SCHEMES FOR THE GENERAL READER. IT IS COMPREHENSIVE IN SCOPE; COVERAGE RANGES FROM ARCHIMEDES TO SATELLITES, FROM OCEAN THERMAL POWERPLANTS TO DESERT POWER FARMS

SOLAR RADIATION/ELECTRIC POWER/SOLAR THERMAL CONVERSION/PHOTOCHEMICAL CONVERSION/ORBITAL POWER STATIONS/OCEAN THERMAL ENERGY CONVERSION/PHOTOVOLTAIC CONVERSION

HAMMOND, A.L.

1977A

PHOTOSYNTHETIC SOLAR ENERGY: REDISCOVERING BIOMASS FUELS.

SCIENCE 197 (4305): 745-746.

BIOMASS, ALREADY LARGEST SOURCE OF SOLAR ENERGY IN THE U.S., AND MAIN SOURCE OF ALL ENERGY IN MOST OF THE DEVELOPING WORLD, CAN BE A RENEWABLE SOURCE OF LIQUID AND GASEOUS FOSSIL FUEL SUBSTITUTES. NEW IDEAS FOR BIOMASS CONVERSION AND USE ARE APPEARING AT A RAPID RATE, AND MANY MAY BE APPLICABLE NOW. POTENTIAL FUEL FEEDSTOCKS INCLUDE WOOD, SUGARCANE, ALGAE, SORGHUM, COKN, AGRICULTURAL AND SILVICULTURAL WASTES, WATER HYACINTH, AND ARTIFICIAL PHOTOSYNTHETIC MEMBRANE PRODUCTS. POSSIBLE HARVESTING SYSTEMS INCLUDE STANDARD AGRICULTURE, TREE FARMS, ALGAL PONDS USING SEWAGE, AND OCEANIC KELP RAFTS. AND PROPOSED CONVERSION TECHNIQUES INCLUDE GASIFICATION, ALCOHOL FERMENTATION, ANAEROBIC DIGESTION, AND USE OF SOLAR-THERMAL SUPERHEATED STEAM TO PRODUCE HYDROGEN FROM ORGANIC WASTE. USE OF BIOMASS FOR ENERGY MUST COEXIST WITH FOOD, FIBER, AND WOOD NEEDS; THIS MAY WORK WELL IN COMPLEX MULTIPLE PURPOSE SYSTEMS WHICH PROVIDE FOR ALL. BIOMASS REFINERIES FALL OUTSIDE FEDERAL INSTITUTIONAL CATEGORIES OF ENERGY AND AGRICULTURE, AND HAVE NOT BEEN STUDIED. FEDERAL FUNDING FOR BIOMASS FUEL RESEARCH IS MEAGER DESPITE APPARENT PROMISE. THE AUTHOR SUGGESTS THAT IT WOULD BE WISE TO EXPLORE THE BIGMASS OPTION MODE THOROUGHLY BEFORE THE U.S. IS FORCED INTO HUGE INVESTMENTS IN FOSSIL-BASED SYNTHETIC FUEL INDUSTRY.

AGRICULTURE/AGRICULTURAL WASTES/HYDROGEN/BIOMASS FUELS/MARICULTURE/SOLAR THERMAL CONVERSION/ECONOMIC PLANTS

0034

HAMMOND, A. L.

1977B

PHOTOVOLTAICS: THE SEMICONDUCTOR REVOLUTION COMES TO SOLAR.

SCIENCE 197 (4302): 445-447.

PHOTOVOLTAIC TECHNOLOGY IS ADVANCING AT AN EXPLOSIVE RATE IN A GREAT DIVERSITY OF DIRECTIONS. THE GOAL IS TO REDUCE COST BY A FACTOR OF 20 TO 40 OR MORE, PERHAPS TO 50 CENTS PER PEAK WATT, IN ORDER TO MAKE SOLAR CELLS COMPETITIVE FOR ON-SITE POWER GENERATION. SOME OF THE APPROACHES BEING TAKEN ARE: SILICON CELL COST REDUCTION BY AUTOMATION, WASTE REDUCTION, NEW RIBBON AND SHEET SILICON CRYSTAL GROWING TECHNIQUES, AND USE OF OPTICAL CONCENTRATORS; DEVELOPMENT OF GALLIUM ARSENIDE CELL SYSTEMS WITH VERY HIGH OPTICAL CONCENTRATION; DEVELOPMENT OF MULTIPLE JUNCTION SILICON CELLS AND THERMOFHOTOVOLTAIC CELLS OF HIGH EFFICIENCY; AND DEVELOPMENT OF VERY INEXPENSIVE THIN FILM POLYCRYSTALLINE OR AMORPHOUS SEMICONDUCTORS (CADMIUM SULFIDE, SILICON, AND OTHERS) AND METHODS FOR MASS PRODUCING THEM. PHOTOVOLTAIC ARRAYS, INHERENTLY MODULAR, MAY HAVE A SUBSPANTIAL DISTRIBUTED RESIDENTIAL MARKET, ALTHOUGH FEDERAL PROGRAM CONCENTRATES ON CENTRAL POWER STATIONS. TERRESTRIAL MARKET IS LIMITED NOW, BUT COULD VERY SOON EXPAND TO INCLUDE REMOTE MILITARY INSTALLATIONS AND ELECTROCHEMICAL PLANTS. DESPITE LIMITED FEDERAL SUPPORT, PHOTOVOLTAIC INDUSTRY IS GROWING RAPIDLY; ONE OR MORE OF THE MANY COST REDUCTION APPROACHES SEEMS BOUND TO WORK OUT.

PHOTOVOLTAIC CONVERSION/SOLAR CELLS/ELECTRIC POWER/MASS PRODUCTION/OPTICAL CONCENTRATION/SIZE EFFECTS/AMORPHOUS SEMICONDUCTORS/ECONOMICS

HAMMOND, A.L./METZ, W.D.

1977

SOLAR ENERGY RESEARCH: MAKING SOLAR AFTER THE NUCLEAR MODEL?

SCIENCE 197 (4300): 241-244.

A CRITIQUE OF THE U.S. FEDERAL SOLAR ENERGY RESEARCH PROGRAM. MOLDED BY HISTORICAL, ORGANIZATIONAL, AND POLITICAL INFLUENCES, THE FEDERAL SOLAL PROGRAM STRONGLY EMPHASIZES DEVELOPMENT OF LARGE CENTRAL POWER STATIONS, DESPITE THE DIFFUSE NATURE OF SOLAR ENERGY AND THE GREAT DIVERSITY AND APPARENTLY GREATER FEASIBILITY OF MEDIUM AND SMALL DECENTRALIZED TECHNOLOGIES. MASSIVE ENGINEERING PROJECTS DESIGNED BY A FEW LARGE AEROSPACE COMPANIES FOR UTILITY CONTROL AND USE DOMINATE THE PROGRAM, REMINISCENT OF THE GIANT PROGRAM TO DEVELOP NUCLEAR POWER. ONLY A FEW LARGE-SCALE DESIGNS ARE SELECTED FOR COSTLY CONSTRUCTION IN SLOW SEQUENTIAL DEVELOPMENT. YET AN ALTERNATIVE STRATEGY OF PARALLEL DEVELOPMENT OF MANY COMPETING MEDIUM-SCALE DESIGNS SUITED TO MASS PRODUCTION WOULD PROBABLY BE LESS COSTLY AND MORE REWARDING. FURTHERMORE, THE PROGRAM SEEMS FRAGMENTED AND INFLEXIBLE; NUMEROUS VERY PROMISING TECHNOLOGIES, INCLUDING PASSIVE SOLAR HEATING, BIOMASS FUELS, HYBRID POWER SCHEMES, COMMUNITY-SCALE TOTAL ENERGY PROJECTS, AND OTHER MULTIPLE-PURPOSE SYSTEMS, RECEIVE LITTLE OR NO ATTENTION. DESPITE ALL THIS, THE PRIVATE SECTOR IS EXPERIENCING AN EXPLOSION OF OPTIMISM, TECHNICAL INNOVATION, AND MANUFACTURING ACTIVITY IN SMALL AND MEDIUM SCALE SOLAR TECHNOLOGIES.

DIVERSITY (TECHNOLOGICAL) / RESEARCH AND DEVELOPMENT/POLITICAL ASPECTS/ELECTRIC UTILITIES/SIZE EFFECTS/COMPETITION/ELECTRIC FOWER/MASS PRODUCTION/ECONOMICS/PASSIVE TEMPERATURE CONTROL/BIOMASS FUELS/HYBRID SYSTEMS/TOTAL ENERGY SYSTEMS/MULTIPURPOSE SYSTEMS

0036

HARRIGAN, R.W.

1975

APPLICATION OF SOLAR TOTAL ENERGY TO A MIXED-LOAD COMMUNITY.

SANDIA LABORATORIES, ALBUQUERQUE, NEW MEXICO, ENERGY REPORT SAND75-0542. 70 P.

INVESTIGATES THE ECONOMICS AND ENERGETICS OF APPLYING A SOLAR TOTAL ENERGY SYSTEM TO A HYPOTHETICAL NEW MEXICO COMMUNITY WITH 2000 DWELLING UNITS (IN 4 RESIDENTIAL DENSITY ZONES), THREE SCHOOLS, AND A COMMERCIAL COMPLEX. THE TOTAL ENERGY SYSTEM WOULD USE HEAT REJECTED BY A SOLAR THERMAL POWERPLANT TO PROVIDE SPACE HEATING, HOT WATER, AND AIR CONDITIONING TO THE VARIOUS BUILDINGS, THUS USING SOLAR ENERGY MORE EFFICIENTLY. ECONOMICS OF SUCH A CAPITAL INTENSIVE SYSTEM WOULD BE MUCH MORE FAVORABLE IF SOLAR EQUIPMENT COSTS WERE CONSIDERED OPERATING EXPENSES, AS IS FOSSIL FUEL, FOR TAX DEDUCTION PURPOSES.

TOTAL ENERGY SYSTEMS/URBAN PLANNING/MULTIPURPOSE SYSTEMS/COMPLEX SYSTEMS/SOLAR THERMAL CONVERSION/ELECTRIC POWER/WASTE HEAT USE/SPACE HEATING/BUILDING DESIGN/SPACE COOLING/WATER HEATING/ECONOMICS/POLITICAL ASPECTS/SOUTHWEST U.S./MODEL STUDIES

HILDEBRANDT, A.F./VANT-HULL, L.L.

1977

POWER WITH HELIOSTATS.

SCIENCE 197 (4309):1139-1146.

A SUMMARY OF TECHNOLOGICAL CONCEPTS FOR SOLAR THERMAL POWER PRODUCTION USING THOUSANDS OF HELIOSTATS (TWO-AXIS TRACKING MIRRORS) TO FOCUS DIRECT SUNLIGHT ON A TOWER-MOUNTED RECEIVER. HISTORY OF SOLAR TOWER CONCEPT IS RELATED, STARTING WITH ARCHIMEDES. MANY FACTORS (MATERIALS, GEOMETRY, CLIMATE, GEOLOGY, THERMODYNAMICS, OPTICS, POWER DEMAND FUNCTION, ETC.) MUST BE CONSIDERED IN CHOOSING OPTIMUM DESIGNS FOR HELIOSTAT FIELD, LIGHT RECEIVER, TOWER, AND ENERGY STORAGE SYSTEMS. SOME OF THESE ARE DISCUSSED IN DETAIL. FINALLY, ENVIRONMENTAL CONCERNS AND ECONOMICS ARE REVIEWED. WITH A USEFUL LIFE OF 30 YEARS, A 100 MWE PLANT WOULD PRODUCE 20 TIMES THE ENERGY NEEDED FOR CONSTRUCTION. ESTIMATED CAPITAL COST PER KILOWATT (1700 DOLLARS) IS COMPETITIVE WITH OTHER POWER SOURCES. COSTS, MATERIALS, AND TECHNOLOGY PROVIDE NO BARRIER TO ESTABLISHING SUCH SYSTEMS. MASS PRODUCTION OF HELIOSTATS WILL LOWER COSTS AND SPEED CONSTRUCTION TIME.

SOLAR THERMAL CONVERSION/CENTRAL RECEIVER-HELICSTAT SYSTEMS/ADAPTATION/ENERGY STORAGE/ENVIRONMENTAL EFFECTS/ECONOMICS/NET ENERGY/MASS PRODUCTION/HELIOSTATS

0038

HIRSCHMANN, J.R.

1970

SALT PLATS AS SOLAR-HEAT COLLECTORS FOR INCUSTRIAL PURPOSES.

SOLAR ENERGY 13 (1):83-97.

SALT FLATS (SALARS) ARE IDEAL LOCATIONS FOR EUILDING SOLAR PONDS. THEY ARE FLAT AND WATERPROOF, AND CRACKS SELF-HEAL. THEY ARE ARID AND STERILE, AND HAVE INTERIOR DRAINAGE AND VERY HIGH SOLAR RADIATION FLUX, ALL AUSPICIOUS PROPERTIES FOR SOLAR POND SITES. THE ANDES OF CHILE, ARGENTINA, AND BOLIVIA HAVE MANY SALT FLATS, AND OTHERS ARE FOUND IN NORTH AMERICA, AFRICA, ASIA, AND AUSTRALIA. GEOLOGY OF SOME CHILEAN SALARS IS DISCUSSED. SOLAR PONDS AT LEAST 1.5 M DEEP COULD BE CREATED AND MAINTAINED WITH GROUNDWATER OR IMPORTED OCEAN WATER. A PLANT COULD BE CONSTRUCTED TO USE SOLAR HEAT COLLECTED BY PONDS TO PRODUCE ANY COMBINATION OF POWER, DISTILLED WATER, AND PURE SALTS.

SOLAR THERMAL CONVERSION/SALT FLATS/SOLAR PONDS/ARID-SEMIARID LANDS/CHILE/ARGENTINA/BOLIVIA/AUSTRALIA/GROUNDWATER/ELECTRIC POWER/DISTILLATION/EVAPORATION/SALT PRODUCTION/GEOLOGY

0039

HIRSCHMANN, J.R.

1975

SOLAR DISTILLATION IN CHILE.

DESALINATION 17(1):17-30.

SEE: SWRA W77-02862.

DESALINATION/DISTILLATION/BASIN-TYPE STILLS/ARID-SEMIARID LANDS/CHILE/AGRICULTURE/WATER CONSERVATION/COASTAL DESERTS/WATER SUPPLY

0040

HODGES, C.N.

1975

DESERT FOOD FACTORIES.

TECHNOLOGY REVIEW 77 (3):32-39.

SEE: SWRA W77-02176.

ARID-SEMIARID LANDS/FOOD PRODUCTION/ABU DHABI/CCASTAL DESERTS/
CONTROLLED-ENVIRONMENT AGRICULTURE/DESALINATION/COMPLEX SYSTEMS/MULTIPURPOSE
SYSTEMS/HYBRID SYSTEMS/GREENHOUSES/MEXICO/ECONOMICS/WASTE HEAT USE/AGRICULTURE/
DISTILLATION

0041

HODGES, C. N. ET AL

1966

SOLAR DISTILLATION UTILIZING MULTIPLE-EFFECT HUMIDIFICATION.

U.S. OFFICE OF SALINE WATER, RESEARCH AND DEVELOPMENT PROGRESS REPORT 194. 159 P.

SEE: SWRA W72-06377.

DESALINATION/DISTILLATION/MULTIPLE EFFECT DISTILLATION/MEXICO

0042

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 EFFECTS/PHOTOVOLTAIC CONVERSION/SCLAR THERMAL CONVERSION/ELECTRIC POWER/GEOTHERMAL ENERGY/HYDROGEN

HULT, J.L./OSTRANDER, N.C.

1973

ANTARCTIC ICEBERGS AS A GLOBAL FRESH WATER RESOURCE.

RAND CORPORATION, SANTA MONICA, CALIFORNIA. 83 P.

ICEBERGS TRANSPORTED FROM ANTARCTICA ARE FOTENTIALLY A SOURCE OF VERY PURE WATER AND A HEAT SINK FOR POWER PRODUCTION AND THERMAL FOLLUTION. TEN PERCENT OF THE ONE THOUSAND CUBIC KILOMETER ANNUAL ICEBERG CROP WOULD SATISFY WATER DEMAND OF AN URBAN POPULATION OF 500 MILLION, FROBABLY WITH LITTLE EFFECT ON GLOBAL CLIMATE. POSSIBLE TECHNOLOGY FOR ICEBERG RECOVERY IS PROPOSED: LOCATION BY SATELLITE, INSULATION BY QUILTED PLASTIC FILM, ICEBERG TRAINS 300 TO 600 METERS WIDE AND UP TO 20 KILOMETERS LONG SLOWLY PROPELLED BY TUGBOATS OR SIDE-MOUNTED PROPELLERS, CUTTING AND MELTING IN PORT, USE OF ICEBERGS AS RESERVOIRS AND RECREATION AREAS. APPARENTLY, LESS ENERGY AND MONEY WOULD BE REQUIRED THAN FOR STANDARD INTERBASIN WATER TRANSFERS AND DESALTING OPERATIONS (30 DOLLARS VS. 100 DOLLARS PER ACRE-FT). GENERAL DISCUSSION OF SOCIETAL AND ENVIRONMENTAL IMPACTS CONCLUDES THE REPORT.

ICEBERGS/ANTARCTICA/WATER SUPPLY/HEAT SINKS/ENVIRONMENTAL EFFECTS/ECONOMICS/DESALINATION/SOCIAL ASPECTS/MULTIPURPOSE SYSTEMS/COMPLEX SYSTEMS/CLIMATIC CHANGE/MODEL STUDIES

0044

JENSEN, M.H. ED.

1976

SCLAR FREEGY: FUEL AND FOOD WORKSHOP. THE UTILIZATION OF SOLAR ENERGY IN GREENHOUSES AND INTEGRATED GREENHOUSE-RESIDENTIAL SYSTEMS. TUCSON, 1976, PROCEEDINGS.

UNIVERSITY OF ARIZONA, TUCSON, ENVIRONMENTAL RESEARCH LABORATORY ERDA/USDA-ARS. 262 P-

GREENHOUSE VEGETABLE PRODUCTION HAS POTENTIAL FOR INCREASING AGRICULTURAL PRODUCTION ON LESS LAND AND IN MARGINAL AGRICULTURAL AREAS. SCLAR ENERGY CAN PROVIDE 80 PERCENT OF THE ENERGY NEEDS OF GREENHOUSE AGRICULTURE. FURTHERMORE, SOLAR COLLECTOR GREENHOUSES CAN HEAT HOUSES WHILE PRODUCING FOOD FOR THE FAMILY MUCH OF THE YEAR. 20 PAPERS ABOUT RECENT DEVELOPMENTS AND DESIGNS FOR SOLAR HEATING AND COOLING OF GREENHOUSES AND INTEGRATED GREENHOUSE-RESIDENTIAL SYSTEMS WERE PRESENTED AT THE WORKSHOP AND ARE PUBLISHED HERE.

GREENHOUSES/FOOD PRODUCTION/AGRICULTURE/CONTROLLED-ENVIRONMENT AGRICULTURE/COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/SPACE HEATING/BUILDING DESIGN

0045

JENSEN, M.H. ED.

1977

INTERNATIONAL SYMPOSIUM ON CONTROLLED ENVIRONMENT AGRICULTURE. TUCSON, 1977, PROCEEDINGS.

UNIVERSITY OF ARIZONA, TUCSON, ENVIRONMENTAL RESEARCH LABORATORY, COLLEGE OF AGRICULTURE. 413 P.

PRESENTS 46 SYMPOSIUM PAPERS ON NUMEROUS ASPECTS OF CONTROLLED ENVIRONMENT AGRICULTURE, INCLUDING: INDUSTRY OVERVIEW, ECONOMICS, PLANT BREEDING AND NEW CULTIVARS, VEGETABLE INTERCROPPING, ENERGY ALTERNATIVES (SOLAR HEATING, SOLAR POND FOR HEATING, DEEP MINE AIR VENTILATION, POWERPLANT REJECT HEAT), GROWING TECHNIQUES, VEGETABLE TRANSPLANT GROWING, FERTILIZERS AND CO2 ENRICHMENT, DIRECT CONTACT HEAT EXCHANGERS FOR HEATING AND COOLING, ENERGY CONSERVATION (PLASTIC SHEET AND LIQUID FOAM THERMAL SCREENS TO CUT HEAT LOSS), PRESENT AND FUTURE GREENHOUSE DESIGNS, AND INSECT AND DISEASE CONTROL. SYMPOSIUM ATTENDANCE WAS FROM 20 COUNTRIES THROUGHOUT THE WORLD.

CONTROLLED-ENVIRONMENT AGRICULTURE/GREENHOUSES/ECONOMICS/FOOD PRODUCTION/AGRICULTURE/ECONOMIC PLANTS/SOLAR PONDS/WASTE HEAT USE/SPACE COOLING/SHADING/HEAT EXCHANGERS/BUILDING DESIGN

0046

KETTANI, M.A./GONSALVES, L.M.

1972

HELIOHYDROELECTRIC (HHE) POWER GENERATION.

SOLAR ENERGY 14 (1):29-30.

DAWHAT SALWAH, PART OF THE ARABIAN-PERSIAN GULF, COULD BE MADE INTO AN ARTIFICIAL DEPRESSION FOR POWER PRODUCTION. TWO DAMS, ONE FROM SAUDI ARABIA TO BAHRAIN, THE OTHER FROM BAHRAIN TO QATAR, WOULD ALLOW EVAPORATION TO LOWER THE LEVEL OF THIS BODY OF WATER. CONTROLLED INFLOW OF WATER FROM THE GULF WOULD DRIVE HIGHLY EFFICIENT HYDROPOWER GENERATORS TO PRODUCE UP TO 300,000 MWH PER YEAR OF ELECTRICITY, EQUIVALENT TO AVERAGE POWER OF 34 MW. A NATURAL EXAMPLE OF SUCH A SYSTEM IS THE ZALIV (GULF) KARA-BOGAZ-GOL, WHERE CASPIAN SEA OVERFLOWS INTO TURKMEN DESERT.

HYDROPOWER/EVAPORATION/ELECTRIC POWER/PERSIAN GULF/SAUDI ARABIA/BAHKAIN/QATAR/CASPIAN SEA/COASTAL DESERTS/DEPRESSIONS (GEOMORPHIC)

0047

KNOWLES, R.L.

1974

ENERGY AND FORM: AN ECOLOGICAL APPROACH TO URBAN GROWTH.

MIT PRESS, CAMBRIDGE, MASSACHUSETTS. 198 P.

DESIGNERS OF THE BUILT ENVIRONMENT CAN CONSERVE ENERGY BY IMITATING SURVIVAL STRATEGIES OF BIOLOGICAL ORGANISMS AND ECOSYSTEMS: LOCAL DIVERSITY RATHER THAN SPECIALIZATION AND COSTLY LONG-DISTANCE TRANSPORTATION, EXPENSIVE GROWTH AND CHEAP MAINTENANCE RATHER THAN THE REVERSE, FLEXIBLE MANUFACTURING RATHER THAN RIGID MASS PRODUCTION, AND ADAPTIVE BEHAVIOR AND FORM (GEOMETRY AND SCALE) OF STRUCTURES. MODERN SOCIETIES WASTE ENERGY TO COMPENSATE FOR DEPARTURES FROM THESE STRATEGIES. SOLAR RADIATION IS THE PRIME DETERMINANT OF ENERGY NECESSARY TO MAINTAIN COMPORTABLE INTERNAL TEMPERATURES. GRAPHICAL AND ANALOG TECHNIQUES ARE PRESENTED AND USED TO DEMONSTRATE THAT PUEBLOS OF SOUTHWESTERN INDIANS MADE GOOD USE OF TOPOGRAPHY AND BUILDING FORM TO TAKE ADVANTAGE OF DIURNAL AND ANNUAL CYCLES OF SUNLIGHT GEOMETRY FOR MICROCLIMATE CONTROL. KNOWLES SUGGESTS THAT WE DO LIKEWISE IN OUR ARCHITECTURE, LAND USE AND URBAN PLANNING, AND LANDSCAPING. AND HE PRESENTS SOME POSSIBLE DESIGNS FOR LARGE THREE-DIMENSIONAL URBAN STRUCTURES WHICH, LIKE THE PUBBLOS, ARE ADAPTED TO SUNLIGHT GEOMETRY.

ADAPTATION/BIOLOGICAL-INDUSTRIAL ANALOGY/SHADING/PASSIVE TEMPERATURE CONTROL/URBAN PLANNING/PUEBLOS/SOUTHWEST U.S./SUNLIGHT GEOMETRY/BUILDING DESIGN/SPACE COOLING/SPACE HEATING/DIVERSITY (TECHNOLOGICAL)/SOLAF RADIATION/SOCIAL ASPECTS/MODEL STUDIES

0048

LEONARD, S. L.

1975

MISSION ANALYSIS OF PHOTOVOLTAIC SOLAR ENERGY SYSTEMS, FINAL REPORT. VOL.1: SUMMARY.

AEROSPACE CORPORATION, EL SEGUNDO, CALIFORNIA, AEROSPACE REPORT ATR-76 (7476-01)-1, VOL. 1. 113 P.

THIS REPORT SUMMARIZES RESULTS OF A MAJOR ANALYSIS OF TECHNICAL AND ECONOMIC FEASIBILITY OF GENERATING ELECTRICITY WITH SOLAR CELLS IN SOUTHWEST U.S. IT CONCLUDES THAT ON-SITE RESIDENTIAL APPLICATIONS AND CENTRAL STATION SYSTEMS (INTERMEDIATE LOAD) ARE EQUALLY PROMISING, AND ARE COMPETITIVE WITH CONVENTIONAL GENERATION TECHNOLOGY WHEN SOLAR CELL ARRAYS COST 100 TO 200 DOLLARS PER PEAK KILOWATT. THEY ARE COMPETITIVE EVEN WITHOUT USE OF CONCENTRATORS, USE OF THERMAL ENERGY FROM COCLING ARRAYS, RELAXATION OF PRESENT RELIABILITY STANDARDS, OR INTRODUCTION OF GOVERNMENT INCENTIVES. ARRAY COST GOALS DEPEND STRONGLY ON FUEL PRICE PROJECTIONS AND ARRAY EFFICIENCY. OTHER CONCLUSIONS ARE THAT INSOLATION FORECASTING IS NOT PARTICULARLY USEFUL FOR GUIDING ON-SITE STORAGE, AND THAT USE OF PHOTOVOLTAIC POWER TO PRODUCE HYDROGEN BY ELECTROLYSIS WILL PROBABLY NOT COMPETE WITH OTHER FUELS AND HYDROGEN SOURCES.

PHOTOVOLTAIC CONVERSION/SOLAR CELLS/SOUTHWEST U.S./ELECTRIC POWER/SIZE EFFECTS/ECONOMICS/HYDROGEN/OPTICAL CONCENTRATION/MODEL STUDIES

-0049

LOEWER, O. J., JR. ET AL

1977

TOWARD A SELF-SUFFICIENT SYSTEM FOR HUMAN HOUSING.

SIMULATION 28(3):65-72.

A HOUSING SYSTEM IN WHICH MOST FOOD AND ENERGY IS PRODUCED LOCALLY HAS BEEN SIMULATED. ENERGY IS PRODUCED BY SOLAR COLLECTORS AND METHANE GENERATORS, AND FOOD IS PRODUCED IN GREENHOUSES, FISH TANKS, AND GARDENS. WASTES ARE RECYCLED AS FERTILIZER AND METHANE. THE MODEL USES SOLAR ENERGY SUBMODELS, ENGINEERING DESCRIPTIONS OF HEATING AND COCLING SYSTEMS, WEATHER AND CONSTRUCTION PARAMETERS, TABLES OF DIETARY NEEDS, AND FOOD PRODUCTION RATES IN ORDER TO ESTIMATE SYSTEM SELF-SUFFICIENCY.

COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/HYBRID SYSTEMS/FCOD PRODUCTION/ AGRICULTURE/BIOMASS FUELS/AQUICULTURE/SPACE HEATING/SPACE COOLING/WATER HEATING/ BUILDING DESIGN/COLLECTORS/GREENHOUSES/MODEL STUDIES

MAKHIJANI, A.

1976

SCLAR ENERGY AND RURAL DEVELOPMENT FOR THE THIRD WORLD.

BULLETIN OF THE ATOMIC SCIENTISTS 32(6):14-24.

SOLAR ENERGY, MAINLY THROUGH PHOTOSYNTHESIS, IS THE PRIMARY AND OFTEN ALMOST EXCLUSIVE SOURCE OF ENERGY FOR PECPLE IN DEVELOPING REGIONS. CROPS, CROP RESIDUES, DUNG, AND WOOD SUPPLY MOST ENERGY FOR ALL PURPOSES; OIL, COAL, AND ELECTRICITY ARE COSTLY SUPPLEMENTS. ENERGY SUPPLY SHOULD BE INCREASED FROM THIS PHOTOSYNTHETIC BASE BY INTRODUCING COMPATIBLE SMALL-SCALE TECHNOLOGIES DESIGNED TO MEET HUMAN NEEDS, PROVIDE MEANINGFUL EMPLOYMENT, BE ENVIRONMENTALLY BENIGN, AND EFFECTIVELY USE RURAL RESOURCES (LOCAL MATERIALS, LITTLE CAPITAL, MUCH LABOR). EQUITABLE SOCIAL ORGANIZATION TO ACCOMPANY NEW TECHNOLOGIES IS VITAL TO SUCCESS. DEVELOPMENT SHOULD NOT IMITATE INDUSTRIAL COUNTRIES. ENERGY NEEDS FOR AGRICULTURE, COOKING, AND HEATING ARE REVIEWED, AND VARIOUS WAYS TO MEET THEM WITH SOCIAL ORGANIZATION AND APPROPRIATE TECHNOLOGY ARE DISCUSSED. SPECIFIC SOLAR-BASED TECHNICAL MEANS CONSIDERED INCLUDE: WINDMILLS (AN INEXPENSIVE SAVONIUS ROTOR DESIGN IS PRESENTED); BIOGAS (METHANE) PRODUCTION BY ANAEROBIC FERMENTATION OF NON-WOODY ORGANIC MATTER; REFORESTATION AND WOOD LOTS; CHEAP, MORE EFFICIENT COOKING STOVES, SOME OF WHICH HEAT WATER TOO; TROPICAL AND SUBTROPICAL BOG HARVESTING (HIGH PHOTOSYNTHETIC RATE); SOLAR COOKERS; BIOGAS FOR VEHICLE FUEL; AND SMALL HYDROPOWER PROJECTS. MUCH RESEARCH IS NEEDED.

DEVELOPING COUNTRIES/AGRICULTURE/FOOD PRODUCTION/BIOMASS FUELS/COOKING/APPROPRIATE TECHNOLOGY/SPACE HEATING/WINDMILLS/HYDROPOWER/SOCIAL ASPECTS/INDIA

0051

MATTER, F.S. ET AL

1974

A BALANCED APPROACH TO RESOURCE EXTRACTION AND CREATIVE LAND DEVELOPMENT ASSOCIATED WITH OPEN-PIT COPPER MINING IN SOUTHERN ARIZONA.

UNIVERSITY OF ARIZONA, TUCSON, COLLEGE OF ARCHITECTURE/COLLEGE OF MINES. 65 P.

SEE: SWRA W 75-04510.

COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/HYBRID SYSTEMS/SCUTHWEST U.S./GREENHOUSES/CONTROLLED-ENVIRONMENT AGRICULTURE/WIND ENERGY/WINDMILLS/TCTAL ENERGY SYSTEMS/ENERGY STORAGE/WATER PUMPING/URBAN PLANNING/COPPER MINES/MODEL STUDIES

0052

MAUGH, T.H., II

1977

GUAYULE AND JOJOBA: AGRICULTURE IN SEMIARID REGIONS.

SCIENCE 196(4295):1189-1190.

JOJOBA AND GUAYULE, TWO PLANTS SUITED FOR GROWING WITH LIMITED IRRIGATION IN SEMIARID LANDS, ARE RECEIVING INCREASED ATTENTION. JOJOBA, A SHRUB CONTAINING SPERM OIL SUBSTITUTE (ALSO CONVERTIBLE TO HIGH-QUALITY WAX) AND

PROTEIN-RICH RESIDUE (POSSIBLE ANIMAL FEED), WILL PROBABLY BE THE FIRST TO BE CULTIVATED ON A SIGNIFICANT SCALE. PLANTINGS ARE PLANNED OR ESTABLISHED ALREADY IN U.S. (ON INDIAN RESERVATIONS AND PRIVATELY-OWNED FARMS), MEXICO, AND ISRAEL. GUAYULE, A SHRUB CONTAINING NATURAL RUBEER AND RESIN, WOOD FIBER, AND WAX BY-PRODUCTS, MAY FOLLOW CLOSE AFTER. A RUBEER EXTRACTION PLANT TO PROCESS WILD GUAYULE IS OPERATING IN SALTILLO, MEXICO, AND CULTIVATION AND RESEARCH PLANS ARE BEING FORMULATED IN U.S. GUAYULE EXPLOITATION IS NOTHING NEW; IT WAS A MAJOR WORLD RUBBER SOURCE IN 1910, AND WAS GROWN AS A CROP IN CALIFORNIA DURING WORLD WAR II. SEVERAL OTHER PLANTS ARE BEING CONSIDERED AS POTENTIAL WATER-SAVING AGRICULTURAL CROPS FOR SEMIABLE REGIONS: LESQUERELLA AND SESAME, OIL SEED PLANTS; SPECIES OF EUPHORBIA WHICH PRODUCE HYDROCARBONS (POSSIBLE PETROLEUM SUBSTITUTE) AND WAX; AFGHANISTAN PINE, WHICH GROWS RAPIDLY WITH LITTLE RAIN; AND BUFFALO GOURD, WHICH OFFERS EDIBLE OIL AND PROTEIN.

JOJOBA/GUAYULE/MEXICO/ISRAEL/SOUTHWEST U.S./ARID-SEMIARID LANDS/AGRICULTURE/ECONOMIC PLANTS/BIOMASS FUELS/WATER CONSERVATION/FOOD PRODUCTION

0053

MCGOWAN, J.G.

1976

OCEAN THERMAL ENERGY CONVERSION, A SIGNIFICANT SOLAR RESOURCE.

SOLAR ENERGY 18 (2):81-92.

THIS OPTIMISTIC REVIEW ARTICLE PRESENTS GENERAL CONCEPTS OF OCEAN THERMAL ENERGY CONVERSION. FIVE DIFFERENT SYSTEM DESIGNS ARE SUMMARIZED AND COMPARED, AND ENVIRONMENTAL AND ECONOMIC ASPECTS OF THIS TECHNOLOGY ARE DISCUSSED. OCEAN THERMAL POWER HAS THE LARGEST ENERGY POTENTIAL OF ANY FEASIBLE SOLAR POWER PROCESS ON EARTH, ACCORDING TO THE AUTHOR. THE FIRST FULL-SIZED PLANT COULD BE DEPLOYED IN SIX YEARS, AND IN AS FEW AS 10 YEARS, OCEAN THERMAL PLANTS COULD DOMINATE U.S. ENERGY SUPPLY.

OCEAN THERMAL ENERGY CONVERSION/ENVIRONMENTAL EFFECTS/ECONOMICS/MASS PRODUCTION

0054

MEINEL, A.B.

1971

A JOINT UNITED STATES-MEXICO SOLAR POWER AND WATER FACILITY PROJECT.

UNIVERSITY OF ARIZONA, OPTICAL SCIENCES CENTER, BRIEFING GIVEN TO THE ARIZONA POWER AUTHORITY. 16 P.

OUTLINES A PROPOSAL FOR EVENTUAL ESTABLISHMENT OF A NATIONAL SOLAR POWER AND WATER FACILITY ALONG THE COLORADO RIVER. SOLAR THERMAL FOWER CAPACITY MOULD BE 1 MILLION MWE., AND WASTE HEAT FROM TUREINES COULD DESALT 50 BILLION GALLONS OF WATER PER DAY, ENOUGH FOR 120 MILLION PEOPLE. SEVERAL POSSIBLE RESEARCH AND DEVELOPMENT STEPS TO BE TAKEN ARE PROPOSED.

SOLAR THERMAL CONVERSION/ELECTRIC POWER/DESALINATION/DISTILLATION/MEXICO/COLORADO RIVER/SOUTHWEST U.S./WASTE HEAT USE/MULTIPURPOSE SYSTEMS/ELECTRIC UTILITIES

MEINEL, A.B./MEINEL, M.P.

1973

THE VILLAGE ENERGY CENTER: A NEW OPTION FOR SOLAR ENERGY UTILIZATION BY SAHEL COMMUNITIES. A REPORT PREPARED FOR UNESCO, PARIS, JULY 1973.

UNIVERSITY OF ARIZONA, OPTICAL SCIENCES CENTER/HELIO ASSOCIATES, INC., TUCSON.

RECOGNIZING THE SUCCESS OF COMMUNITY USES AND THE FAILURE OF FAMILY USES OF SOLAR ENERGY, THE AUTHORS MAKE A NEW PROPOSAL: THE VILLAGE ENERGY CENTER. IT WOULD DISTRIBUTE ELECTRICITY FROM A SOLAR THERMAL POWER PLANT TO MEET DIVERSE ENERGY NEEDS IN THE COMMUNITY, AND TO POWER TUBE WELLS IN SURKOUNDING FIELDS. EARLY DEVELOPMENT CAN PROFIT FROM CURRENT INTEREST IN SOLAR ENERGY IN THE U.S. BECAUSE DEMONSTRATION UNITS ARE SIMILAR IN SIZE TO ACTUAL UNITS NEEDED IN DEVELOPING COUNTRIES. DESIGN OF THE VILLAGE ENERGY CENTER AND ITS APPLICATION TO THE SAHEL ARE DISCUSSED.

APPROPRIATE TECHNOLOGY/DEVELOPING COUNTRIES/WATER PUMPING/SIZE EFFECTS/ SOLAR THERMAL CONVERSION/SAHELIAN ZONE/ELECTRIC POWER/IRRIGATION/AGRICULTURE/ SOCIAL ASPECTS

0056

MEINEL, A.B./MEINEL, M.P.

1975

ENVIRONMENTAL ASPECTS OF SOLAR ENERGY APPLICATIONS. IN CONFERENCE ON WATER REQUIREMENTS FOR LOWER COLORADO RIVER EASIN ENERGY NEEDS, TUCSON, ARIZONA, 1975, PROCEEDINGS, P. 196-205.

UNIVERSITY OF ARIZONA, TUCSON.

SEE: SWRA W76-00755.

ENVIRONMENTAL EFFECTS/BIOMASS FUELS/WATER REQUIREMENTS/WATER HEATING/SOLAR THERMAL CONVERSION/COLORADO RIVER/SOUTHWEST U.S./ELECTRIC POWER/SPACE HEATING/SPACE COOLING

0057

MEINEL, A.B./MEINEL, M.P.

1976

APPLIED SOLAR ENERGY: AN INTRODUCTION.

ADDISON-WESLEY PUBLISHING COMPANY, READING, MASSACHUSETTS. 651 P.

THIS MAJOR TEXT IS AN INTRODUCTION TO THE THEORY NEEDED TO ENGINEER AND EVALUATE SOLAR ENERGY SYSTEMS. THE AUTHORS CONCENTRATE ON THERMAL CONVERSION AND PLACE SPECIAL EMPHASIS ON DISCUSSION OF SOLAR COLLECTOR OPTICS. EACH SECTION PRESENTS BACKGROUND INFORMATION AND THEN REPRESENTATIVE APPLICATIONS; PROBLEMS TO SOLVE ARE INCLUDED AT THE END OF EACH CHAPTER. TOPICS COVERED INCLUDE: BRIEF HISTORY OF SOLAR TECHNOLOGY; SOLAR FLUX AND WEATHER DATA; SOLAR ENERGY AVAILABILITY FOR VARIOUS ORIENTATIONS AND TRACKING MODES: LENS.

ARROR AND FLAT PLATE COLLECTORS; OPTICAL AND SELECTIVE SURFACES; HEAT TRANSFER AND ENERGY STORAGE; THERMODYNAMIC CYCLES; DIRECT CONVERSION; AND A SURVEY OF APPLICATIONS.

SOLAR THERMAL CONVERSION/OPTICAL CONCENTRATION/SUNLIGHT GLOMETRY/
FLAT PLATE COLLECTORS/ENERGY STORAGE/PHOTOVOLTAIC CONVERSION/THERMOELECTRIC
CONVERSION/SOLAR RADIATION/THERMIONIC CONVERSION/CONCENTRATING COLLECTORS

0058

MERRIGAN, J.A.

1975

SUNLIGHT TO ELECTRICITY: PROSPECTS FOR SOLAR ENERGY CONVERSION BY PHOTOVOLTAICS.

MIT PRESS, CAMBRIDGE, MASSACHUSETTS. 163 P.

ASSESSES ECONOMIC AND TECHNICAL PROSPCTS FOR COMMERCIAL DEVELOPMENT OF PHOTOVOLTAIC DEVICES FOR SOLAR ENERGY CONVERSION. FOLLOWING A STANDARD REVIEW OF U.S. ENERGY NEEDS AND SOLAR ENERGY RESOURCES, PHOTOVOLTAIC PHYSICS AND STATE-OF-THE ART TECHNOLOGY ARE SUMMARIZED. COST OF SILICON SOLAR CELLS IS NOW 50 TO 100 TIMES ECONOMICALLY COMPETITIVE COST FOR GENERAL USE. RESEARCH AND TECHNOLOGICAL DEVELOPMENT SHOULD REDUCE COSTS, ENABLING SOLAR CELLS TO PROGRESSIVELY ENTER NEW AND EVER-LARGER MARKETS. SOLAR CELL INDUSTRY PROMISES HIGH GROWTH RATE AND MANY BUSINESS OPPORTUNITIES.

PHOTOVOLTAIC CONVERSION/SOLAR CELLS/ECONOMICS/MASS PRODUCTION

0059

METZ. W.D.

1977A

OCEAN THERMAL ENERGY: THE BIGGEST GAMBLE IN SOLAR POWER.

SCIENCE 198 (4313): 178-180.

ALTHOUGH OCEAN THERMAL ENERGY CONVERSION RECEIVES ABOUT 1/5 OF U.S. FEDERAL BUDGET FOR ALL SOLAR ELECTRIC TECHNOLOGIES, UTILITIES ARE NOT INTERESTED IN IT AND MANY TECHNOLOGISTS ARE SKEPTICAL AEOUT ITS ECONOMIC FEASIBILITY.

THERE ARE MANY REASONS FOR SKEPTICISM. SITES NEAR U.S. ARE LIMITED TO GULF COAST, S.E. FLORIDA, HAWAII, AND PUERTO RICO. ENERGY CONVERSION EFFICIENCY IS LOW, ONLY 2-3 PERCENT, AND 30 PERCENT OF THAT IS NEEDED FOR PUMPING SEAWATER; NET ENERGY PHODUCTION IS IN DOUBT. OCEAN ENGINEERING INVOLVED IS UNPRECEDENTED IN SCALE AND THUS UNTESTED AND PROBABLY MORE COSTLY THAN EXPECTED. ENORMOUS HEAT EXCHANGERS ARE REQUIRED, POSING MAJOR PROBLEMS: CORROSION IF ALUMINUM IS USED, METAL SCARCITY IF TITANIUM IS; AND GREAT SUSCEPTIBILITY TO FOULING BY MARINE SLIME AND BARNACLES. FINALLY, OPTIMISTIC PERFORMANCE CALCULATIONS HAVE BEEN BASED ON ASSUMED OPTIMUM PERFORMANCE OF EVERY SUBSYSTEM; ANYTHING LESS COULD MEAN FAILURE. DESPITE ALL THESE RISKS, WORK CONTINUES AT A RAPID PACE. ACCELERATING FEDERAL INVESTMENT COULD EASILY BEGIN TO MATCH THAT WHICH HAS BEEN MADE IN DEVELOPING NUCLEAR POWER, AN ENTERPRISE OF SIMILAR SCALE, COMPLEXITY, AND UNCERTAINTY.

OCEAN THERMAL ENERGY CONVERSION/ECONOMICS/ENVIRONMENTAL EFFECTS/SIZE EFFECTS/HEAT EXCHANGERS/WATER PUMPING/NET ENERGY/ELECTRIC UTILITIES/LIMITING FACTORS

METZ, W.D.

1977B

SOLAR THERMAL ELECTRICITY: POWER TOWER DOMINATES RESEARCH.

SCIENCE 197 (4301):353-356.

THE POWER TOWER WITH HELIOSTAT FIELD, WHICH DOMINATES THE U.S. FEDERAL SOLAR THERMAL POWER PROGRAM, IS BEING DEVELOPED IN A MANNER REMINISCENT OF NUCLEAR REACTOR DEVELOPMENT: SEQUENTIALLY LARGER PLANTS OF A SINGLE DESIGN BUILT OVER DECADES FOR UTILITY USE BY FOUR LARGE AEROSPACE CONTRACTORS AT VERY HIGH COST. IN CONTRAST, SMALL INTERMEDIATE-TEMPERATURE SYSTEMS FOR ON-SITE USE ARE SIMPLER AND CHEAPER, ARE MORE EFFICIENT WHEN BOTH HEAT AND ELECTRICITY ARE UTILIZED (TOTAL ENERGY SYSTEMS), ARE EASILY ADAPTABLE TO DIVERSE APPLICATIONS, AND ARE SUITED TO NEAR-TERM MASS PRODUCTION OF COMPETING DESIGNS. THE POWER TOWER PROGRAM IS DISCUSSED: PLANS AND PROGRESS, GEOMETRY, HELIOSTAT DESIGNS (VERY HIGH COST, UNCERTAIN TO BECOME COMPETITIVE), RECEIVER DESIGNS (GREATEST TECHNICAL PROBLEMS), AND ENERGY STORAGE. THE FEDERAL DESIGN WILL USE AS MUCH COOLING WATER AS A COMPARABLE FOSSIL FUEL POWERPLANT. OPTIMUM POWER TOWER SIZE AND DESIGN IS UNCERTAIN; A MUCH SMALLER, CHEAPER, SIMPLER UNIT HAS OPERATED SUCCESSFULLY IN ITALY FOR MORE THAN 10 YEARS AND IS ALREADY COMMERCIALLY AVAILABLE. METZ CONCLUDES THAT IT APPEARS FAR TOO SOON FOR THE SOLAR PROGRAM TO NARROW ITS OPTIONS AND SINK THE BULK OF ITS RESEARCH MONEY INTO STEEL AND CONCRETE.

CENTRAL RECEIVER-HELIOSTAT SYSTEMS/SOLAR THEFMAL CONVERSION/ELECTRIC POWER/
SIZE EFFECTS/MEDIUM TEMPERATURE SYSTEMS/ECONCMICS/DIVERSITY (TECHNOLOGICAL)/
POLITICAL ASPECTS/TOTAL ENERGY SYSTEMS/MASS PRODUCTION/COMPETITION/ADAPTATION/
ENERGY STORAGE/HELIOSTATS/WATER REQUIREMENTS/APPROPRIATE TECHNOLOGY/
ELECTRIC UTILITIES/DECENTRALIZED SYSTEMS

0061

METZ, W.D.

1977C

SOLAR THERMAL ENERGY: BRINGING THE PIECES TOGETHER.

SCIENCE 197 (4304):650-651.

ALTHOUGH MOST U.S. SOLAR THERMAL ATTENTION AND FEDERAL FUNDING GOES TO LCW-TEMPERATURE SYSTEMS FOR HEATING AND COOLING, OR HIGH-TEMPERATURE SYSTEMS FOR CENTRAL POWER GENERATION, INTERMEDIATE-TEMPERATURE MEDIUM-SCALE SYSTEMS MAY ACTUALLY HAVE THE GREATEST POTENTIAL FOR PRACTICAL APPLICATION BY 2000. MOST PROMISING APPLICATIONS ARE SOLAR IRRIGATION, POWER GENERATION, COMBINED POWER AND HEAT PRODUCTION (TOTAL ENERGY), AND INDUSTRIAL PROCESS HEAT (30 PERCENT OF WHICH IS NOW USED AT TEMPERATURES BELOW 300 C). ALL COMPONENTS FOR SUCH SYSTEMS EXIST NOW: CONCENTRATING COLLECTORS (COMPARABLE IN COST TO LOW-PEMPERATURE, LESS THERMODYNAMICALLY EFFICIENT FLAT-PLATE COLLECTORS) AND SMALL HEAT ENGINES. COSTS WILL FALL WITH MASS PRODUCTION. COMPONENT DIVERSITY MAKES POSSIBLE FLEXIBLE ADAPTATION TO SITE AND USE. INSTALLATIONS ALREADY OPERATING INCLUDE A SOLAR IRRIGATION SYSTEM IN GILA BEND, ARIZONA, AND A TOTAL ENERGY TEST FACILITY AT SANDIA LABORATORIES, ALBUQUERQUE, NEW MEXICO. UNDER DEVELOPMENT ARE SEVERAL INDUSTRIAL PROCESS HEAT SYSTEMS, AND ONE MULTIPLE-PURPOSE SYSTEM WHICH WILL PRODUCE FLECTRICITY, PROCESS STEAM, HOT WATER, AND SPACE HEATING/COOLING. GOVERNMENT FUNDING IS SMALL AND FRAGMENTED, BUT PRIVATE INDUSTRY IS MOVING QUICKLY TO COMMERCIALIZE THIS TECHNOLOGY.

CONCENTRATING COLLECTORS/DIVERSITY (TECHNOLOGICAL)/SOUTHWEST U.S./WATER HEATING/SOLAR THERMAL CONVERSION/SIZE EFFECTS/MEDIUM TEMPLRATURE SYSTEMS/IRRIGATION/ELECTRIC POWER/SPACE HEATING/TOTAL ENERGY SYSTEMS/PROCESS HEAT/HEAT ENGINES/OPTICAL CONCENTRATION/MASS PRODUCTION/ADAPTATION/SPACE COOLING/MULTIPURPOSE SYSTEMS/ELECTRIC UTILITIES/DECENTRALIZED SYSTEMS

0062

METZ, W.D.

1977D

WIND ENERGY: LARGE AND SMALL SYSTEMS COMPETING.

SCIENCE 197(4307):971-973.

SUMMARIZES WIND ENERGY RESEARCH AND DEVELOPMENT IN THE U.S. WIND SYSTEMS RECEIVE LESS THAN 10 PERCENT OF SOLAR ENERGY BUDGET, DESPITE THE FACT THAT SMALL AND LARGE WIND TURBINES ALREADY WORK AND ARE ONE OF THE CHEAPEST SOLAR ELECTRIC TECHNOLOGIES. LARGE MACHINES HAVE RECEIVED MOST FEDERAL ATTENTION, IN A SEQUENTIAL DEVELOPMENT PROGRAM FROM 125 FT. DIAMETER TURBINE (DISAPPOINTING PERFORMANCE) TO PLANNED GIANT 200 FT. AND 300 FT. MODELS. SMALL MACHINES, DEVELOPED AND MANUFACTURED FOR YEARS BY PRIVATE COMPANIES IN THE U.S., AND USLD FOR MILLENIA BY MANY CULTURES, ARE ONLY NOW STARTING TO RECEIVE FEDERAL SUPPORT. STUDIES PREDICT THAT LARGE MACHINES WILL BE CHEAPER THAN SMALL ONES PER KILOWATT, BUT THIS IS FAR FROM PROVEN. SMALL SYSTEMS SEEM FAR MORE SUITED TO ECONOMIES OF MASS PRODUCTION AND COMPETITION BETWEEN DESIGNS, AND EVEN NOW ARE FOUND TO BE PRACTICAL. A TWOFOLD COST REDUCTION, WHICH SEEMS QUITE FEASIBLE, WOULD MAKE BOTH LARGE AND SMALL WIND SYSTEMS COMPETITIVE WITH CONVENTIONAL POWER IN MANY LOCATIONS. ONCE COMPETITIVE, WIND SYSTEM GROWTH WOULD BE LIMITED ONLY BY THE INDUSTRY'S GROWTH.

WIND ENERGY/WINDMILLS/ELECTRIC POWER/ECONOMICS/TECHNOLOGICAL SUCCESSION/COMPETITION/MASS PRODUCTION/SIZE EFFECTS/DIVERSITY (TECHNOLOGICAL)

0063

MOUMOUNI, A.

1973

ENERGY NEEDS AND PROBLEMS IN THE SAHELIAN AND SUDANESE ZONES: PROSPECTS FOR SOLAR POWER.

AMBIO 2(6):203-213.

REVIEWS ECONOMICS, POLITICS, RESOURCES, AND NEEDS OF ENERGY IN THE SAHEL/SUDAN PEGION OF AFRICA. SMALL-SCALE SOLAR TECHNOLOGY SEEMS PARTICULARLY SUITED TO THIS AREA OF LOW POPULATION DENSITY, LARGE DISTANCES, MODERATE ENERGY NEEDS, AND HIGH INSOLATION. SOLAR WATER HEATERS, STILLS, AND COOKERS COULD SAVE 50 TC 60 MILLION TONS OF WOOD PER YEAR, WITH BENEFICIAL ENVIRONMENTAL CONSEQUENCES COUNTER TO DESERTIFICATION TRENDS. SOLAR AIR CONDITIONING AND REFRIGERATION, SMALL SOLAR ENGINES, AND OTHER DECENTRALIZED SOLAR DEVICES COULD TREMENDOUSLY INCREASE QUALITY OF LIFE. A NETWORK OF SOLAR ENERGY RESEAPCH, DEVELOPMENT, AND DEMONSTRATION CENTERS IS REQUIRED TO BRING THIS ABOUT. CAPITAL COST, HOWEVER HIGH, WILL BE LOWER BY FAR THAN LOSSES RESULTING FROM DROUGHT AND FAMINE. SOLAR ENERGY DEVELOPMENT SHOULD BE PART OF A COHERENT, COMPREHENSIVE APPROACH TO DEVELOPMENT OF ALL LOCAL SOURCES OF ENERGY.

DEVELOPING COUNTRIES/SAHELIAN ZONE/ECONOMICS/POLITICAL ASPECTS/WATER HEATING/APPROPRIATE TECHNOLOGY/COOKING/DISTILLATION/ENVIRONMENTAL EFFECTS/REFRIGERATION/DESERTIFICATION/SPACE COOLING/SOLAR THERMAL CONVERSION/HEAT ENGINES

0064

NATIONAL ACADEMY OF SCIENCES, WASHINGTON, D.C.

1972

SOLAR ENERGY IN DEVELOPING COUNTRIES: PERSPECTIVES AND PROSPECTS. REPORT OF AN AD HOC ADVISORY PANEL OF THE BOARD ON SCIENCE AND TECHNOLOGY FOR INTERNATIONAL DEVELOPMENT, OFFICE OF THE FOREIGN SECRETARY.

SAME AS AUTHOR. 49 P.

THE PAPER ASSESSES THE STATE OF THE ART IN UTILIZING SOLAR ENERGY FOR DEVELOPING COUNTRIES, REVIEWS CURRENT PRACTICAL APPLICATIONS, IDENTIFIES PROMISING AREAS FOR RESEARCH AND DEVELOPMENT, AND EXAMINES THE DESIRABILITY OF ESTABLISHING AN INTERNATIONAL SOLAR ENERGY INSTITUTE IN NORTH AFRICA TO CARRY OUT SOLAR ENERGY RESEARCH AND DEVELOPMENT. CONCLUSIONS ARE THAT ESSENTIAL PROBLEMS ARE ENERGY PROBLEMS, NOT SOLAR, AND THAT SOLUTIONS REQUIRE CONSIDERATION OF ALTERNATIVE SOURCES. THE STATUS AND POTENTIAL OF SOLAR ENERGY APPLICATIONS (EVAPORATION, WATER HEATING, DISTILLATION, AND DRYING) AND THOSE STILL IN EXPERIMENTAL STAGES (SPACE HEATING, AIR CONDITIONING, CONVERSION TO MECHANICAL OR ELECTRICAL ENERGY, COOKING, AND BIOLOGICAL PROCESSES) ARE DISCUSSED.

CROP DRYING/APPROPRIATE TECHNOLOGY/DEVELOFING CCUNTRIES/COOKING/EVAPORATION/WATER HEATING/DISTILLATION/SPACE HEATING/SPACE COOLING/BIOMASS FUELS

0065

NATIONAL ACADEMY OF SCIENCES, WASHINGTON, D.C.

1976

ENERGY FOR RURAL DEVELOPMENT: RENEWABLE RESOURCES AND ALTERNATIVE TECHNOLOGIES FOR DEVELOPING COUNTRIES.

SAME AS AUTHOR. 306 P.

REVIEWS STATE-OF-THE-ART FOR SMALL-SCALE ALTERNATIVE ENERGY TECHNOLOGIES IN SEVERAL CATEGORIES: DIRECT USE OF SOLAR ENERGY (COOKERS, STILLS, HEATING AND COOLING BUILDINGS, REFRIGERATION, WATER HEATING, CROP DRYING, SALT PRODUCTION, AND PHOTOVOLTAICS), INDIRECT USE OF SOLAR ENERGY (PHOTOSYNTHESIS, FERMENTED FUELS, AND WIND AND WATER POWERED DEVICES), GEOTHERMAL ENERGY, AND ENERGY STORAGE. TECHNICAL AND NON-TECHNICAL REVIEWS ARE PRESENTED SEPARATELY, AND READERS ARE PROVIDED WITH MANY REFERENCES AND ADDRESSES USEFUL FOR SEEKING MORE INFORMATION.

DEVELOPING COUNTRIES/APPROPRIATE TECHNOLOGY/COOKING/DISTILLATION/SPACE HEATING/SPACE COOLING/REFRIGERATION/CROP DRYING/EVAPORATION/PHOTOVOLTAIC CONVERSION/BIOMASS FUELS/WIND ENERGY/HYDROPOWER/GEOTHERMAL ENERGY/ENERGY STORAGE/SALT PRODUCTION

NORMAN, R.S.

1974

WATER SALINATION: A SOURCE OF ENERGY.

SCIENCE 186 (4161):350-352. DISCUSSION BY S. LOEB AND REPLY BY R.S. NORMAN, SCIENCE 189 (4203):654-655 (1975).

SALINITY DIFFERENCE BETWEEN RIVER WATER AND OCEAN WATER REPRESENTS POTENTIAL ENERGY EQUIVALENT TO A RIVER MOUTH WATERFALL 225 METERS HIGH. THIS ENERGY CAN BE TRANSFORMED TO MECHANICAL AND THEN ELECTRICAL POWER BY EQUALIZING SALINITY ACROSS OSMOTIC MEMBRANES, THE REVERSE OF DESALINATION. AT ESTIMATED 25 PERCENT EFFICIENCY, FRESHWATER INPUT FLOW OF ONE CUBIC METER PER SECOND COULD GENERATE 0.5 MW OF ELECTRICITY. PLANT COST, PERHAPS 20 CENTS/KWH, IS HIGH, BUT MAY BE WORTHWHILE IN SPECIAL SITUATIONS. FRESH WATER IS PROBABLY MORE VALUABLE FOR OTHER PURPOSES; SEWER OUTFLOW MIGHT SUFFICE AS SALINITY SINK. LARGE SALINATION PLANTS COULD DESTROY ESTUARINE ENVIRONMENTS AND ECOSYSTEMS. LOEB SUGGESTS THAT SALINATION PLANTS COULD BE MORE EFFICIENT AND ECONOMICAL IF SALINITY SINK WERE FRESH WATER OR SEA WATER, WITH SALINITY SOURCE BEING CONCENTRATED BRINES FROM THE DEAD SEA, GREAT SALT LAKE, OR OTHER SALINE LAKE, OR EVEN BRINE DERIVED FROM SOLID SALT MOUNTAINS.

SALINATION POWER/ELECTRIC POWER/OSMOSIS/ECONOMICS/ENVIRONMENTAL EFFECTS/DEAD SEA/GREAT SALT LAKE/ISRAEL/COASTAL DESERTS/BRINES/SALINE LAKES

0067

ODUM, H.T.

1975

ENERGY QUALITY INTERACTIONS OF SUNLIGHT, WATER, FOSSIL FUEL, AND LAND. IN CONFERENCE ON WATER REQUIREMENTS FOR LOWER COLORADO BIVER BASIN ENERGY NEEDS, TUCSON, ARIZONA, 1975, PROCEEDINGS, P. 165-194.

UNIVERSITY OF ARIZONA, TUCSON.

SEE: SWRA W76-00754.

SOLAR RADIATION/ROLES OF WATER/BIOLOGICAL-INDUSTRIAL ANALOGY/ECONOMICS/ARID-SEMIARID LANDS/SOUTHWEST U.S./DESALINATION/DISTILLATION/WATER HEATING/ELECTRIC POWER/NET ENERGY/ENERGY QUALITY/PHOTOSYNTHESIS/AGRICULTURE/LIMITING FACTORS

0068

OLGYAY, A./OLGYAY, V.

1957

SOLAR CONTROL AND SHADING DEVICES.

PRINCETON UNIVERSITY PRESS. 201 P.

SHADING DEVICES FOR PASSIVE CLIMATE CONTROL OF BUILDINGS ARE LIMITED IN DESIGN ONLY BY ENVIRONMENT AND IMAGINATION. METHODS ARE PRESENTED FOR EVALUATING SUN PATH GEOMETRY AND SHADING BY HORIZON OBSTRUCTIONS, FOR ANY BUILDING SITE,

IN RELATION TO CLIMATE AND HEATING/COOLING NEEDS. AND PROCEDURES ARE PRESENTED FOR DESIGNING BUILDINGS AND SHADING DEVICES ON THE BASIS OF SUCH ANALYSES. FINAL SECTION OF THE BOOK IS A PICTORIAL SURVEY AND GEOMETRICAL ANALYSIS OF MANY BUILDINGS FROM AROUND THE WORLD WHICH ARE SYSTEMATICALLY DESIGNED FOR BEST USE OF SHADE AND SUNLIGHT.

SHADING/PASSIVE TEMPERATURE CONTROL/SUNLIGHT GEOMETRY/ADAPTATION/SOLAR RADIATION/BUILDING DESIGN

0069

O'NEILL, G.K.

1975

SPACE COLONIES AND ENERGY SUPPLY TO THE EARTH.

SCIENCE 190 (4218): 943-947.

IT APPEARS FEASIBLE TO ESTABLISH MANUFACTURING FACILITIES/COLONIES IN A HIGH EARTH ORBIT. USING MATERIALS MINED AND LAUNCHED FROM THE MOON, SUCH FACILITIES COULD COMPLETE AND MAINTAIN THEMSELVES, MANUFACTURE SATELLITE SOLAR POWER STATIONS FOR TRANSFER TO GEOSYNCHRONOUS ORBIT, AND CONSTRUCT NEW COLONIES FOR EXPONENTIAL GROWTH. THIS SCHEME APPEARS TO BE MUCH MORE ECONOMICAL THAN MANUFACTURING POWER STATION COMPONENTS ON EARTH AND LIFTING THEM INTO ORBIT, LARGELY BECAUSE LUNAR GRAVITY WELL DEPTH IS ONLY 1/20 THAT OF EARTH. TOTAL EARTH CAPITALIZATION FOR A SELF-SUPPORTING AND GROWING SYSTEM WOULD BE AN ESTIMATED 178 BILLION DOLLARS OVER 14 YEARS; INCOME WOULD EQUAL OUTLAY BY YEAR 17, AND TOTAL PAYBACK WOULD BE ACHIEVED IN 24 YEARS. SOLAR ENERGY WOULD BE USED FOR AGRICULTURE, PROCESS HEAT, AND ELECTRICITY IN COLONIES, AND FOR POWERING MASS DRIVERS WHICH PROPEL POWER SATELLITES AND LAUNCH LUNAK LOADS.

ORBITAL POWER STATIONS/SPACE COLONIES/ECONOMICS/AGRICULTURE/PROCESS HEAT/ELECTRIC POWER/ENERGY TRANSMISSION/COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/HYBRID SYSTEMS/MICROWAVE POWER TRANSMISSION

0070

OTHMER, D.F.

1976

POWER, FRESH WATER, AND FOOD FROM THE SEA.

MECHANICAL ENGINEERING 98 (9):27-34.

THE AUTHOR EXAMINES DESIGN POSSIBILITIES FOR ONSHORE COASTAL PLANTS WHICH USE THERMAL ENERGY DIFFERENTIAL BETWEEN COLD AND WARM OCEAN WATER FOR GENERATING ELECTRICITY IN CONJUNCTION WITH FRESH WATER PRODUCTION AND MARICULTURE. HEATING WARM WATER IN SOLAR PONDS OR COLLECTERS CAN GREATLY INCREASE THERMODYNAMIC EFFICIENCY OF POWER CYCLE. WATER CAN BE DISTILLED FROM TURBINE EXHAUST STEAM OR BY MULTISTAGE FLASH EVAPORATION. MARICULTURE FOOD CHAINS GROWN IN CONDENSER-WARMED NUTRIENT-RICH DEEP SEAWATER COULD INCLUDE ALGAE, SHELLFISH, CRUSTACEANS, FISH, AND SEAWEED. A PLANT WAS DESIGNED FOR PRODUCING 7.2 MW OF ELECTRICITY AND 23,000 CU. MyDAY OF FRESH WATER; MUCH OF ITS 18.4 MILLION DOLLAR COST WOULD BE FOR COLD DEEP WATER SUPPLY PIPELINE. ESTIMATED COST FOR POWER WOULD BE 6 MILLS PER KWH, AND FOR WATER 1 DOLLAR PER 1000 GAL. WITH COMBINED REVENUES FROM POWER, DESALTING, AND MARICULTURE, PAYBACK TIME FOR SUCH A PLANT MIGHT BE ONLY A FEW YEARS.

OCEAN THERMAL ENERGY CONVERSION/COASTAL DESERTS/DISTILLATION/FOOD PRODUCTION/SOLAR PONDS/SOLAR THERMAL CONVERSION/MULTIPLE EFFECT DISTILLATION/ECONOMICS/ELECTRIC POWER/COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/HYBRID SYSTEMS/DESALINATION/MARICULTURE/BUILDING DESIGN

0071

POLLARD, W.G.

1976A

THE LONG-RANGE PROSPECTS FOR SOLAR ENERGY.

AMERICAN SCIENTIST 64(4):424-429.

DESPITE POPULAR HOPES, IT SEEMS UNLIKELY THAT FITHER DIRECT OR INDIRECT SOLAR ENERGY CONVERSION (EXCEPT HYDROELECTRIC) WILL BE ABLE TO COMPETITIVELY SATISFY NEEDS FOR CENTRALLY GENERATED ELECTRICITY, NO MATTER HOW MUCH EFFORT IS EXPENDED TOWARD THAT GOAL. FOR TERRESTRIAL SOLAR THERMAL AND PHOTOVOLTAIC POWER GENERATION THERE ARE UNAVOIDABLE LIMITATIONS: EFFICIENCY LIMITS; LOW INTENSITY OF SOLAR ENERGY, RESULTING IN LARGE LAND REQUIREMENTS AND MANDATORY LOW COLLECTOR COST PER AREA; AND INTERMITTENCY OF SOLAR ENERGY, WHICH CALLS FOR INTERMITTENT USE, HYBRID POWERPLANTS (SOLAR WITH COAL OR HYDRO POWER), OR LARGE THERMAL, ELECTRICAL, OR MECHANICAL ENERGY STORAGES. WIND POWER, SIMILARLY, INVOLVES MANY COSTLY UNITS OPERATING INTERMITTENTLY. OCEAN THERMAL CONVERSION FACES FORMIDABLE PROBLEMS OF COST, REPAIR AND MAINTENANCE NEEDS, AND HEAT EXCHANGER FOULING; THE TECHNOLOGY MIGHT BE BETTER USED ON LAND WITH OTHER TEMPERATURE DIFFERENCE SOURCES. SATELLITE SOLAR POWER STATIONS SEEM IMPRACTICAL COMPARED WITH ALTERNATIVES. IN CONTRAST, SMALL REMOTE RURAL SELF-CONTAINED SOLAR ENERGY SYSTEMS SHOW MUCH PROMISE, AS DO SOLAR WATER AND SPACE HEATING TECHNOLOGIES.

ELECTRIC POWER/SIZE EFFECTS/SOLAR THERMAL CONVERSION/SOLAR RADIATION/ECONOMICS/PHOTOVOLTAIC CONVERSION/HYDROPOWER/HYBRID SYSTEMS/ENERGY STORAGE/WIND ENERGY/OCEAN THERMAL ENERGY CONVERSION/HEAT EXCHANGERS/ORBITAL POWER STATIONS/DEVELOPING COUNTRIES/COMPLEX SYSTEMS/WATER HEATING/SPACE HEATING/LIMITING FACTORS/DECENTRALIZED SYSTEMS

0072

POLLARD, W.G.

1976B

THE LONG-RANGE PROSPECTS FOR SOLAR-DERIVED FUELS.

AMERICAN SCIENTIST 64(5):509-513.

REVIEWS TECHNOLOGIES FOR PRODUCTION OF FUELS DERIVED FROM PLANT MATERIAL:
SOLID FUEL (CHAR-OIL) BY PYROLYSIS OF FOREST AND MARGINAL LAND BIOMASS, AND
SAWMILL AND COTTON-GIN WASTES; LIQUID FUEL BY FERMENTATION AND DISTILLATION
OF SUGARCANE AND CASSAVA (ETHANOL), AND BY PYROLYSIS AND CATALYSIS OF WOODY
MATERIAL (METHANOL); AND GASEOUS FUEL (METHANE) BY ANAEROBIC DIGESTION OF
AGRICULTURAL AND ANIMAL WASTES AND PERHAPS OF CULTIVATED WATER HYACINTHS AND
SEAWEED. THESE TECHNOLOGIES ARE ALREADY WELL-DEVELOPED, AND THEIR
IMPLEMENTATION AWAITS ONLY HIGHER FOSSIL FUEL COST AND TRANSITION OF
AGRICULTURAL AND SILVICULTURAL PRACTICES TOWARD ENERGY PRODUCTION GOALS.
TRANSITION FROM FOSSIL FUELS TO BIOFUELS WILL CCCUR GRADUALLY, STARTING IN
HUMID TROPICAL REGIONS (HIGHEST PHOTOSYNTHESIS RATE), AND BEING SOMEWHAT DELAYED
IN COUNTRIES (LIKE U.S.) WHICH HAVE COAL RESERVES. BURNING SOLAR-DERIVED FUELS
AVOIDS ATMOSPHERIC CO2 INCREASE AND CLIMATIC CHANGE THREATS CHARACTERISTIC OF
FOSSIL FUEL BURNING.

BIOM:SS FUELS/AGRICULTURE/ENVIRONMENTAL EFFECTS/CLIMATIC CHANGE/AQUICULTURE/TECHNOLOGICAL SUCCESSION/MARICULTURE/AGRICULTURAL WASTES

0073

POOLE, A.D./WILLIAMS, R.H.

1976

FLOWER POWER: PROSPECTS FOR PHOTOSYNTHETIC ENERGY.

BULLETIN OF THE ATOMIC SCIENTISTS 32(5):48-57.

EXAMINES THE POSSIBILITY OF USING PLANT BIOMASS FOR FUEL. SIMPLE TECHNOLOGIES ARE INVOLVED, AND PHOTOSYNTHETIC FUELS ARE RELATIVELY CLEAN AND DO NOT RESULT IN CO2 BUILD-UP IN ATMOSPHERE. FUEL FORM CHOSEN (METHANE, HYDROGEN, CHAR OIL, METHANOL, ETC.) DEPENDS ON BIOMASS CHARACTERISTICS, FUEL VALUE, AND MARKET LOCATION. METHANE FERMENTATION OF NON-WOODY MATERIAL ALLOWS NUTRIENT RECYCLING. BIOMASS FUEL IS BETTER FOR INDUSTRIAL BOILER FUEL THAN FOR POWERPLANTS. COGENERATION OF ELECTRICITY AND PROCESS STEAM IS PARTICULARLY EFFICIENT. SCALE PRODUCTION OF BIOMASS IS LIMITED ON LAND BY WATER AND LAND AVAILABILITY. ROUGHLY 500 TONS OF WATER ARE NEEDED FOR 1 TON OF DRY PLANT MATTER. THUS ARID AREAS MAY BE INAPPROPRIATE SITES. WATER USE EFFICIENCY OF PLANTS MAY BE MORE IMPORTANT THAN SOLAR RADIATION USE EFFICIENCY. NUTRIENT LIMITS COULD BECOME IMPORTANT IN THE LONG RUN FOR BOTH TERRESTRIAL AND MARINE BIOMASS FARMS. KELP FARMS WOULD CONSUME LARGE AMOUNTS OF SCARCE PHOSPHORUS FERTILIZER, OR ELSE WOULD RELFASE TO THE ATMOSPHERE 3 TIMES AS MUCH CO2 PER UNIT ENERGY AS FOSSIL FUEL BURNING IF DEEP OCEAN WATER WERE PUMPED UP AS NUTRIENT SCURCE. ORGANIC WASTES (CROP RESIDUE, MANURE, AND FOREST WASTES) APPEAR TO BE MOST PROMISING BIOMASS ONE FIFTH OF U.S. ENERGY NEEDS COULD BE SUPPLIED WITHOUT LIMITING FACTOR COST INCREASES. POTENTIAL IS EVEN GREATER IN MANY DEVELOPING COUNTRIES.

BIOMASS FUELS/COGENERATION/WATER REQUIREMENTS/ARID-SEMIARID LANDS/AQUICULTURE/ENVIRONMENTAL EFFECTS/AGRICULTURAL WASTES/DEVELOPING COUNTRIES/CLIMATIC CHANGE/LIMITING FACTORS/MARICULTURE

0074

ROBINSON, A.L.

1977A

AMORPHOUS SILICON: A NEW DIRECTION FOR SEMICONDUCTORS.

SCIENCE 197 (4306):851-853.

SOLAR CELL COST COULD DROP DRAMATICALLY IF RESEARCH WITH AMORPHOUS (NON-CRYSTALLINE) SILICON CONTINUES TO ADVANCE. CONVENTIONAL SILICON SOLAR CELLS REQUIRE COSTLY CRYSTAL GROWING AND PROCESSING, BUT THIN FILMS OF AMORPHOUS SILICON ARE FORMED BY VERY INEXPENSIVE VAPOR DEPOSITION TECHNIQUES. AN EXPLOSION OF AMORPHOUS SILICON RESEARCH HAS BEGUN, SPARKED BY RECENT DISCOVERY THAT HYDROGEN GREATLY IMPROVES THE MATERIAL'S PROPERTIES. EXPERIMENTAL AMORPHOUS SILICON SOLAR CELLS HAVE BEEN CONSTRUCTED WITH EFFICIENCY AS HIGH AS 6 PERCENT; 15 TO 20 PERCENT IS THEORETICALLY POSSIBLE. PRESENT STATE OF KNOWLEDGE OF AMORPHOUS SILICON SEEMS ANALOGOUS TO THAT OF CRYSTALLINE SILICON 25 YEARS AGO, JUST BEFORE THE SEMICONDUCTOR REVOLUTION BEGAN. THIS NEW TECHNOLOGY MAY RESULT IN EXTREMELY INEXPENSIVE SOLAR CELLS IN FUTURE YEARS.

PHOTOVOLTAIC CONVERSION/SOLAR CELLS/AMORPHOUS SEMICONDUCTORS/HYDROGEN/MASS PRODUCTION

FOBINSON, A.L.

1977B

CHALCOGENIDE GLASSES: A DECADE OF DISSENSION AND PROGRESS.

SCIENCE 197(4308): 1068-1070.

REVIEWS RESEARCH ON CHALCOGENIDE GLASSES, A CLASS OF AMORPHOUS SEMICONDUCTORS. THEORIES EXPLAINING ELECTRONIC SWITCHING IN THESE MATERIALS ARE ADVANCING BUT ARE NOT AGREED UPON BY ALL INVESTIGATORS. APPLICATION OF THESE MATERIALS TO COMPUTER MEMORIES IS NEAR COMMERCIALIZATION, AND WORK IS PROGRESSING ON USING THESE AND SIMILAR MATERIALS FOR PHOTOGRAPHIC FILMS AND EXTREMELY INEXPENSIVE THERMOELECTRIC CONVERTERS AND SOLAR CELLS.

PHOTOVOLTAIC CONVERSION/SOLAR CELLS/THERMOELECTRIC CONVERSION/AMORPHOUS SEMICONDUCTORS

0076

ROSENBAUM, S. ET AL

1975

SOLAR-POWER-PRODUCING MIXED FARMING COMMUNITIES. IN INSTITUTE OF ENVIRONMENTAL SCIENCES, 21ST ANNUAL TECHNICAL MEETING, ANAHEIM, CALIFORNIA, 1975, PROCEEDINGS, VOL. 1, P. 218-222.

INSTITUTE OF ENVIRONMENTAL SCIENCES, MOUNT PROSPECT, ILLINOIS.

AUTHORS PROPOSE THAT FARMING COMMUNITIES BE ESTABLISHED WHICH COMBINE MANY SOLAR ENERGY TECHNOLOGIES IN A COMPLEX SYMEIOSIS, KEYSTONE OF THE SCHEME WOULD BE SUITABLY ORIENTED LARGE GREENHOUSES WHICH COMBINE LARGE SCALE SOLAR POWER GENERATION WITH INTENSIVE AGRICULTURE. CHEAP PLASTIC LINEAR FRESNEL LENSES BUILT INTO ROOF ASSEMBLY WOULD CONCENTRATE DIRECT SUNLIGHT ONTO SPECTRALLY SELECTIVE ABSORBER TUBES FOR POWER CYCLE HEAT COLLECTION. WAVELENGTHS NEEDED FOR PLANT GROWTH (MAINLY RED) WOULD PASS THROUGH TO CROPS BELOW. SOLAR DISTILLATION UNITS COULD ALSO BE PLACED IN THE GREENHOUSES. THE PROPOSED COMMUNITIES WOULD ALSO INCLUDE LIVESTOCK ENCLOSURES, FISH PONDS, ENERGY FORESTS, WINDMILLS, AND FACILITIES FOR USING WASTE HEAT FROM SOLAR POWER GENERATION, ALL SUITABLY INTERCONNECTED. DESPITE LACK OF DETAILED ECONOMIC ANALYSIS, THE AUTHORS ARE CONVINCED THAT SUCH SYSTEMS ARE CURRENTLY FEASIBLE.

AGRICULTURE/COMPLEX SYSTEMS/MULTIPURPOSE SYSTEMS/HYBRID SYSTEMS/GREENHOUSES/CONCENTRATING COLLECTORS/CONTROLLED-ENVIRONMENT AGRICULTURE/ELECTRIC POWER/SOLAR THERMAL CONVERSION/TOTAL ENERGY SYSTEMS/CCGENERATION/BIOMASS FUELS/OPTICAL CONCENTRATION/DISTILLATION/AQUICULTURE/WINDMILLS/WASTE HEAT USE

0077

ROSS, M. H. / WILLIAMS, R. H.

1976

ENERGY EFFICIENCY: OUR MOST UNDERRATED ENERGY RESOURCE.

BULLETIN OF THE ATOMIC SCIENTISTS 32(9):30-38.

ENERGY CONSERVATION SHOULD BE A MAJOR PART OF ANY STRATEGY TO SOLVE U.S.
ENERGY AND ECONOMIC PROBLEMS. IT IS THE BEST ENERGY POLICY FOR EXTENDING
LIMITED FUEL RESOURCES, HOLDING ENERGY COSTS DOWN, MINIMIZING DEPENDENCE ON
FOREIGN SOURCES, AND PROTECTING ENVIRONMENT. CONSERVATION CAN YIELD ENERGY
MORE CHEAPLY THAN ANY NEW ENERGY SOURCE. WAYS TO IMPROVE ENERGY EFFICIENCY
IN RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL SECTORS ARE OUTLINED. IF THESE
MEASURES HAD BEEN IN EFFECT IN 1973, FUEL CCNSUMPTION WOULD HAVE BEEN 40 PERCENT
LESS, AND 18 MORE YEARS OF ENERGY GROWTH AT HISTORIC RATE WOULD HAVE BEEN
REQUIRED TO REACH ACTUAL 1973 LEVEL. HENCE IT APPEARS POSSIBLE TO PURSUE ZERO
ENERGY GROWTH (ZEG) UNTIL EARLY 1990'S WITHOUT JEOPARDIZING ECONOMIC GROWTH OR
VIGOR, SIMPLY BY INCREASING ENERGY USE EFFICIENCY. IN LATER YEARS, LIFESTYLE
CHANGES TOWARD LESS INTENSIVE ENERGY USE CAN CONTINUE THE TREND. THESE CHANGES
MAY BE FORCED BY GLOBAL POLITICS, ECONOMICS, AND ENVIRONMENTAL LIMITS.

ENERGY CONSERVATION/ECONOMICS/POLITICAL ASPECTS/SOCIAL ASPECTS/ENVIRONMENTAL EFFECTS

0078

SELCUK, M.K./TRAN, V.V.

1975

SOLAR STILLS FOR AGRICULTURAL PURPOSES.

SOLAR ENERGY 17(2):103-109.

SOLAR STILL AND GREENHOUSE ARE BEST COMBINED BY KEEPING THE TWO FUNCTIONS SEPARATE: PLANTS GROW BEST WITH TEMPERATURE AND HUMIDITY DIFFERENT FROM DISTILLATION OPTIMUMS. THIS PAPER INVESTIGATES A DESIGN WITH SOLAR STILL AS ROOF OF GREENHOUSE, SAVING STRUCTURE COST AND SHARING HEAT TRANSFER. THERE ARE MANY DESIGN POSSIBILITIES FOR VARIOUS ENVIRONMENTS, OUTPUTS, CONSTRUCTION METHODS, AND COST SCHEDULES. A COMPUTER MODEL TO OPTIMIZE DESIGN WAS DEVELOPED AND COMPARED WITH FIELD TESTS OF AN ACTUAL SYSTEM. WATER CONSUMPTION IN A SYSTEM WITH NO POWER SUPPLY OR BLOWERS WAS LESS THAN 50 PERCENT OF SOLAR STILL PRODUCTION.

DESALINATION/DISTILLATION/GREENHOUSES/WATER REQUIREMENTS/WATER CONSERVATION/MULTIPURPOSE SYSTEMS/BASIN-TYPE STILLS/MODEL STUDIES

0079

SHURCLIFF, W.A.

1976

ACTIVE-TYPE SOLAR HEATING SYSTEMS FOR HOUSES: A TECHNOLOGY IN FERMENT.

BULLETIN OF THE ATOMIC SCIENTISTS 32(2):30-32,37-40.

TECHNOLOGY AND INDUSTRY OF ACTIVE-TYPE SOLAR HOUSE HEATING (USES AIR OR WATER FLOW IN COLLECTORS) ARE IN A FERMENT. THERE IS A GREAT DIVERSITY OF DESIGN APPROACHES: EACH OF HUNDREDS HAS ITS OWN SPECIAL ADVANTAGES AND DISADVANTAGES. NONE CAN BE EVALUATED EXCEPT IN THE CONTEXT OF THE WHOLE DWELLING SYSTEM OF WHICH IT IS A PART, AS WELL AS THE TOTAL PHYSICAL, ECONOMIC, AND CULTURAL ENVIRONMENT. COMPETITION INVOLVES MODIFICATION OF MANY PETTY DETAILS TO IMPROVE SYSTEM EFFICIENCY (VERY DIFFICULT TO DEFINE), DURABILITY, AND COST EFFECTIVENESS. IMPROVEMENT OF ANY ONE OF THESE THREE QUALITIES (SOME OF THE METHODS ARE REVIEWED) MUST OFTEN BE WEIGHED AGAINST DECREASE OF ONE OR BOTH

OF THE OTHERS. THUS SYSTEM DESIGN IS ALMOST AS MUCH ART AS SCIENCE. MOST SYSTEMS HAVE BEEN UNECONOMIC, BUT BENEFITS OF SECURITY, SUBSIDIES, AND ENJOYMENT MAY STILL MAKE THEM WORTHWHILE. DEVELOPMENT DIFFICULTIES HAVE ARISEN WITH RETROFIITING OLD HOUSES, PREMATURE GOVERNMENT STANDARDS, INFORMATION SYSTEM INADEQUACY (PATENTS, SECRECY, AND RAPID EVOLUTION), GOVERNMENT GRANT APPLICATION COSTS, AND UNCERTAINTY OF FUTURE FUEL COST. GOVERNMENT AGENCIES WANT TO START MASS PRODUCTION, BUT THE PIRST TASK IS TO IDENTIFY OR INVENT SCHEMES THAT ARE LIKELY TO SUCCEED.

ACTIVE TEMPERATURE CONTROL/SPACE HEATING/COMPETITION/ECONOMICS/SOCIAL ASPECTS/POLITICAL ASPECTS/MASS PRODUCTION/BUILDING DESIGN/DIVERSITY (TECHNOLOGICAL)

0080

SINHA, E./MCCOSH, B.

1975

SOLAR ENERGY TECHNOLOGY, STATE OF THE ART: AN ANNOTATED BIBLIOGRAPHY.

OCEAN ENGINEERING INFORMATION SERVICE, LA JOLLA, CALIFORNIA, ENERGY RESOURCES DIVISION, OCEAN ENGINEERING INFORMATION SERIES 7. 83 P.

SEE: SWRA W76-06565.

EIBLIOGRAPHIES/RESEARCH AND DEVELOPMENT/PHOTOVOLTAIC CONVERSION/BIOMASS FUELS/SOLAR THERMAL CONVERSION/ELECTRIC POWER/SPACE HEATING/SPACE COOLING/AGRICULTURE/ENERGY STORAGE/TOTAL ENERGY SYSTEMS/ORBITAL POWER STATICNS/SOLAR RADIATION/OCEAN THERMAL ENERGY CONVERSION/DESALINATION/DISTILLATION/ECONOMICS

0081

SØRENSEN. B.

1976

WIND ENERGY.

BULLETIN OF THE ATOMIC SCIENTISTS 32(7):38-45.

WIND ENERGY IS HIGH-QUALITY MECHANICAL ENERGY THAT CAN BE EFFICIENTLY CONVERTED TO USEFUL ENERGY FORMS. IT CAN BE CAPTURED BY DIVERSE MECHANISMS, LARGE AND SMALL, INCLUDING WINDMILLS AND WATER CRAFT. WIND POWER FLUCTUATIONS CAN BE SMOOTHED BY CONNECTING DISTANT UNITS, AND BY STORING ENERGY BY VARIOUS MEANS: PLYWHEELS, HYDROGEN, HEAT, COMPRESSED AIR, FUMPED WATER, ETC. INSTALLATION OF WIND POWER UNITS WITHOUT STORAGE, IN FAVORABLE LOCATIONS, AND TO SUPPLEMENT A MUCH LARGER CONVENTIONAL POWER SYSTEM, IS ECONOMICALLY ATTRACTIVE AT PRESENT. AND EVEN LIPE-CYCLE COST OF WINDMILLS WITH STORAGE IS SO NEARLY COMPETITIVE WITH CONVENTIONAL POWER SYSTEMS THAT FACTORS NOT EASILY QUANTIFIABLE (E.G., FUEL COST AND SUPPLY UNCERTAINTIES) MAY DECIDE WHICH IS MOST FAVORABLE. ENVIRONMENTAL IMPACTS OF WINDMILLS ARE PRIFFLY REVIEWED: VISUAL AESTHETICS, NOISE, ACCIDENT RISKS, INFRASOUND WAVES, TY/RADIC INTERFERENCE, AND POSSIBLE EFFECTS OF LARGE-SCALE DEVELOPMENT ON CLIMATE.

WIND ENERGY/WINDMILLS/ENERGY STORAGE/HYDROGEN/WATER PUMPING/ECONOMICS/ENVIRONMENTAL EFFECTS/CLIMATIC CHANGE/ENERGY TRANSMISSION

STONER, C. ED.

1974

PRODUCING YOUR OWN POWER: HOW TO MAKE NATURE'S ENERGY SOURCES WORK FOR YOU.

RODALE PRESS, INC., EMMAUS, PENNSYLVANIA. 322 P.

SUMMARIZES INFORMATION ON SMALL-SCALE PRIVATE PRODUCTION OF POWER, INCLUDING INSTRUCTIONS FOR DESIGN AND INSTALLATION OF ALTERNATE ENERGY SYSTEMS. DISCUSSES MEANS OF POWER CONVERSION FROM ONE FORM TO ANOTHER, AS WELL AS ENERGY STORAGE. PROVIDES DATA AND FORMULAE FOR CALCULATING PRIVATE OR COMMUNITY ENERGY NEEDS. SUBJECTS COVERED INCLUDE: WIND GENERATORS, SMALL WATER FOWER SITES, WOOD STOVES, FIREPLACES, WINDBREAKS, METHANE GAS DIGESTERS, SOLAR ENERGY, AND CONSERVATION OF ENERGY IN EXISTING STRUCTURES. WAYS TO COMBINE SEVERAL ALTERNATE ENERGY SYSTEMS TO MEET TOTAL ENERGY REQUIREMENT ARE PRESENTED.

APPROPRIATE TECHNOLOGY/BIOMASS FUELS/ENERGY STORAGE/WIND ENERGY/HYDROPOWEL/ENERGY CONSERVATION/DECENTRALIZED SYSTEMS

0083

SWET, C.J./FOX, H.G.

1973

LOW HEAD SOLAR WATER PUMPING. IN INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE, 8TH, PHILADELPHIA, 1973, PROCEEDINGS, P. 341-347.

AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS, NEW YORK.

SMALL AUTOMATIC PUMPS, POWERED BY DIRECT PRESSURE OF SOLAR HEATED AIR (NO COMPLEX COSTLY HEAT ENGINE) AND CONSTRUCTED USING INTERMEDIATE TECHNOLOGY AND READILY AVAILABLE MATERIALS, COULD REPLACE VARIOUS MAN+ OR ANIMAL-POWERED PUMPS FOR LIFTING IRRIGATION AND STOCK WATER IN SUN-RICH DEVELOPING REGIONS. SUCH A DEVICE IS DESCRIBED AND ITS COST AND PERFORMANCE ARE ANALYZED.

WATER PUMPING/DEVELOPING COUNTRIES/SOLAR THERMAL CONVERSION/AGRICULTURE/APPROPRIATE TECHNOLOGY/IRRIGATION/ARID-SEMIARID LANDS

0084

TALBERT, S.G./EIBLING, J.A./LOF, G.O.G.

1970

MANUAL ON SOLAR DISTILLATION OF SALINE WATER.

U.S. OFFICE OF SALINE WATER, RESEARCH AND DEVELOPMENT PROGRESS REPORT 546.

SEE: SWRA W70-09244.

DESALINATION/DISTILLATION/ECONOMICS/BASIN-TYPE STILLS/WATER SUPPLY

TLEIMAT, B.W./HOWE, E.D.

1977

SOLAR-ASSISTED DISTILLATION OF SEA WATER.

NATIONAL WATER SUPPLY IMPROVEMENT ASSOCIATION, JOURNAL 4(1):17-28.

PRESENTS A NEW DESIGN FOR A SOLAR DISTILIATION FLANT WITH 40 CUBIC METER PER DAY OUTPUT. SYSTEM CONSISTS OF A SOLAR COLLECTOR, A 15-EFFECT ROTATING EVAPORATOR, WATER STORAGE TANKS, FLASH TANK, AND VARIOUS PUMPS AND CONTROLS. HIGH HEAT TRANSFER RATES WERE ACHIEVED IN A TEST UNIT, SUGGESTING THAT A FULL SIZE PLANT CAN BE RELATIVELY SMALL. CAPITAL AND OPERATING COST ESTIMATES INDICATE THAT SOLAR DISTILLATION WOULD BE CHEAPER USING THIS TYPE OF PLANT THAN USING STANDARD BASIN-TYPE STILLS.

DESALINATION/DISTILLATION/MULTIPLE EFFECT DISTILLATION/ECONOMICS/BASIN-TYPE STILLS

0086

TOWLE, C.L., JR.

1976

FEASIBILITY OF INTRODUCING SOLAR POWERED IRRIGATION ON A REPRESENTATIVE ARIZONA FARM.

UNIVERSITY OF ARIZONA (M.S. THESIS). 90 P.

ECONOMIC AND TECHNICAL ANALYSIS FOR A TYPICAL PINAL COUNTY FARM INDICATES THAT COST OF SOLAR POWER FOR IRRIGATION (50 MILLS/KWH) IS FOUR TIMES GREATER THAN THE ECONOMICALLY FEASIBLE UPPER LIMIT, I.E. PRESENT COST OF CONVENTIONAL POWER (12 MILLS/KWH). THE AUTHOR ESTIMATES THAT AT BEST IT WILL TAKE 38 YEARS FOR THE PRICE OF CONVENTIONAL POWER TO RISE ENOUGH TO JUSTIFY SOLAR ENERGY USE POR IRRIGATION.

WATER PUMPING/IRRIGATION/AGRICULTURE/SOUTHWEST U.S./ECONOMICS/MODEL SIUDIES/SOLAR THERMAL CONVERSION

0087

UNITED NATIONS DEPARTMENT OF ECONOMIC AND SCCIAL AFFAIRS

1970

SOLAR DISTILLATION AS A MEANS OF MEETING SMALL-SCALE WATER DEMANDS.

SAME AS AUTHOR. NEW YORK. ST/ECA/121. 86 P.

DEFINES CONDITIONS UNDER WHICH SOLAR DISTILLATION MAY PROVIDE AN ECONOMIC SOLUTION TO PRESH WATER SHORTAGE IN SMALL COMMUNITIES. THE STUDY REVIEWS CURRENT STATUS OF SOLAR DISTILLATION: OUTLINES GENERAL CLASSES OF SITUATIONS IN WHICH IT MAY BE THE BEST SOLUTION TO WATER SUPPLY PROBLEMS; PROVIDES A METHOD FOR POTENTIAL USERS TO ESTIMATE PERFORMANCE AND COSTS OF CURRENT STILL DESIGNS IN THEIR AREAS; NOTES PRACTICAL PROBLEMS OF SOLAR STILL DESIGN AND OPERATION;

AND RECOGNIZES SOME POSSIBLE CHANGES IN SOLAR-DISTILLATION TECHNOLOGY AND ECONOMICS WHICH MAY AFFECT THE APPLICABILITY OF THE PROCESS IN THE FUTURE.

DISTILLATION/ECONOMICS/DESALINATION/BASIN-TYPE STILLS/DEVELOPING COUNTRIES/WATER SUPPLY

0088

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, LIVISION OF SOLAR ENERGY

SYMPOSIUM ON USE OF SOLAR ENERGY FOR POULTRY AND LIVESTOCK PRODUCTION, AUBURN, ALABAMA, 1976, PROCEEDINGS.

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, CONF-761156. 248 P.

PAPERS PRESENTED DISCUSSED APPLICATION OF SCLAR ENERGY TO: POULTRY PRODUCTION (AUTOMATED TEMPERATURE MAINTENANCE, LIGHTING, AND VENTILATION), MANURE DRYING, LIVESTOCK PRODUCTION (HEATING BUILDINGS FOR SWINE), AND MILK PRODUCTION (HOT WATER FOR MILKING, WASHUP, EQUIPMENT, AND SFACE HEATING). ALSO PRESENTED WERE BRIEF REVIEWS OF THE SOLAR HEATING INDUSTRY, COLLECTOR MATERIALS, CORROSION PROBLEMS, AND METEOROLOGICAL DATA USE.

AGRICULTURE/AGRICULTURAL WASTES/LIGHTING/WATER HEATING/SPACE HEATING/COMPLEX SYSTEMS

0089

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, TECHNICAL INFORMATION CENTER

1976

SOLAR ENERGY: A BIBLIOGRAPHY.

SAME AS AUTHOR. TID-3351-R1P1 (VOL. 1, CITATIONS, 585 P.). TID-3351-R1P2 (VOL. 2, INDEXES, 398 P.).

WITH ALMOST 10,000 CITATIONS, THIS IS PROBABLY BY FAR THE LARGEST PUBLISHED SOLAR ENERGY BIBLIOGRAPHY IN THE WORLD. REFERENCES (NO ABSTRACTS) TO SCIENTIFIC AND TECHNICAL LITERATURE THROUGH 1975 ARE ARRANGED CHRONOLOGICALLY WITHIN 35 SUBJECT CATEGORIES. MAIN CATEGORIES INCLUDE: RESOURCES AND AVAILABILITY; SITE GEOLOGY AND METEOROLOGY; ECONOMICS; ENVIRONMENTAL ASPECTS; SOLAR ENERGY CONVERSION; PHOTOVOLTAIC, SOLAR THERMAL, AND OCEAN THERMAL POWER PLANTS; SOLAR HADIATION UTILIZATION; SOLAR COLLECTORS AND CONCENTRATORS; AND TIDAL POWER. VOLUME 2 CONTAINS PERSONAL AUTHOR, CORPORATE AUTHOR, SUBJECT, AND REPORT NUMBER INDEXES. THIS IS A LIVING BIBLIOGRAPHY; ERDA (NOW DEPARTMENT OF ENERGY, D.O.E.) PUBLISHES NEW REFERENCES, APOUT 5,000 TO DATE, MOST WITH ABSTRACTS, IN MONTHLY SOLAR ENERGY UPDATE ISSUES. ALL THIS INFORMATION AND MORE IS INSTANTLY ACCESSIBLE FOR COMPUTER SEARCHES THROUGH D.O.E.'S MAMMOTH RECON SYSTEM.

BIBLICGRAPHIES/RESEARCH AND DEVELOPMENT/SOLAR RADIATION/GEOLOGY/ECONOMICS/ENVIRONMENTAL EFFECTS/PHOTOVOLTAIC CONVERSION/SOLAR THERMAL CONVERSION/OCEAN THERMAL ENERGY CONVERSION/FLAT PLATE COLLECTORS/OPTICAL CONCENTRATION/TIDAL ENERGY/SPACE HEATING/SPACE COOLING/ORBITAL POWER STATIONS/WATER HEATING/CONCENTRATING COLLECTORS

VON HIPPEL, F./WILLIAMS, R.H.

1975

SOLAR TECHNOLOGIES.

BULLETIN OF THE ATOMIC SCIENTISTS 31(9):25-31.

SOLAR ENERGY IS BY FAR OUR DOMINANT ENERGY SOURCE, IF TOTAL ENVIRONMENTAL LIFE SUPPORT IS COUNTED. OFFICIAL U.S. ENERGY EUDGET, 75 QUADRILLICN BTU (Q), IS DWARFED BY PLANT PRODUCTIVITY (100 Q), EVAPOTRANSPIRATION (10,000 Q), AND RAINFALL (13,000 Q FOR SEAWATER EVAPORATION). SEVERAL SOLAR ENERGY TECHNOLOGIES ARE BRIEFLY REVIEWED, SHOWING RELATIVE PROMISE AND LIMITATIONS OF EACH: ACTIVE AND PASSIVE SOLAR HOUSE HEATING, SOLAR THERMAL POWER, OCEAN THERMAL POWER, WIND AND WAVE POWER, ORBITAL PHOTOVOLTAIC POWER STATIONS, AND PHOTOSYNTHETIC FUELS FROM AGRICULTURAL WASTES. SOLAR ENERGY SYSTEMS, LIKE ALL ENERGY SYSTEMS, INVOLVE SOME POLLUTION AND MATERIAL RESOURCE LIMITATIONS. IT IS IMPORTANT TO MAINTAIN DIVERSITY OF SOLAR CONVERSION TECHNOLOGIES, AND TO PURSUE ENERGY CONSERVATION CONCURRENTLY WITH SOLAR ENERGY DEVELOPMENT. WIND POWER AND PHOTOSYNTHETIC ENERGY ARE PARTICULARLY WELL SUITED FOR DEVELOPING NATIONS.

ACTIVE TEMPERATURE CONTROL/PASSIVE TEMPERATURE CCNTROL/ELECTRIC POWER/SOLAR THERMAL CONVERSION/OCEAN THERMAL ENERGY CONVERSION/WIND ENERGY/WAVE ENERGY/ORBITAL POWER STATIONS/PHOTOVOLTAIC CCNVERSION/BIOMASS FUELS/ENVIRONMENTAL EFFECTS/LIMITING FACTORS/DIVERSITY (TECHNOLOGICAL)/ENERGY CONSERVATION/DEVELOPING COUNTRIES/AGRICULTURAL WASTES

0091

VON HIPPEL, F./WILLIAMS, R.H.

1977

TOWARD A SOLAR CIVILIZATION.

BULLETIN OF THE ATOMIC SCIENTISTS 33(8):12-15, 56-60.

BECAUSE THERE ARE FUNDAMENTAL PROBLEMS WITH LONG-TERM DEPENDENCE ON COAL OR NUCLEAR ENERGY, HIGH PRIORITY SHOULD BE GIVEN TO DETERMINING THE FEASIBILITY OF ESTABLISHING, WITHIN THE NEXT 50 YEARS, A VIABLE ENERGY ECONOMY BASED PRIMARILY ON SOLAR ENERGY. ONLY BY THIS APPROACH CAN THE ASSOCIATED ISSUES BE DIRECTLY CONFRONTED. SHIFT TO SOLAR ECONOMY COULD PROFOUNDLY RESHAPE OUR WAY OF LIFE. LARGE COLLECTION AREAS, BULKY STORAGES, AND INCREASED EFFICIENCY OF ENERGY USE WOULD HAVE TO BE ENGINEERED. SOLAR COSTS CAN BE REDUCED BY MULTIPLE-PURPOSE SYSTEM DESIGN (PASSIVE SOLAR HOUSES, COGENERATION AND TOTAL ENERGY SYSTEMS, ETC.). UNLIKE GLOBALLY HOMOGENEOUS FOSSIL FUEL NETWORKS, SOLAR EXPLOITATION STRATEGIES WILL BE DIVERSE, VARYING REGIONALLY WITH DIFFERENT SOLAR RESOURCE AND ENERGY DEMAND MIXES. CHEAP SOLAR POWER GENERATION IN REMOTE AREAS MAY ATTRACT ENERGY-INTENSIVE INDUSTRIES, E.G., ALUMINUM AND AMMONIA PLANTS. SOLAL TECHNOLOGIES FOR VARIOUS ENERGY DEMAND CATEGORIES ARE REVIEWED: LOW TEMPERATURE HEAT (HOT WATER, SPACE HEATING/COOLING, AND PROCESS HEAT), ELECTRICITY (CENTRAL STATIONS, AND PERHAPS MORE PROMISING, SMALL DECENTRALIZED SYSTEMS WHICH PROVIDE USEFUL WASTE HEAT AND CAN BE MASS PRODUCED), AND CHEMICAL FUELS (HYDROGEN FROM WATER, AND ORGANIC PUELS FROM BIOMASS). IN SOLAR ECONOMY, ENERGY PRODUCTION AND CONSUMPTION TECHNOLOGIES MUST BE MORE CLOSELY INTEGRATED. SHIFT TO SOLAR REQUIRES BROAD-BASED SOCIAL AND POLITICAL COMMITMENT. A NEW SOLAR ENERGY TECHNOLOGICAL REVOLUTION, WITH SO MANY EXPANDING RESEARCH FRONTIERS THAT NO INDIVIDUAL OR GOVERNMENT CAN MAINTAIN AN OVERVIEW, APPEARS TO BE TAKING PLACE. BEST APPROACH MAY BE TO LET DIVERSITY REIGN, THEN CULTIVATE THE MOST PROMISING VARIETIES.

SOLAR CIVILIZATION/ECONOMICS/BIOLOGICAL-INDUSTRIAL ANALOGY/SOCIAL ASPECTS/
POLITICAL ASPECTS/ENERGY STORAGE/ENERGY CONSERVATION/MULTIPURPOSE SYSTEMS/
COMPLEX SYSTEMS/HYBRID SYSTEMS/PASSIVE TEMPERATURE CONTROL/COGENERATION/
TOTAL ENERGY SYSTEMS/DIVERSITY(TECHNOLOGICAL)/CCMPETITION/ADAPTATION/HYDROGEN/
TECHNOLOGICAL SUCCESSION/WATER HEATING/SPACE HEATING/SPACE COOLING/PROCESS HEAT/
ELECTRIC POWER/DECENTRALIZED SYSTEMS/ELECTRIC UTILITIES/MASS PRODUCTION/
BIOMASS FUELS

0092

WATSON, D.

1977

DESIGNING AND BUILDING A SOLAR HOUSE: YOUR PLACE IN THE SUN.

GARDEN WAY PUBLISHING, CHARLOTTE, VERMONT. 281 P.

THIS UP-TO-DATE SURVEY OF DIVERSE SOLAR TECHNOLOGIES FOR HOUSE SPACE AND WATER HEATING CAN SERVE AS A SOURCEBOOK OF DESIGN IDEAS FOR ACTIVE AND PASSIVE COLLECTORS, STORAGE SYSTEMS, AND SOLAR CELL APPLICATIONS FOR THE HOME. IT IS PROFUSELY ILLUSTRATED WITH PHOTOGRAPHS, DRAWINGS, AND DIAGRAMS. PART OF THE BOOK IS A GENERAL GUIDE TO BUILDING A SOLAR HOUSE AND ADAPTING IT TO CLIMATE (SUN, WIND) AND SITE. AN APPENDIX LISTS AND DESCRIBES SELECTED SOLAR HOUSES IN THE U.S.

ACTIVE TEMPERATURE CONTROL/PASSIVE TEMPERATURE CCNTROL/SPACE HEATING/WATER HEATING/ENERGY STORAGE/SOLAR CELLS/PHOTOVOLTAIC CONVERSION/ADAPTATION/BUILDING DESIGN

0093

WEIHE, H.

1972

FRESH WATER FROM SEA WATER: DISTILLING BY SOLAR ENERGY.

SOLAR ENERGY 13 (4): 439-444.

PROPOSES THE USE OF TRACKING, CONCENTRATING SOLAR COLLECTORS TO RAISE SEA WATER TEMPERATURE FOR MULTISTAGE FLASH DISTILLATION. DUE TO HIGHER TEMPERATURES AND MULTIPLE EFFECTS INVOLVED, THIS METHOD SHOULD PRODUCE FRESH WATER MUCH MORE EFFICIENTLY THAN DO STANDARD BASIN-TYPE STILLS.

DISTILLATION/DESALINATION/OPTICAL CONCENTRATION/MULTIPLE EFFECT DISTILLATION/BASIN-TYPE STILLS/CONCENTRATING COLLECTORS

0094

WEISS, C./PAK, S.

1976

DEVELOPING COUNTRY APPLICATIONS OF PHOTOVOLTAIC CELLS. IN ERDA SEMIANNUAL SOLAR PHOTOVOLTAIC CONVERSION PROGRAM REVIEW, 2ND, LAKE BUENA VISTA, FLORIDA, 1976, PROCEEDINGS, P. 33-54.

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, DIVISION OF SOLAR ENERGY, WASHINGTON, D.C. CONF-760131.

MOST RURAL AREAS IN DEVELOPING COUNTRIES WILL NOT BE KEACHED SOON BY ELECTRICITY DISTRIBUTION GRIDS, SO DEMAND WILL INCREASE FOR SMALL-SCALE POWER SOURCES FOR SUCH APPLICATIONS AS EDUCATIONAL TV SETS, REFRIGERATORS IN CLINICS, AND SMALL APPLIANCES IN TOURIST CENTERS. BATTERIES AND GASOLINE-POWERED GENERATORS ARE NOW WIDELY USED. SOLAR CELLS COST MORE TO INSTALL BUT IN MANY CASES WILL COST LESS IN THE LONG RUN. POTENTIAL SOLAR CELL MARKET IN DEVELOPING COUNTRIES IS A SUBSTANTIAL FRACTION OF ERDA GOAL FOR U.S. PRODUCTION RATE FOR SOLAR CELLS UNTIL THEY BECOME COMPETITIVE WITH LARGE-SCALE POWER GENERATION. POTENTIAL BUYERS ARE LIKELY TO INSIST ON GUARANTEED LONG-LIFE PERFORMANCE IN EXTREME ENVIRONMENTS.

DEVELOPING COUNTRIES/PHOTOVOLTAIC CONVERSION/SOLAR CELLS/ELECTRIC POWER/ECONOMICS

0095

WILCOX, H.A.

1975

HOTHOUSE EARTH.

PRAEGER PUBLISHERS, NEW YORK. 181 P.

IF MEN CHOOSE TO MEET ENERGY DEMANDS WITH REMAINING FOSSIL FUEL RESOURCES AND WITH INCREASED NUCLEAR POWER PRODUCTION, A THERMAL POLLUTION CATASTROPHE MAY RESULT. GLOBAL ENERGY CONSUMPTION AT A LEVEL COMPARABLE TO THAT OF INDUSTRIALIZED NATIONS WILL PRODUCE WASTE HEAT INCREASES OF SERIOUS PROPORTIONS. AS ATMOSPHERE HEATS UP, POLAR ICE CAPS COULD MELT, CAUSING OCEANS TO RISE AND FLOOD COASTAL CITIES AND ARABLE LAND. DISRUPTIONS FROM INLAND MIGRATIONS AND COMPETITION FOR FOOD MAY NOT BE MANAGEABLE. IMMEDIATE DEVELOPMENT OF SOLAR TECHNOLOGY (SOLAR CELLS, WINDMILLS, AND OCEAN TURBINES COMBINED WITH OPEN-OCEAN PARMING) IS A SIEP THAT COULD HELP AVOID THERMAL CATASTROPHE. OCEAN FARMS CAN CAPTURE SOLAR ENERGY FOR FUEL AND FOOD WITHOUT INCREASING GLOBAL TEMPERATURES OR CHANGING ATMOSPHERIC COMPOSITION. ACCOMPLISHING SUCH A MAJOK SHIFT IN FUEL AND FOOD PRODUCTION WILL REQUIRE CHANGES IN LIFESTYLE, STABLE POPULATION, AND HIGH LEVELS OF INTERNATIONAL COOPERATION.

ENVIRONMENTAL EFFECTS/CLIMATIC CHANGE/SOCIAL ASPECTS/POLITICAL ASPECTS/LIMITING FACTORS

0096

WILCOX, H.A.

1976

THE OCEAN FOOD AND ENERGY FARM PROJECT.

DEVELOPMENT DIGEST 14(3):42-48.

PROPOSES TO ESTABLISH LARGE OCEAN FARMS WHICH WOULD GROW SEAWEED ON NETS 40 TO 80 FEET BELOW THE SURFACE. PERTILIZER WOULD BE SUPPLIED BY COLD WATER PUMPED FROM DEPTHS (COULD BE COMBINED WITH OCEAN THERMAL FOWERPLANT), OR IT COULD BE

IMPORTED. SEAWEED AND FISH WOULD BE HARVESTED EVERY 3 MONTHS: FISH FOR FOOD, AND SEAWEED FOR MANY PURPOSES (HUMAN FOOD; LIVESTOCK OR MARICULTURE FEED; AND FEEDSTOCK FOR CONVERSION TO PETROCHEMICALS, FUELS, FERTILIZERS, AND INDUSTRIAL MATERIALS). ALL PROCESSING COULD BE CARRIED OUT ON A MANEUVERABLE FLOATING PLATFORM (POWERED BY SOLAR, WIND, WAVE, OR KELP FUEL ENERGY) WHICH MIGHT CONTAIN: PROCESSING MACHINERY, STORAGE FACILITIES, LIVING QUARTERS, NAVIGATION AND PROPULSION MACHINERY, NUTRIENT DISTRIBUTORS, AND AN UPWELLING PUMP. A SQUARE MILE FARM COULD SUPPLY FOOD FOR 3000 TO 5000 HUMANS, ENERGY AND MATERIALS FOR 300 TO 2000.

OCEAN THERMAL ENERGY CONVERSION/WIND ENERGY/WAVE ENERGY/BIOMASS FUELS/HYBRID SYSTEMS/MULTIPURPOSE SYSTEMS/COMPLEX SYSTEMS/FCCD PRODUCTION/MARICULTURE

0097

WILKE, D.A./FULLER, D.R.

1976

HIGHLY ENERGY EFFICIENT WILTON WASTEWATER TREATMENT PLANT.

CIVIL ENGINEERING-ASCE 46 (5):70-72.

SEE: SWRA W77-00579.

WASTE WATER TREATMENT/WATER HEATING/BIOMASS FUELS/ELECTRIC POWER/SPACE HEATING/ENERGY CONSERVATION/FLAT PLATE COLLECTORS/ENERGY STORAGE/OPTICAL CONCENTRATION/COMPLEX SYSTEMS/HYBRID SYSTEMS/MULTIPURPOSE SYSTEMS

0098

WOLF, M.

1976

PHOTOVOLTAIC SOLAR ENERGY CONVERSION.

BULLETIN OF THE ATOMIC SCIENTISTS 32(4):26-33.

PHOTOVOLTAIC CONVERSION IS QUITE LIKELY TO SUPPLY MOST FUTURE SOLAR ELECTRICITY. TECHNICAL FEASIBILITY IS ESTABLISHED; THE REMAINING MAJOR TASKS ARE SYSTEM OPTIMIZATION AND LOWERING OF COSTS FOR SOLAR CELLS AND ENERGY STORAGE DEVICES THROUGH TECHNICAL IMPROVEMENTS AND MASS PRODUCTION. TO CONTRIBUTE SIGNIFICANTLY TO U.S. POWER PRODUCTION, SOLAR CELL AREA WILL NEED TO BE COMPARABLE TO AREA OF BUILDINGS, AND PRODUCTION RATE WILL NEED TO BE APPROXIMATELY 1,000,000 TIMES PRESENT LEVEL. LARGE SOLAR CELL INDUSTRY SHOULD BE VERTICALLY INTEGRATED TO REDUCE COST. GOVERNMENT SUPPORT IS REQUIRED TO BRING PHOTOVOLTAICS TO THE POINT OF LARGE SCALE COMMERCIAL FEASIBILITY, BUT FUNDS REQUIRED ARE MUCH LESS THAN FOR BREEDER REACTOR DEVELOPMENT. IT WILL BE AT LEAST THE YEAR 2000 BEFORE ENOUGH SOLAR CELL CAPACITY HAS ACCUMULATED TO MAKE A SIGNIFICANT CONTRIBUTION TO U.S. ENERGY SUPPLY. PHOTOVOLTAIC TECHNOLOGY AND CURRENT FIELDS OF RESEARCH ARE REVIEWED.

PHOTOVOLTAIC CONVERSION/SOLAR CELLS/ELECTRIC POWER/ENERGY STOKAGE/ECONOMICS/MASS PRODUCTION

ZENER, C.

1976

SOLAR SEA POWER.

BULLETIN OF THE ATOMIC SCIENTISTS 32(1):17-24.

SEE: SWRA W76-12961.

OCEAN THERMAL ENERGY CONVERSION/ECONOMICS/ENVIRONMENTAL EFFECTS/ELECTRIC POWER

0100

ZOSCHAK, R.J./WU, S.F.

1975

STUDIES OF THE DIRECT INPUT OF SOLAR ENERGY TO A FOSSIL-FUELED CENTRAL STATION STEAM POWER PLANT.

SOLAR ENERGY 17 (4):297-305.

PRESENTS A THEORETICAL STUDY OF 7 POSSIBLE WAYS TO INTEGRATE SOLAR ENERGY DIRECTLY INTO A CONVENTIONAL 800 MWE FOSSIL FUEL POWERPLANT. ALL DESIGNS INCLUDE A FIELD OF HELIOSTATS WHICH CONCENTRATE SOLAR RADIATION ONTO A TOWER-MOUNTED CENTRAL RECEIVER. THE TOWER CAN SERVE SIMULTANEOUSLY AS SOLAR ENERGY COLLECTOR SUPPORT AND AS FUEL EXHAUST SMOKESTACK. VARIABLES CONSIDERED IN THE STUDY ARE CAPITAL COST, ENERGY CONVERSION EFFICIENCY, AND SYSTEM COMPLEXITY. THE PREFERRED DESIGN, USING SOLAR HEAT FOR BOTH EVAPORATION AND SUPERHEATING, OFFERS RELATIVELY LOW COST, HIGH EFFICIENCY, AND MODERATE COMPLEXITY. SECOND PREFERENCE IS TO USE SOLAR ENERGY FOR FEEDWATER HEATING.

HYBRID SYSTEMS/SOLAR THERMAL CONVERSION/ELECTRIC POWER/HELIOSTATS/ECONOMICS/CENTRAL RECEIVER-HELIOSTAT SYSTEMS/MODEL STUDIES

AUTHOR INDEX

(Numbers refer to numbered items in the preceding bibliography, not to page numbers)

ANDERSON, J.H. ANTAL, M.J., JR. ASBURY, J.G. ASSAF, GAD 0004	0001 0002 0003	FINLAYSON, F.C. FOX, H.G. 0083 FULLER, D.R.	0029 0097
BACKUS, C.E. BASSLER, F. BECKMAN, W.A. BLISS, R.W.	0005 0006 0024 0007	GLASER, P.E. GONSALVES, L.M. GRETHER, D.	0030 0046 0019
BLOND, E. 0009 BOCKRIS, J.O'M. BOS, P.B. 0009 BRINKWORTH, B.J. BRODA, E. 0011 BROWN, M.L.	0010	HAGEN, A.W HALACY, D.S HAMMOND, A.L HARRIGAN, R.W HILDEBRANDT, A.F HIRSCHMANN, J.R HODGES, C.N HOWE, E.D	0031 0032 0033 0034 0035 0036 0037 0038 0039 0040 0041
CALVIN, M. 0012 CAPUTO, R.S. CHALMERS, E. CLAMPITT, B.H. CORTELL, B.	0013 0014 0015 0016	HUGHES, E.E. HULT, J.L. 0043 JENSEN, M.H.	0044 0045
DALRYMPLE, D.G DANIELS, F DAVIDSON, M DAY, M.E 0020 DEWINTER, F DEWINTER, J.W., EDS DICKINSON, W.C DICKSON, E.M	0021 0022 0021 0022 0023 0042	KAMMER, W.A. KETTANI, M.A. KIVIAT, F.E KNOWLES, R.L.	0009 0029 0046 0015 0047
DUFFIE, J.A. DUFFIELD, C. DUGUAY, M.A.	0024 0025 0026	LEONARD, S.L. LOEWER, O.J., JR. LOF, G.O.G.	0048 0049 0027 0084
EIBLING, J.A. EPSTEIN, E.	0027 0084 0028		

MAKHIJANI, A.	0050	TALBERT, S.G. TLEIMAT, B.W.	0027 0084 0085
MATTER, F.S.	0051	TOWLE, C. L., JR.	0086
MAUGH, T.H., II	0052	TRAN, V.V. 0078	30 30
MCCOSH, B. 0090		18AN, 1111 0070	
MCGOWAN, J.G.	0053		
MEINEL, A.B.	0054 0055 0056		
005 7			
MEINEL, M.P.	0055 0056 0057		
MERRIGAN, J.A.	0058	U.S. ENERGY RESEARCH	AND DEVELOPMENT
	0059 0060 0061	ADMINISTRATION	
0062		SOLAR ENERGY	
MOUMOUNI, A	0063	U.S. ENERGY RESEARCH	
MUELLER, R.O.	0003	ADMINISTRATION,	
		INFORMATION CEN	
		UNITED NATIONS DEPAR	RIMENT OF ECONOMIC
		AND SOCIAL AFFA	
		0087	
NATIONAL ACADEMY OF			
WASHINGTON, D.	C. 0064 0065		
NORLYN, J.D.	0028		•
NORMAN, R.S.	0066	•	
		VANT-HULL, L.L.	0037
		YON HIPPEL, F.	0090
		VON HIPPEL, F.	0091
		•	
O'NEILL, G.K.	0069		
ODUM, H.T. 0067			
OLGYAY, A. 0068			
OLGYAY, V. 0068		HAMCON D 0000	
OSTRANDER, N.C.	0043	WATSON, D. 0092	
OTHMER, D.F.	0070	WEIHE, H. 0093	
•		WEISS, C. 0094	2005 2026
,		WILCOX, H.A.	0095 0096
		WILCOX, K. 0019 WILKE, D.A.	0097
			0073 0077 0090
		0091	0373 0077 0090
PAK, S. 0094		WOLF, M. 0098	
POLLARD, W.G.	0071 0072	WU, S.F. 0100	
POOLE, A.D.	0073	10, 5.11.	
BODINGON : :	0074 0075	ZENER, C. 0099	
ROBINSON, A.L.	0076	ZOSCHAK, R.J.	0100
ROSENBAUM, S.			
ROSS, M.H. 0077	,		

SCHMIDT, R. A. 0042
SELCUK, M.K. 0078
SHURCLIFF, W.A. 0079
SINHA, E. 0080
SORENSEN, B. 0081
STONER, C. 0082
SWET, C.J. 0083

KEYWORD INDEX

(Numbers refer to numbered items in the preceding bibliography, not to page numbers)

ABU DHABI 0040	CHILE 0038 0039
ACTIVE TEMPERATURE CONTROL	CLIMATIC CHANGE 0013 0043 0072
0022 0024 0079 0090 0092 ADAPTATION 0005 0007 0025 0037	0073 0081 0095
ADAPTATION 0005 0007 0025 0037	COASTAL DESERTS 0001 0006 0015
0047 0060 0061 0068 0091 0092	0017 0028 0039 0040 0046 0066
AGRICULTURAL WASTES 0002 0033	0070
0072 0073 0088 0090	COGENERATION 0073 0076 0091
AGRICULTURE 0012 0017 0025	COLLECTORS 0003 0049
0028 0033 0039 0040 0044 0045	COLORADO RIVER 0025 0054 0056
0049 0050 0052 0055 0067 0069	COMPETITION 0025 0035 0060
0072 0076 0080 0083 0086 0088	0062 0079 0091
AMORPHOUS SEMICONDUCTORS 0034	COMPLEX SYSTEMS 0001 0008 0017
0074 0075	0025 0031 0036 0040 0043 0044
ANTARCTICA 0017 0043	0049 0051 0069 0070 0071 0076
APPROPRIATE TECHNOLOGY 0025	0088 0091 0096 0097
0050 0055 0060 0063 0064 0065	CONCENTRATING COLLECTORS 0009
0082 0083	0010 0013 0018 0022 0026 0057
AQUICULTURE 0049 0072 0073	0061 0076 0089 0093
0076	CONTROLLED-ENVIRONMENT AGRICULTURE
	0017 0025 0040 0044 0045 0051
APG ENTINA 0021 0038	0076
AFID-SEMIARID LANDS 0001 0006	COOKING 0018 0050 0063 0064
0011 0017 0025 0027 0028 0038	0065
0039 0040 0052 0067 0073 0083	COOLING WATER 0005 0019 0023
AUSTRALIA 0021 0038	0025
	COPPER MINES 0051 CROP DRYING 0018 0064 0065
	CROP DRIVING
DAUDATN	
BAHPAIN 3046	
BASIN-TYPE STILLS 0027 0039	
0027 0039 0078 0084 0085 0087 0093	DEAD SEA 3004 0015 0366
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089	DEAD SEA 3004 0015 0366 DECENTRALIZED SYSTEMS 0060
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY	DECENTRALIZED SYSTEMS 0060
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEOMORPHIC) 0006
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEOMORPHIC) 0006 0046
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEOMORPHIC) 0006 0046 DESALINATION 0001 0004 0020
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEOMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEOMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BFINE DISPOSAL 0020 BRINES 0004 0015 0066	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070 0076 0078 0080 0084 0085 0087
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070 0076 0078 0080 0084 0085 0087
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070 0079 0092	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070 0076 0078 0080 0084 0085 0087 0093 DISTRIBUTED RECEIVER SYSTEMS
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070 0079 0092 CANADA 0021	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070 0076 0078 0080 0084 0085 0087 0093 DISTRIBUTED RECEIVER SYSTEMS 0009 0013 0019
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BPINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070 0079 0092 CANADA 0021 CASPIAN SEA 0046	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070 0076 0078 0080 0084 0085 0087 0093 DISTRIBUTED RECEIVER SYSTEMS 0009 0013 0019 DIVERSITY (TECHNOLOGICAL) 0025
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070 0079 0092 CANADA 0021 CASPIAN SEA 0046 CENTRAL RECEIVER-HELIOSTAT SYSTEMS	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070 0076 0078 0080 0084 0085 0087 0093 DISTRIBUTED RECEIVER SYSTEMS 0009 0013 0019 DIVERSITY (TECHNOLOGICAL) 0025 0035 0047 0060 0061 0062 0079
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070 0079 0092 CANADA 0021 CASPIAN SEA 0046 CENTRAL RECEIVER-HELIOSTAT SYSTEMS 0002 0009 0013 0019 0037 0060	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070 0076 0078 0080 0084 0085 0087 0093 DISTRIBUTED RECEIVER SYSTEMS 0009 0013 0019 DIVERSITY (TECHNOLOGICAL) 0025 0035 0047 0060 0061 0062 0079 0090 0091
BASIN-TYPE STILLS 0027 0039 0078 0084 0085 0087 0093 BIBLIOGRAPHIES 0025 0080 0089 BIOLOGICAL-INDUSTRIAL ANALOGY 0025 0047 0067 0091 BIOMASS FUELS 0002 0011 0012 0019 0028 0033 0035 0049 0050 0052 0056 0064 0065 0072 0073 0076 0080 0082 0090 0091 0096 0097 BOLIVIA 0038 BRINE DISPOSAL 0020 BRINES 0004 0015 0066 BUILDING DESIGN 0007 0022 0036 0044 0045 0047 0049 0068 0070 0079 0092 CANADA 0021 CASPIAN SEA 0046 CENTRAL RECEIVER-HELIOSTAT SYSTEMS	DECENTRALIZED SYSTEMS 0060 0061 0071 0082 0091 DEPRESSIONS (GEDMORPHIC) 0006 0046 DESALINATION 0001 0004 0020 0025 0027 0031 0039 0040 0041 0043 0054 0067 0070 0078 0080 0084 0085 0087 0093 DESERTIFICATION 0063 DEVFLOPING COUNTRIES 0002 0025 0050 0055 0063 0064 0065 0071 0073 0083 0087 0090 0094 DISTILLATION 0001 0018 0025 0027 0031 0038 0039 0040 0041 0054 0063 0064 0065 0067 0070 0076 0078 0080 0084 0085 0087 0093 DISTRIBUTED RECEIVER SYSTEMS 0009 0013 0019 DIVERSITY (TECHNOLOGICAL) 0025 0035 0047 0060 0061 0062 0079

FCONOMIC PLANTS	0012 0028	0033	HEAT ENGINES	0010 0013 0019
0045 0052			0022 0025 0061	
ECONOMICS 0002			HEAT EXCHANGERS	
0013 0014 0017	0022 0025	0026	0071	0023 0043 0033
0027 0030 0034 0040 0043 0045	0035 0036	0037	HEAT SINKS 0005	0016 0043
0040 0043 0045	0048 0053	0058	HELIOSTATS 0002	
0040 0043 0045 0059 0060 0062 0069 0070 0071 0081 0084 0085 0091 0094 0098 ECUADOR 0021	0063 0066	0067	0026 0037 0060	
0069 0070 0071	0077 0079	0080	HYBRID SYSTEMS	
0081 0084 0085	0086 0087	0089	0026 0029 0031	0035 0040 0049
0091 0094 0098	0099 0100		0051 0069 0070	0071 0076 0091
ECUADOR 0021			0096 0097 0100	
EGYPT 0004 0006 ELECTRIC POWER 0005 0006 0009			HYDROGEN 0002	0008 0011 0012
ELECTRIC POWER	0001 0003	0004	0025 0031 0033	0042 0048 0074
0005 0006 0009	0013 0014	0023	0081 0091	
0025 0029 0030	0031 0032	0034	0081 0091 HYDROPOWER 0006 0065 0071 0082	0031 0046 0050
0035 0036 0038	0042 0046	0048	0065 0071 0082	
0054 0055 0056	0060 0061	0062		
0066 0067 0069 0080 0090 0091	00/0 00/1	0076		
0080 0099 0091	0094 0097	0098		
	0.000	0000		
ELECTRIC UTILITIES				
0035 0054 0059 ELECTROCHEMICAL CON	0050 0061	0091	ICEBERGS 0015	0043
0015	A EK2 TO N		IMPERIAL VALLEY	0025 0029
PAPECA COACEDANATOR	0077	0000	INDIA 0021 0050	
EMERGY CONSERVATION			IRAN 0021	
0090 0091 0097 ENERGY QUALITY ENERGY STORAGE 0008 0016 0018 0057 0060 0065 0082 0091 0092	0005 0067		IRAQ 0021	
EMERGY CHORACE	0025 0067	0006	IRRIGATION 0025	0028 0055 0061
0.000 0.016 0.010	0002 0003	0006	0083 0086	
0057 0060 0065	0023 0037	0051	ISRAEL 0004	0015 0021 0025
0082 0091 0092	0071 0080	0081	0052 0066	
ENERGY TRANSMISSION				
0018 0030 0069		0013		
FNVIRONMENTAL EFFECT		0013		
0019 0025 0030		0013		
0053 0055 0059				
0073 0035 0039			JOJOBA 0052	
0073 0077 0081	0009 0090	0095	JORDAN 0021	
EUPHORBIA 0012 FVAPORATION	0006 0015	0020		
0025 0038 0046		0020		
0029 0039 0040	0004 0003			
			KUWAIT 0021	
FLAT PLATE COLLECTOR	25	0010		
0018 0057 0089				
FOOD PRODUCTION	0001 0017	0028	LIGHTING 0026	0000
0031 0040 0044				
0052 0070 0096	00.5 0045	0030	LIMITING FACTORS	0003 0005
				0067 0071 0073
			0090 0095	
GEOLOGY 0025	0038 0089			
GEOTHERMAL ENERGY	0025	0029	MARICULTURE	0001 0031 0033
0031 0042 0065			0070 0072 0073	
GREAT SALT LAKE	0004 0066		MASS PRODUCTION	
GPEFCE 0021				0013 0014 0034
GPEENHOUSES	0017 0040	0044	0053 0037 0033	
0045 0049 0051			MEDIUM TEMPERATURE	
GROUNDWATER		002E ·	"" " TOUT OUT OUT OUT	
0038	0005 0016	0025	0009 0026 0060	0061
	0005 0016	0025	0009 0026 0060 MFXICO 0025	
GUAYULE 0052	0005 0016	0023		0061 0040 0041 0052
GUAYULE 0052	0005 0016	0025	MEXICO 0025	

MICROWAVE POWER TRANSMISSION 0030 0069 MCDEL STUDIES 0003 0007 0009 0029 0036 0043 0047 0048 0049 0051 0078 0086 0130 MULTIPLE EFFECT DISTILLATION	REFRIGERATION 001	3 0025 006
0030 0069	RESEARCH AND DEVELOPMEN	r 002
0029 0036 0043 0047 0048 0049	0025 0035 0080 008	9
0051 0078 0086 0100	ROLES OF WATER 002	5 0067
0025 0041 0070 0085 0093 MULTIPURPSE SYSTEMS 0001 0004		
0008 0023 0025 0026 0031 0035		
0036 0040 0043 0044 0049 0051	SAHELTAN ZONE 005	5 0063
0054 0061 0069 0070 0076 0078	SAHELIAN ZONE 005 SALINATION POWER SALINE LAKES 000	0015 006
0091 0096 0097	SALINE LAKES 000	4 0006 001
NET ENERGY 0025 0037 0059 0067 NIGERIA 0021 NILE 0006	0066	
	SALT PRODUCTION 000	4 0020 003
	0038 0065	
NET ENERGY 0025 0037 0059 0067	SALT TOLERANCE 002	8
NIGERIA 0021	SAUDI ARABIA 002	0028
NILE 0006	SENEGAL 0021	0028
	SENEGAL 0021 SHADING 0045 004 SIZE EPFECTS 001	7 0068
	SIZE EFFECTS 001	3 0025 003
	0035 0048 9055 005 0062 0071	9 0060 006
OCEAN THERMAL ENERGY CONVERSION 0001 0019 0031 0032 0053 0059 0070 0071 0080 0089 0090 0096	SOCIAL ASPECTS 000	7 0011 003
OCEAN THERMAL ENERGY CONVERSION	0043 0047 0050 005	
0001 0019 0031 0032 0053 0059	0091 0095	
0099	SOLAR CELLS 001 0034 0048 0058 007	4 0026 003
0099 OPTICAL CONCENTRATION 0010 0018 0026 0034 0048 0057 0061	0034 0048 0038 007	
0018 0026 0034 0048 0057 0061	SOLAR CIVILIZATION	0091
OPBITAL POWER STATIONS 0030	SOLAR PONDS 000	4 0023 003
0032 0069 0071 0080 0089 0090	0045 0070 SOLAR RADIATION 001	
0076 0089 0093 0097 ORBITAL POWER STATIONS 0030 0032 0069 0071 0080 0089 0090 OSMOSIS 0015 0066	0047 0057 0067 006	8 0071 008
0032 0069 0071 0080 0089 0090 OSMOSIS 0015 0066 PAKISTAN 0021 PASSIVE TEMPERATURE CONTROL 0007 0024 0035 0047 0068 0090 0091 0092 PERSIAN GULF 0046 PHOTOCHEMICAL CONVERSION 0010 0011 0012 0018 0032 PHOTOSYNTHESIS 0010 0011 0012	0089	
	SOLAR THERMAL CONVERSIO	N 000
	0003 0004 0005 000	9 00 10 00 3 00 29 00 1
	0033 0036 0037 003	8 0042 005
PAKISTAN 0021	0055 0056 0057 006	0 0061 006
0007 0024 0035 0047 0068 0090	0070 0071 0076 008	0 0083 008
0091 0092	0089 0090 0100 SOUTH AFRICA 002	1
PERSIAN GULF 0046	SOUTHWEST U.S. 000	5 0009 001
PHOTOCHEMICAL CONVERSION 0010	0025 0029 0036 004	7 0048 009
PHOTOSYNTHESIS 0010 0011 0012	0052 0054 0056 006	1 0067 008
0067		9 8 00 1 9 002
PHOTOVOLTAIC CONVERSION 0005	0024 0025 0036 004	5 0047 004
0010 0014 0018 0019 0026 0030 0032 0034 0042 0048 0057 0058	0056 0061 0063 006	4 0065 008
0065 0071 0074 0075 0080 0089	0089 0091 SPACE HEATING 000	7 0010 00
0090 0092 0094 0098	0019 0022 0024 002	
POLITICAL ASPECTS 0011 0024	0047 0049 0050 005	6 0061 006
0035 0036 0060 0063 0077 0079 0091 0095	0065 0071 0079 008	0 0088 008
PROCESS HEAT 0018 0019 0023	0091 0092 0097 SPAIN 0021	
0025 0061 0069 0091	SRI LANKA 0021	
PUEBLOS 0047 .	SUNLIGHT GEOMETRY	0010 004
0046	0057 0068	
QATAP 0046 QATTARA DEPAESSION 0004 0006		
ON CLUKA DESPESSION PAGE 2110		

TECHNOECOLOGY 0025		WASTE HEAT USE	0025 0026 0036
TECHNOECOSYSTEMS 0025		0040 0045 0054	
TECHNOLOGICAL SUCCESSION		WASTE WATER TREATMEN	
0010 0025 0062 0072 0091		WATER CONSERVATION	0005 0013
THERMIONIC CONVERSION	0010	0025 0039 0052	0078
0018 0057			0018 0024 0025
THERMOCHEMICAL CONVERSION	0002	0036 0049 0056	0061 0063 0064
0013	- -	0067 0071 0088	0089 0091 0092
THERMOELECTRIC CONVERSION	0010	0097	
0018 0057 0075		WATER PUMPING	0006 0025 0051
TIDAL ENERGY 0089		0055 0059 0081	0083 0086
TOTAL ENERGY SYSTEMS 0013	0025	WATER REQUIREMENTS	0005 0019
0035 0036 0051 0060 0061	0076	0025 0056 0060	0073 0078
0080 0091		WATER SUPPLY	0025 0027 0039
TUPKEY 0021		0043 0084 0087	
		WAVE ENERGY	0090 0096
		WEST INDIES	0021
		WIND ENERGY	0019 0051 0062
		0065 0071 0081	0082 0090 0096
UDDAM		WINDMILLS 0050	0051 0062 0076
UPBAN PLANNING 0036 0047	0051	0081	