RENEWABLE ENERGY RESOURCE SYSTEMS: A FEASIBILITY STUDY FOR EDUCATIONAL FACILITIES APPLICATIONS

by

Glenn Charles Thomason

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF EDUCATION

in

Educational Administration

APPROVED:

Glen I. Earthman, Chairman

David J. Parks

Richard G. Salmon

Wayne M. Worner

William A. Bost

September, 1986

Blacksburg, Virginia

RENEWABLE ENERGY RESOURCE SYSTEMS: A FEASIBILITY STUDY FOR EDUCATIONAL FACILITIES APPLICATIONS

by

Glenn Charles Thomason

Committee Chairman: Glen I. Earthman
Educational Administration

(ABSTRACT)

High inflation rates, rising energy costs, and resulting school budget problems have forced educators to examine alternative ways to ease the disproportionate impact energy costs have on the total financial resources of school districts. Renewable energy resources offer a wide variety of possible alternative ways to provide situationally appropriate answers to this budget problem. This study described the renewable energy resource system options in such detail as to enable educational leaders to make choices in directing planners to do further feasibility studies and in applying existing technologies to current facilities and new construction. Some of the energy resource categories examined were as follows: solar (including active and passive solar heating, cooling, ventilation and lighting, photovoltaics, and solar salt ponds), wind, hydropower, biomass, and geothermal. A good deal of the task was to describe the systems, to provide examples, to review the literature, resources, and location of usage, to analyze their cost effectiveness, to determine standardization and availability of technology, to review other feasibility considerations, and to examine institutional, governmental and other inhibitors to use of available systems.

All of the renewable energy resource systems have demonstrated successful competition with traditional energy resources in appropriate settings. Solar energy has been most widely utilized and priority consideration was increasingly given to passive solar applications and active solar heating, especially in hot water and district heating. Some of the resources were regarded as more appropriate to remote settings, especially wind power, hydropower, and some forms of biomass. The technology needed was available, even for geothermal energy.

ACKNOWLEDGEMENTS

The professional colleagues, family members, and friends who have been supportive of this educational pursuit are too numerous to mention. However, common courtesy demands that a few individuals be recognized for their contribution.

The topic would not likely have been selected apart from pioneering work in the field of solar energy by Dr. Harry E. Thomason, my second cousin, who also provided useful leads to needed information. My father, G. Spencer Thomason, gave an appreciation of craft skills and varied aspects of facilities construction and operation. My mother, Edith Shuping Thomason, enabled me to perceive myself as a person capable of developing writing skills.

Dr. Glen I. Earthman and Dr. David J. Parks helped me believe that I could manage a project of this scope, while Dr. William A. Bost prepared me to deal with the length of the task. My professional colleagues at Thomas H. Henderson Middle School were supportive when the task produced anxiety and fatigue. Miss Vashti Hammett served as an able substitute for me during two brief periods of educational leave.

Pursuit of the doctoral degree was encouraged by five persons who deserve my thanks, namely, Dr. Esther Davis, Dr. Joseph Cooper, Mrs. Ellen Chewning, Rev. William G. Caperton, and Mrs. Jane Rule. May the tribe of those who are able to affirm hidden potential increase.

As a right-brained person, I have been mislead into a great variety of creative tangents. Consequently, I was most grateful to discover the usefulness of the Word Perfect 4.1 word processing software

in reigning in some of my more distractible tendencies during the final year of this effort.

Several individuals in the Division of Energy of the Commonwealth of Virginia Department of Mines, Minerals and Energy provided assistance in identifying sources of data. The library was made available for use. When it became evident that the vast majority of the holdings accompanied those times in which the energy crisis was most urgent, Kathy B. Erickson, the Program Manager, offered the suggestion that state directors of energy offices would be cooperative in providing more current data.

The pressure of the task would have been too great apart from occasional opportunities to participate in several organizations which occasionally claimed my attention. Specifically, these have included Grace Covenant Presbyterian Church, Habitat for Humanity, Phi Delta Kappa, Richmond Public Schools, and Concord Presbytery.

Finally, Dorthy Gilliam Thomason, my wife, has been a constant source of joy and inspiration. Throughout the process she has ministered to my anxieties and, by effective listening, aided in the development of the organization and long-term commitment needed for completion of the task. During the final stages, she provided material assistance in the effort to be current by sharing some of the skills she employs as a catalog librarian at Union Theological Seminary in Virginia where her friends and colleagues have also been supportive.

Few significant tasks are completed apart from the support of such friends. Thanks for your affirmations of this effort.

TABLE OF CONTENTS

Page

APPROVAL SHEET i

ABSTRACT ii

ACKNOWLEDGEMENTS iv

LIST OF TABLES xvii

LIST OF FIGURES xviii

Chapter

1. INTRODUCTION 1

Basis of the Argument 1

Definitions 2

Statement of Problem 3

Rationale 4

Limitations of the Study 7

Organization of the Study 8

Methodology 12

Current Concern 14

2. USES AND FINANCIAL IMPACT OF ENERGY IN EDUCATIONAL FACILITIES 17

Specific Uses of Energy in School Facilities 19

Space Heating 23

Lighting 24

Cooling 27

Domestic Hot Water 30

Heating, Ventilation and Air Conditioning 31

Elevators 32

Other Equipment and Appliances 30

Relative Increases In Energy Demand 34

3. ENERGY CONSERVATION PRIORITIES 48

Goals and Design Standards 49

Redefining the Comfort Level 49

Avoiding Indoor Pollution 51

Providing Quality Lighting and Energy Savings 55

Services of Energy Management Consultants 60

A Thorough Energy Audit 61

Assessing Heat Losses by Use of Thermal Sensing 64

Recommending Conservation Strategies to Achieve Savings and Facilitate Their Implementation 66

The Limited Impact of Traditional Conservation Measures 67

Selective Closing of Schools and Central Location 70

Summer Shutdown by Custodial Teams 70

Limits of "Quick Fix" Solutions 71

Hot Water Conservation Measures 72

A Decade of Renovation: The 1980's 73

Moving Beyond the Limited Priorities of the 1970's 74

Major Renovations and Additions 76

Preliminary Passive Energy Conservation Measures 77

Modifying or Replacing Active Energy Systems 78

Lighting Conservation Measures 80

Energy Management Systems (EMS) 84

Significant Capital Investment in an Energy Master Plan 91

Modular Design 92

Using Waste Heat of Lights and Bodies 93

Saving by Ventilation to Minimize Air Conditioning 93

Saving Refrigeration Dollars 98

Insulating to Save Heating and Cooling Energy 98

Space Heating Savings 102

Alternative Financing for High Cost Programs 103

Reasonable Conservation Expectations 105

4. EVALUATING RENEWABLE ENERGY SYSTEM OPTIONS 117

Distinguishing Between Conservation Measures and Renewable Energy Systems 118

Team Approach to Design Strategies 120

Evaluation Criteria for Educational Design 122

Building Structure and Use: Passive Features of Energy Savings 127

Utilization of Space 128

Landscaping 129

Solar Control 129

Active Renewable Energy Technologies Now Available 131

Some Factors Influencing the Selection of Energy Systems 140

User Population 140
Kinds and Numbers of Spaces 142

Programs and/or Activities 142

Ability of Primary Energy Resource to Match the Uses Required 143

Potential Reliability or Shortages of Primary Energy Supply 144

Balance of Energy Needs after Conservation Measures 147

Local Climate and Geography 147

Practicality of Location 149

Low Frequency and Cost of Maintenance 149

Conversion Steps from Primary Energy Resource to End-Uses of Energy 151

Lead Time Required to Convert Current Building Stock 152

Wasteful Duplication 154

Safety 155

Affordability 155

Moral Criteria Refected in Scale of Technology 161

Global Energy Ethics 166

Minimizing Environmental Problems 170

Summary 172

5. SOLAR ENERGY SYSTEMS 181

Solar Energy Available 181

Reflecting on Solar History 185

Basic Solar Energy Concepts 186

Solar Orientation 186

Heat Transfer 188

Components of Solar Heating Systems 189

Passive Applications of Solar Energy 191

Natural Cooling, Lighting and Heating Processes 191

Avoiding unwanted heat gain 191

Using natural ventilation and cooling 193

Using natural lighting 197

Using passive solar heating 197

Exemplary Educational Facilities 198

Passive solar heating and lighting: library buildings: New Jersey 198

Sun Mountain School: Santa Fe, New Mexico 201

Barrel-vault skylight: library renovation and addition, California 203

Pyramid-shaped, double-sided skylight: office: New Jersey 203

Innovative lighting design (both passive and active systems) in earthscraper: University of Minnesota 204

Underground solar energy: elementary school: Indiana 208

Earth integrated community college: Southfield, Michigan 208

Passive solar dormitory: Maine 209

Greenhouse and double-envelope design:
house: Virginia 211

Active Solar Heating Systems:
Space and Hot Water 212

Exemplary Active Solar Facilities 214

Terraset School: Reston, Virginia 214

Ralph Bunch Middle School:
Atlanta, Georgia 216

Solar salt pond: Clarke College:
Vancouver, Washington 216

Salt-gradient solar pond heating dormitory:
State University of New York--Buffalo
Amherst Campus 219

Active air-based solar heating system:
Pendleton Junior High School in Oregon 219

Solar heating of domestic water and
swimming pool: New York 220

Solar hot water heating: competing
successfully in Florida 221

Solar Cost Cutting Measures and
Product Reliability 222

Solar Electricity Generation 226

Photovoltaic (PV) Production
of Electricity 227

Photovoltaic technology advances:
California 232

Projected efficiency of 30% in
PV generation 233

Pacific Valley School:
Big Sur, California 235

Solar Salt Ponds Planned to
Provide Electricity:
Six US States 235

Solar ponds to generate electricity: utility company: California 237

Solar salt pond: Utah State University 238

Large-Scale, High-Temperature Plants 239

Hybrid Solar Energy Systems 239

Active and Passive Solar and Wind: Office: Florida 239

Agriculture, Aquaculture and Heating 240

Solar District Heating: Achieving Efficiency Through Large-Scale Energy Storage 241

Level of Usage of Solar Energy 242

6. WIND POWER 255

Wind Energy Available 255

Methods of Harnessing Wind Power 260

Wind Energy Problems 270

High Initial Costs 270

Technical Problems 273

Storage 274

Environmental Problems 276

Varied Settings of Wind Energy Usage 278

Office Wind Energy: Florida 278

Farm Usage of Wind Energy 278

Heating Water by Friction: New York University's Applied Science Building 279

Water and Utility Power: Department of Water Resources Wind Project at Pacheco Pass, California 280

Chelsea Middle School: Chelsea, Oklahoma 281

Tornado Wind Energy Conversion System (TWECS): New York University's Westbury Campus 282

Wind Energy Potential 282

General Assessment of Potential 283

Specific Site Selection 285

Development of Wind Energy 290

Relative Cost of Wind Energy 292

Cost Effectiveness of Wind Energy 284

Future Wind Energy Systems 296

Push-Pull Windmill 296

Tethered Windmills 298

Conclusions 299

7. BIOMASS ENERGY USES 309

Methods of Using Biomass Energy 312

Direct Combustion 314

Wood 314

Municipal waste 318

Wood and fibrous waste 322

School trash 324

Conversion of Biomass to Other Fuels 325

Wood gasification 325

Ethanol 326

Methanol 329

Methane and sludge: energy, fertilizer and humus 330

Methane: marine resources 333

Converting carbon dioxide to fuel: future microbial oil? 334

Biomass diesel fuel 335

Biophotolysis: hydrogen from water 336

Microbial hydrogen production 336

Transfer of Body Heat 337

Bringing Energy Production Elements Together 337

Producing Energy Crops 338

Risks Assocated with the Use of Biomass 343

Conclusions 347

8. HYDROPOWER 358

Evaluating Small-Scale Hydropower 363

The Public Utilities Regulatory Policites Act of 1978 (PURPA) 363

Availability of Falling Water 364

Environmental Impact 370

Availability of Small-Scale Technology 374

Cost Advantages 380

Durability of Equipment 381

Licensing and Other Delays 381

Expanding Resource Use at Hydropower Sites 383

Development of Small-Scale Hydropower 385

Educational Use of Hydropower 387

9. GEOTHERMAL ALTERNATIVES 398

Definition 399

Potential 400

Identifying Potential to Meet Needs: Atlantic Coast Geothermal and Gulf Coast Geothermal 405

Geothermal Energy Information 410

Heating Applications of Geothermal Energy 412

Geothermal Generation of Electricity 424

Enlarging the Geothermal Energy Service Area 428

Tapping Magma Energy 433

International Geosphere-Biosphere Program Planned 434

Conclusions 435

10. RENEWABLE ENERGY RESOURCES IN PERSPECTIVE 444

Implications of Energy Conservation Era for Education 444

Current Educational Facilities 445

Cogeneration, Using Natural Gas 447

Transportation 449

Primary Sources of Electricity 451

Environmental and Social Impact of Energy Decisions 457

Nuclear Energy in Perspective 461

Conclusions 464

BIBLIOGRAPHY 471

APPENDIXES 494

A. Glossary 495

B. State Energy Offices 505

C. Correspondence 511

VITA 517

TABLES

Table | Page

1. Impact of Energy Costs on Maintenance and Operations Costs and New Current Expenditures: Reflected in Annual Percentage of Increase and Cumulative Percentage of Increase over 1973-74 through 1983-84 40

2. Regional and National Comparisons (actual costs--1982-83) (dollars per student) 42

FIGURES

Figure — Page

1. Typical Passive Solar Energy Features: Windows 199
2. Passive Solar Energy Heat Storage Methods 200
3. Optimizing Solar Exposure on Hillside: Stepped Style 210
4. Windmill Configurations 262
5. Low- and High-Head Hydropower 388
6. Closed Loop Down-Hole Heat Exchanger 419

Chapter 1

INTRODUCTION

Basis of the Argument

Leaders in education prove their worth by being appropriately responsive to the real needs and informed values of the society and world they serve. Effective response often means providing information to enable decision makers to choose strategies which depart from the traditional way of doing things. Innovations in the public sector are more likely to receive a favorable response when the merits of the new ideas, methods, or devices are clearly perceived against a background of evident needs and enduring human values.

Educational institutions do not operate in a power vacuum. Startling reminders of the environment of public schools, colleges, and universities have recently come in such forms as California's Proposition 13, renewed political interest in the voucher system, shifting of educational funding away from the federal government and the effects of the Organization of Petroleum Exporting Countries (OPEC) cartel on their energy expenditures and resources. This project provides a partial answer to one of the serious, current threats to the financial basis of public education, namely, the energy drain on educational budgets.

Definitions

When this project began in 1981, the alarming increase in the maintenance and operations costs in school system budgets, from 10 percent to about 14 percent of the total school budget over the last few years, coupled with the declining willingness of the public to address the inflated costs of education in general, made it urgent that school systems discover feasible means of dealing with increasing costs.[1] Renewable energy systems which are not tied so strongly to the disproportionately inflated costs of fossil fuels offer a viable way of saving millions of educational dollars annually.[2]

Dr. Lloyd E. Line, Jr., defined renewable resources as being "virtually inexhaustible" and depending "directly or indirectly on the sun (wood, hydroelectric power, wind, biomass, ocean thermal gradients)."[3] Continuing his definition, he said,

> Virtually inexhaustible resources include geothermal (the earth's) heat and controlled nuclear fission. The sun, the earth's heat, and thermonuclear fusion will probably constitute the energy base of the distant future.[4]

By contrast, he said,

> Non-renewable resources are those which are not replenished as they are used up. Coal, crude oil, natural gas, and uranium on which we depend for 95 percent of our energy today, are non-renewable resources.[5]

These definitions of renewable and non-renewable resources are adequate for contrast purposes to suggest that dependence on traditional sources of energy will present real problems to educators for several decades. The growing scarcity of non-renewable energy sources will inflate their

cost at an accelerating rate, forcing a growing reliance upon renewable energy sources.

Statement of Problem

High inflation rates, rising energy costs, and resulting school budget problems are forcing educators to examine alternative ways to provide energy, moving beyond traditional conservation steps, to ease the disproportionate impact energy costs have on the total financial resources of school districts. Renewable energy resources offer a wide variety of possible alternative ways to provide situationally appropriate answers to this budget problem. This study describes the renewable energy resource system options in such detail as to enable educational leaders to make choices in directing planners to do further feasibility studies and in applying existing technologies to current facilities and new construction. Some of the energy resource categories examined include the following: solar (including active solar collectors, passive solar heating and cooling, and photovoltaics), wind, hydropower, biomass (including biomass conversion), and geothermal. A good deal of the task has been to describe the systems, to provide examples, to review the literature, resources, and location of usage, to analyze their cost efficiency, to determine standardization and availability of technology, to review other feasibility considerations, and to examine institutional, governmental and other inhibitors to use of available systems.

Rationale

School divisions or systems are probably the largest public users of energy in most local communities. In the last few years private foundations, industries, and government agencies have seen the wisdom of evaluating the possible impact of renewable energy resources on the budgets of public users of energy. A recent study evaluated the potential uses of one form of solar energy. The Virginia Solar Energy Feasibility Study included 181 Virginia public buildings in its evaluation, a sample which included 87 public and private school buildings and 22 college and university buildings.[6] These figures suggest that educational facilities may constitute 60 percent of the buildings in the tax supported sector.

The motivation for this study included the inflating cost of fossil fuels and the whole range of ethical and environmental questions related to the depletion of the world's resources. There was a need to reduce the conflict between fossil and nuclear energy production and environmental concerns relative to waste products accompanying their use. One 1979 statistic which pointed to the need of new energy alternatives was the fact that the United States had six percent of the world's population and consumed 30 percent of the world's energy.[7] Other estimates were higher. Harry C. Blaney, III, in Global Challenges (1979), indicated that the "United States currently uses approximately 34 percent of the world's total energy," down from 48 percent in the 1950s and 36 percent during the 1970s.[8]

The first major justification for this study is to enable educational leaders to thoughtfully examine some of the current uses of renewable energy resources in educational facilities. To the extent that these resources are demonstrably feasible and cost effective they will assist in providing at least a partial, speculative resolution of the fiscal and energy problem of school districts. To fail to evaluate these alternatives is to risk early obsolescence of energy systems and, thereby, to increase future energy drain on school budgets.

This leads to a second major reason for the study, namely, to provide practical assistance to educational leaders. This is accomplished by enabling visualization of potential facilities, by analyzing cost efficiency, by providing information on the feasibility of use of these resources in retrofitting old buildings and in new construction, by suggesting criteria for evaluation of the use of various energy resource systems, and by providing a resource guide for further investigation.

A third reason which is central to the whole study is to help educational administrators and school boards make intelligent decisions regarding the use of energy in school facilities. A value judgment implied is that appropriate consideration of contemporary energy and environmental concerns is as much a part of intelligent decision making as tradition, truncated budgets, and available technology. However, technology is now available to most local communities to allow educators to begin to supply twenty-first century answers to twentieth century energy problems.

Finally, the justification for this study is grounded in humanistic and aesthetic imperatives, including the following:

1. Energy, like food, water, clothing and shelter, is a basic need, the availability of which must be safeguarded for future generations.
2. Ecological and environmental concerns must not be ignored, especially, relative to pollution of land, water and air resources.
3. Medical, agricultural, synthetic fiber, and other petrochemical uses of fossil fuels must be safeguarded.
4. The life, liberty, peace and educational opportunities of the poor must be protected by overcoming the disproportionate impact of energy needs on their other resources.
5. Educators must effectively model the use of alternative energy resources as one small way to help stabilize the international economic community against the challenges of OPEC or any other future energy cartel.
6. Educators must reserve an optimal proportion of educational funds for the primary task of educating students.
7. If educators are to live up to their name, they must be leaders in the use of renewable energy resources and in providing models for others to follow.

These are but a few of the pragmatic imperatives relative to energy which are increasingly felt by both the general public and educators.

Limitations of the Study

The study is limited to those renewable energy resources about which educational administrators are likely to make decisions. Therefore, this study does not deal with nuclear fission and nuclear fusion in great detail. Satellite solar power is also excluded for the same reason. Energy systems which are so centralized and capital intensive as to require management by public utilities are seen as being beyond the scope of this study. However, many energy systems, with some scaling down of size, are equally applicable to schools and public utilities.

Furthermore, this study is not intended to diminish the importance of weatherization, energy management systems, and the whole range of conservation measures which in the short range promise significant reduction in energy expenditures. Indeed, these factors are a necessary part of the context in which renewable energy resources must be evaluated. However, this study takes a longer view of the energy management problem. Ultimately, educators and the general public must turn to other primary sources of energy rather than simply reducing the speed of exhaustion of the supply of non-renewable energy resources.

This topical study draws most of its illustrations from the United States. However, allusions are made to other countries where deemed appropriate to broaden the perspective. The main criterion for inclusion of illustrations is their applicability to examination of appropriate use of energy resources in educational facilities.

Organization of the Study

The format of the study is topical in nature and designed to be used by practitioners. The broad, illustrative coverage is more appropriate to the problem and potential users than the more limited and detailed scope of the traditional dissertation. It includes figures, tables and three appendices, including a glossary, a resource guide and summary documentation of personal correspondence.

First, the energy needs of schools, the limits of conservation strategies, and the need to move to alternative energy resource systems provide a context for evaluating the potential contribution of renewable energy systems in meeting educational facility needs. The three chapters devoted to preliminary concerns are intended to clarify the fact that school facilities and their environment are interacting energy systems and to generally describe and define some of the concepts dealt with in greater detail later.

A division of the balance of this work into chapters is necessarily somewhat arbitrary due to the fact that all renewable energy sources examined, except geothermal energy, are in fact various forms of energy from the sun. Since geothermal energy is most remotely related to solar energy, the general movement is from space to the center of the earth.

The main chapters are dealt with under titles of the various renewable resource systems, with a final chapter, entitled "Renewable Energy Systems in Perspective." Four preliminary chapters set the stage by defining the problem, identifying usage of energy, examining planning

and conservation priorities, and explaining the need to deliberately match energy needs and resources. Chapter titles are as follows:

1. Introduction
2. Uses and Financial Impact of Energy in Educational Facilities
3. Energy Conservation Priorities
4. Evaluating Renewable Energy System Options
5. Solar Energy Systems
6. Wind Power
7. Biomass Energy Uses
8. Hydropower
9. Geothermal Alternatives
10. Renewable Energy Systems in Perspective

While reference to educational facilities appears only once in the titles of these chapters, the content leaves the reader with no doubt as to the intended users.

The fifth through the ninth chapters are the core of this project. The preliminary chapters deal with general considerations in such a way as to limit the necessity of redundant explanations in later chapters. At some point in the process the reader will discover the following:

1. Description of the resources, definition of key concepts, historical allusions, and potential users
2. Examples of use of the resources in appropriate educational settings and geographic locations

3. Review of the pertinent literature and resources, addressing concerns about institutional, governmental and political restraints (e.g., building codes and specifications, implied uses, tradition, turf protection of energy suppliers, local architectural interests and skills)
4. Local feasibility criteria for screening energy options, such as,
   a. specific energy needs in educational facilities (e.g., greenhouse, hot water, agricultural education, commons area, space heating, etc.)
   b. geography and climate
   c. availability of primary energy resource
   d. standardization and availability of technology, building materials, skilled workers, etc.
   e. retrofitting (complexity of conversion of energy system) and/or new construction
   f. requirement of supplemental, backup systems
   g. competing energy suppliers (expense of fuels)
   h. potential energy shortages and inflationary impact of periodic energy crises on education
   i. environmental impact (i.e., aesthetic, pollution, and historic preservation)
   j. descriptive example of life cycle operating cost analysis of energy system, building, and replacement considerations, making dollars and cents through the years

k. analysis of cost efficiency (using existing primary and secondary data) relative to existing systems in specific energy uses (hot water, space heating, air conditioning, lighting) and energy resources (coal, electricity, natural gas, fuel oil)

5. Summary, conclusions, and projected, potential uses of energy resources
6. Endnotes
7. Bibliography

The effort is not to deal exhaustively with architectural and engineering questions but to provide educational leaders an intelligent basis for choosing and more deliberately using their consultative services.

The outline above has been used as a guide to collection of data rather than as a description of the coverage of each chapter. It can assist the reader in raising appropriate questions. Editorial efforts have been made to avoid redundancies of outline. Consequently, the dissertation may require reading in its entirety to answer special concerns of the reader.

A modified case studies approach has been used to illustrate the various energy systems. The effort was to clarify broad alternative energy options rather than exhaustively describe the energy systems in a school setting. In some instances this called for more extensive description of a particular facility as a way to demonstrate that a

specific technology can serve multiple uses. In other instances little more than topical allusion is made to the energy systems in specific locations. If the writer's use of illustrations is effective, the reader can visualize and articulate questions regarding the various energy systems so that architects and engineers can supply details.

Methodology

This research effort was aimed at accurate and appropriate synthesis and description rather than exhaustive analysis of a body of knowledge. The primary research method was a review of pertinent literature in the area of energy, with specific emphasis on renewable energy resource systems applications in public facilities. The review of the literature provided a basis for discovery of the data needed:

1. to understand and deal with the problem,
2. to give leads to additional sources of data, and
3. to have a basis for perusal, analysis, accumulation, synthesis, and description of specific and general findings regarding potential applications of renewable energy systems.

The emerging nature of the area of technology involved requires some grasp of the kinds of descriptions evident in future scenarios. Therefore, this body of literature has assisted in providing leads to practical applications which are currently feasible. The practical rather than highly speculative content of this literature is seen as most useful.

Books, periodicals, government publications, legal documents, ERIC documents, and unpublished sources were valuable in this research. The primary data came from government reports and agencies; dealing with energy, education and environmental concerns, and from energy suppliers, public users, private foundations, professional journals and newspaper and periodical accounts of recent innovations.

Interviews, correspondence, telephone conversations, speeches, and site visitation have in some instances provided a basis for understanding and ability to communicate ideas to professional educators who are not engineers and architects. This process assisted in developing the outline for this document. Some useful information has been provided by school systems which are currently using and planning applications of renewable energy systems. However, the extensive effort involved in this research suggests the appropriateness of future study to more accurately define the current level and location of usage.

Data were gathered and have been presented in a form and style consistent with the recommendations of William Giles Campbell and Stephen Vaughan Ballou.[9] Specifically, a tentative outline, which was significantly modified, served as a basis for accumulation of an appropriate bibliography and for taking notes in a manner which lends itself to the writing of a rough draft and having the needed information for final editing of the dissertation.[10]

The use of endnotes seemed more appropriate than footnotes for communication purposes. Consequently, the separate listing and numbering of endnotes by chapter has been selected to provide convenient

access to desired information, while avoiding unnecessary distractions, since an effort has been made to provide adequate details to communicate time frame and other matters within the text itself.

Current Concern

This dissertation was conceived in 1980, immediately following the 1979 energy crisis, which was preceded by the first OPEC-precipitated crisis only six years earlier in 1973. At that time national leaders acknowledged the urgency of research and development and model application of new technologies and seemed more acutely aware of short-term and long-term implications of the crisis than is true at present.

Now, more than five years later, recent worldwide overproduction of oil and disarray in OPEC have robbed the energy problem of some of its immediate sense of urgency. Energy Expo 1982, which opened in Knoxville, Tennessee on May 1, 1982, is a fading memory. However, the likelihood is that the real need to provide adequate alternatives to fossil fuels has become more urgent. The limits of these fuels remain. If overproduction, temporary lower prices, and the consequent glut increase our consumption, settling accounts with the loss of these resources will become more painful at an earlier date as the lead time to change our energy infrastructure is reduced. And, unfortunately, the likelihood is that excessive consumers and excessive producers will suffer most severely, especially, those members of OPEC who forced the world to acknowledge the problem.

Environmental concerns exhibit increasing urgency in many dimensions. These include worldwide environmental pollution controls, social problems, nuclear hazards, and long-term damage to the environment which yields more slowly to remedy than many other aspects of the energy crisis. The global nature of the environmental impact of energy decisions means that the international politics of energy will be vitally involved in energy decisions in the 1990's and the first decade of the next century. The quality of the environment will be effected for centuries by decisions related to nuclear wastes and the level of carbon dioxide in the atmosphere. Many aspects of the environment are not amenable to quick or easy technological, political solutions, even with heavy capital investments.

CHAPTER ONE ENDNOTES

1. Paul Abramson, "8th Annual Maintenance and Operations Cost Study," American School & University, Vol. 51, No. 9, June, 1979, p. 38.

2. Robert R. Somers, II, Alan C. Pritchard, Michael R. Sexton, Marcia C. Hoffman, and Leroy S. Fletcher, Virginia Solar Energy Feasibility Study (Charlottesville, Virginia: Center for Energy Analysis, Department of Mechanical And Aerospace Engineering, University of Virginia, January, 1981), p. 3.

3. Lloyd E. Line, Jr., Energy in the 80s: Facts and Issues for Virginians (Commonwealth of Virginia: Office of Emergency and Energy Services, 1980), p. 199.

4. Ibid., pp. 199-200.

5. Ibid., p. 199.

6. Robert R. Somers, II, et. al., op. cit., p. 57.

7. Chris Buethe, "Energy in Your Curriculum," Educational Leadership, November, 1979, p. 163.

8. Harry Clay Blaney, III, Global Challenges: A World at Risk (New York: New Viewpoints, A Division of Franklin Watts, 1979), pp. 157 & 147.

9. William Giles Campbell and Stephen Vaughan Ballou, Form and Style: Theses, Reports, Term Papers (5th ed.; Boston: Houghton Mifflin Company, 1978), pp. 1-170.

10. Ibid., pp. 4-14.

Chapter 2

USES AND FINANCIAL IMPACT OF ENERGY IN EDUCATIONAL FACILITIES

Energy is just as basic a human need in education as in any other setting. The basic human needs of food, water, and shelter may appropriately be described as energy needs.[1] All of these needs and many more are part of the educational enterprise. Before identifying conservation steps and moving to specific renewable energy strategies to solve the problems created by the energy crisis, it is important to focus on the specific needs and uses of energy in schools and universities. Multiple uses of energy are essential for the achievement of educational goals and objectives.

While building uses of energy, rather than energy demands in transportation, are the focus of this paper, the reader is reminded of the significant impact of busing and other necessary school transportation costs. This project in no way denies the importance of providing energy alternatives for the traditional portable liquids used in most transportation systems today. Fossil fuels must be replaced by other primary energy resources. In 1984 petroleum accounted for approximately 42 percent of all U.S. energy use according to the Energy Department's Energy Information Administration.[2] The very large dependence on fossil fuels in transportation makes solution of the facilities problem more vital, until the transportation infrastructure can be changed.

The urgency of dealing with the transportation component of the energy problem is evident in the fact that increased consumption exceeds the pace of increased production. Charles DiBona, president of the American Petroleum Institute, reported 1984 data on the first year-to-year rise in U.S. oil consumption since 1978, a three percent increase.[3] This followed several years of decline in domestic use of oil. The urgency of solving this problem was suggested by the import statistics:

> Oil imports last year increased 8 percent after four years of decline. The United States buys roughly one-third of its oil supplies from foreign countries. If present trends continue, the level of dependence could rise to one-half or more of U.S. oil consumption by the early 1990s.[4]

Dr. John M. Fowler and King Kryger reported in January, 1979 that, while a high percentage, "about half," of the oil used in the U.S. is burned in transportation, buildings "use most of the rest of our oil for heating."[5] To the extent that energy is saved in facilities, lead time is gained to deal with the energy for transportation problem which offers fewer currently available solutions.

S. V. Szokolay offered some interesting statistics on the proportion of total energy consumed for use in buildings internationally. Szokolay, acknowledging the limits of data in this field, made the following assertion in 1980:

> Precise quantification is difficult, but the available statistics suggest that the share of "domestic and commercial" sector is 23% in Australia, 34% in the USA and 35% in the UK.[6]

According to Szokolay, renewable energy sources, notably solar energy, could provide most of the energy used in buildings more appropriately

than the high grade fuels and electricity now used. The largest portion of building energy is used in low-grade heating of space and hot water.

Specific Uses of Energy in School Facilities

Assessing the ways educational facilities avoidably and unavoidably use primary and secondary energy resources is an important step in identifying solutions to energy problems in education. Accurately labeling uses in terms of proximate energy resources typically used helps raise questions about alternative energy resources.

In 1984 Jerry Lawrence, an architect, provided data indicating the energy needs of elementary and secondary schools. Basically, climate control factors, namely, heating, cooling and hvac (heating, ventilation and air conditioning) required 69 percent of the energy used in elementary schools and 67 percent in secondary schools. In a different format, Lawrence's data were as follows:

Energy Uses	Percentage of Energy Use	
	Secondary Schools	Elementary Schools
1. heating	45	39
2. lighting	22	23
3. cooling	17	19
4. dhw	9	9
5. hvac	7	9
6. elevators	1	1

Presumably machinery, equipment, copiers and the like fall under the heading of lighting, but no further details were offered regarding the data in the graphs.[7]

When Lawrence's space heating and dhw (domestic hot water) categories are combined, they total 54% and 48% for secondary and

elementary schools, respectively. These figures compare favorably with those of Szokolay and, also, with the 50 percent for residential space and water heating in Ontario, Canada.[8] Categories of energy use in schools may be grouped appropriately in terms of the way end-use energy is delivered. Both space heating and hot water require a similar basic input of low temperature heat. The definitions of **low-grade heat** vary from 70°C and lower to 140°C and below.

The categories of energy use identified by Lawrence are interesting when compared to other lists. One such listing is included in an article on energy management at Michigan State University (MSU).[9] The analysis of potential areas of energy savings in the audit included these categories (numbers added):

> (1) space heating and (2) cooling, (3) ventilation (air handling), (4) fluid handling, (5) domestic water heating (appliances), (6) illumination systems and (7) building structure.[10]

Comparing Lawrence's list to the MSU list suggests that the **hvac** category in his list includes (3) ventilation (air handling) and (4) fluid handling in the MSU audit listing. The hvac category describes electricity used by fans, pumps, associated monitors and controls related to air and fluid handling. The MSU listing of building structure as a category offering potential energy savings goes to the very heart of the problem of energy conservation which deals with wasteful uses of energy in schools.

In December of 1983 Glen I. Earthman and others also offered data on "major energy end uses in a typical U.S. educational institution"[11] which differed in a number of respects in grouping from

Lawrence's data. A comparison of Lawrence's and Earthman's statistics suggests that the space conditioning components, including heating, cooling and hvac were all grouped under the heading hvac by Earthman and others. Furthermore, it appears that they divided the general electrical category of lighting to specify 10% as serving special purposes in laboratories and shops. Another marked distinction suggests that the largest proportion of Lawrence's dhw category is used in relationship to food service (7%), with a low of 3% for other uses of hot water. The data offered by Earthman and others indicated energy needs from greatest to least as follows:

Energy Uses	Percentage of Energy Use
HVAC	65
Lighting General Electrical	15
Special: Laboratories, Shops	10
Food Service	7
Hot Water	3

Of greatest interest here is the conclusion that those items grouped under HVAC offer an "area of great energy saving potential."[12]

The energy requirements of facilities vary widely according to location and other building variables. Attempts to precisely quantify and itemize uses of energy tend to be useful for specific areas and specific kinds of facilities rather than a matter worthy of a great effort at generalization on a larger scale. Of course, the collective national and international scope of uses and particular resources is important when dealing with potential shortages of energy resources and the inevitable impact on educational budgets.

A comparison of residential electrical energy use in Ontario, Canada, which is colder than the vast majority of the U.S., indicates the diversity of needs in specific facilities, suggesting the inappropriateness of broad generalizations. These statistics are of interest in colder areas where schools provide residences for students and faculty. The energy needs in that setting were listed as follows: space and water heating (50%), air conditioning (1%), clothes dryers (4%), lighting, refrigeration, cooking, electronics, and small appliances (45%).[13] The grouping of space and water heating in terms of the way the energy is delivered, that is, as low-grade heat, is instructive for identifying matching resources to meet both needs. C. A. Hooker and others indicated that currently available technology can provide at least 50 percent of the low-grade heat requirements for space and water heating needs from renewable energy resources, primarily solar energy.[14]

How do U.S. residential uses of energy compare to those of Ontario, Canada? Lillian A. Clinard described the total energy consumption in homes as follows:

> About one-fifth of the energy used in the United States is used in our homes. More than half of this energy goes into heating and cooling. Heating water takes about 15 percent of energy used in the home. Lighting, cooking, refrigeration and operating appliances account for the rest.[15]

The hot water heating requirement is a significantly greater part in U.S. residential (15%) use than in general school use (9%).

Industrial energy needs are very different from school energy

needs. In Canada the figures offered by Hooker and others included 10 percent for space and water and 75 percent for power motors in industrial settings.[16]

Space Heating

Thermal energy for space heating is the greatest single energy requirement in both elementary and secondary schools. Consequently, it offers the single greatest area of potential savings. Forty-five percent of the total energy consumption is for heating in secondary schools as compared to only 39% in the elementary setting, according to Lawrence.[17]

Writing in general, concerning all U.S. uses of energy (including transportation etc.), rather than in specific reference to educational facilities, Auer and others indicated that "space heating can require from 20% to 50% of total primary energy use" in cool parts of the world.[18] Space heating uses "about 20% of the primary energy" in the United States which is lower than the demand in school facilities.[19]

A number of features of schools' use of energy stand in marked contrast to other consumers. In 1978 Donald Burr described some of the characteristic features of energy use in schools. He first noted the low occupancy rate of heated spaces in schools, implying a very large opportunity to conserve energy in this area, saying,

> One unique condition is the startling fact that in the majority of cases, nearly 90 percent of heating energy in a school is used to heat unoccupied space. In theory, most schools operate eight hours per day for 180 days, or 1,440 hours per year. A national study of school occupancy shows quite a different story. . . . that schools are heated and cooled from 2,000 to 4,000 hours per year. The majority of these

hours represent heating and cooling an almost entirely vacant building.[20]

Dr. Robert H. Pusey reported the heating requirements for schools. He stated,

> . . . In July, 1980, AASA reported that the median of fuel consumption in 1979 was 13 million Btu per pupil. The median consumption per pupil ranged from 7 million Btu in the southwest region to 20 million Btu in the north central region.
>
> The median fuel consumption for the nation was 10 million Btu per 100 sq ft of floor space, with a range from 6 million Btu in the southwest to 12 million Btu in the north central region. Thus, the annnual heating requirements may range from 2 billion Btu for a small school in the south to as much as 30 to 40 billion Btu for a large school in colder areas.[21]

Lighting

Lighting is the second most demanding use of energy in schools in Jerry Lawrence's list. It requires a slightly higher percentage of building energy use in elementary schools (23%) than in secondary schools (22%).[22] A comparison to Richard C. Dorf's statistics may be useful. Dorf described the general use of electricity as a secondary energy resource in the U.S. in 1978. He indicated that the U.S. used 26 percent of its total energy to generate electricity.[23] When Lawrence's lighting, hvac and elevators, all of which require electricity, are combined, they total to 30% and 33% for secondary and elementary schools, respectively.[24] The comparison of Dorf and Lawrence's figures suggests that use of electricity for lighting in schools is excessive. The absense of a listing of electricity usage in appliances and other equipment operations, except hvac and elevators, suggests the possibility that such aspects of energy use are grouped in with lighting by Lawrence.

Educators are increasing questioning whether all of the specific interior and exterior locations and scheduled uses of electricity in schools truly represent a need which can not be met by natural means. Is the typical indoor classroom lighting which is evenly distributed throughout the area necessary? Can natural daylighting provide most of the lighting needed in classrooms, libraries, hallways, cafeterias, recreational areas, labs and offices? What savings can task lighting, which means varying the level of illumination with user needs, provide in libraries, offices and elsewhere? While offices tend to have a uniform lighting throughout the area, there is frequently the possibility of saving energy by zoning lighting for particular tasks or work stations, with different requirements for close clerical work, as opposed to the needs of general copying areas.

The level of illumination, flexibility, and control requirements of the user in a theater or auditorium, whether presenter or audience, is most demanding of precision for the desired effect. Stage lighting, audience lighting, projection, and exit lighting are among the requirements in this setting.

Hall lighting levels and security systems requirements vary significantly from a classroom setting. Of course, security lighting makes both interior and exterior demands for energy. Security, safety, and visibility requirements need to be met on parking lots and ball fields and vary with the time of day and level of use.

The energy demands in lighting lend themselves to a variety of

remedies, some of which reduce electricity costs. Some of the goals to be achieved are as follows:

(1) Increase lighting while using reduced wattage.[25]

(2) Provide the needed quality of light for the specific educational activities.[26]

(3) Offer adequate switching and control.[27]

Characterizing the ways school facilities use energy is more than a matter of quantity since there are environmental quality requirements for appropriate educational facilities' use of energy. A number of **criteria** may be defined for determining what is appropriate lighting for schools. Some of these relate primarily to the user rather than the costs. Three criteria which are evident in what has been stated thus far are (1) effective utilization of naturally occurring daylight in a manner which addresses the problem of glare, (2) lighting specific task areas according to needed level of light, and (3) satisfactory visibility of color, details, and perspective. Albert E. Brooks demonstrated the importance of a clearly visible and attractively lit environment as (4) contributing to user comfort and improved public relations which often includes fee paying users.[28] One of the criteria of concern to Bea Scala was that good lighting enhances "worker productivity and comfort."[29]

Cost-oriented criteria for good lighting often have human user advantages. Two of these are closely related, namely, ease of control and flexibility of use. The flexibility afforded by controls saves wattage in unoccupied areas and permits control of lighting close to the

end use. Another writer described "use-oriented lighting levels."[30] Lighting should permit a regular maintenance and cleaning schedule which is not exhaustive in labor costs. Periodic replacement of bulbs and fixture cleaning, when minimized by the nature of the equipment, can save significant sums of money on maintenance and utility costs. Among other features, therefore, durability of equipment is important. A low wattage bulb which delivers a high quantity and quality of light is important in satisfying both cost effectiveness and human user considerations.

Cooling

Cooling is the third most costly energy expense in school buildings, with the figure estimated at 17 percent in secondary schools and 19 percent in elementary schools by Lawrence.[31] The need to create a cool climate as "an incentive to greater learning and better teaching" has tended to make disproportionately large financial demands on school systems across the country in the form of air conditioning.[32] Bill Benton reported that a large percentage of the energy bill in one Louisiana school system, ". . . . a $1.2 million utility bill--almost a 50% increase in less than three years, . . . is directly attributed to the cost of air conditioning."[33] The accepted standard of cooling interior space to 78°F is widely acknowledged as being consistent with achievement of educational goals. In the educational setting classrooms, kitchens, and equipment rooms, such as, computer and copier areas, demand active cooling systems. Electricity is the secondary source of energy when air conditioning and unit ventilation systems are

employed. Of course, cooling needs, like heating needs, vary greatly with the climate of the area in which the school facility is located as well as with user demands.

Donald Burr's second characteristic feature of energy use in schools is that ". . . . users of schools come in groups."[34] Groups of users generate heat. Consequently, schools have to deal with the excess heat energy generated by many bodies in a fairly confined space. Burr said, "The group is a class, occupying a tight space and generating heat. The average well lit classroom with 25 students and a teacher generates approximately 20,000 Btu's of heat energy per hour."[35]

C. DiMercurio described this phenomenon of school facilities' energy use in greater detail, concentrating on the heat sources which call for cooling of occupied classrooms even in winter.[36] Perhaps the explanation is easier to visualize mathematically, as seen here:

Heat Sources in a Typical Classroom
(24 x 38 x 10 Feet)

Heat Sources	Btu Per Hour
lights, 2,500 W, generating	8,500
students (30), each generating at least 260 Btu, for total	7,800
sun, solar load, 100 to 200 Btu per sq ft of glass range: 1,000 to 10,000 (basis, window space):	+ 1,000
Total: either	17,300
(older school, large windows)	+ 9,000
or (to 10,000 Btu)	26,300

Although classrooms are subject to both heat loss and heat gain, the occupied classroom usually has to deal with the heat gain by providing cooling. DiMercurio explained,

> With today's tight buildings, that generally means cooling in occupied classrooms whenever temperature is above 37F. Occupied perimeter rooms with a strong solar heat gain may require cooling when temperatures are well below zero. December and January are periods of highest solar **gain** and generally coldest temperatures.[37]

Maintaining fresh air at an appropriate temperature is crucial to teacher effectiveness and student achievement.

Cooling and ventilation needs often require a combination of strategies. Electricity is required in use of air conditioning (also referred to as refrigeration or mechanical cooling), in the fans of air distribution systems and pumps of liquid distribution systems, in heat exchangers and in unit ventilators, when apppropriate. The very heavy heat gain in kitchens, occupied classrooms, showers, copier rooms, computer and some other lab areas calls for rapid exchange of air, with

as much as possible of the need satisfied by outside air by way of unit ventilators. Dust and vapor removal is an important part of the process in vocational labs. The general potential for detrimental effects on student learning and health of indoor pollution in too tight facilities is an important consideration in selection of unit ventilators where the outside air source is relatively good. The question is, not whether to use electricity for cooling, but instead, which technology, aided by what natural processes, is best suited to reducing energy consumption while meeting the varied needs of the educational setting.

Refrigeration consumes electricity in a variety of uses in schools. Food preservation in the cafeteria and use in lab and lounge refrigerators may be most obvious. Refrigeration is used to cool milk and other liquids in the cafeteria and water in drinking fountains. Science labs frequently require refrigeration of certain materials to demonstrate their properties.

Domestic Hot Water

Jerry Lawrence indicated that domestic hot water (dhw) accounts for about 9 percent of the energy load in both elementary and secondary school buildings.[38] This similarity is surprising because of the greater emphasis on physical education at the secondary level.

Dr. Kenneth B. Woodbury, Jr., provided a checklist of ideas on energy conservation.[39] He recommended 100°F as the hot water temperature setting, with additional heat for the cafeteria hot water, as initial conservation measures to avoid excessive dhw costs.[40]

The uses of hot water in schools fall into a number of areas. The primary distinction is the temperature needed at the point of use. A satisfactory temperature of hot water for most uses is 125°F or less, with washroom use at "100F to 125F" being adequate.[41] Dishwashing in school kitchens requires a higher level of heat, about 180°F, with a heat booster for water as close to the point of use as possible to avoid the waste of heat in transfer and to avoid having all hot water excessively heated to match a specific use in washing dishes.[42]

Heating, Ventilation and Air Conditioning

Lawrence distinguished heating, ventilation and air conditioning (hvac) as a separate category of energy demand from heating and cooling.[43] Cooling and heating are appropriately distinguished from the energy required for their distribution and control (hvac). As indicated earlier, fans, pumps, and associated monitors and controls related to air and fluid handling fall under the hvac category. Those aspects of energy use involved in hvac are more closely tied to the requirement of electricity as a secondary energy resource than are cooling and heating which offer renewable energy alternatives more readily with fewer energy conversion steps. More importantly, more Btus are expended in heating and cooling water and air than in their handling and control. Lawrence listed the hvac demand as 7 percent at the secondary level and 9 percent at the elementary school level.[44] This hvac cost contrasts sharply with the 7 to 9 times greater combined costs of heating and cooling.

One specific way of reducing energy needs highlights the opportunity for confusion in examining the energy needs of schools. C.

DiMercurio emphasized the merits of unit ventilators in meeting three of the school energy needs in Lawrence's list.[45] This method highlights the difficulty of differentiating uses of energy in schools since heating and cooling are hard to distinguish from hvac (heating, ventilation and air conditioning), all of which unit ventilators have offered to schools as "the most popular heating cooling system in schools over the past 60 years."[46] Cooler exterior air is brought in while warmer interior air is exhausted rather than cooling warm interior air. Similiar confusion is associated with the multiple uses of heat exchangers.

Woodbury indicated in 1980 many conservation measures already being practiced in the area of hvac. Humidifiers, heat recovery systems, attic fans, solar screens, reduced window size, heat exchangers, heat pumps and boiler maintenance were among the techniques already receiving wide application.[47] Humidifiers, for example, can alter the comfort level without altering the temperature. Furthermore, exchange of heat energy from one location to another is less expensive than generating heat.

Elevators

Jerry Lawrence's sixth and smallest category of energy use in school facilities was elevators, contributing an estimated one percent of demand in elementary and secondary schools.[48] This energy use seems certain to increase in the future with increased consciousness of the needs of handicapped individuals and the elderly and as population growth places a higher premium of urban land use.

Other Equipment and Appliances

Apparently a variety of use of electricity in educational settings were grouped under the general heading of lighting in Lawrence's listing. Some of the other equipment requiring electricity is designed to deliver medium and even high (seldom) temperature heat for a variety of uses, some of which are far more common in industrial processes than a school or university. However, microwaves and other electrical cooking devices are found in most schools. P. L. Auer and others defined medium temperatures in the context of treating renewable energy resource potential to include temperatures of 100-600°C. According to Auer and others, "Higher temperatures are required for high temperature material testing and for solar-thermal energy conversion to electricity."[49]

Equipment operation usually requires electrical energy. A variety of appliances, maintenance equipment, vacuum cleaners, and other cleaning equipment is expected. Many school restrooms use hot air dryers for hands. Hair drying is required in some vocational classes. Science labs and vocational labs use a great variety of appliances and equipment. The multiple aspects of communication requiring electricity include communication or public address systems, sign-making and engraving equipment, computers, typewriters, word processors, duplicating equipment, copiers, test-scoring devices, scoreboards, audiovisuals, sound systems, projection and security systems. Teachers and other staff members expect the occasional lift provided by a well

equipped lounge, including vending machines. Electrical energy is also used in such processes as heat transfer to save waste heat.

Relative Increases in Energy Demands

The anticipated cost of energy in schools in the year 2000 is $31 billion, according to DOE projections. In June of 1985 Shirley J. Hansen's reflection on the data indicated that, by that time, ". . . average energy costs are expected to be almost $700 per pupil."[50] Similar data point out the urgency of designing and building the next generation of school facilities with energy conservation as a primary consideration. Furthermore, the vital role of the engineer in providing equipment capable of delivering an acceptable range of British Thermal Units per square foot at an acceptable cost is increasingly viewed as equal in importance to that of the architect who has a different set of information and skills.

Hansen reported that a projected increase in school-aged population in the U.S. would be 18.2 percent from 1985 to the year 2000.[51] The U.S. Department of Education's statistics indicated that migration would cause disproportionately higher demands for new school facilities in the Sunbelt. Complacency in dealing with energy conservation in building design due to temporarily lower oil prices was seen as a real current risk in dealing with projected new educational demands associated with population trends and rising expectations regarding reduced student/teacher ratios and increased classroom spacial demands.

New construction has been a regional phenomenon. Three of ten geographic regions, which included California, Texas and Florida, experienced a greater percentage of new construction than reconstruction in 1983, going against a general trend toward reconstruction.[52] Texas and California, while experiencing declining profit in oil production, bear a disproportionate share of the baby boomlet's educational costs. As reported by the New York Times Service on April 28, 1985, "Half of the population growth in the nation since the 1980 census has occurred in just three states--Texas, California and Florida--according to middle-of-the decade estimates."[53]

Increasing educational demands were evident in August, 1983 when Stephen L. Canipe and others reported, "Approximately 25% of the country's population is enrolled in school."[54] The energy impact of this increasing educational demand is equally striking.

> . . . This population segment requires energy for transportation to and from school as well as space conditioning and lighting. Schools may account for 11% of the nation's energy space conditioning budget. With energy costs in the inflationary spiral, it is important to be aware of the fact that for each penny rise in school costs, the national school budget must be increased by about $5 million.
>
> . . . .
>
> Energy costs have risen faster than most other program costs and there appears to be no end to price increases. The ultimate result of energy cost increases is getting the student to school and providing a healthy and safe environment at school will probably impact the school program and teacher salaries. Cuts in program and salary are likely since these two areas are financially more elastic than transportation and space conditioning.[55]

Delays in implementation of conservation measures which are capital intensive, but could save thousands of dollars in life cycle costs, only add to the future burden. Furthermore, deferred maintenance

leads to much more costly maintenance and even more costly construction of new facilities. In February, 1984, Richard M. Esteves reported,

> Virtually all schools have undertaken energy conservation efforts, usually the relatively low-cost, fast payback items. But very few have made major dollar investments in a more comprehensive, higher cost program, despite the apparent needs and desirability for such cost cutting programs.[56]

Such programs are a casualty of "federal cutbacks and of austerity in state and local government budgets."[57] This contrasts sharply with earlier expectation that the federal government would fund major conservation initiatives.[58]

Concern about dropouts, remedial education, illiteracy, crime and crime prevention may be natural allies of the changing emphasis on reconstruction in older, established school districts. Abramson made a useful distinction between modernization and rehabilitation, which, taken together, comprised 44.2% of the reconstruction in school districts in 1983, while additions accounted for 55.8% of the money spent on reconstruction.[59] Abramson said,

> . . . <u>modernization</u> involves taking an old building and making it better, more modern, structure through reconstruction; <u>rehabilitation</u> involves taking a deteriorated building and bringing it up to par. . . .[60]

Modernization and rehabilitation of old facilities are appropriate allies of the growing emphasis on vocational and continuing education. The development of skills in conversion of existing building stock to greater energy efficiency can provide useful work to many residents of central cities while reducing the impact of the continuing energy crisis.

U.S. energy expenditures in education are in part a product of general excessive demands and inefficiencies. The U.S. leads the world in per capita energy consumption, with Canada in second place.[61] By contrast, Sweden offers a model of conservation since it "consumes less than two-thirds the energy per capita to achieve essentially the same gross national product per capita as Canada, though both countries have similar economies, climates and styles of living."[62] Educators can rise above the institutional inertia of their societies to provide more appropriate models of energy usage.

In the winter of 1976-77, following of dramatically increasing energy costs, there were school closings due to shortages of natural gas.[63] Against this background, President Carter called for new national energy policy, seeing energy as the greatest challenge except war prevention.[64] Some energy experts may argue that President Carter was being excessively dramatic, but few would deny the seriousness of shortened hours in business and industry, long lines for scarce gasoline, and school closings.

While schools have experienced declining educational revenue and increasing educational demand, they have coped with a disproportionate increase in energy costs in education. The annual maintenance and operations cost studies, conducted for American School & University, reveal a history of greater inflation in energy-resource-dependent costs than in net current expenses.[65] The separate designation of actual percentage of increase in cost of "heat" (11.5%) and "other utilities" (16.2%), as compared to "net current expenditures" (10.3%), from 1981-82

to 1982-83 illustrates this fact. When comparing custodial salary, maintenance salary, heat, other utilities, other maintenance and operations expenditures, and net current expenditures, Jerald L. Deriso found that other utilities and heat were the clear inflation leaders. He clarified "other utilities" only by saying, "i.e., electricity."[66] Deriso attributed some success in holding the line on maintenance and operations costs to "better control of energy consumption and reduced revenues," among other factors.

The definition of educational costs needs clarification. The writers of the "Ninth Annual Maintenance & Operations Cost Study" of American School & University defined net current expenditures, over against maintenance and operations budgets, to include "all spending by school districts for current day school operations except transportation, capital outlay, and debt service."[67] Labeling these large areas of educational expenditure highlights the pervasive influence of energy in educational decision making. Comparing the groups of costs, on the heels of the 1979 oil and gas shortage, they said,

> While the cost of education was rising at 12%, the cost of maintenance and operations went up much faster at a rate of 17.2%. The net result is less dollars for education than the previous year. Much of the increase can be attributed to catching up on deferred maintenance and the continually nagging problem of declining student enrollment without a corresponding reduction in the size of facilities.[68]

The dramatic effects of fuel on educational budgets are seen in a perspective preceding the energy crisis. The writers noted in March,

1980 that "since these studies began in 1968-69 the rate of increase for fuel is twice the rate of net current expenditures."[69]

The increasing clarity of definition of an acceptable climate for education has led to greater expenditures for heating and/or air conditioning. The comfort level seems to range from 65°F to 68°F on the lower extreme and 73°F to 78°F on the upper extreme of temperatures, depending on who is defining comfort.

The impact of energy inflation over an extended period of time is evident in Deriso and Feldman's comparison of these categories of maintenance and operations costs in dollars per student from 1973-74 through 1983-84. In Table 1 Deriso and Feldman's dollar amounts have been converted to cumulative percentage of increase over 1973-74. By converting dollar amounts to cumulative percentage of increase relative to 1973-74 the impact of other utilities and heat is seen to be far more serious than the yearly percentage of increase sometimes indicated. This is a more reliable indicator of the seriousness of the problem since heating costs declined one year and other utilities costs declined one year, while net current expenditures consistently increased.

Feldman's report of actual 1983-84 expenditures in March, 1985 indicated that other utilities led the way with a cumulative cost increase of 327.9 percent over 1973-74. Heat ran a close second with a 311.1 percent increase. The 194.8 cumulative percentage of increase in all maintenance and operations (M&O) costs for the period exceeded the cumulative net current expenditures (N.C.E.) increases of 190.6 percent. Although a similar overall position of M&O as a percentage of N.C.E. was

Table 1

Impact of Energy Costs on Maintenance and Operations Costs and Net Current Expenditures: Reflected in Annual Percentage of Increase and Cumulative Percentage of Increase over 1973-74 through 1983-84

Item	Year							Year		
	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82[f]	82-838	83-84
TOTAL M&O[c]	(17.4)[d]	(15.9)	(3.5)	(12.2)	(9.0)	(24.7)	(11.0)	(10.2)	(7.4)	(4.4)
	17.4[e]	36.1	40.9	58.0	72.3	114.8	138.4	162.8	182.3	194.8
Salaries	(15.9)	(10.7)	(1.0)	(17.3)	((-8.4))[f]	(11.6)	(13.1)	(28.1)	(8.7)	(3.5)
	15.9	28.3	29.6	52.0	40.2	56.4	76.9	126.5	146.3	154.9
Heat	(48.6)	(26.6)	(7.2)	(25.0)	(31.9)	(9.7)	(17.6)	((-28.5))	(11.5)	(10.4)
	48.6	88.1	101.6	152.0	232.4	264.8	329.2	233.9	272.3	311.1
Other Utilities	(20.3)	(25.6)	(10.3)	(19.8)	((-3.7))	(33.8)	(16.3)	(8.3)	(16.2)	(13.6)
	20.3	51.0	66.6	99.6	92.4	157.5	199.5	224.3	276.7	327.9
Other M&O	(10.6)	(11.7)	(5.3)	((-18.3))	(67.7)	(51.4)	(2.7)	(0.2)	((-4.5))	((-6.9))
	10.6	23.6	30.1	10.1	84.6	179.5	187.1	187.8	175.5	157.7
Net Current Expend.	(14.1)	(9.9)	(7.9)	(7.2)	(13.5)	(17.1)	(8.9)	(19.4)	(10.3)	(5.0)
	14.1	25.4	35.3	45.1	64.7	92.9	110.0	150.8	176.7	190.6
M&O as % of N.C.E.8	12.4	13.0	12.5	13.1	12.6	13.4	13.6	12.6	12.2	12.2

[a]Data for 1973-74--1981-82 came from Deriso and Lane.[71]

[b]Data for 1982-83--1983-84 came from Feldman.[72]

[c]M&O = maintenance and operations costs.

[d]Annual percentage of increase in cost in parentheses.

[e]Cumulative percentage of increase in cost, relative to 1973-74 cost per pupil, not in parentheses.

[f]Declining annual percentage, indicated by double parentheses.

[8]N.C.E. = net current expenditures.

maintained, other M&O costs and M&O salaries experienced significant declines relative to energy. The data did not reveal whether the 154.9 percent increase in custodial and maintenance salaries, taken together, reflected a reduction of needed employees due to conservation strategies. During the period studied, the N.C.E. increased by 190.6 percent, suggesting that total budget appropriations for teacher salaries may have increased relative to custodial and maintenance workers salaries.

Table 2 reveals the regional impact of heat and other utilities costs. American School & University studies divide the U.S. into ten geographic regions for descriptive purposes. Obviously the climate is not uniform within regions. However, differences in energy demand between regions are quite apparent in the statistics. Deriso used eleven charts which enable those who manage maintenance and operations to compare their cost to national and regional averages.[70] The charts make distinctions between custodial and maintenance worker. For the purposes of this dissertation, statistics are extracted which illustrate the regional differences in heating and other utilities costs, as seen in Table 2. The total M&O costs and a percentage of net current expenses, also, are noted. The regional range in heating cost is from .5 to 2.0% and in other utilities is from 1.7 to 2.9%. Although Deriso provided no such detail, heating and cooling costs may vary more within regions than between regions.

Accurate assessment of the true impact of energy systems and potential cost reductions would demand some analysis of the proportion

Table 2

Regional and National Comparisons[71]
(actual costs--1982-83)
(dollars per student)

Location	Total M&O Costs	% of NCE	Heat	% of NCE	Other Utilities	% of NCE
National	$346.91	12.1	34.70	1.2	71.69	2.5
Region 1: CT, ME, MA, NH, RI, VT	$349.65	12.6	54.93	2.0	65.67	2.4
Region 2: NJ, NY	$442.51	11.2	56.33	1.4	92.69	2.3
Region 3: DE, DC, MD, PA, VA, WV	$389.74	13.8	41.82	1.5	75.34	2.7
Region 4: AL, FL, GA, KY, MS, MC, SC, TN	$291.02	10.1	14.47	.5	84.57	2.9
Region 5: IL, IN, MI, MN, OH, WI	$378.83	13.6	55.83	2.0	66.55	2.4
Region 6: AR, LA, NM, OK, TX	$307.02	11.8	25.67	1.0	63.58	2.4
Region 7: KS, MO, NE, IA	$405.95	15.2	45.07	1.7	60.62	2.3
Region 8: CO, MT, ND, SD, UT, WY	$310.87	10.7	39.39	1.4	66.02	2.3
Region 9: AZ, CA, NV, HI	$288.74	11.9	18.18	1.0	71.23	2.9
Region 10: AK ID, OR, WA	$408.00	13.1	42.02	1.4	53.35	1.7

NCE = net current expenditures

of custodial and maintenance worker time devoted to energy systems. Deriso offered no details in this regard. He also failed to define other M&O costs. It is possible, however, to determine from his statistics that salaries are a greater cost than other energy expenses.

While there is little doubt that the long-term trend will be a significant and disproportionate increase in cost of traditional energy resources, fluctuating reserves and energy prices leave short-term estimates of energy costs in doubt. Samuel E. Bleecker and others expect energy costs to continue rising. In January, 1982, Bleecker warned, "Energy costs are predicted to double or triple in this decade."[72] In December, 1983, Rebecca Vories reported that the Cheyenne Mountain School District 12 in Colorado Springs, Colorado was experiencing "energy costs escalating at 25-40 percent a year" prior to the conservation measures initiated there.[73] The potential impact of rising energy costs on school programs and teacher salaries is seen in the fact that the assistant superintendent of schools was dealing with a "school's energy budget, which represented 50 percent of the non-payroll costs."[74] This is consistent with Richard M. Esteves' indication that energy cost is "second only to personnel salaries in the drain it puts on limited school budgets" in "many schools."[75]

CHAPTER TWO ENDNOTES

1. George McRobie (with a Foreword by Verena Schumacher and E. F. Schumacher: on Technology for a Democratic Society), Small Is Possible (New York: Harper & Row, Publishers, 1981), p. 152.

2. "Energy production set record in 1984," Richmond Times-Dispatch, May 5, 1985, p. A-22, cols. 1-4.

3. Charles DiBona, "U.S. Faces Clouded Energy Future," The Richmond News Leader," April 25, 1985, p. 12, cols. 3-6.

4. Ibid. The reference is to 1984 data.

5. John M. Fowler and King Kryger, "Energizing Vocational Instruction," Vocational Education, 54:1:41-43, January, 1979.

6. S. V. Szokolay, World solar architecture (London: The Architectural Press, 1980), p. 1.

7. Jerry Lawrence, AIA, "Energy-Conscious Design, Part I," American School & University, 56:12:43, August, 1984.

8. C. A. Hooker and others, Energy and the Quality of Life: Understanding Energy Policy (Toronto: University of Toronto Press, 1981), p. 122.

9. "Energy management yields results," American School & University, 52:9:32-35, May, 1980.

10. Ibid., p. 34.

11. Glen I. Earthman and others, "Guiding the Project for Energy Efficiency," Building for Energy Efficiency: Helpful Homework for School Administrators, ed. Herbert S. Wheary (Richmond, Virginia: State Office of Emergency and Energy Services, December, 1983), p. 6.

12. Ibid.

13. Hooker, op. cit., p. 122.

14. Ibid., pp. 123-124.

15. Lillian A. Clinard, "Conservation--We Have Met the Enemy!," Vocational Education, 54:1:37, January, 1979.

16. Hooker, op. cit., p. 123.

17. Lawrence, loc. cit.

18. P. L. Auer, Renewable Energy Resources (New York: IPc Science and Technology Press, 1978), p. 26.

19. Ibid.

20. Donald Burr, "Conerning Energy at School," Vocational Education, 54:1:22, January, 1979.

21. Robert H. Pusey, "Why schools should consider coal," American School & University, 53:11:51, July, 1981.

22. Lawrence, loc. cit.

23. Richard C. Dorf, Energy, Resources, & Policy (Reading, Massachusetts: Addison-Wesley Publishing Company, 1978), p. 143.

24. Larwrence, loc. cit.

25. Kenneth B. Woodbury, Jr., "A Practical Guide to Energy Conservation," American School & University, 52:7:70, March, 1980.

26. Ibid.

27. Gerald F. Bender and Jack F. Probasco, "Include passive solar in your renovations," American School & University, 53:8:41-42, April, 1981.

28. Albert E. Brooks, "In Lighting Less Is More," American School & University, 55:8:57, April, 1983.

29. Bea Scala, "Light It Right But Save the Power," Administrative Management, XXXVII:10:28, October, 1976.

30. "One energy miser's plan," American School & University, 53:8:65, April, 1981.

31. Lawrence, loc. cit.

32. Bill Benton, "Solar screens give schools comfort . . . while they save energy!," American School & University, 54:5:42, January, 1982.

33. Ibid.

34. Burr, op. cit., p. 24.

35. Ibid.

36. C. DiMercurio, "Ventilation cooling: an old solution to new problems," American School & University, 53:11:40, July, 1981.

37. Ibid.

38. Lawrence, op. cit., p. 43.

39. Woodbury, op. cit., pp. 68-70.

40. Ibid., p. 68.

41. "Energy audit . . . here's how," American School & University, 55:12:42, August, 1983.

42. Ibid.

43. Lawrence, loc. cit.

44. Ibid.

45. DiMercurio, op. cit., pp. 38, 40, 42-43.

46. Ibid., p. 43.

47. Woodbury, op. cit., p. 69.

48. Lawrence, loc. cit.

49. Auer, Renewable Energy Resources, op. cit., p. 26.

50. Shirley J. Hansen, "This time, let's put energy conservation on the blueprint for new schools," The American School Board Journal, 172:6:38, June, 1985.

51. Ibid.

52. Paul Abramson, "10th Annual Report on Educational Construction," American School & University, 56:8:16-17, April, 1984.

53. New York Times Service, "Half of U.S. population growth since '80 is in 3 states," Richmond Times-Dispatch, April 28, 1985, p. A-9, cols. 1-4.

54. Stephen L. Canipe, Charles Harman and Robert Pittillo, "Energy Retrofit--Step One," American School & University, 55:12:29, August, 1983.

55. Ibid.

56. Richard M. Esteves, "Creative Financing," American School & University, 56:6:48, February, 1984.

57. Ibid.

58. "Ninth Annual Maintenance & Operations Cost Study," American School & University, 52:7:50, March, 1980.

59. Ibid., p. 19.

60. Ibid.

61. C. A. Hooker and others, Energy and the Quality of Life: Understanding Energy Policy (Toronto: University of Toronto Press, 1981), p. 23.

62. Ibid., p. 34.

63. Richard C. Dorf, Energy, Resources, & Policy (Reading, Massachusetts: Addison-Wesley Publishing Company, 1978). p. 11.

64. Ibid., p. v.

65. Jerald L. Deriso, "13th Annual Maintenance & Operations Cost Study," American School & University, 56:7:14,16,18,20,24,26,28,32 and 35, March, 1984.

66. Ibid., p. 18.

67. T. J. Meredith, Jerald L. Deriso, Edwin B. Feldman, "Ninth Annual Maintenance & Operations Cost Study," American School & University, 52:7:52, March, 1980.

68. Ibid., pp. 52 & 58s.

69. Ibid., p. 58s.

70. Deriso, "13th Annual . . . Cost Study," op. cit., pp. 26,28,32 & 35, March, 1984.

71. Ibid., pp. 26, 28, 32 & 35.

72. Samuel E. Bleecker, "Energy management system uses the phone to keep costs in line," American School & University, 54:5:76, January, 1982.

73. Rebecca Vories, "Conservation for School District," Solar Utilization News, 8:6:5, December, 1983.

74. Ibid.

75. Richard M. Esteves, "Creative Financing," American School & University, 56:6:48, February, 1984.

Chapter 3

ENERGY CONSERVATION PRIORITIES

Appropriate steps must be taken to reduce energy expenditures in educational facilities. Cutting personnel is not a viable alternative due to the new baby boomlet and increasing educational demands created by revolutionary changes in medicine, communications, and many other aspects of science and technology. Furthermore, the transportation problem is amenable to fewer currently available remedies than facilities.

Scarcity of traditional energy resources and energy obsolete facilities and equipment limit the speed of bringing energy costs under control, but, fortunately, there are many paths to significant energy savings. The preparatory readings for the landmark conference which brought worldwide scientists, engineers and theologians to Massachusetts Institute of Technology, under the sponsorship of the World Council of Churches, offered useful estimates of potential savings and the kinds of energy saving steps needed in housing and other buildings.

> . . . Architecture and siting for best heating and cooling, coupled with proper insulation, are initial steps in the right direction. Direct burning of fuels for heating rather than use of electricity is energy saving. It is estimated (US figures) that savings in operation could be 30-50% in existing buildings, 50-80% in new ones. The lower figure in each case is for optimal insulation and most efficient heating, lighting and air conditioning. The higher savings are with the addition of solar devices, heat pumps and total energy systems.[1]

The high level of consumption of energy in school facilities affords an opportunity for flexible, planned response to growing energy

costs. Traditional energy resources and the local fads may not satisfy those who seriously evaluate the options available. The varied alternatives demand deliberate choices and setting of priorities in solving the energy problem. Recognizing energy conservation possibilities, identifying priorities, and choosing alternative energy systems are all part of the process of matching energy uses and resources. School systems have discovered the possibility of reducing energy bills by 50% or more when extensive consultation, funding and retrofitting are applied.[2] To achieve such reductions school systems need to follow logical steps in a phased implementation of established priorities to meet energy needs.

Goals and Design Standards

Ultimately, school programs and goals determine the level of energy demand. Quality programs and energy systems need not and should not be sacrificed to save energy. The goals and standards have been focused more narrowly for the purposes of this paper on adequate and appropriate lighting, heating, cooling, ventilation and other electrical and mechanical needs.

Redefining the Comfort Level

Redefining the comfort level to achieve savings often sets a standard which schools have not yet achieved. Needed measures often include reducing the lighting levels, decreasing the window area to avoid heat loss and/or heat gain, setting the thermostats during the day to redefine the comfort range **from** 68°F to 73°F **to** 65°F for heating and

78°F for cooling, respectively, adding supplemental heating in the cafeteria to 140°F to permit a 100°F setting for hot water in other uses, and reducing ventilation to standards consistent with the avoidance of indoor pollution. Thermometer setbacks, time clocks and automatic controls for shutting down of unnecessary energy systems are allies in the redefinition of comfort level.

There are significant regional differences in the cost of energy which go beyond population changes. To some extent the differences may be attributed to relative affluence and consumer demand. More important, however, are the variations in climate. Some energy concepts are defined in terms of standard comfort levels. Jennifer Adams helped clarify the variation in regional demand when she pointed out the importance of remembering outside temperature measurements in terms of reasonable level of comfort for user purposes in choosing heating and cooling systems. One such measure of outside temperature is the **degree-day (DD)**, a unit of measurement of the declination of the mean temperature for the day from a given point, usually 65°F (18°C), which represents a comfort level during normal activity, and therefore, a difference which is used to measure heat requirements for buildings in specific outdoor environments.[3] Cumulatively degree days represent how cold a location typically is over a one year period. Another measurement of outside temperature effects, **Cooling Full Load Hours (CFLH)**, deals with the need for cooling to maintain a comfort level. Adams said, "Cooling Full Load Hours represent the number of hours per

year that an air conditioner would have to run in order to keep the building at 75° to 78° during the summer."[4]

Study reveals a lack of uniformity in the definition of comfort level in areas of potential energy savings. Dimming the lights may reduce safety in hallways, recreational facilities and other uses. Reducing window openings may pass up opportunities to achieve cooling and ventilation through open windows and heating through passive solar energy measures. DiMercurio suggested that 65°F provides the accepted heating standard rather than 68°F in winter. A higher humidity level permits comfort at lower temperatures. Lower humidity permits comfort in the higher ranges of the comfort level. Furthermore, comfort level is not only a function of temperature and humidity, but, also, of air volume, so that use of the unit ventilator with greater fresh air volume may accommodate a higher temperature and still maintain comfort as opposed to stuffiness and inattentiveness due to too little fresh air.[5] When the level of ventilation is cut back and buildings are well insulated to conserve energy, one of the consequences may be indoor pollution. Consequently, there is a need for clear definition and assessment of safe standards in school facilities where new conservation measures are practiced.

Avoiding Indoor Pollution

Alan Caruba illustrated the need of standards when he reported on "Indoor Pollution: The Invisible Enemy" in April, 1984. Caruba stated,

> The problems associated with poor indoor air quality are far more widespread and far more serious than is generally known to the public at present.
>
> . . . .
>
> The fact is, there are no current standards for indoor air quality in buildings.
>
> To correct this, Robert E. Sheriff, a member of the Board of Directors of the American Industrial Hygiene Association (AIHA), is working to establish such criteria.[6]

The seriousness of the problem of indoor pollution was evident when Caruba asked Sheriff to enumerate some common indoor air pollutants recirculated in educational facilities. Caruba said,

> . . . Sheriff names them in quick order:
>
> - Formaldehyde from tobacco smoke, insulation, particle board resins in paneling and furniture, as well as resins in cloth, carpeting and adhesives.
> - Carbon monoxide from tobacco smoke, furnaces and kerosene heaters.
> - Particles of asbestos and fiberglass from insulation and fire retardants.
> - Radon (radioactive) particles from the ground, cement and bricks.
> - Pesticides both inside and outside a building.
> - Organic chemicals from copiers and paints.
> - Nitrogen oxides from kitchen appliances.
> - Microorganisms from people, plants and animals. These microorganisms are incubating in furnishings, ducts and cooling towers.
> - Allergens from dusts and insects.
> - Carbon dioxide from human breathing.[7]

In blind test, where students and teachers were unaware of increasing concentrations of carbon dioxide (CO_2), J. E. Wood demonstrated the detrimental effects of higher levels of CO_2. Caruba summarized the results of the CO_2 pollution study conducted in a junior high school this way:

> . . . Students in the room with the CO_2 felt that the room was warmer, there was less air movement, the air was stale, and they themselves felt warmer and more uncomfortable as a result. And that was just carbon dioxide as would normally be breathed into the room by its human occupants.[8]

James L. Repace indicated that, where there are persistent indoor sources of pollutants, such as, those listed by Sheriff, "'indoor concentrations of such pollutants will generally exceed the outdoor levels considerably.'"[9] The sick building can make students and teachers ill "by rapidly circulating flu and virus in a building where up to 90% of the air is recirculated via air conditioning and 50% of the heating air is recirculated as well."[10]

Furthermore, Caruba noted an instance of a lethal building where diethylamino ethanol (DEAE) was routinely used to prevent corrosion in the Herbert F. Johnson Museum at Cornell University. "DEAE . . . can convert to a potent carcinogen,"[11] according to Caruba. A similar problem was noted relative to potential "fires in electrical transformers insulated with poly-chlorinated biphenyls (PCBs)"[12] by Dr. Arnold Schechter.

In spite of the importance of detecting and eliminating such threats to the health and safety of students, Caruba found very few professionals so engaged. Against this background of obvious need, Repace reported that

> "a major federal role in dealing with indoor air pollution is by no means assured. In an era of declining research budgets, the lack of legislative authority to regulate indoor air quality may seriously retard the development of a national indoor air pollution research program" as had been announced by the EPA and Government Accounting Office.[13]

If superinsulation becomes a standard feature of energy conservation in facilities, matching steps must be made to increase the infiltration of fresh air in a way that conserves heat and cool in the process. Such answers as "recycling interior air through a charcoal

filter system" to reduce "the quantity of fresh air necessary to replace oxygen and eliminate odors" will obviously solve only part of the indoor pollution problem.[14] While superinsulation can delay the exhaustion of fossil fuel supplies, with some loss of interior air quality, use of renewable energy resources may afford opportunities to economically maintain air quality.

Winslow Fuller reported the results of studies of indoor pollution levels in tightly built residences in June, 1981. The level of occupancy of space is significantly different in residences from closed classrooms, so that one-to-one comparison is not possible. However, dormitories are numbered among school facilites. The pollutants studied included most of those listed by Caruba, with sulfur dioxide (SO_2), ozone, lead, and water soluable sulfate, among the additions. The concentrations were sometimes higher inside than outdoors in "nitrogen dioxide, total suspended particulates and respirable suspended particles."[15] In sharp contrast to the level of alarm raised by Caruba in the educational setting, Fuller found that low air infiltration rates can provide real benefits in residential settings by providing not only energy savings but protection from dangerous concentrations of some outdoor pollutants.[16] However, this must be coupled with a rate of ventilation that "maintains low indoor pollutant concentrations."[17] The suggested level of air infiltration in residences to avoid drastic effect on air quality was between 0.4 and 0.6 air changes per hour (AC/hr).[18] On the basis of various studies referred to by Fuller, he concluded, "A consensus seems to be developing

in the building industry that an air infiltration rate of 0.5 AC/hr can keep air pollutants below critical levels in residences."[19] Presumably this would be consistent with requirements in dormitories.

Schools have tended to be pressed for increasing levels of climate control. This is reflected in the desire to maintain comfort levels during the day, in extended, afternoon and evening community use, in heated pools in winter and in summer programs or year-round schooling. Consequently, conservation measures often have limited impact on total energy expenditures as progressive programs are implemented and "as heated swimming pools and air conditioning are accepted design standards."[20]

Providing Quality Lighting and Energy Savings

In 1976 Bea Scala described the decisions necessary to provide good, economical lighting in an office setting. Scala credited Robert T. Dorsey, a lighting engineer, with the details regarding **five decision areas** for good office lighting, namely, (numbers added) "(1) the right light source, (2) fixture, (3) maintenance program, and (4) lighting control system, as well as (5) a pleasant working environment."[21]

The right light source was dealt with in greatest detail. Based on the definition given, fluorescent lighting is usually the choice in offices since it provides more and better lighting using less energy. Scala's description of Dorsey's points was as follows:

> The right light source is one that delivers a high number of lumens-per-watt, and full-spectrum color. Fluorescent has a high output of lumens-per-watt, approximately 70 to 80 lumens,

> while ordinary incandescent light puts out about 22 lumens-per-watt. . . .
> . . . .
> For example, a fluorescent light source such as Duro-test's line of 40-watt Vita-Lite tube simulates the full-color spectrum of sunlight, according to the company. Woody Bickford, manager of environmental lighting for Duro-Test, says the lighting researchers have found that people can work longer without eye fatigue under full-spectrum color light than they can under most cool white fluorescent lighting which does not include some colors in the spectrum. The company claims that Vita-Lite has the highest rating of any source for being most like natural light.[22]

Since the concern is to save energy, while not interfering with productivity, work quality and employee morale, Scala described some lighting that does not satisfy the full-spectrum color aspect of the definition of the right light source. Scala said, "High pressure sodium light puts out between 100 and 140 lumens-per-watt, a significant increase over fluorescent light, but the color rendition it affords is considerably less."[23] The recent shift from use in outdoor street illumination to increasing use indoors deals with utility budget limits, while providing a lot of light for some kinds of clerical tasks and other indoor uses, has nonbudgetary limits. The restriction to appropriate office use was clearly stated as follows:

> . . . For those offices in which it is not important that color be distinguished accurately, such as clerical areas where clerks deal mainly with black print on white paper, this may be an alternative to high electricity bills.[24]

General Electric claimed leadership in efficiency. The company asserted that their Lucalox high pressure sodium lights were "the most energy efficient white light source available."[25]

Dr. Kenneth B. Woodbury, Jr., illustrated the range of opportunities to gain increased lighting, reduced wattage and long life

in lighting systems. He emphasized the extended life of several systems relative to incandescent lamps:

sodium lamps	16 times
mercury lamps	32 times
fluorescent fixtures	24 times[26]

Lawrence G. Spielvogel noted wasted wattage in lighting due to use of incandescent bulbs which cost less to buy, but more to burn, perhaps twenty times the original purchase price in one year of use.[27]

Gerald F. Bender, an energy management engineer, and Jack F. Probasco, facilities planner at Ohio State University, Columbus, in April 1981, recommended changing from incandescent to fluorescent lighting fixtures inside and consideration of "converting outside lighting to high pressure sodium or metal halide."[28] Usually a more complete spectrum of light is preferable inside of school facilities to enable a clearer perception of the range of colors of materials. The distinction between inside and outside use is important.

Scala, when writing regarding the second decision area in providing good lighting, was equally clear in defining the right fixture and indicated that

> the right fixture for any light is one that diffuses illumination so that people working under it can't see the bulb. Fluorescent troffers with covering lenses patterned with diamond shapes are particularly popular because of their ability to make the tube unnoticeable to the viewers while distributing light evenly.[29]

Scala would obviously take exception to the questionable conservation practice of removing diffusers to gain more light and heat, while eliminating diffuser washing.

However, the maintenance program affords another area of significant savings potential in maintenance and utility costs. Scala recommended a regular schedule of bulb replacement and periodic cleaning of fixtures.

Scala offered few details concerning the lighting control system. Basically, Scala suggested a deliberate match between placement of lighting and where and when it is to be used. This departs from the common, wasteful practice of splashing "large amounts of wattage evenly over a wide area" even though the lighting needs differ markedly.[30]

Switching and control methods offer potential savings. Additional switching can avoid the waste associated with lighting unoccupied areas and make better use of natural lighting. Bender and Probasco suggested using microprocessor switching when buildings are completely rewired to improve lighting controls, including "precise scheduling of all lighting" and "time clock and/or photocell control" of outside lighting.[31]

The last area of decision may be the most important, creating a pleasant working environment. The distinction between merely conserving energy and managing energy is evident here. Scala said, "Energy management is not only a matter of reducing watt usage, but of creating a pleasant work atmosphere based on the wise use of energy to enhance worker productivity and comfort."[32] Removing light diffusers from fluorescent fixtures neglects the importance of creating a pleasant study environment.[33]

Scala estimated the potential savings to be achieved while providing good office lighting. Scala reported in 1976,

> By using more efficient light sources (bulbs) and fixtures, available lighting design technology, and life cycle costing methods, a 20 percent gain in efficiency can be achieved without sacrificing productivity.[34]

Appropriate goals can be met by good, thrifty office lighting. Scala concluded with this assertion:

> **Good office lighting** can mean greater productivity, lower operating and maintenance costs, higher returns on investments, more efficient use of human resources, fewer mistakes and rejects, and better employee morale.[35]

The evaluation of current lighting practices is vital. Woodbury recommended illumination audits as a means to reduce "interior lighting to the recommended levels of the Illuminating Engineering Society."[36]

Spielvogel offered helpful comments on values achieved by conducting lighting energy audits. He placed lighting second, after heating, as a priority for conservation. However, he emphasized the importance of people rather than equipment as wasters of energy. Among the important people are maintenance crews, custodians, and users. Spielvogel emphasized the value of user complaints and, especially energy conscious custodians.[37] He believed that those persons in charge of lighting and heating systems make more diligent efforts to conserve energy when they are able to monitor energy consumption and to see the results of their work.

In conducting the lighting energy audit in classrooms and offices, Spielvogel made a number of specific suggestions. His practice was to "check the type of lighting everywhere," to note the "condition

of windows, presence of shades, blinds or drapes," to "measure the footcandles in the classrooms and offices under various conditions . . . lights on, lights off, blinds raised and blinds lowered," and to "note available light at the center of the room and at the window side."[38] If rooms are used at night, accurate auditing of artificial light must be done at night. The auditor notes "the number, wattage and type of light fixtures."[39] The auditor also notes whether the natural daylight from windows is given adequate consideration in the switching controls.[40]

Services of Energy Management Consultants

The importance of establishing energy priorities in energy management calls for public awareness and a willingness to invest money in the services of energy management consultants who can develop strategies and solutions. Basically, the public at large and school boards and administrators in particular must first become aware of the implications of the First and Second Law of Thermodynamics.[41] The First Law of Thermodynamics indicates the constancy of the total amount of energy in the universe or, in other words, that ". . . energy can neither be created nor destroyed."[42] The universe will not get any more or less energy.

However, its practical usefulness can be unnecessarily diminished by the manner in which it is used. This is the important lesson of the Second Law of Thermodynamics which indicates that ". . . every system left to itself changes in such a way as to approach a definite final state of rest or equilibrium."[43] When the energy of the

sun, for example, is used up or dissipated throughout the universe, it is no longer conveniently available. Even the wind does not blow when the temperature is in equilibrium. Practically speaking, the drift of concentrated energy is toward what might be described as widely dispersed waste heat rather than usable energy. The process of collecting dispersed energy requires great energy use. Once fossil fuels' Btus have been scattered, for example, the process of replenishing this resource takes thousands or millions of years of photosynthesis and other processes to recover a useful energy resource in fossil fuel form. Energy systems which collect rather than dissipate energy are renewable in the short term.

When the U.S. consumed .8% of the world's known total oil reserves in 1982, it was consuming at a rate which would exhaust the world oil reserves of that year in about 31 years, several years before the natural gas reserves.[44] Once the heat energy potential of fossil fuels has been dissipated, it is, practically speaking, irrecoverable. Consultants can not only explain such energy principles; they can also recommend priorities for solving energy problems and financing these improvements.

A Thorough Energy Audit

Having first conveyed the importance of dealing with the energy problem, the next step is to identify wasteful practices and utilize professional help in setting priorities. Professional consultants are needed to provide insights which go beyond common sense measures like caulking and weather stripping and may provide the difference between

saving 10 percent and 75 percent on energy saving measures. Most energy wasteful practices offer a wide variety of solutions rather than one obvious solution. Too little insulation, oversized heating and cooling systems, excessive glass on northern and western walls, and improper control of heating, lighting and ventilation are features which may readily identify the need to secure consultants to provide a thorough audit of wasteful practices, to assist in setting priorities, and to suggest which projects could provide a relatively quick payback as well as projects offering the greatest life cycle advantages in solving the problems.

In December, 1983 Rebecca Vories reported that the Cheyenne Mountain School District 12 in Colorado Springs, Colorado, secured a "complete energy audit of the school facilities and energy use" for $30,000.[45] Frank Rocchio, the assistant superintendent of schools, offered several keys to a successful program of evaluation of ways energy dollars are spent and strategies for savings. Leading the list was this one: "Hire an expert--particularly someone with mechanical and electrical engineering skills who can look at how all the elements of your energy system work together."[46] For optimum energy saving results, the best advice is "Use a consultant."[47]

A thorough energy audit includes the exterior and interior of all facilities, including both passive and active energy features, and consultation with appropriate individuals. Lawrence G. Spielvogel suggested, "The initial meeting should establish building use patterns and user complaints as well as the maintenance crew's schedule for

managing the building's utilities."[48] Utility bills may immediately clarify use patterns and priorities for energy savings. Spielvogel indicated that, since the heating/cooling plant demands the most energy dollars, it is the most important room to be audited.[49] The points of air and light infiltration, type and efficiency of lighting, lighting level, the presence or absence of shading devices, heating, cooling and ventilation system, the control system, the temperature and volume of hot water used at various points, the efficiency of appliances and the level of utilization, the presence or absence of passive or active heat and/or cold storage, leaking vents, waste heat recovery, and the glazing, location and extent of windows are numbered among the features involved in a thorough energy audit.[50] Auditors are expected to use a formal checklist to guide their observations.

In the case of the Shawnee Mission School District consumption for each school was documented on a computer prior to involvement of the energy management consultant. The findings led to several immediate energy savings. Utility rates were adjusted in 17 schools due to discovery of administrative oversight of possible rate changes with the consolidation of 13 prior districts into Shawnee Mission. Thermometer setbacks and heating system recalibrations were also made prior to involvement of the Viron Corporation.[51]

Michigan State University's phased in energy management program "began with an intensive audit of energy consumption characteristics on campus." It was briefly described as follows:

This was a thorough study of the entire physical plant, its

> operating systems, use patterns and historic energy consumption data to determine the potential for energy savings.
>
> A properly conducted analysis uses a variety of tools to analyze present energy consumption and potential energy savings in several areas of building operation. These areas include: space heating and cooling, ventilation (air handling), fluid handling, domestic water heating (appliances), illumination systems and building structure.[52]

Two energy consultants in Richmond, Virginia, have experienced remarkable growth in their business which is 80% renovation. They design plumbing, heating and electrical systems for new and renovated structures. "Energy-efficient mechanical and electrical systems" are sought by clients who use their services in new construction. In one instance recovery of waste heat from a bank's computer system was used to heat the building and domestic water. Ed Crews reported, "The system was so effective that it cut the center's use of fuel oil from 25,000 gallons to less than 1,000 gallons per year."[53] This system provides a useful model for some school settings. The value of energy consultants is seen in John M. Ziegler's report that "the energy-conservation service and equipment industries . . . did business worth $5 billion in 1980." Furthermore, that figure was expected "to grow to $10 billion by 1985 and almost $100 billion by 1995."[54]

Assessing Heat Losses by Use of Thermal Sensing

The audit of insulation and glazing exposes numerous opportunites to avoid waste of energy due to obvious structural flaws. Dr. Bob N. Cage described alternative uses of **thermography** to pinpoint energy leaks at various points on the building's exterior. Such studies suggest appropriate energy investments in building renovation.[55] They

may point to ways to utilize waste heat by transferring it to where it is needed rather than simply venting it to the outside. The remarkable savings achieved in some facilities through adding roof, wall and foundation insulation, glazing, and weather-stripping windows and doors, reducing window areas, and waste heat recovery point to the wisdom of using this energy management consultant's tool.

Thermography or thermal sensing identifies sources of heat loss. Cage reviewed the concepts and equipment available for diagnosing air leaks and insulation performance. Cage said,

> To date, the identification and location of air leaks and the evaluation of insulation performance has been a difficult task. A diagnostic tool called thermography gives promising results. Thermography is a combination of photography and infrared (IR) sensing. Infrared sensing pemits direct measurement of apparent surface temperatures. Thermal information from an infrared sensor can be photographed with a 35mm or Polaroid camera, or recorded on videotape. With training, a person can interpret the thermograms and locate insulating void and air leaks. This information is a useful guide for retrofit decisions and for evaluation of corrective actions.[56]

Cage clarified the various methods used to estimate building energy losses. The three categories from least to most complex were grouped as follows: (1) energy audit, (2) remote sensing technology, and (3) architectural or engineering study.[57] The more extensive engineering studies usually lead to "suggestions for major capital investments, either in the heating and cooling (HVAC) plant or in the structural shell."[58] Extensive studies are appropriate in new construction and extensive renovation of older buildings to assure "that the building will be as energy efficient as is technically possible once the work is completed."[59]

Cage believed the information obtained through thermal sensing as a supplement to the basic energy audit was adequate for most public schools.[60] Accordingly, Cage described four types of thermal sensing technology, namely "the spot or infrared thermometer," "the thermal line scanner," "a thermal imager," and "a downward-looking infrared line scanner," the last of which is used in an aircraft to gather data.[61] Cage reported that "for our purposes the thermal imager system gives the best information for the cost."[62] Cage also offered a useful outline for appropriate application of thermography and the use of consultants in meeting local needs.[63]

Recommending Conservation Strategies to Achieve Savings and Facilitate Their Implementation

Examples of use of the services of energy management consultants suggest a wide variety of conservation strageties are used to achieve significant savings. The College of Lake County in Illinois increased their facility use by 30% while achieving a more than 25% reduction in energy consumption. Conservation measures in that all electric facility included reduction of excessive illumination levels for a recommended wattage saving of "50% in work areas and 75% in corridors."[64] Also included were reduced hot water use and temperatures, automatic control of rooftop electric heating and control units, reduced air volume, load shedding and demand monitoring to avoid high peak load charges.[65] The central automation system included "electric demand limiting, start time optimization and enthalpy control."[66]

The Viron Corporation of North Kansas City, Mo., a professional energy management consulting firm, studied each of the 67 schools of the Shawnee Mission School District in Kansas. Their study resulted in a short-term expectation that nine of the schools could reduce their energy bills by 50% by using extensive retrofitting.[67] Two of the special factors analyzed in Kansas, not evident in Illinois college, may help to explain the higher level of savings. They were effects of solar and wind energy for heating, lighting and cooling, and resizing fans and boilers.[68] Viron also assisted the district by preparing the grant application which paid half the cost. One nine year cost recovery item was deleted by the Kansas Energy Office which used a five-year payback criterion before sending grant requests to DOE.[69]

A mechanical engineering firm enabled a Colorado school district to achieve an anticipated savings of 19.3 percent when the first full year of a four phased series of conservation strategies was implemented. Among the features receiving less emphasis than might have been desirable were central control and monitoring, solar and wind effects, and downsizing of equipment to achieve greater efficiency. While the percentage of savings achieved was not dramatic, the school board approved "all measures with a 10-year or less payback period."[70]

The Limited Impact of Traditional Conservation Measures

Traditional conservation measures are an important step to energy saving in school facilities. However, they are more appropriate to a short-term crisis situation than in long-term solutions to the

problem of current resource limits. In the 1970's educational journals emphasized energy conservation. Many of the remedies offered one time advantages in reducing energy expenditures in schools. The total savings achieved by relatively low cost strategies to conserve existing energy resources, when applied, were in the range of 20% to 50% of total energy usage. Continued use of measures like "installing automatic thermostats, reducing lighting levels in hallways, upgrading heating system controls and installing more efficient air distribution systems" may be more or less appropriate depending on the total energy system and all of the interactions.[71] Very significant savings can be and have been made by changing from incandescent to fluorescent lighting, by plant and program curtailment, by improvements in the heating, ventilation and air-conditioning systems, through increased use of such practices as installing humidifiers, and use of heat recovery systems and heat pumps to exchange waste heat, by improved use of insulation in roofs and walls and double and triple glazing of windows, especially on the north and west sides.[72]

Spielvogel emphasized the importance of motivated people in achieving energy conservation, especially in the areas of heating and lighting, with heating as the number one priority. He said, "Thermostat settings are probably the most important means of reducing energy in school buildings."[73] School administrators need to look for ways to avoid unnecessary energizing of unoccupied spaces to comfort levels. Spielvogel recommended saving heat energy by allowing the temperature to

drop "into the fifties or high forties overnight and on weekends during the heating season."[74]

School administrators should consult architects and engineers about the design specifications of existing building materials prior to applying severe cutbacks in temperature at night and rapid warm up in the morning. Depending on the repeated expansion and contraction tolerances of the roofing materials, the risk of this conservation measure may be thermal shock, major roof repair and interior water damage. In widespread retrofit application of energy management systems, failure to deal with the interaction of energy systems and structural design can result in extensive thermal shock. Costly retrofitting of the building skin may be a necessary energy saving innovation prior to determination of the feasibility of an energy management system in a specific facility.

New school buildings and many existing buildings can be upgraded in use of conventional energy sources to provide substantial savings. Increasing use of heating engineers is a vital part of such planning. More appropriate consideration may be given to such matters as "site location, building orientation, building configuration, fenestration, glazing and shading devices, interior space planning, energy source, transmission coefficient of the walls and roofs, heat recovery system and lighting."[75]

Selective Closing of Schools and Central Location

Selective closing of old schools and central location of new schools are useful conservation strategies in many locations. Many school divisions have experienced and continue to experience declining school enrollment. Due to the high cost of energy, high priority may be given to closing those buildings which are energy inefficient. Such decisions place increasing burdens of public disapproval on administrators relative to local school patrons.

Central location of schools tends to save transportation costs and facilitate community utilization of the facilities. Until less resource wasteful and more appropriate transportation can be provided, the location of school buildings to permit convenient accessibility to walking, cycling and mass transportation helps cut costs. Schools can be located, built and operated to accommodate the real needs of citizens, while acknowledging the impact of wasteful uses of energy relative to providing food, facilities and transportation.

Summer Shutdown by Custodial Teams

Use of custodial teams enables a quicker closing down of energy systems for summer when schools are unoccupied. The Shawnee Mission School District in Kansas saved about $50,000 in its end-of-the-year refurbishing of 10 of 67 schools by employing teams rather than having one or two custodians use the whole summer. The teams tackled the job of refurbishing the facilities in 10 to 20 working days. This permitted

all power to be shut down other than "exit and security lights, and indispensable food service refrigeration units."[76]

Limits of "Quick Fix" Solutions

The "quick fix" solutions of the energy crises of the 1970's fall far short of the savings which long-range planning can achieve. In the 1970's the expense, time and disruption of daily operation of buildings tended to delay modification or major renovation of the passive or structural elements of buildings until the 1980's. Some campuses failed to take even simple measures, such as dimming the lights, turning down the thermostats, insulating drafty buildings and glazing window panes, although they provide immediate savings. In March, 1984 Christopher E. Crittenden urged institutions of higher education to move beyond the "quick fix" mentality of the 1970's to "capital investment that can have a short payback period."[77] He indicated that the quick fix energy-cutting efforts on most campuses in the 1970's resulted in "a 17% reduction in higher education's energy use."[78] This was significantly below the expected 20% to 50% achievable by comprehensive conservation measures.

Short-term remedies, like delayed maintenance and low capital conservation measures can not solve the energy problem. They can only delay the time when more capital intensive answers must deal with the long-term problem effectively.

An example of limited conservation initiatives is seen in the measures undertaken in eleven buildings of the University of Northern Colorado where the annual savings was expected to reduce the

university's energy costs by one-twelfth. Whether truly adequate responses to the need suggested by about $3 million a year in utility payments would be made was still in doubt, although significant energy conservation projects were to be implemented with the assistance of "a 50-50 federal Department of Energy and State of Colorado grant."[79] The low technology improvements included "weatherstripping, less costly lighting, attic insulation, time thermostats and the like."[80] Numbered among the improvements was one major technological improvement; a central computerized controller enabled a reduction of custodian and mechanic labor in tasks of adjusting valves and switches. Heaters, ventilators, fans, pumps and lights can be turned on and off for nights, weekends or vacation periods more efficiently. Outside contractors were expected to complete these improvements in about six months.

Hot Water Conservation Measures

Conservation measures frequently halve the required energy before primary energy systems are selected. For example, Joe Carter and Robert G. Flower recommended cutting the domestic hot water energy load in half by simple conservation measures prior to determining the size of solar water heating collector to use. Their recommendations included pressure reduction in lines, low flow shower head, faucet flow controls, cold-water laundry for some purposes, reduction in tank temperature from 150°F to 120°F, insulation of tank, habit of use changes, pipe insulation, time clock, stack heat recovery, and grey water heat recovery.[81] They also described "the tankless, or point-of-use electric or gas water heater, which is commonly used in Europe and Japan."[82]

This latter measure permits boosting water temperature to 140°F in dishwashers, which compares to the 115°-120°F water useful for most other domestic purposes.[83]

A Decade of Renovation: The 1980's

Renovation, modification and additions are the trend of the 1980's. Paul Abramson characterized the shift in educational facilities away from new construction as a "Focus on the 'Three Rs': Repair, Refurbish, Renovate."[84] The term reconstruction was used by Abramson to include both additions and modernization. A year later Abramson added another R, namely, rehabilitation. The percentage of funds devoted to new construction, as a fraction of all expenditures nationally, had declined from 67% in 1980, to less than 57% in 1982,[85] and to 44% in 1983.[86] One of Abramson's guesses as to the motivation for the trend was "the need for energy improvements."[87] The need to catch up on deferred maintenance to protect the current investment in exisiting facilities and the realization of savings to be achieved by energy retrofitting and avoidance of costs of new construction are likely to maintain the trend to use more than fifty percent of all construction dollars on additions and modernization of current educational facilities.[88] Dorothy Wright wrote in the 1983, "School facilities built during the 1950s and 1960s are nearing the end of their lifespans, necessitating rehabilitation or replacement."[89]

Moving Beyond the Limited Priorities of the 1970's

The conservation efforts of the 1970's did not end the tremendous energy drain on college resources. In reference to the 1982-83 academic year, Crittenden said, "It costs our country's 3,250 campuses more than $3.4 billion--scarce, precious dollars that in these days of academic and financial crisis they simply cannot afford to burn up needlessly."[90] The escalating energy costs are having a dramatic impact on higher education. Crittenden succinctly stated the problem as follows:

> Following the 1974 oil embargo, costs shot up like a rocket, sending shock waves throughout higher education. That year colleges spent just $700,000,000 for energy. Only 2-4% of a campus' operating budget went to energy then, as opposed to nearly 10% now.
>
> This situation by necessity means fewer dollars for books, lab equipment, computers and teacher salaries. Tuition has been raised to cover some of these increased costs, but they can be raised only so much. They are already at such levels that many bright students have been shut out.
>
> Energy is a big drain on a campus, but it also represents one of the best opportunities to save huge sums of money that could be used to help strengthen its academic life. The money higher education spent for energy last year is enough to pay the salaries of 129,000 full-time faculty, or one and a half times what colleges spend on libraries each year.[91]

The 1980's and later require movement beyond the "quick fix" mentality of the 1970's which failed to address the real limits of traditional energy resources. In addition to resource limits and potential savings of approximately 25%[92] or more, one obvious reason for moving beyond the "quick fix" conservation strategies to serious energy management is that curtailment and redefining of comfort levels may adversely effect the purposes of the educational institution. Although

some aspects of plant and program curtailment deal with obviously wasteful energy practices, the educational goals of the institutions must guide the decision making process relative to selective school closing, closing of unused areas, and rescheduling of activities.[93]

In the 1980's tight budgets and the leveling off of student enrollments have tended to limit new construction to selected replacement and to make major renovation more appealing. Protecting the current investment in existing facilities calls for preventative maintenance and upgrading of structures to accommodate changing curriculum demands. Bender and Probasco said, "Many older buildings will require renovation in order to meet today's safety and code standards as well as the technological requirements of the educational programs."[94] An important aspect of renovation of existing facilities is the need to curtail normal operations while the structural elements are being modified to accommodate new usage patterns. These factors highlight the importance of anticipatory rather than delayed renovation projects.

Crittenden made a plea for capital investment in energy conservation. A higher level of capital investment in the 1980's can provide savings that go significantly beyond obvious waste of energy for lighting, heating, and cooling of unoccupied space.

A more comprehensive energy management approach to energy conservation in buildings was recommended for the 1980's as over against 1970's priorities. Many of the 1970's modifications were not in proper sequence since the 1980's improvements in "the building envelope

(exterior walls, windows, doors, roof), the landscaping, the usage of space within the building, and even the effects of solar energy on the structure" reduce the size, cost and energy consumption of the active system.[95] A list of specific recommendations by Bender and Probasco, indicated at appropriate points in chapters 3 and 4, was impressive in its coverage of and sensitivity to the relationships between passive and active aspects of energy conservation. Many facilities which are now relatively energy efficient may be adapted to achieve additional savings by utilizing passive and active solar energy.

Major Renovations and Additions

Major renovations and additions are the next step in energy savings. This capital intensive step usually responds to spacial needs of a growing school population and protects the capital investment by providing needed maintenance. In budgets for 1983-84 school administrators anticipated a 21% annual increase in dollars per square foot in renovation and construction costs, according to Jerald L. Deriso.[96] In November, 1983 Dr. C. William Day said, "By the year 1985, fifty percent of all construction dollars will be spent on additions and modernization of our educational facilities."[97] His projections were accurate except for colleges and universities where private donations were a large part of the funding. Catching up on deferred maintenance through major renovations is an appropriate response to the slight rise in school-aged population, following several years of decline.

Jim Sneathen found in Grand Rapids, Michigan, Public Schools that deferred maintenance can be effectively packaged for sale to school

boards in the context of "a program of energy management, concentrating on boiler replacements and upgrading of heat/air conditioning systems."[98] Apparently school boards wanted both improved space and new energy savings for their capital investments. Due to the generally high cost of energy and maintenance costs in older buildings, renovations and additions should be made in such a way as to hold down future maintenance costs in both the facilities and the new energy equipment.

Preliminary Passive Energy Conservation Features

Many aspects of passive solar energy and wind energy utilization came under Bender and Probasco's topical treatment of room utilization, landscaping and solar control. These topics properly preceded increasing the efficiency of active systems. However, since the decision of the 1970's was usually to deal with more limited aspects of the building envelope and active systems first, topical treatment of passive features is similarly limited here. Treatment of room utilization, landscaping and solar control is delayed to the next two chapters although they are all part of the integrated mix of needed passive energy features recommended by Bender and Probasco.

Bender and Probasco offered several items in a checklist relative to the building envelope.

> When evaluating the condition of the building to determine the degree of renovation required, consider modifications which will enhance energy conservation or make use of available solar energy. Assuming the payback period is acceptable, review the following:
>
> 1. Provide additional insulation for exterior walls to reduce heat transfer by conduction and thereby reducing heat loss in winter and heat gain in summer.

2. Provide additional insulation in the attic to reduce heat transfer by conduction through the ceiling.
3. Caulk exterior wall joints to reduce heat transfer by infiltration, thus reducing heat loss in winter and heat gain in summer.
4. Install new windows with insulated glass and thermal break frames to reduce heat transfer both by conduction through the glass and frame and by infiltration around the frame.
5. Use stack vents and operable windows for natural ventilation in spring and autumn.
6. Reduce the size and/or number of windows, especially on the north, east and west sides.
7. Add vestibules at the main entrances to reduce air infiltration caused by traffic in and out of the building.
8. Install insulating shades or shutters inside windows that can be closed at night to prevent heat loss.[99]

Here wind and solar energy are important, especially in items 5 and 6.

Modifying or Replacing Active Energy Systems

Modifying active energy systems and their controls logically follows changes in the passive energy systems involved in the buildings skin and sources of penetration of light and air. This runs counter to the actual experience in many settings since more energy savings were initially attainable, with less costly and less disruptive effects by modifying the active system, including light, heating, ventilation and air conditioning. Bender and Probasco indicated that modification of the active systems in energy wasteful buildings enabled energy managers to achieve "energy savings as high as 50% or more."[100] Crittenden pointed out the need to modify or replace inefficient equipment, noting that energy efficient improvements provide profitable investments as well as energy savings.[101] Similarly, when C. A. Hooker and others described inefficiencies in Ontario, Canada, they stated that as much as

50 percent of the energy wasted there was due to "inefficient design of buildings and machinery."[102]

Having listed the preliminary passive features of landscaping, building utilization, the building envelope and solar control, Bender and Probasco turned to list nine specific recommendations to increase the efficiency of active systems which can offer significant energy savings. These 1970's conservation measures still merit attention.

> . . . The following measures should continue to be used to improve system efficiency in the 1980's:
>
> 1. Reduce lighting fixtures to a more efficient type--incandescent to fluorescent. Consider converting outside lighting to high pressure sodium or metal halide.
> 2. Consider additional switching to permit lights in some areas to be turned off when occupants are out, or if natural light from nearby windows is sufficient. Also, improve the lighting controls by installing microprocessors. This should be considered if the building is to be completely rewired. Microprocessor control would provide precise scheduling of all lighting, outside lighting should be put on time clock and/or photocell control.
> 3. Reduce air volume. Most ventilation systems designed during the 1950s, 60s and 70s are fixed volume systems. Consider converting to a variable air volume system which delivers only as much air as is necessary to heat or cool a space or zone. This saves energy by reducing the horsepower necessary to drive the main system fans.
> 4. Use outdoor air for cooling by considering the use of an "economizer cycle" which can make use of cool outside air during spring and fall, rather than using mechanical refrigeration to reduce space temperature.
> 5. Replace inefficient air dampers. Many ventilation systems were initially constructed with low quality air dampers that do not allow accurate control. These dampers should be replaced with high quality, opposed blade dampers with air seals at the blade edges and ends.
> 6. Install HVAC cycle control by using time clocks or a microprocessor control to automatically turn the system on during building occupied hours and off during unoccupied hours.
> 7. Isolate off-line boilers. Idling boilers consume energy, so unless such a boiler is scheduled for immediate use, it should be secured and isolated from the rest of the heating system. Boilers should be equipped with isolation valves and stack dampers to permit isolation.

> 8. Isolate off-line chillers. Light cooling loads on a multiple chiller installation are often handled by circulating chilled water through all chillers even though only one chiller needs to be operating or on-line. This procedure wastes pump energy. By the installation of isolation valves, off-line chillers can be isolated and chilled water flow rate reduced.
>
> 9. Install a heat reclamation system. Consider installing a heat reclamation system which would remove the heating or cooling energy from the exhaust air and transfer this energy to the incoming fresh air. As much as 80% of the exhaust air energy can be recovered in this manner.[103]

Bender and Probasco also offered a basis for judging the economic feasibility of each modification of the active system and each renovation of the passive energy system. The study of each modification

> . . . . should include an estimate of the annual energy cost savings resulting from the modification, the cost to implement the modification, and a calculation of simple payback. . . . All modifications which show reasonable payback should then be considered for implementation.
>
> Some modifications may show a better payback when done in conjunction with a renovation project than they would be if done alone.[104]

They suggested that salvaging the existing building stock and making them energy efficient to achieve long-term savings merit recognition in "a decade of renovation."[105]

Lighting Conservation Measures

Major causes of energy waste in lighting have suitable conservation remedies. According to Paul Farnworth, the two primary causes of energy waste are "overlit areas and lights left on in unoccupied areas."[106] Describing the situation in January, 1984, more than ten years after the first energy crisis in 1973, his statements were a tribute to the slow response of American institutions to this aspect of energy waste. He said, "According to present lighting

standards established by the Illuminating Engineering Society, it is estimated that most existing facilities are overlit by 40-50%."[107] Farnworth recommended two devices to deal with the two major causes of energy waste in lighting by industrial, commercial and institutional users. He offered an alternative method of dealing with the problem other than major lighting renovation, delamping and "use of low-watt fluorescent lamps which give only minimal, fixed reductions."[108] He recommended the FLEC Controller as "a better alternative." The method was described as follows:

> . . . Overlit areas can be reduced to a comfortable functional level for the tasks being performed. Once the Controller is installed on a per circuit basis, it can be adjusted to the precise light level desired, without major renovations. As much as 50% reduction in wattage can be realized.[109]

Farnworth indicated that lighting systems were wastefully serving classrooms and other areas about 50% of the time and urged the use of electronic personnel sensing to eliminate the lighting of unoccupied areas.[110] He described one technology available for this purpose.

> . . . The Per-Sen was developed by FLEC Systems to turn light off when no one is in the area, and on when they are. The Per-Sen uses ultrasonic technology to sense the presence of people by detecting motion. While anyone is in a controlled area the lights remain on, and when the last person leaves, the lights are automatically turned off.[111]

The advertisement accompanying the article said in part,

> The PER-SEN ultra-sonic personnel sensor is a small, easy to install, solid state device that detects the presence of people through sound wave modulation.
>
> . . . The PER-SEN covers approximately 450 sq. ft., or a group can be wired in parallel to cover a large area. And because of the state technology the PER-SEN can pay for itself in a matter of months.[112]

Farnworth indicated that a 50% cut in lighting costs may be expected to permit payback in less than a year.

When major lighting renovation is selected as a method of saving energy, low-watt fluorescent lamps provide the usual indoor method of savings. However, in physical education centers metal halide lamps and fixtures have in some instances paid for themselves in energy savings in as little as 172 days. Metal halide lamps were providing annual savings of 71% in Merrimack College's physical education center in North Andover, Mass.[113]

Albert E. Brooks recommended a number of favorable outcomes of switching from mercury vapor lamps to metal halide lamps in a physical education center at Ohio State University, Columbus.[114] A part of the process was the elimination of the "all on" or "all off" circuit breakers which had meant about 3,000 hours per year with the mercury vapor system.[115] The switch to the metal halide system offered these advantages, according to Brooks:

1. eliminate objectionable ballast noise
2. avoid frequent replacement costs
3. avoid raising electricity costs, including relamping labor, lamps, ballasts
4. secure efficient lighting, lower kwh/year for 72% savings
5. achieve better quality of light for greater visability with consequent increases in fee paying users[116]

This retrofit lighting system paid for itself in less than half a year. Its durability offered an estimated 20-year savings in excess of "$2.1 million assuming general inflation of 8% and energy inflation of 10%."[117]

Based on this experience of improved lighting quality at reduced cost, Brooks changed his bias from an emphasis on energy conservation to one of energy management. He clarified the distinction with these words:

> . . . With energy conservation, the goal is to save money without giving a thought to why the lighting is installed to begin with.
>
> With energy management the purpose of the lighting is considered foremost. It may mean more energy consumption rather than less, but the additional expense can be justified.[118]

Brooks recommended a disciplined emphasis on energy management to achieve the desired lighting quality with conservation.

Significant savings can be achieved while providing more appropriate lighting. The range of potential energy savings by installation of more efficient lighting and sensible conservation measures appears to be from 20 to 80 percent. With good planning, this can result in both improved quality of lighting and increased facility utilization.[119] For example, the Lake Catholic High School in Mentor, Ohio found the energy efficiency and quality of lighting in the gym made the long-lived mercury vapor lamps seem very inferior to the new high-pressure sodium (HPS) fixtures. They achieved the elimination of unwanted glare and shadow while experiencing "an energy savings of more than 71% and an overall cost savings of 67%."[120] Significant savings were expected in group relamping, energy efficiency (more than 60%), scaffolding, and ballast replacement (34%) costs due to reduced number of fixtures to achieve desired lighting, and operation and maintenance cost (68%).[121] Simple payback from savings achieved took only nine months. Furthermore, savings due to the change were expected to

continue for a 20-years period, "almost $300,000, . . . assuming that energy inflation will proceed at 8% per year and general inflation at 6%."[122]

Although William F. Liuzzo expressed some initial reservations "about the golden white color rendition of the HPS lamps" which "tends to distort some colors," he was very pleased to achieve "the additional light and superior distribution, along with significant cost savings."[123] Liuzzo listed some of the advantages of high-pressure sodium lights in this gym setting as follows:

> First of all, despite the fact that we switched from 91 400W lamps to just 40 250W lamps, lighting levels were almost tripled; from 35 foot-candles (fc) to 100fc. The additional light, plus better quality distribution, has given us far better quality illumination. . . . Signifiant safety improvements have resulted, too. . . . "The total illumination of the gym allows us a wider range of practice routines without a concern for 'blind or dark spots' that would create a safety hazard." (quoting baseball coach at end)[124]

Identifying lighting conservation measures can point to other potential energy savings in schools. When Kenneth B. Woodbury, Jr., provided a checklist of potential areas of energy savings, he included lighting as one of four primary headings, along with plant and program curtailment, heating/ventilation/air-conditioning, and insulation. Woodbury observed, for example, that both lighting and heating costs are saved by "rescheduling school activities from evening to day or to Saturday" and by "closing off unused areas of buildings."[125]

Energy Management Systems (EMS)

Energy management systems improve control and zoning of mechanical and electrical systems. They afford more flexible use of

space and effective monitoring as as means to informed energy management decisions. One advantage is reducing peak load demand to save on utility bills. In March, 1984 Deriso attributed part of the emerging flattening out of the energy costs curve to such systems, along with vigorous energy conservation programs and student and public awareness of the problems faced by school administrators.[126] Energy management systems permit the automatic turning on and off of energy systems periodically to deal with unoccupied space and unneeded equipment. Spaces such as hallways are only periodically used by enough people to require ventilation. Finally, EMS controls and monitors reliably indicate that equipment is being used as and when it should be, whereas, human error and other priorities make utility engineers less reliable.[127]

Energy management systems are increasingly employed in large school divisions. These systems are invaluable for central monitoring and control of temperature, lighting, humidity and the like. T. K. McGowan and G. F. Feiker described a control system for lighting which uses a "minicomputer chip, a numeric keyboard much like a calculator, and a receiver/switch located in the electrical supply line to the fixture."[128] Such a system provides flexibility in the use of space without heavy expenditures to modify equipment. Although lighting energy reductions as high as 47 percent were reported in experimental stations, the typical energy reduction from use of such systems was expected to be about 20 percent or more.[129] These systems are expensive

to initiate, but the savings have proven significant. They merit increasing application in schools.

When school systems evaluate computerized energy management systems, they will want to be certain that the savings achieved merit the high cost of the various points of sensing and control in the facilities.[130] Organizing in-service training to sensitize custodial and teaching staff to potential savings may eliminate the need of many central control points and a great deal of custodial labor. Specific building application, especially in retrofit situations, are important in assessing the merits of such systems.

Samuel E. Bleecker reported in January, 1982 that an affordable energy management system was being installed at Essex Community College in Baltimore to save 8 to 10% beyond 68% energy conservation saving already achieved. Bleecker credited the wedding of a "Bell System DIMENSION^{R} Private Branch Exchange (PBX) . . . to a recently developed Energy Communication Service (ECS)."[131] This was "the first system in the nation to fully integrate energy management and telecommunications," according to Bleecker. The ECS feature can be added to the DIMENSION PBX system which was "already in use in almost 20% of colleges and universities . . . as an on-premises central telephone network."[132] A large part of the additional savings at Essex was due to eliminating the need of custodial labor to regulate the manual system in each of eight major buildings on a 140 acre campus. Energy and labor savings were expected to pay for the system in about a year.

Savings of energy costs, other than labor, were to be achieved by three thrift strategies and one human error factor which were described as follows:

> One of three thrift strategies made possible by the system is demand management or load shedding that can trim utility bills dramatically. For instance, since electric bills for massive energy consumers are based on the highest level of consumption during a particular measured period in the billing cycle, the higher the peak, the greater the cost of energy. ECS is engineered to watch for the peak demand levels, then automatically turn off or reduce equipment use in a predetermined order to level out the demand below peak power rates.
>
> The system also cuts energy use with two other strategies: time of day switching off of unneeded equipment and time cycling, or periodic turning off of energy using devices such as ventilating equipment in hallways. This was previously done manually, but now the ECS turns on or off 62 points of control automatically at times keyed into the system.
>
> Another advantage, Klarner notes, is that "now we really know controls are operating the way they should be. Before, a lot depended on the attitude of the utility engineer. If, perhaps, he didn't feel up to par or was tied up with other priorities at the time, he might not want to make sure that every single thing was turned off precisely at the exact time."[133]

Thus, lower peak load power demands with consequent lower rates, periodic turn off of unneeded equipment, and overcoming human error offer substantial opportunities to save by use of such systems.

William P. Stump recommended integrated building management systems. He explained a number of alternative ways of utilizing "computer based microprocessors known as controllers" to coordinate "all devices, sensors, and other signal equipment transmitting a message of one type or another" in an integrated system.[134] While needs vary, depending on existing equipment, facilities and utilization patterns, integrated systems often provide significant savings in building

management. In reference to design or planning of new facilities, Stump said, "Colleges and schools can use these effectively to eliminate costly duplication of mechanical, electrical, and other building control systems."[135]

In a copyrighted (1983) chart of Burns International Security Services, Inc., Stump exhibited the many vital building functions which can be included in an integrated building management system.[136] The "audio/video systems" are grouped under three headings, as follows:

Fire Alarm/Security System:
- Smoke Detection
- Intrusion Detection and Access Control
- Sprinkler/Standpipe Monitoring
- Patrol Tour

HVAC/Mechanical Control Systems:
- Temperature Control
- Equipment Monitoring Control
- Elevator and Fan Control
- Telemetry/Command Operations

Cost Reducation Programs:
- Energy Conservation
- Programmed Maintenance/Operations
- Personnel Scheduling and Evaluation
- Telecommunications[137]

Appropriate application of an integrated building management system depends on the use of the building or facilities. When school or college facilities are occupied primarily during the daytime, Stump suggested the advisability of integrating heating, security, energy management, etc.[138] Most facilities maintain telecommunication as a separate function.[139] According to Rippeteau, Don Spiegel indicated that "computer systems are most effective when linking a variety of building types and space uses. . . . Airports and large university campuses also lend themselves well to energy management systems."[140]

Protection, energy management and automation of monitoring and control are the basic uses.

Stump gave two university illustrations of use of the systems described. The University of Utah was, according to Stump, ". . . giving the computer more and more decision making functions based on outside and inside temperature, building schedule, and time of day."[141] Energy related controls of the integrated system at Wright State University included the monitoring of energy emergencies and an electricity demand report every half hour which is printed three times a day.

Stump noted that the system could pay for itself in two or three years of reduced operating costs "by automatically managing and controlling energy usage, building systems and maintenance tasks."[142] As Stump said,

> Growing crime rates, increasing fire insurance rates and rising energy costs are making it more expensive than ever to manage today's schools and universities. A coordinated security/energy management/building automation system now makes it possible to combine all the individual monitoring and control functions into one economical system.[143]

The potential savings achieved by use of energy management systems depend on a number of factors, including technology selected, comprehensiveness of the control system, retrofit or new application and previous conservation measures. Examples have indicated the kind of payback period which may be expected. Essex Community College projected energy savings of only 8 to 10% to pay for the system in one year.[144] The coordinated security/energy management/building automation systems described by Stump permitted a two or three year payback period in

1983.[145] When Michigan State University did a feasibility study of a phased energy management program in retrofit application, they expected payback "in the range of 20-30%, over and above what had already been accomplished with previous energy conservation measures."[146]

Energy efficient design in new construction may eliminate the economical value of adding a computerized energy management system. In 1980 Jane U. Rippeteau quoted Dan Spiegel, saying, "'Spending a lot of money picking up that last 5 percent may not be worth it.'"[147]

Nevertheless, Rippeteau proceeded to describe some of the design features used by Encon Corp. of Toronto, Ont., "one firm committed to the creation of energy efficient buildings to guarantee life-cycle energy consumption."[148] A project of Encon's, the Gulf Canada Square Building, Calgary, Alta., was expected to require "only 35,000 Btu's per square foot a year."[149] Rippeteau outlined some of the devices employed to attain this low energy consumption as follows:

> o **Curtain-wall air ducting.** This patented wall system blankets the window with conditioned air from a continuous slot in the sill. It provides insulation of the glass area against heat and cold and drafts.
>
> o **Coffered ceilings.** An integrated ceiling design provides better reflected lighting at one-third the normal energy requirement for a comparable building general illumination of 100 footcandles. Integrated with air supply diffusers and return air openings, it also acts as a funnel to collect ambient heat from lighting, people, and equipment, and returns it to the system.
>
> o **System control.** To maintain a temperature of 73 degrees, plus or minus two degrees, and a relative humidity of 35 percent, Gulf Canada Square will have 800 sensors feeding back to Encon's patented computer control energy input, storage, and output, in order to minimize energy consumption.[150]

The language was unclear regarding the percentage of energy savings anticipated through the computer control system aspect of the design.

With such levels of climate control in energy management systems, declining costs of energy management systems make them very appealing for use in new construction.

Significant Capital Investment in an Energy Master Plan

A movement from 2-4% to nearly 10% of campus' operating budgets to energy strongly suggests that more extensive energy saving measures, involving significant capital investment, are needed. Crittenden estimated that "the average campus could cut its energy use by 25% by devising and implementing an energy master plan tailored to its situation."[151] At least twelve campuses around the country were demonstrating this conservation potential, with funding by The John A. Hartford Foundation of New York City.[152] The potential salvaging of 32,250 faculty positions in higher education alone by saving 25% of energy expenditures merits some alteration of institutional inertia in the area of energy decision making. Crittenden emphasized involvement of all parties, coordinated decision making, and installation of a computerized energy information management system to identify wasteful buildings and permit appropriate decisions regarding upgrading energy systems and scheduling use of buildings.

More is needed than an effective energy information and decision making system. The mentality which sees modification or replacement of inefficient equipment solely as an expense must be changed. Investment in energy efficiency improvements pays for itself in savings. "In fact," said Crittenden, "campuses can earn a rate of return as high as

40% by investing in energy efficiency, much more than through traditional investments."[153] For example, Brown University of Providence, Rhode Island, invested in a computerized system of zonal temperature control in a dozen buildings. The system was expected to pay for itself in savings in less than three years.[154] He advised colleges not to ignore the many other cost-effective conservation measures available. Long-term answers provide more significant savings. Quick payback period and investment values may alter the mentality of those who have not taken Crittenden's advice.

Faced with shrinking financial resources, Cheyenne Mountain School District 12 took a longer energy investment perspective.[155] The administrative staff was dealing with 25-40 percent a year increases in energy costs. The district's school's energy budget "represented 50 percent of the non-payroll costs."[156] In order to maintain educational programs, provide adequate salaries and reserve a large portion of funds for direct educational costs, they approved and hoped to implement within one year all of the conservation measures recommended by the consulting engineers "with a 10-year or less payback period."[157]

Modular Design

When Donald Burr identified the low occupancy rate of heated spaces as a characteristic energy problem in schools, he also suggested partial solutions. First, extensive modernization breaks down the central heating plants so that component parts of buildings can be heated or cooled on a modular basis rather than providing essentially uniform thermal conditioning to all spaces. He spoke of "buildings

within buildings" as a working concept.[158] Such space conditioning gives school buildings greater value for community occupancy-use in non-traditional functions of school facilities. Community school functions tend to reduce the ratio of wasteful use of energy relative to occupancy, while modular zoning of the heating system reduces the total heating bill. The net effect is greater utilization at reduced costs.

Using Waste Heat of Lights and Bodies

Energy systems should be designed to use the heat generated by human bodies and the lights in classrooms. To avoid reverting to the inefficient practice of using even more energy to cool the room shortly after classes begin, Burr recommended the use of heat collecting devices to conserve body and light heat. This process can include energy storage bins from which heat can be retrieved when it is needed.[159] The 17,300 to 26,300 Btus (depending on the amount of solar gain) of energy generated by body heat, lights and solar gain of the typical, occupied classroom make a lot of heat energy available for use most of the year from these sources. Indeed, excess heat is usually available in a well insulated, occupied classroom when the interior temperature is above 37°F.[160]

Saving by Ventilation to Minimize Air Conditioning

Appropriate design features minimize the extent of seasonal dependence upon air conditioning. The financial implications of using mechanical (refrigeration) cooling instead of a standard unit ventilator make the point. In July, 1981 DiMercurio wrote,

> Typically, it costs 35 times as much to use refrigeration cooling as it does to operate the 1/8hp motor driven fans of a standard unit ventilator.
>
> Consider a 40 classroom school paying an electrical rate of 5¢ per kwh and a clear, mild day in the 50 to 60°F range. An average energy use for mechanical cooling is 5.825 kw per hour per classroom. The 40 room school would need 233 kwh, costing $11.65, to provide mechanical cooling for one hour if an air system without economizer is used.[161]

Unit ventilators serve well when outside temperatures are only about 10°F below the interior comfort level. DiMercurio found in "the now accepted thermostat settings of 78°F for cooling and 65°F for heating" new support for use of "the only kind of HVAC system designed specifically and exclusively for schools."[162]

The need to achieve climate control in buildings can be satisfied in various ways. When cooling thermostats are set at 78°F, unit ventilators can provide superior air quality while achieving significant savings in cooling. Unit ventilators "move more air than other kinds of systems", typically "1,000 to 1,500 cfm of air."[163] Air mixture is controlled by dampers and filtered to remove dirt. DiMercurio said,

> . . . Room air fans operating at constant volume control the air flow. Even when mechanical cooling is off, ventilation cooling can be provided until room temperature rises to 78°F. This means more comfortable temperatures, like 74°F, as long as outdoor temperatures permit.[164]

The variable air volume (VAV) systems "became popular in office buildings with large core areas and relatively stable cooling loads in the late 70s."[165] Reducing the amount of air being circulated to save on air conditioning costs is to defeat the purpose of the school if the consequence is "stuffiness and inattentive students."[166]

The switch to mechanical cooling optimally occurs "when outside temperatures go much above 60°F."[167] However, DiMercurio added, "With cooling thermostats set at 78°F, it takes air no higher than 70°F to do an effective cooling job."[168] Below such outside temperatures, the superior ability of unit ventilators to move more air at much lower costs recommends their use in the cooling season.[169]

The savings achieved by use of ventilation cooling in Atlanta in a typical week in October and January illustrate its value. Ventilation cooling was adequate for 22 hours of a forty-hour week in October and 32 hours of a forty-hour week in January. Some form of cooling was required for all hours of school occupancy in October and for "part of every day during the typical January week."[170] Evidently hundreds or thousands of dollars may be saved by schools which use both ventilation cooling and refrigeration cooling.[171]

DiMercurio made several observations regarding the kinds of unit ventilators and their more or less appropriate uses.

> . . . Both ceiling and floor unit ventilators are available and they come in the following types: (numbers added) (1) water source and air source heat pump heating and cooling units, (2) hydronic heat units, (3) all electric heating units, (4) two pipe and four pipe heating and cooling units and (5) units that have built in, self contained refrigeration cooling with a choice of steam, hot water or electric heating.
>
> All types of unit ventilators operate on the same principle. By definition, unit ventilators can bring in up to 100% outside air for ventilation cooling.[172]

In some settings the typical energy savings reported do not apply and first cost considerations assume greater importance. DiMercurio offered these ideas under the heading, "First cost considerations":

> Along with (numbers added) (1) operating costs and (2) temperature control capability, design professionals and school administrators cannot ignore (3) first cost in choosing HVAC systems. The installed costs of unit ventilator systems vary considerably with the kind of unit ventilator system--heat pump, self contained, hot and chilled water--and the kind of structure involved.
>
> Unit ventilators would be more costly for interior rooms of a multistory school building, for example. Ceiling unit ventilators could be used but the cost increase for running insulated ductwork from the units to an outside air source might be prohibitive.
>
> On the other hand, a one or two story structure, even with a large interior space in relation to the perimeter, should be comparatively economic since the unit ventilators could be connected to roof air intakes with a minimum amount of ducting.
>
> A combination system such as a water source heat pump unit ventilators on the perimeter and roof mounted hydronic heat pumps for the core area, might prove more economical when considering the life cycle cost of the structure.
>
> Even water source heat pump unit ventilator systems that require only a small water heater and evaporative cooler, compared with a central boiler and chiller for a two or four pipe system, generally offer attractive installed costs in schools with a cooling load of at least 50 tons--roughly 20 classrooms or more.[173]

DiMercurio comforted the school administrator by a reminder of the resources available this way:

> Whatever the configuration of the school and the type of unit ventilator system employed, architects, engineers and contractors accustomed to designing and building schools are going to be familiar with the economics of the system. Installed costs can be calculated without great difficulty and compared with the costs of other kinds of systems.[174]

The conclusion of DiMercurio is this:

> Quite often unit ventilators will prove to be not only the least costly system to operate, but also the least costly to purchase and install. Such costs have played a big part in making unit ventilators the most popular heating cooling system in schools over the past 60 years.[175]

High-rise mechanical cooling energy systems, used to cool interior rooms in some modern multistory buildings, are evidently less appropriate than

one or more of the several unit ventilation systems in the more typical one- or two-story structure.

Where other means can be found to eliminate the need for refrigeration cooling the potential savings are even greater. Use of such a system, with cooling thermostats set at 78°F, in combination with cool storage and cooling tubes to precool intake air by natural processes, may well virtually eliminate the need of air conditioning in many educational settings.

Rita Robison described another strategy for saving energy in cooling, namely, the operation of "evaporative chilling--a process that links a cooling tower to the chilling equipment."[176] Although the potential saving is less than that achieved by the unit ventilator, as compared to refrigeration, it was important. She said,

> . . . During the fall, winter and spring, the tower can produce water cold enough to eliminate the need for running the chiller. Equipment that consumes about 0.2 kw per ton is substituted for a refrigeration machine which normally consumes about 1 kw per ton. This is an 80% energy reduction.
>
> Evaporative chilling can be designed into new chilled water systems or into existing systems. It can produce dramatic energy savings even in warm climates.[177]

Robison described several aspects of this technology. These included four basic types of evaporative chilling systems:

1. Cooling tower and heat exchanger.
2. Industrial fluid cooler.
3. Chiller vapor cycles.
4. Filtration systems.[178]

She described the three basic types of cooling towers associated with evaporative chilling: counter flow, parallel flow and crossflow. The latter poses icing problems during the winter.[179] Robison explained

ways to reduce demands on pump and fans, the only two components of the old cooling towers that consume energy. In addition, she described energy saving innovations in the "fill (the material which breaks the water into droplets)", louvers, drift eliminators and fans. In each area real savings have been achieved.[180]

Robison also gave specific ideas to schools attempting to evaluate bids when buying cooling towers. Helpful suggestions were made concerning locating cooling towers and insistence upon field testing of the tower in bid evaluation to determine whether it performs at its design rating.[181]

Saving Refrigeration Dollars

Although significant savings can be achieved by the quick fix method of unplugging underutilized refrigerators, especially those which are not in use in summer,[182] other strategies can provide additional savings. Increased appliance efficiency offers a significant opportunity for savings in refrigerators and other appliances. Government standards and user awareness can be instrumental in reducing energy demand is this area.

Insulating to Save Heating and Cooling Energy

Insulation is one appropriate conservation remedy for structural flaws in buildings. Thermography can identify the areas of a facility needing improved insulation through "color variations picked up via infrared scanning and photography."[183] Insulation deals with undesirable heat gains or losses which would require air conditioning or

heating. Of course, the remedial tightening of the building skin suggests the need of compensatory measures to add adequate ventilation to avoid indoor air pollution.

Energy efficient design features were employed in sub-zero temperatures in town houses at St. Michael's College in Winooski, Vermont. These features contrast sharply with poorly insultated facilities. The design/build contractor,

> . . . built exterior walls (from the inside to the outside) with a half inch of sheetrock, a six mil vapor barrier, six inches of fiberglass insulation, a half inch of asponite siding, two one inch layers of styrofoam, a half inch of dead air space and four inches of brick.
>
> Foundation walls on the units are separated from the slab by a two inch styrofoam thermal break. Additional styrofoam is placed under the slab along all exterior walls and there are 12 inches of fiber glass insulation in the ceiling. Triple glazed windows are placed, wherever possible, with maximum glass exposure on the south side of the buildings and roof overhangs protect the interior from the most intense summer sun.[184]

Another energy efficient design feature used in these dormitories which relies on an insulated storage area helps hold down fuel demand peaks. Electric heated, brick storage units are "controlled by a central load shedding energy computer." Warmed by electric heat coils, the heated bricks provide an additional heat source during high use hours.[185]

Dr. Kenneth B. Woodbury, Jr., indicated that the potential savings through installation of insulation in roofs and walls alone could be as high as thirty-five percent.[186] Commonly insulated aspects of buildings are walls, ceilings, roofs, pipes, windows and doors. Reducing the transmission coefficients of these surfaces saves energy. The quality and quantity of the original insulation will obviously

determine the values to be achieved by retrofit additions. The insulation of walls and roof of Oakton Community College, Des Plaines Ill., illustrates the technical aspects implemented there:

> The insulated walls are composed of 3 3/4 in. face brick, 1/2 in. air space, 1 1/2 in. foil backed polyurethane board, 5 3/8 in. concrete block, 7/8 in. air space and furring, and 5/8 in . gypsum board. . . . The roof, a built up, four ply surface with rigid insulation, also keeps out extremes of temperature.[187]

By slowing heat and cold absorption insulation saves energy used in heating and air conditioning.

At least two panes of glass have now become a standard way of insulating windows. Three panes are often recommended for use in reduced window areas on the north side of buildings.

A number of other opportunities are available to save energy by insulation in some settings. Thomas W. Raftery recommended Thermo-Fold draperies as a solution to a heat loss and heat gain problem in glass walled, open space school buildings. When used in combination with styrofoam insulation for the roof and overhangs in Tompkins-Cortland Community College, in the rolling hills of New York State's Finger Lakes Region, the energy consumption decreased by nearly fifty percent.[188] The Thermo-Fold draperies were also valued for reducing acoustical problems, contributing flexibility in use of the open space, and letting in and keeping out sunlight as desired.

Ruth E. Fillion recommended a brand of heat retaining blanket (HRB) to save energy in pools. This feature permitted the Lincoln-Hancock Community School in Quincy, Mass. to keep its pool open during the winter for swimmers. The HRB is described as "minimizing pool water

and natatorium heating requirements, ventilation demands and chemical consumption."[189] The pool blanket "nearly eliminates evaporation which accounts for 80% of pool water heat loss, and cuts down the humidity," allowing "the air handling system to shut down during the evening hours, reducing electrical consumption dramatically."[190] Furthermore, Fillion stated, "Lower humidity will . . . maximize building integrity for years to come."[191] The five-year limited warranty on the reel system and the "average payback period of less than one year" make this a valuable item in insulation where it is needed.[192]

Earth berming is a method of utilizing the insulative properties of the earth itself to save heating and cooling expenses. Earth berming lends itself to both new and retrofit applications. Potential use of berming is an important consideration in landscaping and site selection of modern buildings. It is most helpful where the temperature is highly variable, especially on the cold end of the spectrum, and facilities need some shielding from high wind speeds.

More or less total earth sheltering of the roof area is often an appropriate conservation measure in new facilities. The desire to minimize heat loss and unwanted heat gain due to climate can be satisfied to a large degree by earth sheltering schools. Such construction readily copes with heat loss through the roof which "typically exceeds 50% of the total heat losses through the building envelope."[193] Very substantial savings can be achieved by appropriate earth sheltering of north, east and west walls where the amount of heat

loss may sometimes be as much as 35 times as great in severe winter weather without the insulating value of the earth.[194]

North, east and west wall berming offers an economical alternative to the fully recessed structure. This is a particularly suitable choice where the landscape slopes gently around the building. The bermed wall loses only about 5% more heat than a fully-recessed structure. The difference is not great enough to warrant major structural alteration in retrofit applications to permit total sheltering. In summer cooling is provided by the surrounding earth as opposed to unwanted heat gain from even well designed windows.

Accompanying earth berming, south facing windows can provide solar heat gain in winter. Minimal use of windows on north, east and west walls will help avoid winter heat loss.

Space Heating Savings

Auer and others have indicated that a 50% reduction in space heating needs can be achieve "through aggressive and cost-effective energy conservation measures."[195] Reducing thermostat settings, ceasing to heat and ventilate unoccupied space, sealing leaky outside dampers, installing insulation, weather stripping, caulking, earth berming, resizing fans, closing north windows, double glazing windows, upgrading and automatic controls and monitors, improving the effiency of air distribution systems, heat recovery, load shedding, regular maintenance schedules, and downsizing and installing more efficient burners to match reduced needs are among the conservation measures used.

Donald R. Price said, "The quickest and most economically sound practice to reduce energy consumption is by conservation."[196] He defined conservation as "an operation that improves the efficiency of an operation with regard to energy utilization."[197] In the same context he advocated the use of sophisticated electronic equipment to control and monitor energy use and heat exchangers to recover waste heat.[198]

Alternative Financing for High Cost Programs

The sequence of implemenation of conservation measures varies with the setting, budget limitations and so on.[199] If efficient building design and people factors related to control of energy waste can be dealt with first, the sizing of active systems can be reduced to achieve savings. However, even quick payback items are often expensive. Consequently, alternative financing may be needed to realize savings. Likewise, many energy saving strategies which afford great life cycle advantages require a long period to payback the capial investment through savings. Financing decisions should be evaluated in a manner which acknowledges the comprehensive, long term values to be achieved.

In February, 1984 Richard M. Esteves highlighted the limited use of comprehensive, capital intensive conservation measures which offer significant energy savings in schools.[200] To deal with the (1) skepticism of administrators and (2) lack of needed funds he recommended that schools explore the creative financing alternatives being offered by more than 100 companies dealing with energy conservation on a regional or national basis.[201] These creative alternatives "assure the

benefits of energy improvements while reducing the risks and eliminating the need for internal funding," according to Esteves.[202]

Schools and universities are increasingly following the suggestions outlined by Esteves. The five creative methods of financing are as follows: (1) saving guarantees, (2) cash flow leasing, (3) shared savings, (4) guaranteed shared savings, and (5) cooperative savings programs.[203] Esteves said "most schools and similar facilities whose annual energy bills are above a minimal $30,000-$50,000 level are normally eligible" for these programs.[204] The savings guarantee option is essentially the securing of value sought by having a third party insurer provide a "warranty on the savings projected."[205] The cash flow leasing option was used to cover 36 buildings in Washington County, Maryland, "probably the single largest creative financing agreement for schools in the United States."[206] The shared savings approach is "the fastest growing of the alternative conservation programs," offering energy audit, engineering, design, purchase, installation, maintenance and service at no cost other than "a portion (usually 50% or more) of any resulting savings."[207] The guaranteed shared savings works essentially like the shared savings except that a minimum cost savings is guaranteed, with the private company keeping most of the excess savings.[208] The final option, a cooperative savings program, provides financial, administrative and other resources for school systems which desire to use local contractors and engineers while enjoying the benefits of creative financing."[209]

These options are short-term answers to financial limits on appropriate energy savings. However, future technology and the best remedy currently available may be missed by the private supplier who offers fairly long-term contract for guaranteed earnings. Some of these plans may limit potential additional savings. Nevertheless, the merit of the whole process is that life cycle costing will tend to support renewable energy technology development even in a conservative climate in school financing of major improvements in energy systems.

Esteves illustrated creative financing by use of specific schools and private suppliers. He recommended additional sources of information, including "state and federal energy offices and many utilities."[210] He indicated that innovative conservation financing companies would be aware of a broad range of technologies and equipped to deal with the life cycle advantages and disadvantages of low-technology and high-technology equipment.

Reasonable Conservation Expectations

Extrapolation from energy conservation achieved in a variety of settings suggests the possibility of achieving an overall level of 30% to 50% savings through conservation measures without resorting to renewable energy systems. Eric R. Zausner reported in September, 1979 that "few responsible analysts" believed that conservation would "be able to reduce the historic demand growth rate by more than half."[211] The estimate of David Rose in the same year was that the U.S. could sustain the present GNP with half as much energy. However, it would take 40-50 years to achieve that goal. Rose, therefore, recommended

"conservation incentives, including rising energy cost, . . . structured so that by the year 2020 half as much energy as is now used would suffice for today's national total of goods and services."[212] The fact that in 1979 Sweden was consuming more than one-third less energy per capita than Canada, with a similar economy, climate and lifestyle, suggests the reasonableness of achieving the same GNP with half the energy through extensive use of conservation measures and more use of renewable energy resources.[213] Hooker and others indicated that inefficient design wastes 50 percent of Canada's energy.[214] Dealing with the combination of wasteful "energy-intensive lifestyles" and inefficient design offers many opportunities for educators to have a real impact in achieving conservation goals.

CHAPTER THREE ENDNOTES

1. Paul Abrecht, ed., Faith, Science and the Future: Preparatory Reading For a World Conference Organized by the World Council of Churches At the Massachusetts, Institute of Technology, Cambridge, Mass., USA, July 12-24, 1979) (Geneva, Switzerland: Church and Society, World Council of Churches, 1978), p. 96.

2. "One energy miser's plan," American School & University, 53:8:64, April, 1981.

3. Jennifer A. Adams, The Solar Church (New York: The Pilgrim Press, 1982, p. 94.

4. Ibid., p. 13.

5. C. DiMercurio, "Ventilation cooling: an old solution to new problems," American School & University, 53:11:38, July, 1981.

6. Alan Caruba, "Indoor Pollution: The Invisible Enemy," American School & University, 56:8:46, April, 1984.

7. Ibid.

8. Ibid.

9. Ibid.

10. Ibid. Repace was "an environmental policy analyst for the U.S. Environmental Protection Agency."

11. Ibid.

12. Ibid.

13. Ibid., p. 47.

14. "Facilities newsfront," American School & University, 52:7:81, March, 1980.

15. Winslow Fuller, "What's in the Air for Tightly Built Houses?," Solar Age, 6:6:30, June, 1981.

16. Ibid.

17. Ibid., p. 32.

18. Ibid., p. 31.

19. Ibid., p. 32.

20. Ibid.

21. Bea Scala, "Light It Right But Save the Power," Administrative Management, XXXVII:10:27, October, 1976.

22. Ibid., pp. 27-28.

23. Ibid., p. 28.

24. Ibid.

25. Ibid.

26. Kenneth B. Woodbury, Jr., "A Practical Guide to Energy Conservation," American School & University, 52:7:70, March, 1980. Woodbury was "dean of humanities and social sciences at Northampton County Area Community College, Bethlehem, Pa."

27. "Energy audit . . . here's how," American School & University, 55:12:45, August, 1983.

28. Gerald F. Bender and Jack F. Probasco, "Include passive solar in your renovations," American School & University, 53:8:41, April, 1981.

29. Scala, op. cit., p. 28.

30. Ibid.

31. Bender, op. cit., pp. 41-42.

32. Scala, op. cit., p. 28.

33. "Energy audit," op. cit., p. 45. Spielvogel made the observation without making a recommendation regarding the practice of removing light diffusers.

34. Scala, op. cit., p. 27.

35. Ibid.

36. Woodbury, op. cit., p. 70.

37. "Energy audit," op. cit., pp. 40, 42, 44 & 45.

38. Ibid., pp. 42 & 44.

39. Ibid., p. 44.

40. Ibid., pp. 42, 44 & 45.

41. C. A. Hooker and others, Energy and the Quality of Life: Understanding Energy Policy (Toronto: University of Toronto Press, 1981), p. 10.

42. Richard C. Dorf, Energy, Resources, & Policy (Reading, Massachusetts: Addison-Wesley Publishing Company, 1978), p. 34.

43. Ibid., p. 38.

44. R. W. Ferrier, "Energy: Petroleum," Britannica Book of the Year (1984) (Events of 1983), Chicago: Encyclopaedia Britannica, Inc., 1983, pp. 347-348.

45. Rebecca Vories, "Conservation for School District," Solar Utilization News, 8:6:5, December, 1983.

46. Ibid. Their experts: "For more information, contact BHCD Engineers, P.O. Box 5237, Denver, Colorado 80217. Phone (303) 893-8880."

47. "Use a consultant," American School & University, 55:4:24, December, 1982.

48. "Energy audit . . .," op. cit., p. 40.

49. Ibid.

50. Ibid., pp. 40, 42, 44 & 55.

51. "One energy miser's plan," op. cit., p. 64.

52. "Energy management yields results," American School & University, 52:9:34, May, 1980.

53. Ed Crews, "Consultants help solve energy-related design problems," Richmond News Leader, p. 7, col. 7, July 5, 1982.

54. Ibid., col. 8.

55. Bob N. Cage, "Thermography," American School & University, 56:12:37-40, August, 1984.

56. Ibid., p. 37.

57. Ibid., pp. 37-38.

58. Ibid.

59. Ibid.

60. Ibid.

61. Ibid., pp. 39-40.

62. Ibid., p. 40.

63. Ibid., pp. 38-39.

64. "Use a consultant," American School & University, 55:4:24, December, 1982.

65. Ibid., pp. 24-25.

66. Ibid., p. 24.

67. "One energy miser's plan," American School & University, 53:8:64, April, 1981.

68. Ibid., p. 65.

69. Ibid., p. 64.

70. Vories, op. cit., p. 5.

71. "One," loc. cit.

72. Kenneth B. Woodbury, Jr., "A Practical Guide to Energy Conservation," American School & University, 52:7:68-70, March, 1980.

73. "Energy audit," op. cit., p. 45.

74. Ibid.

75. "High Efficiency Building Recognized for Conservation," American School & University, 52:7:79, date.

76. "One," loc. cit.

77. Christopher E. Crittenden, "Campus Dollars Go Up in Smoke," American School & University, 56:7:541, March, 1984.

78. Ibid.

79. "Energy 'on the House,'" American School & University, 55:8:341 & 34n, April, 1983.

80. Ibid., p. 34n.

81. "The Solar Age Domestic Hot Water Directory," Solar Age, 6:6:2-9, June, 1981. This is a detachable center supplement by several authors.

82. Ibid., p. 9.

83. Ibid., pp. 8-9.

84. Paul Abramson, "9th Annual Report on Educational Construction," American School & University, 55:8:40, April, 1983.

85. Ibid.

86. Paul Abramson, "10th Annual Report on Educational Construction," American School & University, 56:8:19, April, 1984.

87. Ibid.

88. C. William Day, "The Shape of Schools to Come," American School & University, 56:3:8, November, 1983.

89. Dorothy Wright, "A Preface to Architectural Portfolio," American School & University, 56:3:3, November, 1983.

90. Crittenden, loc. cit.

91. Ibid.

92. Crittenden, loc. cit.

93. Kenneth B. Woodbury, Jr., "A Practical Guide to Energy Conservation," American School & University, 52:7:68-70, March, 1980.

94. Gerald F. Bender and Jack F. Probasco, "Include passive solar in your renovations," American School & University, 53:8:38, April, 1981.

95. Ibid.

96. Jerald L. Deriso, "13th Annual Maintenance & Operations Cost Study," American School & University, 56:7:16, March, 1984.

97. C. William Day, "The Shape of Schools to Come," American School & University, 56:3:8, November, 1983.

98. Thomas Werner, "Things Fall Apart," American School & University, 56:6:63, February, 1984.

99. Bender and Probasco, p. 41.

100. Ibid., p. 38.

101. Crittenden, loc. cit.

102. C. A. Hooker and others, Energy and the Quality of Life: Understanding Energy Policy (Toronto: University of Toronto Press, 1981), p.102.

103. Bender, op. cit., pp. 41-42

104. Ibid., p. 42.

105. Ibid.

106. Paul Farnsworth, "Lighting energy dramatically reduced," American School & University, 56:5:42, January, 1984.

107. Ibid.

108. Ibid.

109. Ibid.

110. Ibid.

111. Ibid.

112. Ibid.

113. Albert E. Brooks, "In Lighting, Less is More," American School & University, 55:8:20, April, 1983.

114. Ibid., pp. 20 & 57.

115. Ibid., p. 20.

116. Ibid., pp. 20 & 57.

117. Ibid., p. 57.

118. Ibid.

119. Ibid., p. 20.

120. William F. Liuzzo, "Easy on the Eyes," American School & University, 56:12:34d, August, 1984.

121. Ibid.

122. Ibid., p. 34h.

123. Ibid., p. 34d.

124. Ibid., p. 34h.

125. Woodbury, op. cit., pp. 68-70.

126. Deriso, "13th Annual. . . .," op. cit., p. 20.

127. Samuel E. Bleecker, "Energy management system uses the phone to keep costs in line," American School & University, 54:5:76, January, 1982.

128. T. K. McGowan and G. E. Feiker, "A New Approach to Controlling Lighting Systems," Administrative Management, XXXVII:10:29, October, 1976.

129. Ibid., p. 30.

130. Janue U. Rippeteau, "Making Your Buildings Energy Efficient," Administrative Management, XLI:4:55, April, 1980.

131. Samuel E. Bleecker, "Energy management system uses the phone to keep costs in line," American School & University, 54:5:76, January, 1982.

132. Ibid.

133. Ibid.

134. William P. Stump, "'Similify, Simplify': Here are the ABCs of integrated systems," American School & University, 55:8:26, April, 1983.

135. Ibid.

136. Ibid., p. 28.

137. Ibid.

138. Ibid., pp. 26 & 28.

139. Ibid., p. 28.

140. Rippeteau, op. cit., p. 55.

141. Stump, op. cit., p. 28.

142. Ibid., p. 33.

143. Ibid.

144. Bleecker, op. cit., p. 76.

145. Stump, op., cit., p. 33.

146. "Energy management yields results," American School & University, 52:9:33.

147. Rippeteau, op. cit., p. 55.

148. Ibid.

149. Ibid.

150. Ibid.

151. Crittenden, op. cit., p. 541.

152. Ibid.

153. Ibid.

154. Ibid.

155. Rebecca Vories, "Conservation for School District," Solar Utilization News, 8:6:5, December, 1983.

156. Ibid.

157. Ibid.

158. Donald Burr, "Conserving Energy at School," Vocational Education, 54:1:22 & 24, January, 1979.

159. Ibid., p. 24.

160. C. DiMercurio, "Ventilation cooling: an old solution to new problems," American School & University, 53:11:40, July, 1981.

161. Ibid.

162. Ibid., p. 38.

163. Ibid., p. 43.

164. Ibid.

165. Ibid., p. 40.

166. Ibid.

167. Ibid., p. 42.

168. Ibid.

169. Ibid., p. 43.

170. Ibid., p. 42.

171. Ibid.

172. Ibid.

173. Ibid., p. 43.

174. Ibid.

175. Ibid.

176. Rita Robison, "New directions for evaporative cooling systems," American School & University, 54:2:56.

177. Ibid.

178. Ibid., pp. 56-58.

179. Ibid., p. 58.

180. Ibid., pp. 59 & 61.

181. Ibid., p. 60.

182. "Energy audit," op. cit., pp. 44 & 45.

183. Bob N. Cage, "Thermography," American School & University, 56:12:37-40, August, 1984.

184. "Heated Bricks," American School & University, p. 45, August, 1983.

185. Ibid.

186. Kenneth B. Woodbury, Jr., "A Practical Guide to Energy Conservation," American School & University, 52:7:69, March, 1980.

187. "Best of college architecture: AS & U's Architectural Competition," American School & University, 53:11:32, July, 1981.

188. Thomas W. Raftery, "Raftery's Thermo-Fold draperies save energy," American School & University, 54:5:100, January, 1982.

189. Ruth E. Fillion, "Pool blankets keep Qunicy in the swim," American School & University, 56:5:53, January, 1984.

190. Ibid.

191. Ibid.

192. Ibid.

193. Underground Space Center, University of Minnesota, Earth Sheltered Housing Design: Guidelines, Examples, and References (New York: Von Nostrand Reinhold Co., 1979), p. 56.

194. Ibid., p. 59.

195. P. L. Auer, Renewable Energy Resources, pp. 26-27.

196. Donald R. Price, "A New Energy Ethic for Farmers," Vocational Education, 54:1:48, January, 1979.

197. Ibid.

198. Ibid.

199. Vories, loc. cit.

200. Richard M. Esteves, "Creative Financing," American School & University, 56:6:48, February, 1984.

201. Ibid., pp. 48 & 52.

202. Ibid., p. 48.

203. Ibid., pp. 50 & 52.

204. Ibid., p. 50.

205. Ibid.

206. Ibid.

207. Ibid.

208. Ibid.

209. Ibid.

210. Ibid., p. 52.

211. Eric R. Zausner, "Without a Workable Energy Policy--WHY?," USA Today, 108:2412:16, September, 1979.

212. David J. Rose, "Towards a Sustainable Energy Future," Roger L. Shinn, ed., Faith and Science in an Unjust World, 1980, p. 244.

213. Hooker, op. cit., p. 34.

214. Ibid., p. 102.

Chapter 4

EVALUATING RENEWABLE ENERGY SYSTEM OPTIONS

Attention now shifts from characteristic energy uses and conservation priorities in school facilities to efforts to match renewable energy resources to uses within appropriate restraints, some of which are set by limitations of the users and the setting. Various energy resources have more and less appropriate uses and some mixing and matching of several technologies is often more appropriate than a single source. Schools need to keep all energy options open while moving toward renewable energy self-sufficiency. The short- and long-term needs can be met with less disruptive effects along a whole line of technological, climatological, governmental, environmental, economic and social dimensions by mixing and matching sources and uses.

The movement toward use of renewable energy resources is a movement which acknowledges that the environment in which facilities are built is a total energy system involving the interaction of such diverse elements as ocean currents, volcanic activity, solar flares, seasonal changes, mountain ridges, landscaping, radioactive decay and environmental pollution. Latent, sensible, indigenous, diverse and decentralized are some of the words which characterize these resources which were inadequately utilized for several decades due to cheap and plentiful supplies of fossil fuels. The myth of plentiful, cheap fossil fuels must give way to new realities and, first, to the necessity of

conservation while the useful life of the current infrastructure of western civilization is being changed.

Distinguishing Between Conservation Measures and Renewable Energy Systems

Conservation measures and renewable energy measures involve some degree of overlap, but they can usually be distinguished as more nearly fitting one or the other category. Increasing lighting controls, utilizing task lighting rather than extensive general lighting at a similar level, reducing wattage and using more energy efficient light sources and fixtures clearly fit in the area of conservation measures. Automatic thermostats, more efficient ventilation systems, downsizing fans, pumps and boilers, increasing localization and automation of HVAC controls are also useful conservation measures. So is use of a ventilation system instead of air conditioning when the outside temperature permits. Shutdown of unnecessary energy systems, based on carefully planned schedules and computer monitoring, maintaining a lower more appropriate hot water temperature, providing additional insulation and reducing air leakage through windows and doors are important conservation measures. Regular maintenance schedules which help avoid labor costs and the use of custodial teams for cleaning provide two additional examples of conservation strategies.[1]

Sometimes it is difficult to distinguish conservation measures from renewable energy systems. This is especially true in the case of the use of passive solar energy features which might appropriately be

described as effective design utilization of climate and light influx. To the extent that insulation in walls and roofs slow heat and cold absorption they are in fact controllers of solar energy and wind energy. Conservation measures used in insulation and glazing also accommodate control of solar heat gain and natural lighting. When Elizabeth Holland described an airy office complex in Princeton, N. J., which made heavy use of passive solar energy features, conservation was also evident in the insulation.[2] The R-20 insulation in the walls and the R-30 insulation in the roof are usually associated with conservation. The use of movable insulation for skylights and windows, the use of 2 or 3 plys of glass in glazing, and the use of awnings on south windows are are also features which conserve energy. Certainly features like use of rockbeds to store heat and cool, water walls, skylights, a significantly greater proportion of south glazing and spraying the roof for evaporative cooling make use of renewable solar energy.[3] The use of the double-envelope design concept is also a distinctly passive solar energy feature which achieves energy conservation, but should be distinguished from insulation.[4] Most well designed solar energy features also provide insulative values regardless of the part of the building skin involved. Recovery of waste heat can be a conservation measure, but it certainly utilizes renewable body heat energy and solar energy in part. The lines of distinction between conservation measures and renewable energy systems are not always clearly drawn in integrated energy systems.

Team Approach to Design Strategies

Today architecture, engineering and education must respond to the scarce and expensive energy resources with "innovative change in building design . . . to achieve cost-effective, energy-conscious design."[5] Based on the energy crisis, Jerry Lawrence said, "New approaches to conceptual design of buildings are having the greatest impact on the profession of architecture since the beginning of the Industrial Revolution."[6]

Lawrence called for a team approach to design strategies for energy savings adaptable to schools. The team conceptual approach brings together the skills of architects, engineers and client/users to cooperatively develop building form and shape, machines and system designs, and management of the building to satisfy school needs while saving energy.[7] From the beginning of the project the owner, the architect and the engineers must work in close cooperation with the understanding that energy use is "a high priority in the hierarchy of design issues and decisions."[8] Lawrence said,

> . . . Energy performance of buildings is an integral part of architectural design. Virtually every basic design effects energy conservation and cost. The interaction of non-mechanical (envelope, internal materials, etc.) with mechanical and electrical systems (heating, cooling and lighting systems) will be largely determined during the schematic and design development process. However, one should not think of energy as the **prime** shaper of architectural form. Program, structure, and physical and cultural context all interrelate with energy considerations in creating building form.[9]

A cooperative effort to achieve energy-conscious design will achieve the best, cost-effective, energy-efficient building.

In school facilities projects energy goals should be established early. The importance of this aspect of the design process led Lawrence to state emphatically, **"Approximately 80% of all the decisions that will affect the energy efficiency of the building are made in the first 10% of the design process."**[10]

The next adjustment in the sequential process of energy-conscious design calls for the design team to establish **"energy-design elements adaptable for schools."**[11] The varied elements must work together to achieve the energy and other priorities established for the building design. Specific techniques employed in building design to achieve contextual energy goals may include maximizing daylighting, using air-curtain windows and emphasizing storage of heat in the building materials. Lawrence illustrated these and several other energy design elements adaptable for schools.

When the local situation warrants construction of new facilities, the focus should be on achieving the highest level of use of renewable energy resources consistent with achieving the most efficient building on a total life cycle cost. To focus on the lowest initial cost is to be "penny wise and pound (dollar) foolish." Among the specific factors to be considered to save energy are the following:

> site location, building orientation, building configuration, fenestration, glazing and shading devices, interior space planning, energy source, transmission coefficients of the walls and roofs, heat recovery system and lighting system.[12]

The integration of energy efficient design features has the effect of reducing redundancies and excessive energy equipment, thereby, reducing overall cost. A. Lovins noted that there is a "powerful

synergism between efficiency and cost-effective renewable energy systems."[13] The thermal efficiency of one system may very significantly reduce the size or need of other systems. In fact, some energy features, which taken singly may appear very attractive, may not make sense in the context of other conservation measures when design has been a high priority. One energy efficient builder was doubtful that a computerized energy management system was cost effective if it picked up only 5% of the energy tab because design solved 95% of the problem.[14] Energy efficient design enables much greater savings by utilizing solar energy and waste heat, by avoiding unwanted heat loss or gain and by total energy management.

Evaulation Criteria for Educational Design

When "79 outstanding projects" of educational construction were described in November, 1983 in an Architectural Portfolio for American School & University, some of the evaluation criteria were indicated. Dorothy Wright listed the following:

- approriateness of design to function
- contextual fit, with the site and in relation to other campus buildings
- use of materials, color and composition
- technical innovation
- the success of the design in matching users' needs
- clarity of solution--the logic of the design for user, technical and architectural point of view[15]

Noticably missing is the lack of specific reference to energy conservation as a specific criteria. However, energy comments are

frequently included in the brief narratives describing the photographs and drawings.

In the same American School & University publication, Dr. C. William Day, one of the four members of the jury that made selections for the Architectural Portfolio, described some of the trends in educational facilities which promise to continue or become more important in the 21st Century.[16] Primary among the implied energy criteria of building design is the trend to optimize energy conservation in a way which is consistent with 21st Century trends. Consequently, energy-efficient design places a high value on the need to reduce operating costs, rather than an excessive emphasis on initial capital costs. Day declared, "Since operating costs can exceed capital costs within a few years, some education institutions will elect to replace excessive energy consumers with more efficient systems."[17] Specific technologies foreseen by Day as being used more frequently include "active and passive solar systems, alternative fuel sources, and new mechanical-electrical concepts such as heat recovery, heat pumps and heat storage."[18]

Earth berms, building orientation and micro-climate will be incorporated in facilities planning as conservation measures. Earth berming and underground design offer significant protection against heavy winds, environmental noise and severe climate conditions. Building orientation facilitates solar gain and utilization of natural lighting and ventilation. The provision of a micro-climate avoids the waste of needless energizing of unoccupied space.

Day emphasized conservation and the dependability and efficiency of energy systems and sources.[19] This includes their durability and availability, rather than scarcity. More efficient energy systems and sources are vital to satisfaction of performance criteria in the area of energy conservation.

Appearance is an important factor in energy systems. With increasingly automated, centralized energy systems of the last two decades, energy systems were becoming a background feature until higher prices and scarcity called for alternative energy systems. Depending upon the aesthetic values of the observer and the skills of the architect, solar energy systems, especially, active energy systems have been subject to criticism. School settings with massive roof areas usually afford the opportunity to hide solar energy features. Balanced design to accommodate significant areas of rooftop photovoltaic or active flatplate collector systems is essential where the collectors are visible. Wind energy systems have raised aesthetic objections to their effect on the landscape and background noise.

Rosalie Ruegg and Harold Marshall, economists with the National Bureau of Standards, Washington, D. C., suggested the inclusion of nonmonetary benefits in the evaluation of energy aspects of school architecture. Often the task of needs assessment in school systems reduces itself to the less than optimum goal of getting the most for the least money. In the area of energy this tends to neglect nonmonetary benefits of investments, such as improving occupants' comfort by reducing drafts, energy independence, prestige associated with the use

of new technology, respect received for acting in the public interest, societal benefit of reducing U.S. vulnerability to supply deficits, environmental air quality, and aesthetic values of landscaping and design of buildings.[20] The safety, health and comfort achieved by the avoidance of indoor pollution are values offered by appropriate energy systems.

Energy systems should be consistent with user values and needs, including specific educational concerns. "Spacial relief," the creation of more "humanistic learning environments for students," and "protection of the natural environment" may be as much a consequence of new energy technologies as new technologies are the consequence of these values. C. William Day singled out indications of better use of the sun's energy as having this effect. He said, "Today, we find innovations emerging such as atriums, skyways, student malls and outdoor learning laboratories that provide more warm and personal spaces for people."[21] Much more effective use can be made of natural lighting and ventilation in addressing both the need to conserve energy and the need to create more humane learning environments. Strange as it may seem in the context of an underground facility, the highly praised "earthscraper" at the University of Minnesota in Minneapolis offered the advantage of "some welcome open space--including a landscaped plaza over a part of the building--on the university's crowded urban campus."[22]

The interactions of different aspects of the energy system make descriptions redundant while pointing to many previously lost opportunities for energy savings. Light, heat, insulation, ventilation,

waste heat and controls interact in energy efficient design to significantly reduce life-cycle energy consumption. Double glazing the south wall permits natural light. However, light must be controlled to avoid excessive solar heat. The controls can insulate the space against undesirable heat gains or losses and permit natural ventilation. Waste heat, controlled and utilized, can provide heat when and where it is needed in other parts of the facility. The total impact can be significant reductions in lighting, heating, cooling and ventilation costs.

The architect and builders of the new armory of the South Boston, Va., National Guard unit, estimated that the combination of passive solar techniques, thermal mass, earth sheltering and elimination of north and west-facing windows can be provided at a cost comparable to facilities which do not incorporate these features. The continuous energy costs for the life of the building were expected to be "at least 25 percent less than those of a conventional design."[23]

Passive solar screens provide another illustration of the way passive energy technology can respond to total energy needs. They permit natural light while blocking "up to 70% of the sun's heat and glare to reduce air conditioning loads."[24] Opening windows for natural ventilation is still possible when outside temperatures and wind conditions are appropriate.

When passive opportunities for conservation and utilization of indigenous energy resources have been made, the total energy system planner is ready to examine the size and kind of active energy system(s)

which is (are) appropriate to meet the residual energy needs. Gerald F. Bender and Jack F. Probasco noted that 1980's improvements in "the building envelope (exterior walls, windows, doors, roof), the landscaping, the use of space within the building, and even the effects of solar energy on the structure" reduce the size, cost and energy consumption of active systems.[25]

Building Structure and Use: Passive Features of Energy Savings

Less costly passive opportunities to interact with the total energy system can be more effectively utilized, especially, those which are not so capital intensive and offer time to use scarce capital to develop new active energy technologies. Underground, earth insulated or earth sheltered facilities offer an excellent example of working passively with natural energy forces, particularly, when accompanied by utilization of solar energy on the southern and eastern exposure. These passive energy opportunities are suitable to most new facilities and retrofit applications, especially where there are wide swings in surface temperature.

When Gerald F. Bender and Jack F. Probasco provided a checklist of ideas to consider in energy conservation and renovations, they identified many features which tend to maximize the use of passive solar energy. These include the location of classrooms which gain a lot of body heat and solar heat away from the south wall, the library, staff work area and student lounge on the south wall to use passive solar energy since the occupancy level is lower, and faculty and staff offices

on the eastern wall to "protect them from cold winter winds and the hot afternoon summer sun."[26] Their ideas, many of which are included here, were topically treated under room utilization, landscaping techniques, building envelope, solar control and active systems.

Utilization of Space

Bender and Probasco's suggestions regarding energy-conscious design offered many opportunities to alter internal arrangement and use of space to advantage. They deal with the fact that energy conservation was not an important design consideration when most buildings were originally built. Under the heading "Room utilization" they said,

> . . . The following considerations should be part of any major building renovation or remodeling program to conserve and manage energy:
>
> 1. Locate classrooms and lecture halls along the east, north and west perimeter of the building to act as a buffer for rooms in the inner core.
> 2. Locate open areas such as staff work area, library, student lounge or study room along south wall of the building. These areas more easily adapt to the use of passive solar storage devices.
> 3. Locate faculty and staff offices along the east perimeter of the building. This will protect them from cold winter winds and the hot afternoon summer sun.
> 4. Locate any type work area that is continuously occupied through the work day in the inner core of the building. Comfort levels can more easily be maintained here.
> 5. Locate laboratory facilities on the ground floor or basement level. These levels are generally cooler year around.
> 6. Locate activities that normally do not function during the summer on the top floor. It is desirable to shut off the top floor during summer to ease air conditioning load.[27]

Energy savings as high as 50% or more may be achieved in energy wasteful facilities built in the 1950's through the early 1970's by use of energy management strategies such as these in combination with modifications in

active systems, including lighting, heating, ventilation and air conditioning.[28]

Landscaping

Bender and Probasco also emphasized several important aspects of landscaping and the building envelope which help save energy.[29] The checklist of landscaping techniques, while dependent on the regional climatic conditions, offers significant opportunities to deal with heat loss and gain in buildings. The techniques they offered were recommended as applying to "areas of the country which experience winter conditions such as the Midwest."[30] Their recommendations follow:

> Examine the layout of the existing sidewalks, streets and parking areas in the immediate vicinity of the building. Determine what portion of the walkways, streets and parking are really necessary for access to the building by people and vehicles. Then consider the following landscaping techniques.
>
> 1. Use earth berming along sides of the building to shield it from outside temperatures and wind.
> 2. Replace concrete and/or asphalt near building with grass, mulch or shrubs. This will keep the building cooler in summer as grass and shrubs absorb, store and reflect less heat.
> 3. Remove any evergreen trees or shrubs on south side of building that shade windows from winter sun.
> 4. Plant evergreen trees or shrubs in a dense pattern along north and west sides of building to provide a shield from cold winter winds.
> 5. Plant deciduous trees on east, south and west sides to shield the building from summer sun but let in winter sun.[31]

Solar Control

Several suggestions were offered by Bender and Probasco specifically dealing with solar control.

> The following are typical of what can be done to control the solar energy available to the building:
>
> 1. Add additional glass area on the south wall to capture available solar energy in winter.

2. Use passive thermal storage devices such as concrete or brick walls, water filled columns or ceramic tile flooring.
3. Install awning or overhang on south windows to block summer sun, but let in winter sun.
4. Use thermally insulated skylights to provide natural lighting in areas on the top floor.
5. Install attic ventilator(s) to prevent summer heat buildup in attic.[32]

The obvious potential of passive solar energy to provide desirable and undesirable heat gain is evident in DiMercurio's assertion that "occupied perimeter rooms with a strong solar heat gain may require cooling when temperatures are well below zero."[33] Faced with the highest solar gain in December and January, when external temperatures are coldest, architects must design to deal with both desirable and undesirable heat gain.

A large number of solar control strategies may be applied to meeting the need for cooling and heating in schools. When the weather is warm, but not so hot as to require air conditioning, in a properly designed building cross-ventilation through open windows can deal with heat gain. David Godolphin, in describing the Sun Mountain School on a hillock outside Santa Fe, N.M., illustrated the possibility of securing useful heat while dealing with the excess through natural processes. He estimated that the body heat of occupants would contribute 25% of the annual heating load, with passive solar heating techniques providing the balance. Cross-ventilation through open windows deals with excess heat "during the day for much of the winter."[34] The passive cooling process also involves "ducts buried four feet underground" which "pull cool night air through the earth and into the school, where it is exhausted through operable clerestory windows at the peak of the building."[35] If

the passive cooling process proves to be inadequate, "the fan for the backup evaporative cooler can be used to assist."[36]

Active Renewable Energy Technologies Now Available

Potential long-term energy savings in new educational facilities call for careful evaluation of a broad range of energy options. Varied needs and costs will be experienced in different regions of the country. The sun belt states in regions 4, 6 and 9, including Florida, Texas and California are expected to continue to show the greatest needs of new construction.[37] In April, 1981 Paul Abramson reported the startling cost of new buildings completed in 1980, with the average elementary school rising in one year from "just under $42 per square foot . . . to almost $50."[38] This rising tide of facilities costs, which exceeded the high general inflation rate, then in the teens, is a part of the background in which energy systems must compete. Evidently, with high costs of construction in general and relatively greater increases in energy costs, a high priority in new construction is designing for energy efficiency while carefully evaluating primary energy systems to be used.

Some writers argued in 1980 that the energy savings afforded by solar energy systems failed to justify installation of a solar system at that time, but, also, argued that new facilities should be "designed to easily incorporate a solar system in the future."[39] Many who were reluctant to endorse widespread application of active solar energy systems in 1980 were supportive of designing new educational facilities

for passive solar heat.[40] The tendency in 1980 was to take a guarded look at active solar as an energy system of the future when fossil fuels were more scarce and expensive.[41]

Abramson provided a table indicating percentages of heat energy coming from four sources in new construction completed in 1980. The sources were gas, oil, electricity and solar. School districts favored gas and electricity over oil and solar. Colleges relied most heavily on oil and electricity.

The percentages of use of solar energy as a renewable energy heat source in new buildings in 1980 is of interest here. The figures noted were as follows:

Type of School	Percentage of Solar Usage in 1980
Elementary schools	2.0
Middle schools	5.0
High schools	2.6
Vocational schools	.0
Two year colleges	4.3
Four year colleges	5.0[42]

Elements of passive solar gain and avoidance of gain may not be accurately reflected in these figures. Abramson's one comment on the topics was this: "This use of solar energy is still rather limited and probably always is limited to supplementary hot water heating."[43] Because of the wide acceptance of passive solar in the energy market and other known exceptions, his conclusion is most useful in describing the now recognized feasibility of solar water heating in schools.

Mixing and matching of energy resources is preferable in most places. The scenario of integrated small-scale technologies utilizes a variety of solar energy products and systems for space heating and hot

water. In some locations biomass and geothermal energy may satisfy these needs. Municipal waste can be used to generate heat and electricity. Supplemental heat can be provided by methane gas from biomass waste products or wood where it is in plentiful supply by energy efficient, slow combustion stoves. Windmills, photovoltaics and small-scale hydropower are renewable sources of electricity which have proven competitive in a number of settings. Renewable energy technologies can offer self-sufficiency in facilities. Integrated technologies in energy efficient design, with accommodation of sensible or latent energy storage, make this feasible with currently available products.

Renewable energy technologies are available to match a substantial portion of the total heating needs. Most of these needs can be met by solar collectors for the purpose of providing hot water, space heating and a significant number of industrial processes, such as, drying of foods.[44] Reflectors and focusing lenses can be applied in the solar heat absorption process to achieve very high grade heat, indeed, heat of such intensity as to prove useful in the nuclear energy industry. Biomass energy from methane gas, firewood used renewably, and municipal and agricultural wastes are available for supplementary heating purposes.

Many lighting needs can be met by solar energy. Double and triple glazing of windows to trap heat gain and enable natural lighting are now being used in various ways. Increasing use is being made of central atria and other devices to admit natural light.

Some worldwide experts believe renewable energy technologies can offer self-sufficiency in housing and other facilities. Facilities permit the mixing and matching of renewable energy sources to appropriate uses to achieve this goal. This 1978 statement suggests a possible mixture in some residential settings.

> . . . It turns out that an integrated use of small-scale technologies is required for complete autonomy: solar absorbers for hot water and space heating, methane digester to produce gas and fertilizer from the family wastes, a windmill for electricity generation, and perhaps a slow combustion stove for supplementary heating. The principle of the integration of renewable energy technologies so that they work together is capable of application in many other areas.[45]

This line of reasoning supports solar energy. Those who have argued against solar energy tend to argue that it is never adequate alone. The negative argument is most persuasive for those who desire to save initial investment capital and least persuasive for those who understand that energy savings provide a quick recovery of additional capital costs. A solar energy system, coupled with appropriate conservation measures, calls for a significantly smaller backup system than duplication of present systems. The mixing and matching of small-scale technologies often permits a lot of common hardware rather than isolated systems in heating, for example.

The estimates of the speed of development of renewable energy resource potential are widely varied. The range of estimates of U.S. solar power for 2010 range from as "low as 5%" to "as much as 30%."[46] The same report indicated that the transition could not be so rapid for the world as a whole. Abrecht and others went on to say,

> The generation of energy from urban wastes (approx. 2% of US energy needs, at most), animal feed lot wastes (approx. 2-3%), forest and food crop residues (a larger but unknown fraction) figure as part of the sustainable strategy, broadly classified as "solar". The provision of the necessary facilities and institutions makes the transition long.[47]

Among the other important sources of energy will be nuclear fusion, which some experts regard as renewable.[48]

Donald L. Duggan, writing in 1979 relative to "the long term, after the year 2000," stated that "we must make the transition to renewable energy sources, perhaps in the fields of solar electric and fusion energy."[49] Duggan asserted that these "technologies of the next century . . . are neither sure nor . . . cheap."[50]

C. L. Boltz, dealing with events in 1983, foresaw coal and uranium as the fuels for the large-scale generation of electricity in the foreseeable future in developed industrial countries. By contrast, in sparsely populated areas, Boltz found that diesel-powered small electric generators were being challenged by renewable energy sources.[51]

Electricity is being produced at present by renewable energy technology of various kinds, sometimes in cogeneration to satisfy heating needs at the same time. Urban waste can be burned to generate electricity. Wind energy can make useful contributions for both electrical and mechanical energy. In rural areas small-scale water powered generators are being used with increasing frequency. Large-scale hydro-power projects are very important possibilities for growth in developing countries. There have been very substantial reductions in the relative cost of photovoltaic production of electricity directly from sunlight. This technology is becoming increasingly popular in

remote sites and in localities which support diverting surplus electricity to the public utility company. Tidal power is limited in its potential uses.

Future development of such methods of production of electricity will no doubt be accompanied by grand, high technology uses of other emerging renewable technologies. Some of these are as follows:

> . . . For the future, there are prospects of electricity from wave power, and the large-scale solar-electric plants--the solar farm based on chemical processes, the power tower based on reflection by mirrors to a central tower, and solar sea-power based on differences in ocean temperature at different depths.[52]

A less positive projection of market penetration of renewable energy for the present and near future was made in November, 1980 in official channels emphasizing production of energy by large utility companies. The combination of hydro, geothermal and other renewables yielded only 8.28% in 1985 and 8.54% in 1990 in the U.S. domestic production.[53] Biomass and solar together were expected to contribute approximately 4% of the increased share of replacement of traditional fuels in the industrial sector.[54] The 1980 International Energy Agency (IEA) report expected a more protracted entry of renewable energy resources into the energy mix than current competition and market penetration suggest. The IEA briefly anticipated a protracted entry of renewable energy resources into the energy mix as follows:

> The Windfall Profits Tax and the Energy Security Act of 1980 both provide additional encouragement (through tax credits, the Solar Energy Development Bank and loan/price guarantees) for the expansion of renewable energy use in a wide variety of forms. Passive solar, wind and biomass are likely to be the major elements. While renewable energies are a long-term option for the United States, they are unlikely to make any major contribution by 1990.[55]

Auer projected only a 4-6% of primary energy usage in the U.S. to come from solar-thermal sources.[56] Auer and others argued that solar-thermal technologies can be used in hot water and space heating applications to displace only "5% of the world's energy needs" and "10% of total thermal demand" in the industrialized countries.[57] Their argument called for large-scale "solar-generated electricity and fuels" in addition to solar-thermal technologies to supply more needs.[58]

By contrast, Senator Alan Cranston of California, a renewable energy leader in a state which has supported its development, called for "increasing the use of renewable energy--such as solar, wind, geothermal, biomass and hydroelectric—to supply as much as 25 percent of the nation's energy needs by the year 2000."[59] Similarly, Abrecht, anticipating broad based changes in energy production and use in the next three decades, concluded,

> . . . With conservation improvements through insulation of buildings, higher efficiency of power consuming equipment, redesign of commercial heating and ventilation processes, introduction of energy-recovery equipment in production plants, and the practice of recycling of wastes, it is conceivable that the solar-related energy resources can account for as much as 20% of the needs of industrialized societies and for even larger portions in regions where sunlit days are the rule.[60]

Renewable energy systems enthusiasts expect the real energy competition of the future to be between renewable technologies. These advocates have approached the task of competing with traditional sources with the zeal of inventors who know they have a better idea about the long term uses of the world's resources. They have challenged the large utilities, oil company subsidies and huge government appropriations to the nuclear industry. They have proven their ability to compete, while

reducing the scale of the disruptive impact of energy production on the environment. Renewable energy systems on a small scale can be much friendlier neighbors than those who use large scale dislocations of people and long-term destruction of the environment and natural resources in their efforts to avoid energy shortage and excessive energy costs.

Many renewable energy resource delivery systems are now competing against one another to provide even better answers. For example, an ad in Solar Age, in June, 1981, by Whirlwind Power Co. of Denver, Colorado, was apparently addressed to users of renewable energy in fairly remote settings. The windmill was intended to produce the "most power in light winds" at "one-tenth the cost of photovoltaics."[61] The competition was between wind powered generators and photovoltaic powered generators rather than between wind power and a gasoline or oil powered generator. Competition between renewable energy systems may well be the primary distinguishing characteristic of the energy industry of the 21st Century. A struggle between large-scale and small-scale energy systems will continue, with arguments over economies of scale.

Since a high quality of technology is already available in several renewable energy areas, a phasing in of these energy resources can be expected to meet the goals of renewable energy advocates. Amory Lovins and others provided statistics in 1981 to support their belief that the U.S. was expected to have a potential renewable supply to satisfy 19-35% (depending on car efficiency) of the demand in 2000 and 100% of demand in 2025 or 2030.[62] In 1980 the Carter administration's

solar energy goals targeted 2000 as "the time when solar should account for 20% of the country's energy sources."[63] The DOE's 1980 allocation was "646 million for solar energy projects, all largely considered to be experimental or developmental."[64] Rita Robison cited a research report which expected the solar industry to grow from $150 million a year in 1980 "to a $20 billion a year industry" in 2000.[65] The relatively low assessments of solar penetration of the market contrast sharply with Amory Lovins' larger perspective. Lovins reported that some of the soft technologies "are being sold in large quantities: the two million solar collectors in Japan increased by $0.5 billion worth in 1980, and 1979-81 commercial commitments to windpower in the US probably total several billion dollars."[66] Lovins' 1981 forecasts have proven to be true in the area of photovoltaics, consistent with DOE projections, which are now competing in U.S. utility grids without a congeneration heat credit.[67] Ample wall and roof areas are available even in U.S. cities for solar energy to provide all space heating, hot water and electricity,[68] and storage of energy can be provided to deal with cloudy weather conditions, if this were to be chosen as a soft technology path.

Amory Lovins and others reminded the U.S. of the unnecessary risks created by use of traditional energy resources.[69] The long list of disadvantages of fossil fuels and nuclear energy is an unnecessary burden assumed due to failure to act in accordance with the fact that "soft technologies provide all the forms of energy that end-users require, mainly heat and portable liquids."[70] Writing in 1981, Lovins

saw a rapid transition in progress which was described in part as follows:

> It is hard to find a part of the US that does not have a unique blend of renewable energy ferment. Many observers who travel the country remark that although the activities are concealed from governments' view by their dispersion, small individual scale, and diversity, they add up to a quiet energy revolution that is reshaping the American energy system . . . with unprecedented speed. The proof of success: collectively, renewables have contributed more new energy to the US since 1977 than all other supply sources . . . --probably even more than the vast expansion of coal-mining that has so concerned climatologists.[71]

Some Factors Influencing the Selection of Energy Systems

School boards and administrators need to evaluate a number of factors in planning the most appropriate use of energy resources in schools and universities. These factors include both the practical need of spaces to accommodate programs and feasibility considerations like availability and reliability of resources in coping with the local climate and geography. The limits of conservation measures, the mainteance requirements, the existing building stock and other practical considerations should be weighed along with more long-term ethical and environmental impact questions.

User Population

The examination of factors influencing the selection of energy systems begins with user population. In addition to unique characteristics of space utilization in schools, a number of other considerations have a bearing on the type of energy system used and the

feasibility of its selection. The varied size of the user population served prohibits some uses and encourages others. Significant temperature fluctuation is a greater cause for alarm where young children or the elderly are served. To the extent that programs and scheduling vary widely from elementary to middle school to high school to specific programs in higher education, energy decisions regarding primary energy resources may be effected.

Donald Burr has shown that energy conservation measures can serve to increase the number of potential users of a school facility while saving energy. An increasing level of occupancy of heated space tends to occur when central heating plants are broken down so that component parts of buildings can be heated and cooled on a modular basis rather than supplied with uniform thermal conditioning of all spaces.[72] The various user needs lend themselves to more of a mix of energy systems when modules of a facility are energized separately.

Users of schools, including students, teachers, community users and school boards, can be influential in the selection and effectiveness of energy systems when there is energy awareness in these various segments of the population served. For example, teachers who understand the impact of inflated energy prices on salaries are more likely to provide required user interaction with the energy system to enable conservation or the use of an alternative energy resource. Unless school administrators educate the public to long-term benefits of renewable energy systems, resistance is encountered to a system which has higher initial costs, even though it may be less expensive when

viewed in terms of life cycle costs. Energy consultants who understand the life cycle advantages of renewable energy systems may be more persuasive with school boards when they weigh very high cost maintenance and operations costs of traditional energy systems against long-term savings with renewable energy systems.

Kinds and Numbers of Spaces

The kinds and numbers of spaces influence the types of primary energy resources appropriate for the facilities of a school or college. Some important descriptions of space are the following:

Size

Interior/exterior

Vertical/horizontal

Underground

Isolation of uses

For example, underground facilities lend themselves both to the insulative properties of the earth itself, which maintain a rather stable temperature, and to use of solar energy where good use is made of southern exposure and, to lesser degrees, eastern and western exposures.

Programs and/or Activities

Programs and/or activities, and, specifically, the time of day, week and year facilities are used, impact energy systems selection. Day use only substantially reduces the need of heat and lighting. However, if both night and day uses are planned, the required energy facilities for lighting and heating are more extensive. Structural modifications

can reduce the cooling load in the afternoon and early evening hours where there are summer programs. Weekend use reduces the down time of traditional energy systems and requires greater energy expense. Partial use of facilities often allows one system of energy to meet occasional needs, while total use of a facility may require other backup energy systems dependent upon different primary resources. These are some of the main ways scheduling and programs affect energy system needs.

Ability of Primary Energy Resource to Match the Uses Required

Not every primary energy resource is available in adequate quantity at reasonable cost to match either certain specific energy needs or all energy needs collectively. However, many energy resources not commonly used in particular localities can be made available to satisfy specific energy needs at lower cost than existing primary energy resources.

In September, 1979, Hooker and others described the goals of the Ministry of Energy relative to use of renewable energy resources in meeting new energy needs of Ontario, Canada. Increasing goals have been set for the provision of indigenous energy from renewable energy resources. The primary energy resource base for implementing these plans was as follows:

> . . . Energy generated from renewable resources, including energy from waste (municipal solid wastes, forest wastes, industrial by-product heat, and synthetic liquid fuels from agricultural wastes) plus solar, wind, and wood (both direct burning and conversion to liquid fuels or gases), is targeted to be about one-third of the overall increased self-sufficiency, the remainder being largely due to increased nuclear generating capacity. Of this renewable energy contribution, about two-

> thirds is attributable to solid wastes with one third attributable to solar, wind, and wood. Overall, the policy goal is to have non-hydraulic renewables meet a minimum of 5 per cent of 1995 primary energy demand in Ontario. This is a five-fold increase over the goals set out three months previously and presumably implies a major program to develop renewable resources in the province.[73]

Hooker and others noted the importance of "distributed seasonal storage facilities" in achieving long term cost reductions and making solar energy to be perceived as a more viable option. They argued that the credibility of "most present comparative studies" may be limited since they "do not consider such options or indeed substantial storage options of any sort."[74] The rationale for the assessment of storage potential as a means to achieving cost reductions was as follows:

> . . . Since seasonal storage facilities could be expected to show low maintenance rates, long life times, and to decline sharply in cost with mass development, they could be expected to improve life-cycle costs substantially in the long term.[75]

By contrast to the relatively low estimate of renewable energy in some reports, there is real potential for meeting all energy needs in facilities in many locations. This can be achieved by matching primary energy resources to the tasks they can do most efficiently rather than by relying on a single-source, large, utility company mentality.[76]

Potential Reliability or Shortages of Primary Energy Supply

The potential reliability or shortages of primary energy supply is a problem which must be considered in installing solar, wind, small scale hydro electric and biomass energy systems. Reliability problems can be overstated. For example, solar energy storage can be useful for several days of inclement weather. Other renewable backup systems can

also function to enable well designed solar energy systems to provide up to 100% of space heating and hot water needs, except in the harshest of circumstances.

Auer and others illustrated the utility companies' concern about the reliability of renewable energy systems. The utility argument follows:

> During the period of cloud cover, all solar systems in that particular area will become inoperative and may require backup from an electric utility equal to the demand customarily met by those solar systems. Consequently, the utility must install the same generation capacity as it would if no solar system had been introduced. In this event, equally large capital expenditures would be required by the utility to back up the solar systems, while delivering electric power for heating and cooling only on cloudy days, thereby adversely affecting the utility's load factors.[77]

The solar-assisted heat pump system was recommended as a partial answer to the utility concern about the load factor and capacity during bad weather. When the heat pump is a backup to solar energy, the time of day of supplemental assistance is not critical. This allows for use of electricity only "during off-peak hours, thus helping to level system loads and, possibly, reduce installed capacity requirements at the utility."[78] The heat pump can utilize the heat of lukewarm water and permits the use of a smaller array of solar heat collectors.

The heat pump system, coupled with solar storage, also offers warm weather advantages. Auer and others reported, "Operating from cold storage, the heat pump can efficiently operate throughout the air conditioning season at a high coefficient of performance, while improving the utility load factor."[79]

Jennifer Adams illustrated some features of passive solar energy systems contributing to rapidity of warm up or heat transfer which make these systems more desirable for providing heat when it is needed. Water walls provide greater efficiency than masonry walls by carrying heat from the exterior to the interior wall face more rapidly. Unfortunately, water containers are more expensive and more susceptible to vandalism. Heat transfer can be speeded up in mass walls by using vents. Adams recommended unvented walls as "suitable for churches with light daytime loads."[80] When both daytime and evening heating are needed, vented walls are preferred, since "convective currents will deliver heated air to the building during the day, and the heat stored in the mass will warm the church at night."[81] Adams said that "the upper limit of energy contribution (about 80,000 Btu's per square foot of glazing per year) is achievable" when a mass wall of the proper size is used, providing efficiency similar to direct gain systems.[82] The storage capacity makes the mass wall preferable to thermosiphoning air panels (TAP) where buildings have both daytime and evening heating loads. The environment is both more stable and comfortable due to the available supply of radiant heat.[83] Adams concluded, "Mass wall is the least expensive method using a combination of south glazing and mass."[84] The maintenance and shading requirement are similar to those for TAP systems.

Balance of Energy Needs after Conservation Measures

The balance of energy needs not met by conservation measures is an important practical consideration in determining what energy system to use. If, for example, superinsulation is coupled with effective architectural and engineering use of passive solar energy, the need for other heating energy resources will be quite limited. Thus, the sensible use of conservation measures is a high priority since it tends, along with climate and level of facility use, to determine the level of energy use.

Local Climate and Geography

The local climate and geography set site advantages and limitations on the practicality of specific energy systems. Remote rural sites which would require an extensive electricity transmission infrastructure provide a prime location for appropriate use of several renewable energy technologies which would be less feasible in an urban environment. The amount of solar radiation (insolation) being received, the length of day, level of cloud cover and inclement weather, effect the selection of methods of dealing with heat gain and loss, lighting and other energy needs. Nearby mountain ranges, lakes, oceans, and angle of exposure to sunlight impact the energy needs and potential energy systems. The usual wind speed effects requirements for ventilation and the relative merits of use of wind energy systems.

Both the average annual temperature and humidity and their range are important. Jennifer A. Adams, in describing the application of

solar energy systems in church settings, emphasized cool and temperate regions where heating is the major energy concern. These are two of four regions which she described in terms of climate characteristics relative to energy needs.[85] She wrote in a brief, practical, nontechnical, and well illustrated way concerning the relative merits of solar energy systems with an appropriate concern for environmental considerations. In four months of investigation in 1980, Adams discovered thirty-five churches in the United States with either operating solar systems in their buildings or working plans to incorporate them.[86] The other two regions are hot-humid and hot-dry. Adams recommended Victor Olgyay's Design with Climate[87] and "The National Climate Center in Ashville, North Carolina, a part of the U.S. Department of Commerce National Oceanic and Atmospheric Administration," as sources for "climatological data for major cities around the country" which "includes daily and annual temperature, amounts of snowfall and rain, windspeeds, percentages of possible sunshine, cloudiness, relative humidity, and heating and cooling degree days."[88] The earth sheltering of buildings is suited to energy conservation goals in a great variety of settings, with emphasis on extremes of climate, dense settlement, surface areas which can be put to more appropriate uses and a southern exposure permitting utilization of solar energy.

Solar ponds can provide hot water, space heating, fresh water, electricity production and aquafarming in a great many settings. Since the technology lends itself to both artificial and natural sites, it is not limited to coastal lagunas, salt flats and salty lakes. However,

the collection and storage of solar heat for its varied uses is facilitiated by matching geography and technology.[89]

Practicality of Location

A number of factors must be considered in determination of the practicality of energy systems in specific locations. Some energy systems are much less expensive to install in new facilities than in retrofit applications. While active solar energy systems can be used in both new construction and retrofit applications in existing buildings, additional expense will usually be encountered in existing facilities due to difficulties in providing ideal storage and distribution networks. Consequently, packaged active solar systems, which may rely on a high degree of replicability to be competitive, will need to be evaluated carefully. The ability to adapt and replicate usage is an important criteria when considering wide application of a technology in a particular area.[90]

Another concern is to select a system which is consistent with available building materials, equipment, architects, engineers and skilled workers. This includes education for user interaction with equipment. The original availability of these things may avoid delays in maintenance which could lead to school closings.

Low Frequency and Cost of Maintenance

Related to the problem of durability and reliability is the whole question about reasonable warranties and maintenance contracts to backup energy systems. All energy products should demonstrate

durability and reliability, with product warranty and service availability for the useful life of the product.

Of course, an assessment of low frequency and cost of maintenance problems is also important. Ed Stephan suggested a delay in widespread application of solar energy systems and cautioned users of solar "to get good estimates on maintenance and talk to people who have already put in systems."[91] He had recently observed a high level of maintenance problems in five relocatable classrooms in Warrenton, Virginia, where active solar energy systems were used. However, a review of the literature revealed a high level of variability within the various energy systems in reference to the incidence of maintenance problems. Consequently, this consideration was not an appropriate basis for approval or disapproval on a broad basis of any primary energy resource system. Nevertheless, Stephan's point is strengthened due to the variability of performance.

Frequently higher gradations of technology are both more expensive and characterized by more opportunities for system failure.[92] Technology which is simple, available and reliable need not be frowned upon because of its simplicity. David J. Rose, in describing a range of solar technology, suggested several criteria to make these systems economically attractive: simple and ingenious design and construction, commercial availability of improved systems, and system reliability.[93]

Conversion Steps from Primary Energy Resources to End-Uses of Energy

Energy consuming activities include lighting, equipment operation, elevating, ventilation, heating and cooling. These are not the most useful categories for identifying the relative merits of different primary energy resources for producing and delivering the kinds of end-use energy needed in schools. Appropriate, primary energy resources tend to be delivered in a manner which reduces the conversion steps from one energy form to another and which reduces the transmission distance from generation of energy to its consumption. Although not all energy needs lend themselves to this generalization, a review of specific energy answers to energy problems described in this dissertation illustrates the importance of thinking backward from end-use needs of low grade heat for space heating and hot water, space and water cooling, electricity for lighting, refrigeration, ventilation, equipment operation and so on to proximate energy solutions which are renewable rather than nonrenewable.

Wasteful mismatches of resources and end-use of energy abound. An obvious example of excessive conversion steps, long transmission lines and expensive transportation is seen in the use of electricity to provide for low-grade heating needs. By contrast, where solar energy is plentiful, it provides an ideal resource for space heating and hot water. Since several resource wasteful energy steps are necessary to make traditional electricity available, use of electricity for low-grade heating is a poor match between source and use.[94] In hunger zones,

where biomass fuels are scarce, reforestation is an obvious first step before biomass energy resources could be considered an appropriate alternative in meeting energy needs. There are many other current mismatches of energy source and use.

Lead Time Required to Convert Current Building Stock

The conversion of the existing building stock to greater efficiency and reduced heating and cooling demands will take a long time. Fortunately, however, more appropriate energy systems can usually be incorporated along with other traditional conservation measures. The program to improve the building infrastructure of societies as a short- and medium-term strategy has the merit of creating new jobs and satisfying for many the need for meaningful work.[95]

C. A. Hooker and others pointed out the energy intensive aspects of changing infrastructures of society. Consequently, they emphasized the importance of implementing conservation measures and pursuing the development of safe, secure, reliable and durable energy systems "now, while our fossil fuel bridge to the future still exists."[96] At the end of the 1970's they anticipated that Canada would escalate the capital investment in making energy from 3.5% (1975) to 6% of the gross national product (GNP) in 1990.[97] The growing proportion of the GNP spent on one aspect of energy production, distribution and use suggests the broad impact of the necessary infrastructure of energy on economic systems and the need for deliberate measures to take advantage of the lead time still available to lessen any catastrophic impact of change.

Long lead time requirements to change energy infrastructure indicates that it is too late for tentativeness or long delays in the development of renewable energy alternatives and other alternative energy systems. When Hooker and others reported in 1979 that fossil fuels were satisfying 90 percent of Canada's energy needs, with an expected quadrupling of use of fossil fuels between 1972 and 2000, it was abundantly clear how major the infrastructure change will be in some industrialized societies.[98] The time to use a wide variety of measures to recover waste heat, to conserve energy and to work with nature to utilize naturally occurring, sustainable energy is now. The long lead time required for planning new facilities and a new energy infrastructure strongly suggests the need of educational leadership and government and private incentive grants to facilitate changes, especially in situations where there is reluctance to accept the needed changes. Due to higher capital costs, new buildings and their energy systems require a longer lead time than renovation projects in schools for planning and funding.[99] Highly visible institutions, like churches and schools, can help address the problem of meeting long lead time requirements by providing good models of effective use of alternative energy systems.[100] If schools and colleges facilitate, rather than inhibit, future installation of renewable energy devices, at least that much of a lead will have been achieved prior to the stringent measures scarcity can demand.

Wasteful Duplication

Hard and fast generalizations are difficult to make about appropriate primary energy resources to meet energy needs. One obstacle to such generalizations is the ease with which some systems meet multiple energy needs that remain after appropriate conservation measures have been taken. Continuous planning is needed to integrate systems to take advantage of the merits of different systems without unnecessary duplication of hardware.

Some experts argue that compression type heat pumps, employing phase-change technology, offer an example of an ideal solution which moves in this direction. Technology which has traditionally been used in refrigeration machines can be applied to provide heating and cooling by utilizing the transferred heat. S. V. Szokolay has offered helpful descriptions of the merits of such systems.[101] The technology permits use of the advantages gained by removal of very large quantities of heat from a liquid or gas when evaporation occurs and addition of an identical amount of heat to a liquid when condensation occurs. A similar phenomeon is available in the freezing and melting processes. In each cycle of heat pump operation both evaporation and condensation occur. Ammonia, methyl chloride and many Freon compounds are available for use in such processes. The effects are demonstrated when the exterior vent of a closed refrigerator or the exterior side of an air conditioning unit releases the heat transferred during phase change processes which also cool liquids and air inside the refrigerator.

Safety

Safety is another important aspect of energy system performance which should be weighed in the selection process. If energy systems create high temperatures in wood framing of buildings over an extended period of time, the wood may char and ignite.[102] This suggests the need of both safe products and knowledgable and reliable installers. Safety considerations, if overlooked, can make a building lethal. A superinsulated building which lacks compensatory measures to provide adequate ventilation illustrates a potentially lethal level of indoor pollution.[103]

Opponents of nuclear fission and breeder reactors as sources of energy raise questions regarding the extent of the problem of safety, including the potential misuse of plutonium by terrorists or others. Safety questions of broad consequences are also raised relative to the combustion of fossil fuels.

Affordability

Affordability of energy systems depends on a great number of factors. Conservation measures prior to the installation of energy systems make possible major reductions in the size and cost of the system. The cost of energy systems in 1990, 2000 and 2010 can not be accurately predicated. The current potential for alternative sources of energy, the instability of the international energy market and even the viability of political and economic systems make the cost of energy raw materials and labor unpredictable. Straight-line, mathematical projections of current energy trends have been unreliable for the last

fifteen years. Consequently, it is more useful to examine some of the individual factors that effect affordability.

First cost or initial capital investment is less important than life-cycle costs of energy systems and educational facilities in general. If schools follow private investment practices, they may erroneously conclude that fast turn around of capital investment via quick sale at a slightly lower price is more important than durability and virtually free energy, with minimal maintenance. While initial capital investment in renewable energy systems is often greater, the life-cycle costs tend to be smaller. Sound school investment in facilities and equipment requires an accurate assessment of life expectancy and energy efficiency. The reasonable educational administrator aspires to achieve long term savings rather than focusing too narrowly on low first cost. However, low first cost can be important when other factors are similar.

The idea of a payback period helps justify greater initial capital investment. **Payback period** usually refers to the time required to recover the initial investment through fuel savings relative to less-capital-intensive, traditional systems which would continue to make relatively larger demands for fossil fuels or electricity from a public utility company.

An important criterion of affordability is relatively quick payback of additional cost of energy improvements through energy savings. It was used in the Shawnee District. The Kansas Energy Office screened the heavily documented plans to identify projects for grant

eligibility, using five year payback for approval and sending them on to the Department of Energy. Some of the initial conservation steps dealt with aspects of solar energy as follows: using "outside air for free cooling," "possible solar heating," "daylighting," and using "shading devices to reduce solar gain."[104]

The relatively high initial cost of some renewable energy systems makes them economically practical only if the builder can provide a high level of confidence in the durability of the system so that life-cycle-cost analysis can demonstrate merits in addition to reducing the demand for non-renewable resources. Today life-cycle costing tends to support long term conservation measures and renewable energy technology development in schools. Perhaps the best evidence is the willingness of private firms to finance energy systems in schools through guaranteed savings.[105] Capital investment is paid back long before the end of the useful life of energy systems which continue savings by avoided cost of fuel. If a backup energy system is needed, its size is reduced substantially.

Capital cost is also less important than the reliability or sustainability of the energy system. If the fuel supply becomes prohibitively expensive, the system is unreliable. Indigenous resources tend to be more reliable than those which may be subject to embargo or scarcity for other reasons such as the disruption caused by military conflicts like the Iran-Iraq war. Reliable energy is also supported by the use of multiple sources of energy on a small scale rather than heavy reliance on a central facility which may be shut down for a variety of

reasons. Stored sensible heat can be used gradually until it has dissipated to the extent that it is below the lowest usable temperature unless additional heat is applied.[106] The provision of storage for heat, coolness and electricity add to their relatively short-term reliability which is usually adequate except in extreme weather conditions. Of course, any energy system may require backup or auxiliary resources during downtime for maintenance or major renovation. However, downtime need not bear the additional burden of increasing rates or total change of energy systems due to prohibitive expense which will eventually be the case again with fossil fuels.

When viewing the relative merits of traditional and renewable energy systems, initial cost frequently assumes greater importance than warranted due to short-sighted budgetary practices. Long-term budgetary restraints demand careful attention to all potential energy sources and the impact of other criteria of affordability. Many school systems have not used matching federal funds which have been available as incentives to change traditional uses and to reduce usage of wasteful, polluting and import-dependent energy systems.

One example of application for and use of matching federal funds, with the assistance of a professional energy management consulting firm, was seen in the Shawnee Mission School District in Kansas.[107] The first cycle grant of $342,000 for retrofitting nine schools dealt mainly with conservation measures rather than alternative energy systems, an appropriate first step.[108]

Foundation funds are available to schools and churches wishing to utilize alternative energy systems and conservation methods which have a reasonable payback period. Another recent avenue to dealing with capital investments is energy entrepreneurs who are experts in saving energy dollars and are willing to finance energy system improvements through guaranteed savings schools will realize.

Lifetime (life cycle) operating costs of maintenance, custodial work and associated demands of management time are important considerations in evaluating energy systems. These are the human equivalent of the unfavorable comparison of kilowatt hours used by incandescent bulbs instead of fluorescent bulbs.

Reduced life cycle energy consumption in energy efficient buildings is evidence of the importance of building design. Efficient design limits the need of some energy features. Jane U. Rippeteau evaluated energy management systems in the context of energy efficient building design. Rippeteau cited studies which showed the contrast of "some pre-1973 commercial buildings in New York City . . . using as much as 223,000 Btu's per square foot a year," as compared to a project of Encon's, the Gulf Canada Square, Calgary, Alta., which was expected to require "only 35,000 Btu's per square foot a year."[109] With this level of savings, due to use of features like curtain-wall air ducting, superinsulation and coffered ceilings to utilize waste heat, the value of energy management systems may be limited mainly to light, temperature, ventilation and humidity control in the area of energy rather than significant additional energy savings.[110]

Potential cost increases in energy supply and shortages which may cause school closings seriously affect the affordability of energy systems. While the time shortage of fuels and energy-related products will occur is difficult to anticipate, little doubt remains that the practical feasible limits of oil and gas at affordable prices will be reached early in the next century. Consequently, early obsolescence of energy equipment due to shortage of fuel supplies may alter very significantly the life cycle costs. A few decades of supplies at ever higher costs stand in marked contrast to the estimated six billion years of remaining solar energy. Non-traditional energy systems can be designed to last for the useful life of school facilities to avoid early energy obsolencence in buildings.

Amory Lovins and others have emphasized the need to exercise care in the selection of appropriate energy systems and, also, of appropriate suppliers if savings are to be realized. Some traditional and renewable energy suppliers share two characteristic qualities, level of skill and avarice, which make smart buyers cautious. Lovins described the marketing structure as highly varied, saying:

> . . . Indeed, there is ordinarily a scatter of at least twofold in the installed price of identical gas furnaces put in at the same time in apartments in the same part of California, depending on the skills and avarice of the contractor; so it is not surprising that solar hardware, which is more diverse and has less mature marketing structure, should show an even wider price variation, requiring careful shopping for best buys.[111]

Moral Criteria Reflected in Scale of Technology

Values on an even larger scope than the immediate school setting can be satisfied more readily by the selection of some energy systems than others. Political action groups, entertainers, theologians, architects, engineers and educators are among those individuals and groups who are articulating ethical concerns related to energy which go beyond the need of school systems to balance budgets. Donald R. Price, a professor of agricultural engineering, in describing energy resource answers in agricultural settings and agricultural education, said, "Our educational programs today should stress the importance of conserving energy and develop in students a new energy ethic."[112]

Some of the dimensions of ethical choice in the area of energy are indicated here:

1. Some energy systems are so technically complex, so prohibitively expensive and require energy infrastructure on such a large scale as to be practically unavailable to broad segments of the world population.

2. Long-term environmental and social costs of energy systems are potentially more crucial criteria for evaluation of energy options than technical and short-term economic considerations.

3. With increasing national and international unemployment problems, labor-intensiveness of the energy industry may become far more important than industrial satisfaction of the profit motive in capital-intensive energy systems.

4. The former economies of large-scale energy production may have increasingly negative impact along a whole range of value dimensions which may be grouped under concerns for justice, sustainability and participation.[113]

5. In some parts of the world energy choices and energy inequities literally deprive human beings of essential food, clothing and shelter, with consequent impact on the hope of world peace.[114]

6. Currently known, crucial uses and unforeseen future uses of limited oil, natural gas and coal may still exist when affordable supplies are exhausted.

7. The appropriate time frame for ethical decisions regarding renewable and nonrenewable sources of energy may be billions of years of geohistory to permit the Second Law of Thermodynamics to sustain human habitation for the foreseeable future.

Fowler and Kryger saw the necessity of dealing with the long-term energy problems and making choices between systems earlier than most of their contemporaries. They said,

> Oil and gas may be hard to find anywhere by 1996, and we will not be using much of either by 2020. Coal will go longer, if we can stand to burn it, but the next century must be fueled by something else. Will it be solar energy, fission energy, or fusion energy? These three paths are all costly ones. We can't go along all three. Vocational educators must understand these options because in our students' lifetime one will dominate.[115]

Since schools and universities express a growing appreciation of the important role education plays in instilling humane, socially functional values, affordability must take into account moral criteria as well as financial criteria. Fortunately, when educational administrators make decisions based on broad comprehension of energy issues and with a reasonably long perspective, both moral and financial criteria can be satisfied together. E. F. Schumacher and the World Council of Churches are numbered among those individuals and organizations who have eloquently expressed this concern.

E. F. Schumacher indicated that both highly industrialized and developing "countries of the world must start to devise technologies that are more in harmony with people, and with the environment, and less dependent on non-renewable resources."[116] The suggested criteria for sustainable technologies of the future were "small, simple and non-

violent."[117] Schumacher made it clear that high technology which tends to be capital intensive and wasteful of natural resources is not necessarily the best or most appropriate technology. He called for improvements in the intermediate technology which has tended to disappear in this century with the rise of less labor intensive technology designed to return a quick profit on large capital investments. The demise of the small farm and the destructive drift toward monoculture in agricultural practice are important consequences of wasteful use of energy and capital in agriculture, for example.

Schumacher and some of his friends set up the Intermediate Technology Development Group Ltd. early in 1966 to help. The goal of providing appropriate technology was expected to cost 1/50th to 1/100th of the capital per workplace which is typical in rich countries.[118] George McRobie fulfilled Schumacher's hope of demonstrating that small is both beautiful and possible. With illustrations from several continents, he demonstrated technology in energy and other fields which satisfied the four criteria that gradually developed to distinguish intermediate technology: "smallness; simplicity; capital cheapness; and non-violence."[119] The first criterion is appropriate small-scale technology, without which another characteristic polarization occurs—"vast congestion in a few places and enormous emptiness elsewhere."[120] Rural areas tend to become colonies of big metropolitan areas, simply producing raw materials and children who move on to the cities for jobs.

The second criterion of appropriate technology which can be broadly applied is simplicity. Schumacher said, "It takes better

engineers--even a third rate engineer can make a complicated thing even more complicated. It takes a bit of genius to recapture the basics and simplicity."[121] Unlike highly complex technology, simple technology is applicable to rural and small town areas of the world.

The third criterion is low cost per workplace. Schumacher was concerned about the costliness of capital equipment for which only multinational companies can afford to create workplaces.[122] This leaves out those who can not afford high technology and completely misses those who are unemployed and lack the ability to form capital sufficient to provide a workplace.

The fourth criterion of appropriate, intermediate technology is its nonviolence towards nature. Many facets of energy use fail to meet this criterion. The killer, chemical pesticides used in energy intensive agriculture fail to meet this criterion. Schumacher said,

> Of course the greatest readiness to resort to violence we are now experiencing in our attempts to cope with the energy problem, where we are prepared to put into the world large amounts of plutonium, a substance of a really unbelievable ghastliness, which the good Lord never made. He knew where to stop. It is a manmade thing. And it will be there for all time: the half-life radioactivity of plutonium is 24,400 years. In fact, before it is really quite harmless it takes a matter of 3 million years.
>
> All this is a readiness to apply extremely violent processes to that sacred and unbelievably complex system called nature. We don't know what we are doing.[123]

McRobie indicated that the intermediate technology needed to solve world problems is not an exclusive concern of poor, developing countries. In preparation to write Small Is Possible, illustrating the vision Schumacher had in Small Is Beautiful, McRobie discovered,

> . . . A rapidly growing number of individuals and groups on both sides of the Atlantic have concluded that the only sane alternative lies in the direction of technologies that are relatively small, simple, capital-saving and non-violent, and economics as if people mattered.[124]

The need is increasingly apparent even in countries which can afford high technology. McRobie wrote, concerning Schumacher,

> . . . During my own conversations with him shortly before he died in September 1977, he had become increasingly convinced that the need of the rich countries to restructure their technologies and life-support systems was, if anything, more urgent than that of the poor countries.[125]

In the 1950s and 1960s Schumacher advocated the development of renewable sources of energy. As McRobie said,

> . . . Today his foresight is acknowledged, and rich and poor countries alike are becoming increasingly interested in ways of getting useful energy from the sun, the wind, water, and vegetable material--biomass--though many of us believe that in practice the amount that is being done in this field is negligible in relation to the need.[126]

The Group has come a long way since it started its energy program in 1968. McRobie said,

> . . . From the outset it has been associated with the Department of Engineering Sciences at the University of Reading, and the energy unit operates from workshops on the university campus.[127]

Some of the renewable energy strategies developed by the Group are alluded to in the appropriate chapters of this dissertation. They include such strategies as windmills for low-lift irrigation, solar cookers and biogas (methane) digesters, all of which are "designed to use low-cost technologies in ways that integrate with village life."[128] They are demonstrating the effective "use of renewable resources to meet the basic human needs of food, shelter and energy."[129] They have recognized the fact "that conventional industrial society is on a

collision course with human nature, with the living environment, and with the world's stock of non-renewable resources."[130]

Schumacher hoped to help

> overcome the fateful polarization which modern technology has produced, under which the rich become richer and the poor become more desparate, and society disintegrates--something that you can observe on a world scale, and you can also observe in all big countries.[131]

Enormous welfare expenditures, now serving many third generation welfare recipients have not served to integrate the poor into society. Consequently, Schumacher said,

> And even the great United States has come to the conclusion that with the present easily available technology, we cannot solve the problem. So they have set up a national centre for appropriate technology, not for the developing countries, but for the United States. They said, "We must re-think technology, and try to make it appropriate to our actual problems." These problems are not simply more and more production. The actual problems are the reintegration of a sizable proportion of the total population into the mainstream of society.[132]

Global Energy Ethics

In addition to traditional concerns about durability, reliability and safety of energy systems, various other values are met to greater or lesser degree by energy systems. In 1979 a consensus was emerging among many leaders of world stature that the values of justice, sustainability, and participation are better satisfied by small-scale, decentralized use of renewable energy resources.[133] Some of the leaders looked for "inequality-reducing technologies" adequate to meet the basic needs of everyone.[134] Instability and excessive inflation in the price of fossil fuel, by contrast, bring devastating effects to the poor, the

old and aspirations of two-thirds of the world's population in less affluent sections of developing countries.[135]

The economic and social instability associated with countries dependent on fossil fuels was evident in Mexico in the first quarter of 1986. The inflationary spiral tended to undo the promised alleviation of poverty with major oil and gas discoveries of the 1970's. As oil prices fell and price controls failed to work, the country was near bankruptcy.

In many ways current energy uses are distinctly unjust. Americans consume far more than their fair share of nonrenewable resources. Furthermore, current usage and trends are simply unsustainable. Sustainability as an energy criterion acknowledges the value of future generations of people who may need the resources wasted today.[136] This concern and other quality of life considerations call for an energy policy making machinery which is participatory on as broad as possible a basis rather than a creature of high technology, big government, or very large utility companies. Energy production and use which involves short- and long-term health risks, energy deprivation, environmental/ecological damage, denial of individual freedom, and social instability must be governed by "energy choices in the context of justice, sustainability and participation."[137] In reference to participation, it has been argued that "democracy must not yield its place to technology."[138]

While sustainability is probably the ultimate criterion society and educational facility planners will be forced to deal with in energy

policy making, participatory decision making may be most crucial for ethical and rational choices of energy policy. Technical, economic, political and social pressures inhibit basic changes of direction in a society. Existing pressure groups tend in largest numbers to represent short-term solutions as desirable. Therefore, ethical and rational decision makers, who act on the criteria of justice, sustainability and participation, face the dilemma in formulating energy policy that their long-term strategies involve many conflicting approaches which only approximate solutions to "the underlying social, ethical, technological and resource problems."[139]

Current energy issues demand education on a broad base, not just in the domains of national energy policy makers, educational facility planners, technical training programs and science and mathematics teachers. Appropriate energy decisions require educated and properly motivated people. One of the crucial concerns perceived by many worldwide leaders is a tendency of highly complex and capital-intensive energy technology to remove decision-making from users to centralized leaders. The linkage of values associated with free, approriate education, human liberties and participatory energy decisions[140] merits some consideration by those who make energy decisions in educational settings.

Educational leaders who make energy decisions should acknowledge the impact, however slight it may seem to be, of their decisions on justice as a formative value in society. Justice provides a "fairer distribution of energy between rich and poor, within countries as well

as between countries."[141] Fairness demands sharing energy resources and appropriate technologies for use of these resources. Ethical methods of supplying and using energy can help to "avoid the creation of further exploitative dependencies."[142]

The argument for justice as it relates to energy resources, production, technologies, distribution and uses is seen in the context of a society where "everyone would have access to the energy necessary to meet their basic needs."[143] Basic needs are distinguished from wants "which derive from adopted life styles."[144] They are also distinguished from demands which must have reasonable limits. Current energy practices are seen as contributing a great deal to the total amount of injustice in the world in each of the basic areas of human need, ranging from survival needs of food and shelter to quality of community life and the need of meaningful work.[145]

Renewable energy resources are also limited in appropriate use, although they tend to be more favorably regarded than fossil fuels and nuclear energy resources. Consider, for example the following restraint on the use of biomass energy.

> It should be recognized that large-scale utilization of biomass conversion as a long-term energy strategy would undoubtedly lower food production in the world because it would make additional demand on the limited arable land available. This problem will be intensified as the world's population and its nutritional needs increase.[146]

David J. Rose described solar power in the context of development of long-term energy resources for a sustainable energy future.[147] His emphasis on sustainability led to the honest conclusion that solar energy also raises questions in this regard. He said,

> Solar radiation is a diffuse source of energy and large amounts of materials are needed for collectors, storage devices, and so on. To build equipment that can capture and convert solar energy to useful forms requires capital investments employing non-renewable resources that are far from free, even though sunlight itself is free.[148]

The quality of ubiquity makes solar power attractive, while its diffuseness makes its many potential transformations to useful energy forms expensive in capital investment. This is true for solar power in its various forms including "direct conversion of sunlight, . . . hydro-electric power, winds and biomass (organic matter).[149]

Rose described various solar applications, including low, intermediate and high technology. These gradations of technology also describe the capital investment.[150] Rose's descriptions suggest the rich contribution solar energy can make to the whole long-term energy problem. Part of the technological and capital investment problem is the need of back-up energy sources when solar energy and storage capacity prove to be inadequate.[151]

Minimizing Environmental Problems

The whole host of effects of pollution due to use of fossil fuels on buildings, monuments, forests, agriculture, lakes and other physical aspects of the environment of schools heighten the need to make decisions early about which alternative energy systems to use. Applying appropriate energy remedies today can reduce the future loss of educational funds to deal with unnecessary environmental damage. Large areas of coastal cities and agriculture may be lost due to flooding. Major capital investments may be necessary to reduce the damaging

effects if the "greenhouse effect" of CO_2 leads to the hypothesized melting of the polar ice caps and a consequent rise in the ocean level.[152] The long term use of fossil fuels on a large scale, even if supplies were available, is "unattractive" (to say the least), "because of the buildup of carbon dioxide in the atmosphere, and a consequent increase in the global temperature due to the trapping of an ever-larger portion of the earth's radiated heat."[153] The durable, and perhaps unendurable, consequences of the "greenhouse effect" make alternative energy resources imperative, totally apart from considerations of availability of supplies of fossil fuels at reasonable cost and ethical considerations about the exhaustion of coal, oil and natural gas as chemical resources for unforeseeable and known uses. It may be that the problem is understated, as follows:

> . . . This "greenhouse effect" appears to be long-lasting, and without any reasonable technical fix. The carbon dioxide takes many centuries to be absorbed in the deep ocean waters. If present energy trends continue, the carbon dioxide concentration will double early in the next century, leading to substantial climatic effects.[154]

Major climatic shifts and consequent disruptions of agriculture and the support systems of agriculture have been anticipated by researchers. The effects of acid rain on lakes, rivers, forests, health and so on have been established as major reasons for finding environmentally cleaner solutions to the energy problem even before shortages force the solutions upon the world's leaders in government, education and industry. Many of the world's leading scientists have stressed the importance of having in place by 2010 sustainable energy resource

systems to lessen the impact of damaging environmental factors already in process.

The burning of gas, oil and coal as an energy resource for school facilities fails to meet long-term criteria of reliability, safety, and economic feasibility. Major agricultural and population shifts will occur due to past and present delays in providing adequate energy alternatives to fossil fuels. The long-term costs of energy demand timely choices of energy systems and appropriation of funds to supply them.

Summary

Educational leaders must make decisions concerning the relative merits of conventional and renewable energy systems in meeting users' energy needs. Building on a broad base of energy efficient planning and design, involving all relevant parties throughout the process, wise educators will keep all of their primary energy resource options open. These will include renewable energy resources, especially those which have already demonstrated their feasibility in some educational settings, namely, solar, wind, biomass, water and geothermal energy resources. The local appropriateness and technical complexity of systems will affect payback time, cost effectiveness, system efficiency, maintenance requirements and other user considerations. However, educators may expect to discover renewable energy answers which satisfy a broad range of user criteria.

CHAPTER FOUR ENDNOTES

1. "Energy management yields results," American School & University, 52:9:32-33, May, 1980. and "One energy miser's plan," American School & University, 53:8:64-65, April, 1981.

2. Elizabaeth Holland, "An Airy Office Complex," Solar Age, 6:7:31, July, 1981.

3. Ibid.

4. Allan L. Frank, "The SOLAR CLIPS," Solar Age, 6:7:19, July, 1981. The usage described occurred in Wilmington, Vt., luxury condominiums.

5. Jerry Lawrence, "Energy-Conscious Design, Part I," American School & University, 56:12:43, August, 1984.

6. Ibid.

7. Ibid.

8. Ibid.

9. Ibid.

10. Ibid., pp. 43 & 46.

11. Ibid., p. 46

12. "Facilities newsfront," American School & University, 52:7:79, March, 1980.

13. Amory B. Lovins and others, Least-Cost Energy: Solving the CO_2 Problem (Andover, Massachusetts: Brick House Publishing Company, 1981), p. 116.

14. Jane U. Rippeteau, "Making Your Buildings Energy Efficient," Administrative Management, XLI:4:55, April, 1980.

15. Dorothy Wright, "A Preface to Architectural Portfolio," American School & University, 56:3:3, November, 1983.

16. C. William Day, "The Shape of Schools to Come, American School & University, 56:3:12, November, 1983. Day was professor of education at Indiana University, Bloomington, Indiana.

17. Ibid., p. 8.

18. Ibid.

19. Ibid., p. 8.

20. Rosalie Ruegg and Harold Marshall, "Economics of Building Design," Solar Age, 6:7:26, July, 1981.

21. Day, op. cit., p. 7.

22. Jamie James, "Earthscraper," Discover, 5:2:74, February, 1984.

23. John Hoke, "Guard building puts sun to work," Richmond [Virginia] Times-Dispatch, March 24, 1985, sec. E, p. 1.

24. Bill Benton, "Solar screens give schools comfort . . . while they save energy!," American School & University, 54:5:42, January, 1982.

25. Gerald F. Bender and Jack F. Probasco, "Include passive solar in your renovations," American School & University, 53:8:38, April, 1981.

26. Bender and Probasco, op. cit., pp. 38-39.

27. Ibid., pp. 38 & 40.

28. Ibid., p. 38.

29. Ibid., pp. 40-41.

30. Ibid., p. 40.

31. Ibid.

32. Ibid., p. 41.

33. C. DiMercurio, "Ventilation cooling: an old solution to new problems," American School & University, 53:11:40, July, 1981.

34. David Godolphin, "Simplicity in Adobe," Solar Age, 6:6:27-29, June, 1981.

35. Ibid., p. 28.

36. Ibid.

37. Paul Abramson, "10th Annual Report on Educational Construction," American School & University, 56:8:16-17, April, 1984.

38. Paul Abramson, "Educational Construction: Seventh Annual Cost Report," American School & University, 53:8:55, April, 1981.

39. "Facilities newsfront," American School & University, 52:7:80, March, 1980.

40. Rita Robison, "Solar Energy Now?," American School & University, 52:9:42, May, 1980.

41. Paul Lippin, "Offices Go Solar," Administrative Management, XL:9:34, September, 1979.

42. Abramson, "Educational Construction: Seventh Annual Cost Report," op. cit., p. 55.

43. Ibid.

44. Paul Abrecht, ed., Faith, Science and the Future: Preparatory Reading For a World Conference Organized by the World Council of Churches At the Massachusetts Institute of Technology, Cambridge, Mass., USA, July 12-24, 1979 (Geneva, Switzerland: Church and Society, World Council of Churches, 1978), p. 102.

45. Ibid., p. 101.

46. Ibid., p. 79.

47. Ibid.

48. Ibid.

49. Donald D. Duggan, "Toward Meeting the Nation's Energy Needs," Vocational Education, 54:1:29, January, 1979.

50. Ibid.

51. C. L. Boltz, "Energy: Electricity," Britannica Book of the Year (1984) (Chicago: Encyclopaedia Britannica, Inc., 1984, p. 344. This is included among longer articles on energy. Data reported are from 1983.

52. Abrecht, 1978, op. cit., p. 102.

53. International Energy Agency. Energy Policities and Programmes of the IEA Countries. 1980 Review. (Paris: OCDE, OECD, 1981), pp. 199-300.

54. Ibid., p. 302.

55. Ibid., p. 305.

56. P. L. Auer, Renewable Energy Resources (New York: IPC Science and Technology Press, 1978), p. 27.

57. Ibid., pp. 26-27.

58. Ibid., p. 27.

59. Senator Alan Cranston, "The Cranston Energy Plan," Solar Utilization News, 8:7:7, January, 1984.

60. Abrecht, 1978, op. cit., pp. 84-85.

61. Whirlwind Power Co., Solar Age, 6:6:48, June, 1981.

62. Lovins, op. cit., p. 120.

63. Robison, op. cit., p. 42.

64. Ibid.

65. Ibid.

66. Lovins, op. cit., p. 109.

67. Ibid., p. 110.

68. Ibid., p. 111.

69. Ibid., pp. 145 & 119, etc.

70. Ibid., p. 108.

71. Ibid., p. 145.

72. Donald Burr, "Conserving Energy at School," VocEd, 54:1:22, January, 1979.

73. C. A. Hooker and others, Energy and the Quality of Life: Understanding Energy Policy (Toronto: University of Toronto Press, 1981), p. 143.

74. Ibid., p. 140.

75. Ibid.

76. Abrecht, 1978, op. cit., p. 101.

77. Auer, op. cit., p. 24.

78. Ibid.

79. Ibid.

80. Jennifer A. Adams, The Solar Church (New York: The Pilgrim Press, 1982), p. 16.

81. Ibid.

82. Ibid.

83. Ibid.

84. Ibid.

85. Adams, op. cit., p. 3.

86. Ibid., p. 23.

87. Ibid., p. 3.

88. Ibid., p. 5.

89. Jacques Constans, Marine Sources of Energy (New York: Pergamon Press, 1979, United Nations) pp. 78-87.

90. Don Best, "Measured Output of Two Active Systems," Solar Age, 6:7:44, July, 1981.

91. Robison, op. cit., p. 43.

92. David J. Rose, "Towards a Sustainable Energy Future," Faith and Science in an Unjust World: Report of the World Council of Churches' Conference on Faith, Science and the Future, Volume I: Plenary Presentations, ed. Roger L. Shinn (Geneva, Switzerland: Church and Society, World Council of Churches, 1980), pp. 246-247.

93. Ibid., p. 246.

94. Paul Abrecht, ed., Faith and Science in an Unjust World: Report of the World Council of Churches' Conference on Faith, Science and the Future, Volume 2: Reports and Recommendations (Geneva, Switzerland: Church and Society, World Council of Churches, 1980), p. 94.

95. Ibid., p. 95.

96. Hooker, op. cit., p. 90.

97. Ibid., p. 34.

98. Ibid., p. 33.

99. Abramson, "10th Annual Report," op. cit., p. 16.

100. Adams, op. cit., p. 44.

101. S. V. Szokolay, World solar architecture (London: The Architectural Press, 1980), pp. 21-22.

102. Peter Temple, "Thermal Degradation of Wood Associated with Solar Collectors," Solar Age, 6:6:42, June, 1981.

103. Alan Caruba, "Indoor Pollution: The Invisible Enemy," American School & University, 56:8:46-47, April, 1984.

104. "One energy miser's plan," American School & University, 53:8:65, April, 1981..

105. Richard M. Esteves, "Creative Financing," American School & University, 56:6:48, 50 & 52, February, 1984.

106. Szokolay, op. cit., pp. 19-20.

107. "One energy miser's plan," op. cit., p. 64.

108. Ibid.

109. Jane U. Rippeteau, "Making Your Buildings Energy Efficient," Administrative Management, XLI:4:54-55, April, 1980. "A Btu, or British thermal unit, is a measure of heat energy and is now commonly used to express levels of energy consumption." (p. 54)

110. Ibid., p. 55.

111. Lovins, op. cit., p. 117.

112. Donald R. Price, "A New Energy Ethic for Farmers," Vocational Education, 54:1:50, January, 1979.

113. Abrecht, 1980, op. cit., pp. 91, 95, & 159.

114. Price, op. cit., p. 48 & Abrecht, op. cit., p. 94.

115. John M. Fowler and King Kryger, "Energizing Vocational Instruction," Vocational Education, 54:1:42-43, January, 1979.

116. George McRobie (with a Foreword by Verena Schumacher and E. F. Schumacher: on Technology for a Democratic Society), Small Is Possible (New York: Harper & Row, Publishers, 1981), p. 1.

117. Ibid.

118. Ibid., pp. 29 & 34.

119. Ibid., p. 36.

120. Ibid., p. 9.

121. Ibid., p. 10.

122. Ibid.

123. Ibid., pp. 10-11.

124. Ibid., p. 14.

125. Ibid.

126. Ibid., p. 51.

127. Ibid.

128. Ibid., p. 70.

129. Ibid., p. 152.

130. Ibid., p. 189.

131. Ibid., p. 8.

132. Ibid.

133. Abrecht, 1980, op. cit., pp. 91-92.

134. Ibid., p. 91.

135. Hooker, op. cit., p. 126.

136. Abrecht, 1980, p. 159.

137. Ibid., p. 91.

138. Ibid., p. 92.

139. Ibid.

140. Ibid., p. 93.

141. Ibid., p. 91.

142. Ibid.

143. Ibid.

144. Ibid., p. 93.

145. Ibid., p. 94.

146. Ibid.

147. David J. Rose, "Towards a Sustainable Energy Future," Faith and Science in an Unjust World, ed. Roger L. Shinn (Geneva: Switzerland: Church and Society, World Council of Churches, 1980), pp. 241-252.

148. Ibid., p. 246.

149. Ibid.

150. Ibid., pp. 246-247.

151. Ibid., p. 247.

152. Abrecht, Faith, Science and the Future, 1978, op. cit., p. 78.

153. Ibid.

154. Ibid.

Chapter 5

SOLAR ENERGY SYSTEMS

The global context in which educators choose energy systems is characterized by severe inequalities which seriously impact the delivery of educational services. Deliberate choice of energy resources systems which are more generally available and relatively simple technologically by US educators can model energy answers which help solve America's long-term energy problems, while demonstrating to poor countries the potential of investing their scarce foreign exchange in educational tools rather than prohibitively expensive energy equipment and fuels. Peter E. Glaser said, "Only solar energy can contribute significantly to balanced global development."[1] Consequently, choices like the use of solar energy can enable US educators to add immeasurably to the task of developing human potential.

Solar Energy Available

The rate at which new technologies can be developed to satisfy energy needs was one of the critical questions dealt with by Abrecht and others in 1978. In reference to solar development rate, they said,

> . . . The most detailed estimates which we know are made by the US. Solar power optimists state with an "all out" effort as much as 30% of the present US energy use (i.e. 22 quad of energy per year out of 75 total) could be produced by AD 2010, but the cost of such a programme has not been documented. Others put solar power in AD 2010 as low as 5% of US energy (3.5 quads), with it being just one of several sources (e.g. coal, fission, fusion, etc.). Under the political conditions imposed by this scenario, a figure approaching the upper limit may be possible

> for the US, and probably for certain other countries. However, the world as a whole could not make such a rapid transition. Hence the heavy pressure on nuclear power and on draconian conservation measures.[2]

Four to five percent of this potential development was derived solar energy and fell under biomass energy headings of urban wastes and animal feed lot wastes, with large, unknown, additional quantities listed under forest and crop residues.[3]

The vast distance of the sun from the earth makes it seem to be an unlikely point of origin for "the most available energy source" for earth; nevertheless, it is accurately described in this way.[4] Linda Baine McGown and John O'M. Bochris, who defined renewable energy resources simply as "those which will not run out",[5] explained the process of conversion of the "mass of hydrogen nuclei in the sun to form helium."[6] They estimated that this entire mass of hydrogen will complete the process in "about 11 billion years, and its present age is about 5 billion years." That leaves our world a healthy balance of "6 billion more years" before the sun burns out and can no longer produce energy.[7] They described the sun as "a hundred billion billion megawatt generator"[8] which sends the earth "about two hundred billion megawatts."[9]

Solar energy users know that, whether the energy is primary or derived, such as wind, solar energy can make a very significant contribution to satisfying man's energy needs for the duration of the life of this solar system. Renewable energy technology converts the readily available forms of solar energy to other purposes besides the naturally occuring raw solar energy for light and heat. A great deal of

management of light and heat is also necessary. McGown and Bochris noted in How To Obtain Abundant Clean Energy that, if the 40 megawatts per person of solar energy theoretically available were accessible in useful form, it would be about 4,000 times "more than the most energy-demanding society needs per person."[10]

P. L. Auer and others indicated that the solar energy striking the earth is about "20,000 times greater than the total present worldwide mobilization of fossil fuels and uranium."[11] They identified a number of favorable attributes of this primary energy source, stating,

> . . . It is globally distributed, of high thermodynamic quality, nondepletable, and available in the same quality year after year. In addition it is not expected to introduce major environmental problems.[12]

They also described practical limitations on the economical and reliable use of solar energy.[13] Since the sun's energy is not always available in adequate quantity, energy provisions must be made for those times by storing the energy when it is available or by use of some backup energy system. Furthermore, solar energy is spread thinly rather than concentrated, requiring costly equipment to collect this diffuse energy resource. Auer and others listed the three problematic aspects of solar energy this way:

> . . . In the first place, diurnal, seasonal, and climatic variations in available sunlight require the extensive use of secondary energy storage and transport facilities, or hybrid use of other sources, in order to ensure reliable energy supply. Second, solar radiation is of a diffuse nature over most of the world. It therefore requires expensive, capital-intensive systems to tap its potential energy. These must be long-lived in order to be economically feasible. Third, sunlight is limited to a maximum power density of 1 kW/m^2 and a maximum average rate of incidence of 250 W/m^2 and 400 W/m^2 for global insolation and direct-beam insolation, respectively. . . .[14]

This dissertation acknowledges these limitations and also illustrates a number of economical ways to deal with the surface absorption area and storage demands for effective use of low-density solar energy.

They divided the solar resource base into two primary categories, **direct and indirect**, as follows:

> Direct-beam and diffuse radiation are considered direct forms of solar energy. Indirect manifestations include wind, waves, tides, thermal gradients in large bodies of water, hydropower, and photosynthesis.[15]

Solar energy is, when converted from direct to indirect energy, "the source of energy for the climatic system, providing the power necessary to sustain the biosphere."[16]

Auer and others offered a model description of the way energy coming from the sun is distributed. Clouds reflect more than one-third of the energy back to space. The remaining solar radiation flows primarily in two ways. First, about 43% heats the ground and atmosphere. Second, about 25% is involved in the circulation of water on the earth's surface, in soil and rocks and in the atmosphere.[17]

Approximately nine times as much energy is involved in wind, waves, convection and currents as in photosynthesis. Only about one-thirteenth as much energy is involved in tidal action as in photosynthesis.

Practically speaking, solar energy is much more readily available in some places and some forms than in others. The annual average solar energy available for consumption ranges from about two kilowatts per square meter to six kilowatts per square meter, depending upon location and climate. Auer and others were primarily interested in

electrical usage of solar energy which is most economically used where it is available in large quantity. Consequently, they were interested in the sunny arid regions of the world where ". . . the annual average of direct radiation . . . can be as high as 7-8 kWh/m^2 per day on a surface continuously oriented toward the sun."[18]

By contrast, while their interest was somewhat restricted, school superintendents have greater need of space conditioning than of electricity. Solar energy can provide efficient heating, cooling and lighting in far less than ideal circumstances, contributing useful gain even at the lower end of the spectrum of this resource's availability.

Reflecting on Solar History

Passive solar energy features which do not require electrical energy for distribution of lighting, heating, cooling or ventilation have a long history in architecture. Paula Lippin indicated that ". . . the Roman Baths . . . were heated by mountain water running across sun-warmed, black slate."[19] While offering no description of the passive or active methods used, she noted that "By 1941, there were about 50,000 residential and agricultural solar installations."[20]

Active solar energy systems which rely upon pumps and fans for the distribution of solar energy received increasing attention in the 1920's and 1930's. The first Massachusetts Institute of Technology solar house, built in 1939, used flat plate collectors.[21] As early as 1948, a flat plate solar energy collector provided 86 percent of the heat needed by the Rose Elementary School, Tucscon, Arizona.[22]

A comparison of data from Lippin and Lovins indicated a twentyfold increase in the use of solar energy from 1941 to 1981. The greatest increase has been in passive solar design. Amory Lovins described the extent of solar energy use in the U.S. in 1981, as follows:

> . . . The US . . . is now approaching its millionth solar building, of which half are passive, and half of those are retrofits (mainly greenhouses, plus some glazing of exterior masonry walls to form Trombe walls). Many of these were built on the basis of word-of-mouth or popular journal information, few from officially provided information. In the most solar-conscious areas, about 6-7% of all space heating is solar, and 25-100% of the new housing starts are passive solar design. Nationally, about 15% of the contractors building tract houses, and virtualy all purveyors of prefabricated and packaged-planned houses, are offering thermally efficient, passive solar designs.[23]

Basic Solar Energy Concepts

The sun's energy reaches earth as three different wavelengths of light: visible, infrared, and ultraviolet. Ultraviolet light, the shortest in wavelength, contains the most energy.[24] The task of solar energy design is to find ways to use the fraction of solar radiation that reaches the earth.

Solar Orientation

The initial design decision of those who use the solar energy which is not reflected, reradiated, transmitted or absorbed prior to striking a particular site is to determine how to maximize the desired collection of the remaining energy for needed uses. A solar collection device is ideally oriented to receive maximum sun exposure at the time

of energy use. The solar orientation or angle of exposure of facilities to solar influx varies with the season due to the changing relative positions of the earth and the sun. The sun does not climb as high above the horizon in the colder months and the length of the daylight observed in a given setting is shorter. Fortunately the angle of exposure in the northern hemisphere facilitates a high level of solar thermal energy gain in the winter in a properly oriented and shaded building. The sun's light strikes the earth with greatest intensity from a southerly direction in winter. Practically speaking, this means that in winter a northern wall will receive no direct sunlight while a southern glazed room will be warmed by the direct heat of the sun. Since the sun is perceived to rise in the east and set in the west, it follows that the preferred orientation of solar heat collection surfaces will be to the south, southwest and southeast, in that order, to achieve maximum heat gain.[25]

For most purposes the preferred orientation of glass surfaces and collectors in school facilities to receive solar energy is to the south and southeast. If maximum solar energy is desired, an active tracking device permits exposure of reflective and receiving surfaces to the southeast, south, southwest and variant seasonal exposures to match the angle of solar influx. Since most schools need heat gain primarily in the morning hours, a southeasterly exposure is frequently chosen to match the sun angle of the early morning. When reflected light of less intensity is desired for a particular setting, such as an art class, a

northern window or diffused, reflected light from another exposure will be preferred.

Heat Transfer

Conduction, convection and radiation are three methods of transfer of heat energy. **Conductivity** is the property of a material indicating the amount of heat that will flow through it with changes in temperature. Depending upon the use of the material, the user will desire to have heat move away from the collecting surface at a faster or slower rate. Heat moves away from metals faster than it moves away from woods of the same temperature, exhibiting metal's greater conductivity. Heat flows from warm to cold areas of solid objects and, therefore, temperatures become balanced within solids.[26] This process of heat transfer helps explain the value of sunlight as a heat source.

When the sunlight which is usually converted to heat is not available at night, materials tend to balance themselves with their surroundings. Heat is conducted from hot objects to cooler objects in direct contact. When cool air receives the transfer of heat from warmed objects, they cool and the warmed air rises pulling in more cool air to be warmed. This heat transfer process is called **convection.**[27] The warm, rising air transfers its heat to adjacent surfaces as it rises. With the loss of heat and buoyancy the air falls again, creating a heat convection loop, one of the most striking features of passive solar collection systems which depend heavily upon this natural process. Fans can be used to speed this materials-to-air-to-materials heat transfer process, creating faster and sometimes more appropriate forced

convection currents to areas needing the heat for human purposes. Convection currents can also occur in a liquid or gas. Water can pick up heat from one surface and transfer it to another surface in its channel path.

Radiation is a third method of heat transfer. In this method heat energy flows between objects separated by space, "even when a vacuum exists between them."[28] More heat is radiated from a surface as it becomes hotter.[29] In radiant energy heat transfer the flow is from warmer to cooler areas. The **emissivity** of a surface is the amount of energy it radiates.

Components of Solar Heating Systems

Three basic components make up solar heating systems and define the process which accounts for the value of solar heating. They are the collector, the storage, and the distribution system. The same materials sometimes perform the tasks of all components, a reality more likely to occur in a passive solar energy system.

The materials of a facility absorb that portion of light energy which is not reflected or transmittted. The absorptance of dark surfaces is greater than that of light surfaces, for example, flat black paint (0.96) and white paint (0.20).[30] The solar energy of light is converted to heat when it is absorbed by building materials, all of which serve to some degree as solar heat collectors.

The first component of a solar energy system is the solar **collector.** Jennifer Adams said, "Most solar collectors have four parts: the glazing, the absorber plate, the heat transfer fluid (liquid or

gas), and an insulated container."[31] The glazing accomplishes two basic purposes. It allows sunlight to pass through to the absorber where it is converted to heat. The glazing also traps much of the heat within the collector. The absorber plate may be such things as a metal plate, a dark concrete wall, a brick floor or other materials of the building contacted by the light which passes through the glazing. In various types of collectors the heat energy is conducted to a heat transfer liquid or gas. This usually occurs within an insulated container to reduce heat loss and to prevent unwanted heat gain in the roof or other structural areas. This last feature is important since collectors can be efficient enough to char wood and lead to roof fire if insulation (and/or spacing) is not adequate. The goal is usually to mazimize the transparency of the glazing to permit more light to strike the plate and to minimize the reflection of light from the absorber plate so that more light energy will be converted to heat energy. Materials should be selected to quickly absorb the energy and conduct it away from the surface so that reradiation of energy through the glazing and convection of heat to the airspace between collecting material and glazing may be minimized. Adams stated the nature of the problem in collector efficiency as follows: "The hotter the surface of the plate and greater the temperature difference between inside and outside, the faster the heat will be driven to the outside."[32]

The second major component of a solar energy system is **storage.** Heat energy may be transferred from the collector to another area of the facility for use where and when it is needed. The capacity of heat

storage per volume of storage material varies widely. Water has a significantly greater heat storage capacity per volume than rock or brick. Some solar energy systems utilize a mixture of the three materials. Phase change materials, such as, eutectic salts, have an even greater storage capacity of latent heat per volume.

A **distribution system** is the third component. In passive systems this occurs through natural convection loops and the other natural heat transfer processes. In practice today most systems are hybrid rather than simply passive or active, meaning that at least some use is made of fans, pumps and other electrical controls of heat flow and humidity.

Passive Applications of Solar Energy

Passive uses of the sun's energy facilitate the natural transfer, collection, storage and distribution of solar energy. A truly passive system does not require electrial energy to function. However, user involvement is usually required.

Natural Cooling, Lighting and Heating Processes

A wide variety of methods for controlling the rising cost of energy is available. Both the costs and appropriate methods of reducing costs vary widely in different parts of the country. Happily, much of the cost can be avoided by working with natural processes.

Avoiding unwanted heat gain. A high priority in energy system design is avoiding unwanted heat gain. A number of strategies assist in

this process. These include adequate insulation, shades, trees and natural ventilation. The passive coolness provided by shading and ventilation are usually among the first options chosen to reduce the energy demands for coolness. According to a United Press International article, published in March, 1985,

> Using calculated shading, ventilation and other essentially passive methods, engineers and builders have demonstrated that summertime temperatures in almost any home can be maintained 10 to 20 degrees Fahrenheit cooler than those outdoors. Furthermore, for most passive cooling systems, the initial cost is negligible and cost of operating them is either pennies a day or nothing.[33]

Among the several passive features of the Times Publishing Co. in Clearwater, Fla., two are of special interest in preventing heat buildup from the hot Florida sun and, thereby, reducing energy demands for cooling. These are "a 13-foot earthen berm (ledge)" which surrounds building and seven feet of air space between two complete roofs which provide insulation at the roof level since the top one shades the bottom roof.[34]

Avoiding heat gain, while permitting natural ventilation, offers the opportunity for significant energy savings. Bill Benton recommended SunScreen solar screens for economical window shading in schools. He claimed that the sunscreens block

> up to 70% of the sun's heat and glare to reduce air conditioning loads, according to James C. Plunkett, market manager of decorative textiles of PPG Industries Fiber Glass Division. The screens are woven from vinyl coated fiber glass yarn and give best results when installed on the building exterior 1 1/2 to 3 in. in front of the glass. . . . "According to the U.S. Department of Housing and Urban Development, devices such as SunScreen, which stop heat outside the windows, are seven times more effective for cooling than interior devices, such as blinds, shades or drapes," Pluckett says. "SunScreen solar

> screens permit windows to be opened for natural ventilation without losing their heat blocking effect, yet the sun's natural light is allowed to enter," he adds.[35]

Benton's claims for the values achieved by solar screens certainly merit attention in the Sun Belt where the cooling demand is unusually large.

A local distributor of the solar screens in Mobile, Ala., estimated a payback time for the installation in one school would be 1.5 years, for an annual saving of almost $5,900 on utility bills.[36] This is an impressive saving by use of an economical device which avoids unwanted heat gain, permits natural ventilation and light, and, by partial shading, reduces the sun's glare.

Tom Cave, utilities engineer at Georgia Tech at the time of a dormitory installation of solar screens, said, "Studies estimated that for every 50 sq ft of solar screening on the building, about one ton of air conditioning is saved when the sun is at its maximum angle."[37] In the dormitory setting Benton claimed the device cools buildings at lower cost and makes students feel safe in ground level dormitory rooms due to a greater sense of privacy. In the main library, Georgia Tech was spared the cost of new draperies on the southside while gaining greater utilization of tables near windows "because the fiber glass screens eliminate hot spots and glare."[38]

Use of solar screens was also reported in Sun Belt schools in Kentucky and Virginia. These included "Western Kentucky University, Bowling Green and . . . William and Mary College, Williamsburg."[39]

Using natural ventilation and cooling. Natural ventilation requires operable windows which are shaded or partially screened in some

way. In the case of Pendleton Junior High, in Pendleton, Oregon, a catwalk provides both accessible maintenance for solar collectors and shading for the operable classroom windows which provide natural ventilation.[40] The use of operable windows on opposite sides of the library facilities of the Mercer County Library (N.J.) provides natural ventilation for energy saving in the spring and fall.[41]

The designers of the Princeton Professional Park of Princeton, N.J., provided a cooling system design which demonstrated a way to make solar energy cost effective. Consequently, the airy office complex design was "honored in the commercial category at the Fifth National Passive Conference."[42] The designers employed Harrison Fraker's "principle of using system components for multiple purposes."[43] Their calculations in 1981 indicated that components of the system design for cooling could effectively serve several other purposes, including lighting, ventilation and heating. Two primary components of the cooling system were natural ventilation and a wet roof heat rejection system. These two systems were expected to "reduce the annual cooling load of the building by 80 to 90 percent," according to Elizabeth Holland.[44]

Climate analysis indicated that natural ventilation would adequately cool the office building during "a considerable portion of the air-conditioning season"--"April through June, and from mid-September through October."[45] The central **atrium** provides a thermal chimney effect. Office air is pulled into this naturally lighted area to exit by the vent ridge. Operable, exterior windows and the atrium

walls provide a channel for good cross-ventilation during the swing season.

Having satisfied many of the lighting, ventilation and cooling needs naturally during most of the cooling season, the Fraker team took more active steps to deal with the hot and humid months of July and August. While the humidity levels are typically high, the temperature is comfortable at night. This seasonal climate, in combination with a one-story facility, provided an appropriate setting to use rockbed storage for both cool in hot weather and heat in cold weather. The active equipment needed provided "controlled intermittent spraying of the roof, with pauses for complete evaporation," driving the peak, afternoon "surface temperatures down from 180°F to close to 90°F," affording major savings in air-conditioning costs.[46] Spraying the roof at night provided a relatively inexpensive way to reject unwanted heat. The cooled air below the roof, as low as 60°F, circulated through the rockbed which was cooled to about 65°F. Subsequently, during the day, pre-cooling of return air by circulation through the cool rockbed provides additional savings on air-conditioning without additonal materials. However, careful craftsmanship is required when the roof insulation is installed "to ensure that a thin natural plenum, or duct is properly formed."[47]

The Robert E. Kennedy Library of California Polytechnic State University at San Luis Obispo, California, avoided air-conditioning expenses in a five-story, reinforced concrete, structure in a moderate climate. The need of air conditioning was eliminated by "precast

concrete sun shades, horizontal on the north elevation, vertical on the three other sides."[48]

Passive energy systems can be used in a number of ways to prevent excessive heating during summer. These include "shade trees or vines, roof overhangs or trellises, external shutters or operable windows near the top of a sunspace."[49] The reader was reminded,

> . . . Southern plantation owners long ago used wide verandas and large trees to protect their houses from the ravages of the sun. In hotter climates, west-facing glass should be kept at a minimum and south-facing glass should be shielded from the sun. The north may be opened up to refreshing breezes.[50]

Interesting experimental work by the Southern Solar Energy Center calls for the use of shaded interior mass walls since they retain cool longer and can draw heat from the surrounding air to reduce air conditioning loads.[51]

Another technique which seems clearly applicable to schools, but has not received wide attention in the literature "uses earth-cooling tubes," buried in the ground to provide fresh, cool air. Fresh, shaded intake air enters the tubes which are about 100 feet long from the outside and enter through the floor or through the normal ventilation system. In a passive system, when "outside air passes through the pipes it loses heat to the coolness of the surrounding earth."[52] To complete the natural ventilation process, warm, inside air is vented through the roof. Such systems could be used in combination with earth berms and earth sheltering to keep the air intake above the water table to provide cooling for most of the year, and precooling even when the outside air is quite hot. With the additional feature of unit ventilators, this

would suffice for most of the cooling season even in the hottest areas of the US.

Using natural lighting. Where natural daylighting is appropriate to user needs it can be the most economical source of lighting since it requires little if any energy other than the backup lighting system when it is not available. Double and triple glazing of windows, in combination with roof overhangs and other appropriate shading devices, permit the needed light without the sacrifice occasioned by unwanted heat gain or loss through windows. Solar energy for lighting is increasingly used in school. Stephen Mitchell articulated the important basic concept, namely, "to deliver light rather than electricity to produce light."[53]

Using passive solar heating. Achieving heat gain and avoiding heat losses are at the heart of energy savings in school facilities. A great variety of more or less appropriate measures are now widely practiced to provide an effective mixture of energy conservation and solar energy methods. Passive solar heat gain can satisfy a large portion of the space heating needs in cold weather. Features of building design that facilitate one use of naturally occurring energy can usually be modified to accommodate other uses. In some facilities 100% of heating needs are being met by passive solar energy, in combination with body heat and heat from light fixtures.

Exemplary Educational Facilities

A number of features tend to recur in the various facilities. Figures 1 and 2, pages 199 and 200, are intended to assist the reader in visualizing some of the architectural features involved.

Passive solar heating and lighting: library buildings: New Jersey. Natural lighting innovations have been used in varied educational settings. The main library and six branch libraries of Mercer Country Library, N.J. made extensive use of passive solar energy features in heating and lighting.[54] Daylighting from high clerestory windows served both the reading and stack areas. Closable, translucent curtains avoided unwanted glare. Other control features included ". . . photoelectrically controlled dimmers which adjust the interior lighting in response to changes in natural lighting levels."[55] Light is also admitted through south-facing windows.

A special natural lighting feature of the renovated main building of the Mercer County Library was a passive solar greenhouse. Daylight was admitted through "a skylight with adjustable louvers."[56] The louvers precluded glare in the central reading room.

Passive solar heating and lighting features made substantial energy savings possible in the seven buildings of the Mercer County Library.[57] South-facing "Trombe walls (heat absorbing glazed masonry walls)" and "high clerestory windows with night insulating curtains", and thermal storage in "water columns (water filled fiberglass tubes)" were numbered among the important heat energy features.[58] In addition to insulating glass, walls and roofs were insulated to an R-22 standard.

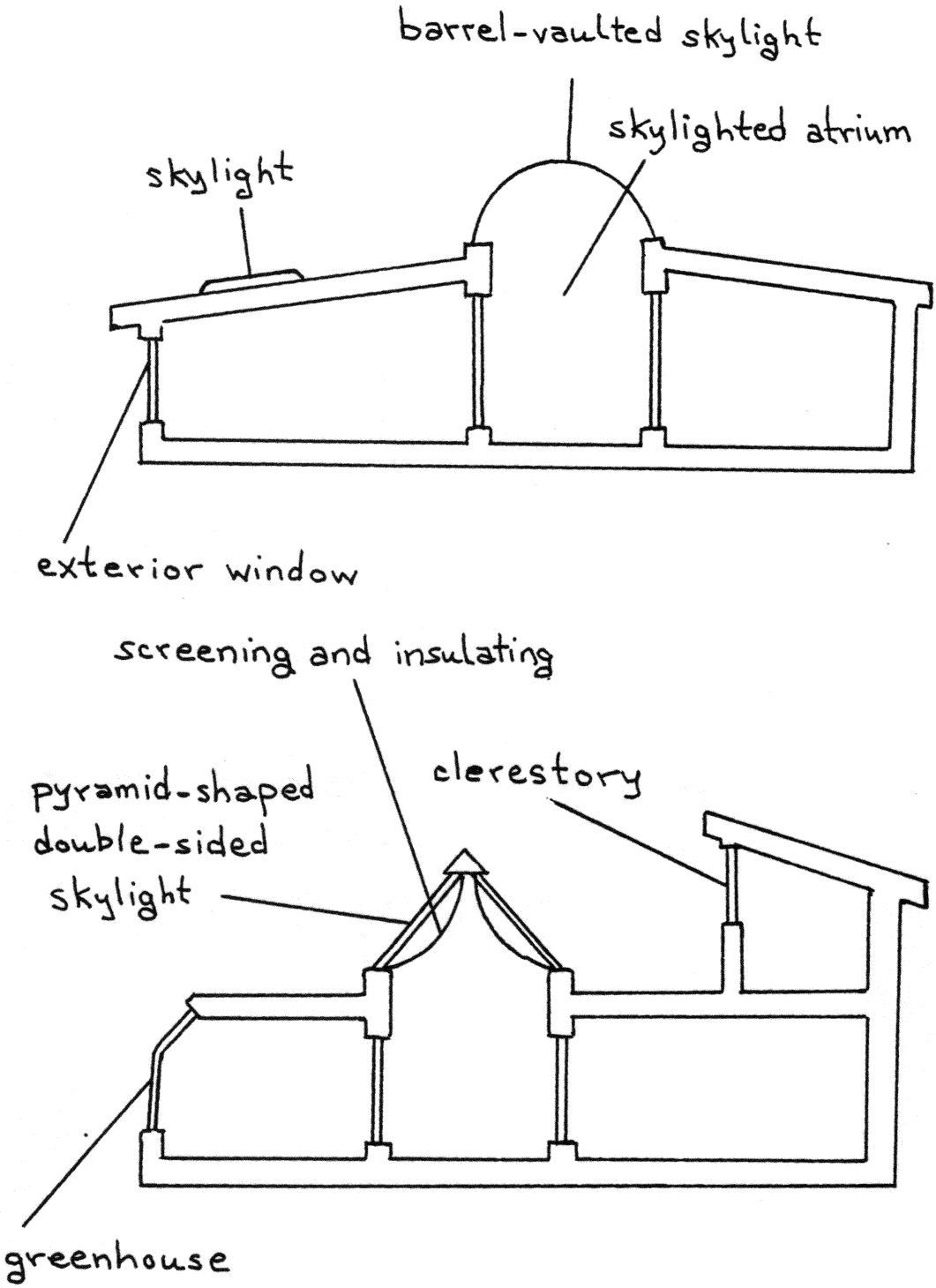


Figure 1

Typical Passive Solar Energy Features:
Windows

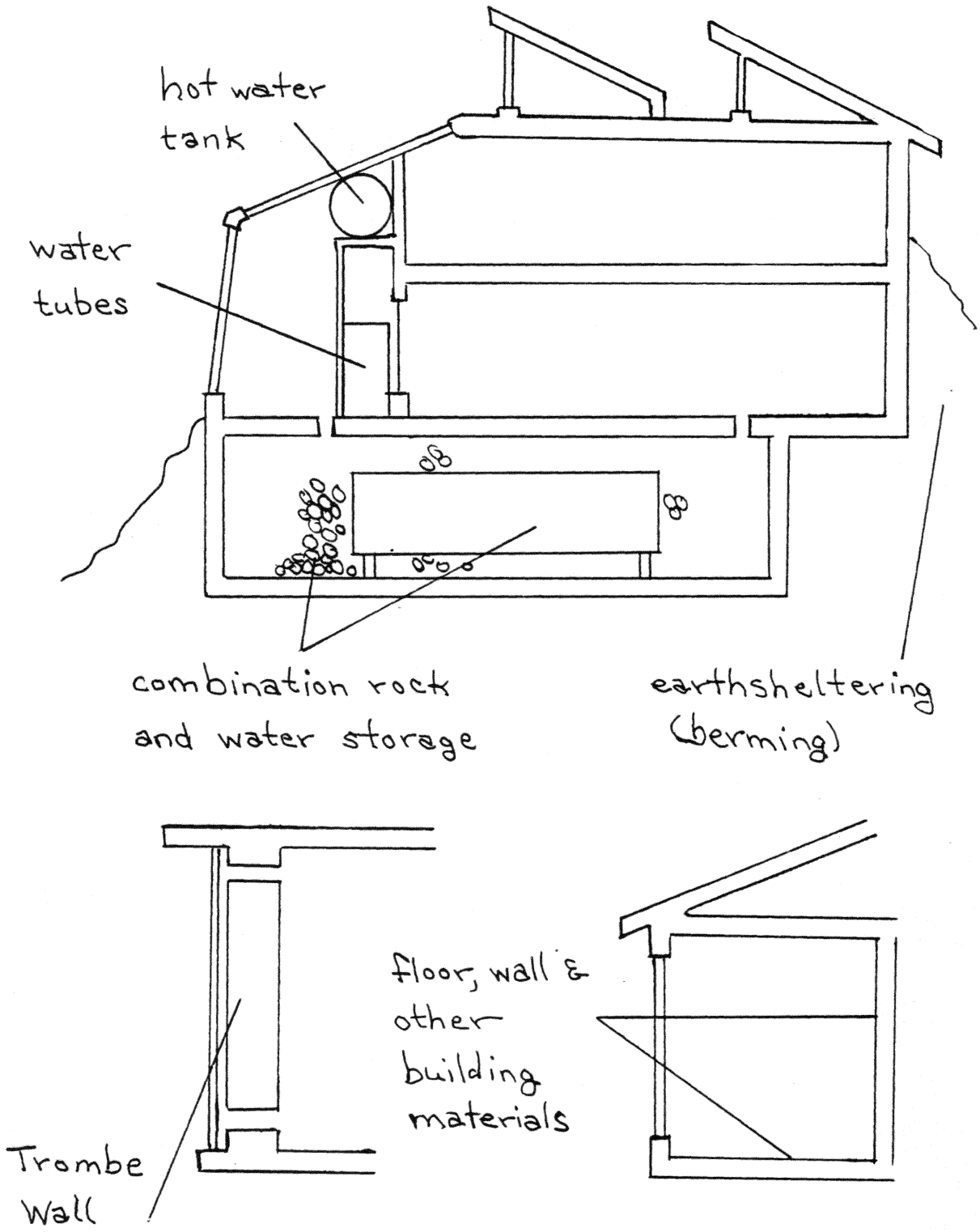


Figure 2

Passive Solar Energy Heat Storage Methods

The six new branch buildings were expected to provide significant savings, according to Marcia Wallach and Frank K. Coleman. The anticipated annual energy consumption was only about 58 percent of the $2 per square foot cost in a similar conventional building. In addition, the initial construction cost was regarded as being low at "$60 per square foot for the building alone and a total of $70 per square foot including the site work."[59]

A smaller saving was achieved in the renovated main building. It included some earth berming, a passive solar greenhouse, and "a skylight with adjustable louvers," among its energy features.[60] All of these were handled in a manner consistent with the provision of appropriate heating and lighting for areas designed for reading.

Sun Mountain School: Santa Fe, New Mexico. The Sun Mountain School, located on a hillock outside Santa Fe, New Mexico, satisfied the trustees' goal of providing "as much daylighting as possible, but not at an extreme cost."[61] However, the clerestories, skylights, extensive south wall glazing, and **Kalwall water tubes** supplied much of the schools heating and lighting load without satisfactorily resolving the problem of glare. Kalwall water tubes not only store passive solar heat but also "add to the potential glare problems." Teachers elected not to change the classroom seating to an east-west orientation, although the glare problem was worse in a north-south orientation. Floor-to-ceiling Kalwall water tubes were at the corners of each south-facing wall, with a central window area and short water tubes below them, providing a pleasing visual effect.

The daylight entering the school was deadened somewhat by adobe walls in every room, a significant feature under overcast skies.[62] No completely satisfactory solution was provided to deal with the fluctuations in quality and quantity of light. Godolphin wrote,

> . . . White surfaces were used on the roof and ceilings to get as much light as possible into the rooms, but the combination of light and dark in the interior does not effectively buffer it from fluctuations in the quality and amount of skylight.[63]

The specific integration of a greenhouse for use in teaching biology at the southwest corner of the building also provided daylighting and solar heat to the adjacent area. The lunch room/library space was heated and lighted by vertical glazing of the greenhouse, with storage and transfer of heat and light occurring through a row of Kalwall tubes which divides the library from the greenhouse. The combination of glare problems and potential vulnerability to vandalism (not harmed at date of writing) of the water tubes left the builder somewhat doubtful about the appropriate use of this design feature in a school or public building.[64]

The materials used and their application in the exterior wall of the greenhouse were of interest. Sun Builders avoided overheating problems in the New Mexico setting by using vertical glazing rather than a lean-to design. Godolphin said, "The wall of translucent SDP sheets meets the ceiling of white SDP sheets in an extruded aluminum joint at the roofline of the greenhouse."[65]

The total heating load (100%) is being satisfied by solar heat and body heat of students and staff.[66] This experience could be common in the future in the area of heating.

Barrel-vault skylight: library renovation and addition, California. Other effective uses of natural light have been described in the Carl M. Reinert Alumni Memorial Library of California Polytechnic State University at San Luis Obispo, California.[67] The Reinert Library used a **barrel-vault skylight** as a "zipper" between a renovation and an addition, using a cantilevered structural system, and "bringing natural daylight deep into the large horizontal floors."[68] The natural light from the barrel-vault skylight is shielded from glare.

The treatment of the balance of light, supplied by electricity, is also of interest. The designers created a sense of intimacy by "use of 90% task lighting" in furniture mounted lighting and at the stacks.[69]

The Kennedy Library used a large central court to introduce natural light to the building interior. This arrangement also permitted outdoor reading terraces which take advantage of a moderate climate.[70]

Pyramid-shaped, double-sided skylight: office: New Jersey. The predominant feature of the construction of the Princeton Professional Park was the "pyramid-shaped, double-side skylight" used to create a central atrium with a garden environment.[71] This feature provided natural light, ventilation, and heat gain without enlarging the building envelope. Natural light can enter the office spaces bordering the atrium in somewhat different ways from the facilities described earlier. Holland said, "Light from the skylight enters offices through . . . glass walls, either through the upper clerestory or the lower, office-level window glazing."[72] Good natural lighting serves 15 feet of the width of the space bordering the atrium. Exterior windows provide

good lighting to 15 feet of space on the north and south sides. Tenants may "choose a landscape office arrangement with an open slope ceiling" in which case "the upper clerestory windows will provide enough diffuse light from the atrium for the center of the office."[73] If, instead, partitions and suspended ceilings were installed, "the reflective surface of the ceiling near the atrium would act as light shelf, beaming light into the center zone."[74] This serves to even out the light levels.

The principle of allowing building features to serve several purposes was evident in the control of light in the atrium. This was accompanied by

> moveable insulation--Thermoshade II--manufactured by Simtrac, Inc. of Skokie, Ill. The R-2 curtain, a woven white fabric that admits light, rides on a track or cable, pulled by a motor. The curtain will cover the south side of the skylight during clear summer days for sun protection, and both sides during winter nights for heat retention. It will be completely open on overcast days to maximize daylighting.[75]

Other options were available to improve light distribution, some offering increases in passive heat gain, especially, the installation of water walls which suffer some marketing problems. A design analyst thought the "drop ceilings with diffusing panels might be preferable to an open slope ceiling" since "they eliminate overhead glare."[76] Inverted blinds could control light at windows bordering the atrium.

Innovative lighting design (both passive and active systems) in earthscraper: University of Minnesota. One of the recent school facilities applauded for innovative design in lighting is the Underground Space Center, a building of the Department of Civil and

Mineral Engineering at the University of Minnesota.[77] The American Society of Civil Engineers awarded it recognition of "the Outstanding Civil Engineering Achievement of 1983."[78] According to Jamie James, in an article, entitled "Earthscraper", "About 95 per cent of the 150,000 square feet of floor space . . . lies below the surface of the earth, where it is insulated from the wide swings in temperature above."[79] Some of the energy-related needs met by the underground structure and its solar equipment were the following: heating, air conditioning, electricity generation, lighting, sound and vibration proofing, and constant and moderate temperature and humidity.

Pioneering aspects of the facility were achieved in the area of lighting. Winter sunlight enters half of the rooms of four floors from a sunken courtyard through "one-inch insulation glass windows" oriented to the south and southwest, while overhangs provide shade in summer.[80] Much less typical of new construction than the sunken courtyard and central atrium as light sources for underground buildings is the optics system of mirrors and prisms for transmitting light to interior areas. Jamie James noted, "Possibly the largest periscope in the world" pipes in daylight and an outside view to avoid claustrophobic responses to this underground space.[81] This "Ectascope remote-view optical system" is one of several methods of admitting natural light. "It runs down a shaft to the seventh floor, where on a television-like screen it projects a bright, sharp, three-dimensional outside view of a lecture hall surrounded by lawn and trees," according to James.[82] Consequently, the employees can check the weather before going to lunch. Actual

experience quickly dispelled the fear of user rebellion about the time spent underground. The solar lighting apparently assisted in providing a quick adjustment by everyone to the subterranean environment.[83]

Mitchell more precisely described "the $28,000 'Ectascope'" which uses the principle of the periscope to provide "the immediacy and three-dimensional quality of looking through a window."[84] Mitchell said, "A 132-foot periscope, the largest in the world, bounces a street scene to a 2x3-foot window 110 feet below ground."[85]

The building incorporated both active and passive solar lighting designs. In addition to the view provided by the periscope to lower floors, James described an active "sun-tracking system . . . controlled by a $300 Hewlett Packard programmable calculator."[86] James said,

> . . . An experimental solar lighting system in an above-ground cupola follows the sun with moving plastic mirrors, collecting sunlight that is focused and relayed by lenses and other mirrors down a shaft running alongside the periscope system. The sunlight emerges through a glass panel in the ceiling of the seventh floor, providing illumination for an office.
>
> The above-ground mirrors are steered by a clock-drive system that keeps them facing the sun. . . .[87]

Changes were planned to improve the reflective quality of the mirror system, with the federal Department of Energy supplying glass mirrors to replace the plastic mirrors in the cupola. Glass mirrors reflect more light to serve the seventh floor since they absorb less light than plastic mirrors. The use of mirrors permits one exterior light source to serve many interior spaces. James said,

> Bennett thinks that of all the inventions in the building this one holds the greatest promise. In the future, he says it could be used at night with a brilliant artificial source, such as a xenon arc lamp, to illuminate space at a fraction of the cost of fluorescent light.[88]

A passive solar lighting system is sometimes the only lighting used in the huge structures laboratory on the fourth floor.[89] Light is reflected by stationary mirrors that stretch along the building's above-ground roof through narrow windows on the first floor. There, another series of mirrors transmits the sunlight throughout the laboratory.[90] The effectiveness of this passive system surprised even Bennett when it focused diffused light of cloudy, gloomy days to provide a fair amount of light.[91] When it is sunny outside, the illumination is preferable to both artificial light and to direct sunlight.[92]

The combination of innovative optics, use of mirrors to reflect light to where it is needed, an exterior courtyard to admit light to most faculty offices, and clerestory windows to provide natural lighting in public areas which lack an exterior wall facilitated optimum use of daylighting. All of these features could be applied on a modified scale in most school settings. Stephen Mitchell pointedly stated, "The concept is to deliver light rather than deliver electricity to produce light."[93]

Mitchell described the two primary lighting innovations, active tracking of the sun and "stationary Fresnel lens mirrors."[94] He said,

> These passive solar optical systems save energy in two ways: first, they reduce the amount of artificial light needed; and, second, natural lighting produces less internal heat, thus reducing the cooling load.[95]

Minnesota's extremes of climate offered a suitable setting for the combination of passive and active solar energy systems and earthsheltering to provide significant energy savings. The savings attributed to the 95 percent underground placement of the facility alone

is remarkable. The University of Minnesota in Minneapolis' new Civil and Mineral Engineering Building saved about "30-40 percent as compared to a similar above ground building, . . . taking advantage of the year-round 50 degree temperature the Minnesota earth provides."[96]

Underground solar energy: elementary school: Indiana. Extensive use was made of solar energy at a largely underground elementary school site in Indiana, avoiding much of the need of electrical energy by natural lighting, heating and ventilation, while providing natural insulation. Furthermore, easy access was a part of the facility design.

The North Harrison Elementary School of Ramsey, Indiana, completed in August, 1982, illustrated these possibilities while utilizing other energy conservation features and an energy efficient backup system. The mechanical system used incorporated "'individual electric heat pump units for year-round HVAC in all classrooms and a variable air volume system with electric heating and cooling in the central core areas.'"[97]

Earth integrated community college: Southfield, Michigan. Gerald B. Wellner described the solar energy and earth integrated design features which provided a saving of "about 50% of the yearly energy costs, compared to a conventional structure," in a new building at Oakland County Community College, Southfield, Michigan.[98] The southeast orientation of a window wall, two floors high, provides the prime energy source for "maximum solar heat and sunlight."[99]

Every major area of the building, including a wide variety of classroom, laboratory, media and administrative spaces, receives natural light from one or more of two sources. First, glass-enclosed classrooms receive sunlight from the two story open corridor running the length of the southeast exposure of the building. Second, a clerestory above the learning center provides light to another corridor leading to three sections of the building.

The landscaped wall and roof contours provide a pleasing contrast to the adjacent highrise building. Wellner wrote primarily for the benefit of those who were concerned about waterproofing this kind of facility.

Passive solar dormitory: Maine. (Figure 3, page 210, is intended to depict a concept rather than to sketch a facility.) The architects and engineers chose a passive solar design to achieve energy efficiency in a new dormitory at Colby College in southcentral Maine. The building was designed in stepped style on a hillside which slopes toward the east, permitting even rooms on the north wall to gain sun from the south. Various design features were valued both for the dormitory's visual appeal and the savings.

> The passive solar and heat retention features of the dormitory were designed to save up to 25,000 gal. of oil annually, a 60 to 70% reduction in heating costs. One quart of heating oil is used per sq ft per year, vs. one gal. per sq ft per year consumed in a conventional building.[100]

Other energy conservation features help to explain the greater percentage of reduction in use of fuel oil. The features include

> insulation, double and triple glazed windows with nightime insulation, and computer control to monitor all heating and duty

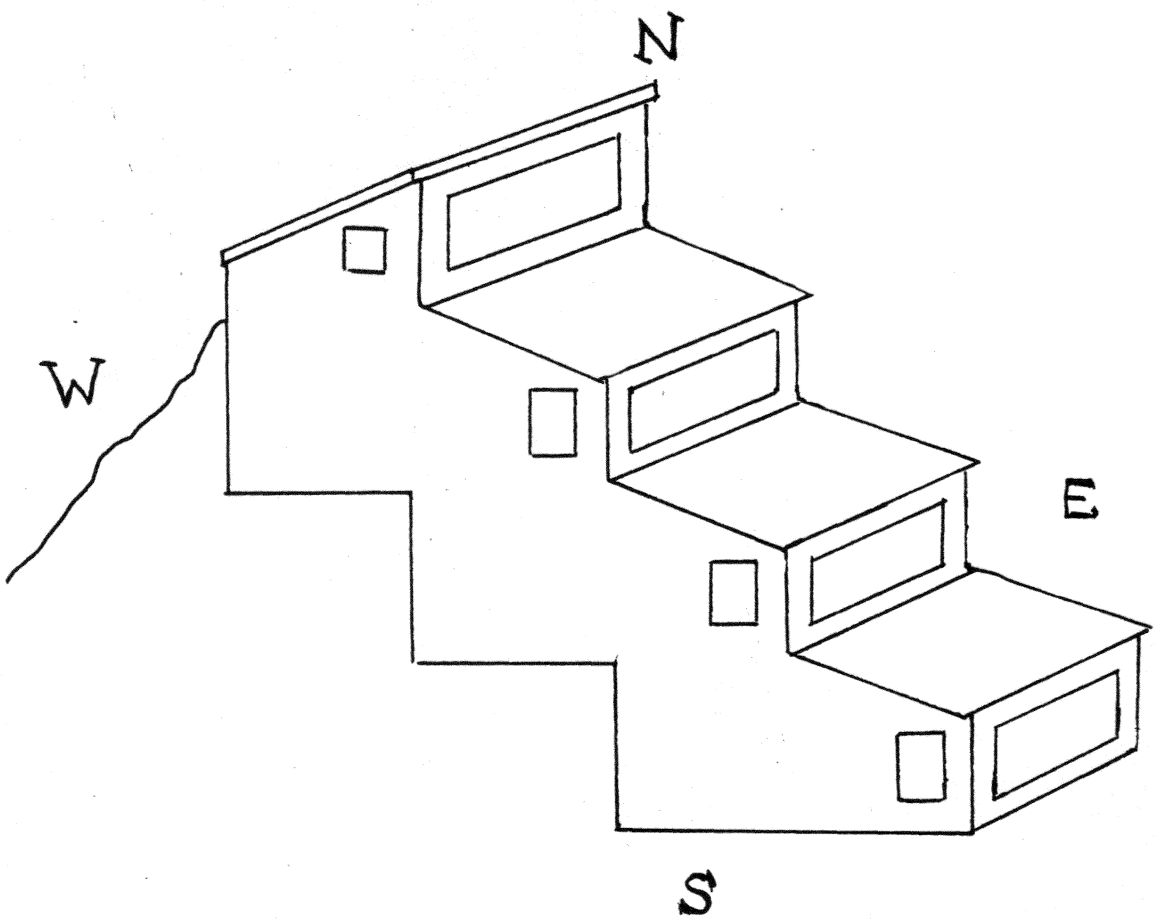


Figure 3

Optimizing Solar Exposure on Hillside:
Stepped Style

> cycle all fans. A large wood stove takes care of hot water and heat until late November, and then again in the spring. Five boilers equipped with high efficiency burners use No. 2 fuel oil when necessary.[101]

Greenhouse and double-envelope design: House: Virginia. Schools which provide small units of housing for faculty, staff and students could profit by understanding the energy efficiency made possible by double-envelope design. Essentially, such a system provides an air space between two structurally sound wall, floor and ceiling areas through which solar heat can flow in a natural, heat convection loop to storage and to permit use as needed of stored heat. A two-story, 1,500-square-feet house near Montpelier, Virginia, employing this design feature, was heated by a greenhouse, with only a backup wood stove having a "maximum heating output" of "only 47,000 Btus."[102] Heat rising in the south-facing, two-story greenhouse was "directed into the dead air space around the house and into the crawl space" where the heat was stored in the ground for use at night and in cloudy and cold weather conditions.[103]

A Virginia Tech study, reported in 1980, revealed the cost effectiveness of residential uses of solar energy in the central Virginia area.[104] When a properly sized solar collector was used, solar/electric outperformed solar/oil, natural gas, electric/heat pump, coal, wood, oil and electricity, with the costs appearing approximately

in that order, from least to greatest costs, in the winter of 1980 in residential settings.[105]

Active Solar Heating Systems: Space and Hot Water

In May, 1980, when Rita Robison wrote an article, entitled "Solar Energy Now?," she suggested the appropriateness of solar energy depended on the geographic location of the school.[106] William A. Hamlen, Jr., of the New York State University at Buffalo reported that studies by the School of Management had "identified a narrow geographical band where the sun seems to shine most favorably for solar energy use."[107]

> It's not the southern Sun Belt, though. Four major cities lie in this band, which stretches from Binghamton, N. Y. through Pittsburgh, Indianapolis and Denver. The study was made of existing houses in 21 cities, and was limited to current conditions that make solar feasible for homeowners.[108]

Writing from the perspective of large utility companies, Auer and others whittled down the potential use of solar energy for both space heating (3 to 5%) and hot water (1%) to about "4-6 percent of the primary energy usage in the United States."[109] This stands in sharp contrast to much higher projections by those who recognize the merits of decentralized energy resources.[110] For example, C. A. Hooker and others have recognized the potential of solar energy systems to provide 100 percent of building heat needs now.[111]

Amory Lovins has argued that active solar heating is less expensive than nuclear-electric heat pumps.[112] Giving the advantage of unrealistic efficiences in use of heat pumps, he was convinced that soft

technologies have shown "severalfold price advantages 'over' their marginal competitors."[113]

Lovins tried to overcome the "common misconception concerning the influence of clouds."[114] Lovins stated,

> . . . Passive solar systems work particularly well in cloudy weather, photovoltaic and photosynthetic systems merely reduce their output in proportion to the reduced intensity of total insolation, and even non-focusing active solar, heating systems can work well if designed for these conditions. This is because diffusely scattered light, although somewhat reduced in intensity, is still extremely high in quality. . . .[115]

He provided some mathematical and engineering details regarding the use of selective surfaces to tap this thermodynamic potential.[116] He concluded suitable solar collector and storage design could overcome the handicap of cloudiness at reasonable cost.[117]

Both passive and active solar energy systems are well matched to the task of providing the low-grade heat, variously defined from 70°C to 140°C or lower, needed in space and water heating in school facilities. Solar collectors have been readily available for several years to meet the approximately fifty percent of all school energy needs included under the headings domestic hot water and space heating, with space heating making the greatest demands. Indeed, David J. Rose stated,

> The most immediately promising solar application is the production of low- and intermediate-temperature heat from about 70°C for domestic hot water to about 200°C for a variety of commercial, agricultural and industrial purposes.[118]

Furthermore, as far north as Ontario, Canada it was recognized in 1981 that the combination of active and passive solar heating systems could provide 100 percent of building heating needs in most settings.[119]

About 80 percent of the heat energy requirement of Canada can be satisfied at temperatures below 140°C.[120]

The space (air) heating component of low grade heat requirements can be met by a wide variety of flat plate solar collectors. These can often be adapted to use of existing piping and/or ductwork. The storage of heat gain is usually quite extensive and the controls are altered to provide space heating and hot water. In addition, Auer and others noted that "through operation of absorption and compression refrigeration cycles, air condition and refrigeration" can be provided, with appropriate traditional energy system backup.[121]

Exemplary Active Solar Facilities

Terraset School: Reston, Virginia. Terraset School serves a primary school population of about 1,000 pupils with about one-fourth of the non-renewable energy used in a comparable conventional school building for heating. The school was built in 1975 at a cost of $2 million. The solar system was provided at a cost of $625,000.

Terraset was aptly named since it was built inside a hill. The semi-underground or earth-sheltered, thermally efficient aspect of the design was the largest saver of energy, contributing about half of the heat energy saving.[122] The earth was cut away and replaced by a reinforced concrete shell of the facility. The excavated earth was filled back to a large portion of the wall area. S. V. Szokolay reported that the roof was covered to a thickness of 0.6 to 0.9 meters.[123] Kathleen Courrier and others reported that the shell was

"covered by a water-tight membrane, four inches of gravel, and 12 inches of soil."[124] The insulative properties of the earth provided a thermal buffer adequate to permit heat generated by lights, machinery and people to keep the school warm in the heating season. However, there were residual cooling needs year round in some areas of the facility.

The solar system was funded by a grant from a Saudi Arabian university and the Dir'iyyah Institute. Courrier reported, "Terraset's direct monetary saving from October 1978 through July of 1979 was $31,626, representing an energy savings of over one million kilowatt hours."[125] The evacuated glass tubular collectors were impressively mounted over a sunken courtyard entrance in a manner consistent with avoidance of any potential damage to the roof. However, the relatively high cost of the specific collectors used in the system did not offer the opportunity of boasting about a quick payback period. Indeed, the original plan called for the earth-sheltered design, but not for the solar system which was significantly more expensive than other solar systems which might have been chosen.

The self-draining system uses water as a collection fluid. The circulation, cooling and storage systems were of interest.

> . . . The hot water provides energy for the school's baseboards, an absorption chiller unit, and the domestic water heater. Excess hot water is stored in one of three 10,000-gallon dual temperature tanks. These tanks are also used to store cool water generated by the system in the summer months.
>
> The entire plumbing, heat reclamation, and collector complex is controlled by a compact microprocessor computer.[126]

A 500 kW conventional chiller was provided in addition to the "175 kW

cooling capacity absorption chiller . . . operated by solar hot water."[127]

The interior visual impact of Terraset is very impressive. The central media center is naturally lighted by a large skylight. Four large, open space classrooms surround this focal point. In spite of the earth-sheltering, rather than feeling closed in, it is possible to see the outside through several windows from any point in the learning centers.

Whatever the financial merits of the solar system may have been, Fairfax County was so impressed by the success of the facility that it underwrote the $5 million cost of a second such facility. The 1980 facility in Burke, Virginia, was called Terracenter.[128]

Ralph Bunch Middle School: Atlanta, Georgia. The Ralph Bunch Middle School, Atlanta, Ga., used a prototype for this area of energy production. The Aerospace Engineering Department of Georgia Institute of Technology assisted in the design and monitoring of the active solar space heating, domestic hot water and cooling system. American School & University reported in May, 1980, "Solar power is providing about 60% of the school's space heating and hot water, and about 22% of the cooling load."[129]

Solar salt pond: Clarke College: Vancouver, Washington. A salt gradient solar pond, proposed to "supply about 60% of the demand" of the 18 campus buildings of Clark College in Vancouver, Washington, was expected to demonstrate that solar energy can provide the needed

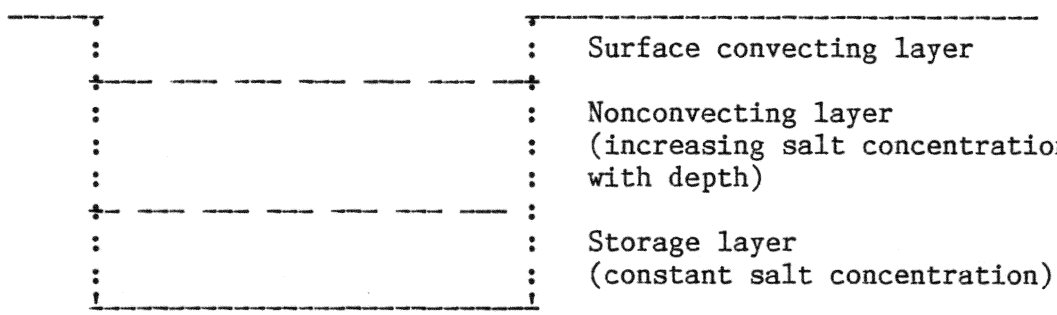
heating temperatures.[130] The designers expected the bottom of the pond to reach 180-200°F and to maintain a high temperature. Similar ponds have reached 100°C. This technology is adaptable for use in colleges and schools in meeting needs for space heating, hot water and electricity.[131] In December, 1980 Clark College was planning to create "the largest solar heating pond in the United States."[132] The college was waiting for the state legislature to approve the proposal which called for a lined, four acre reservoir, holding "20 million gal. of salt water with a layer of fresh water at the surface."[133] Such a pond serves the dual purpose of solar collector and heat storage. This project demonstrates the applicability of the salt gradient solar pond in a northwest location, with less available sunlight, to the task of heating facilities.[134] During the winter months only, a backup heat pump would deal with limited sunlight by providing a temperature lift while extracting "heat from the saltwater returned to the pond from the heat exchanger."[135] The other 40 percent of the heat would come "from building lights, body heat of occupants, electrical resistance heat and new electric boilers."[136]

The system itself is of interest. This brief explanation was offered:

> Because of the properties of the brine, the warmest water will collect at the bottom of the 10 ft deep pond at temperatures expected to reach 180-200F. The heated brine will be piped to a heat exchanger where water in a closed loop will be heated to a high temperature and then pumped to heating coils in each building.[137]

An accompanying diagram and an abstract "from Solar Ponds by T.

S. Jayader and Michael Edesess, published by the Solar Energy Research Institute, April, 1980," provided additional explanation.



Non-convecting layer of water keeps heated brine at bottom of solar pond.

The abstract is as follows:

Solar ponds are probably the simplest and least expensive technology for conversion of solar energy to thermal energy. Their cost per unit area is considerably less than that of any active collector available today. Their only drawback is that they cannot be put on the roof of buildings in urban areas.

Solar ponds can be operated at virtually all habitable latitudes. If their surfaces freeze in winter, storage temperatures will remain high enough for low temperature applications, and some insulation will still penetrate the ice.

Nonconvecting ponds prevent heat loss by preventing the warmed waters from rising to the surface. The salt gradient pond does this because salt is dissolved in high concentrations near the bottom with low salt concentration or fresh water at the surface.

Solar radiation enters the pond and whatever is not absorbed in the water on the way down is absorbed on the dark bottom, which may be a black liner. If there were no salt concentration in the pond, there would be continuous convection of the warmed water from the bottom of the pond to the layers near the top. The increased density created by the salt, however prevents this thermal buoyancy convection. Heat transfer to the surface occurs primarily by conduction, which is slow enough to enable the lower regions of the pond to maintain a high temperature (100C has been measured in actual ponds).

In practice, the salt gradient pond has three layers. In the top layer vertical convection takes place due to the effects of wind and evaporation. This layer serves no useful purpose and is kept as thin as possible.

> The middle layer contains an increasing concentration of salt with increasing depth and is nonconvecting. The bottom layer is convecting layer which provides most of the thermal storage available for heat extraction.[138]

Salt-gradient solar pond heating dormitory: State University of New York--Buffalo Amherst Campus. In the summer of 1983 the New York State Energy Research and Development Authority reported plans to begin construction of a one-acre salt-gradient solar pond in early autumn of 1983, with monitoring of performance for two years. The solar heat collected by the pond on the State University of New York--Buffalo Amherst Campus was to satisfy the water heating requirements of a dormitory. The utilization of the 100°-180°F heat source requires excavating about four feet of earth to build edges for a depth of eight feet, "installing a strong, temperature-resistant polymeric liner to prevent leakage into the ground and then filling the pond with a salt-water solution."[139] The lower salt density at the top than at the bottom of the pond keeps the dense heated salt water from rising, preserving it in storage for nights and cold weather. The rest of the task is performed by circulating the heated brine through a heat exchange cycle to transfer the heat to where it is needed in the dormitory, while maintaining the equilibrium of the pond.

Active air-based solar heating system: Pendleton Junior High School in Oregon. Pendleton Junior High, in Pendleton, Oregon, has improved maintenance and reduced energy costs by use of an active air-based heating system. The 16,400 square feet of solar panels "provide 57% of the space heating and domestic water heating."[140] Catwalks

suspended on the face of the panels permit easy maintenance for the solar collectors on the southerly exposure while shading operable windows from the sun. Rock storage of solar heat is on the south side also. The already commonly used practice of berming the north facade to insulate against cold winds is in fact an illustration of both conservation and passive storage of energy. The curved roof which rises from the north serves the twofold purpose of reducing heat loss, by deflecting the wind, and housing the mechanical heat distribution system.

Solar heating of domestic water and swimming pools: New York. Many illustrations of solar heating of domestic water and swimming pools are available in school settings and other public use settings. A vicinity including "lake effect" blizzards, three miles from the northeastern shore of Lake Ontario in New York, the site of Pulaski Junior-Senior High School, seems to be an unlikely setting for a solar heated swimming pool and domestic water. Nevertheless, with "an average of only 78 clear days a year and only 25% available sunshine in winter months," an array of solar collectors was doing the job in 1981 for 600 students at an expected annual savings of $4,000.[141] The collectors use an antifreeze solution. Heat is transferred by two heat exchangers and a heat pump. A private foundation and 76% state funding helped provide this system, the total cost of which was expected to be recovered by savings in electricity costs in about 15 years.[142]

Numerous examples could be cited in various settings using a variety of collectors and heat transfer systems. A K-12 school at

Geneseo, N.Y., in the snow belt region provided a heated swimming pool and 25% of shower water with evacuated tube solar collectors and its control and integrated heat exchanger.[143] In another example, the Richmond (Virginia) Redevelopment and Housing Authority installed solar collectors as a water heating system on the roof of 205 apartments for the elderly. The solar hot water systems' collectors, heat exchangers and the large storage tanks for water were expected to pay for themselves in energy savings in eight to ten years, while providing 80% solar hot water in the largest U.S Department of Housing and Urban Development project of this type in 1983.[144]

Solar hot water heating: competing successfully in Florida. Most of the demands made for low-temperature hot water can be met by renewable energy resources, especially, solar and geothermal energy, where available. Of course, electrical energy is required to handle water even when it is not heated by electricity. Fluid handling in the school setting requires electrical energy for pumps.

Tim Merrigan, a research engineer, following completion of a "year-long monitoring project that compared four types of domestic water heating systems" in Florida homes, concluded that solar was both most efficient and capable of reducing peak load demand of utilities. Merrigan stated, "'Compared with conventional electric water heaters, heat pump water heaters, and waste heat recovery units, solar is by far the most efficient.'"[145] System efficiencies, as seen in the coefficient of performance (COP) for each system option, were as follows for hot water heating:

Hot Water Heating System	COP
Solar	2.5
Heat Pump	1.5
Waste Heat Recovery	1.1
Conventional Electric	0.8[146]

Comparisons were made of the utility peak load profile to determine "the time of day that each unit used electrical energy," according to Merrigan.[147] The definition follows: "The utility peak load profile is a graphic representation of how much electricity customers are using at any time."[148] Severe peaks of electricity demand push utility plants to their production capacity limits and tend to require the building of new electric plants, with rising construction costs being passed on to the consumer. He reported that both " . . . solar water heating systems and waste heat recovery could substantially reduce electrical demand during traditional peak periods."[149]

Solar Cost Cutting Measures and Product Reliability

Hooker and others suggested cost cutting measures to make solar more competitive, including designing more efficient systems, production on a mass production scale, and experienced suppliers and installers.[150] Site assembled systems are much cheaper than packaged systems which are marked up three or four times in distribution. Furthermore, simplicity of design reduces the cost of solar systems.[151]

Solar district heating is the label given to heating several facilities with the same solar system. After passive solar heat and solar district heating, Lovins indicated that a well designed active solar heating system is least expensive or most cost effective.[152] He

offered his descriptions of effective design in the context of describing the Saskatchewan conservation house which was "nearly in convective and radiative equilibrium," meaning that "any point source of heat (e.g., one short piece of uninsulated pipe) will heat the whole house evenly, so no heat distribution system is needed."[153] Although this is not a feature likely to be applied in a one-to-one fashion in a school setting, the idea of providing a slight oversizing of the water-heating system as a source for space heating makes sense for the school setting too, especially if waste heat can be cycled around water storage. In a well-designed residential setting of efficient construction, Lovins saw the use of "100% active-solar heating" as being "cheaper than partly solar heating, because the storage has become so small that it cost less than backup heating", such as a gas furnace or wood stove.[154] On the scale of the school facility a high level of modular design would be required to use the basic set of ideas due to the concentration of body heat, lighting and ducting for ventilation and cooling purposes.

Hooker and others examined studies of life-cycle costs of solar and conventional heating systems. The working definition they used was as follows:

> . . . The life-cycle cost of a heating system can be regarded as the sum of money that if deposited in a bank today to earn interest would be just sufficient to cover all the necessary disbursements for installation, maintenance, and fuel over the life of the system.[155]

They found that economic considerations favored "the adoption of solar systems with gas backup" in residential settings.[156] The reference was

to space heating and hot water systems providing 30 to 60 percent and 50 to 70 percent respectively.[157]

Failure to incorporate solar design by architects and engineers is wasteful of energy resources. C. A. Hooker and others have concluded that residential solar heat and hot water can be provided at less cost, using life-cycle cost, than conventional heating systems in Ontario, Canada. They recommended 100 percent solar heating of facilities by use of both active and passive solar collection. Passive design features reduce the volume of active solar collection required, make storage facilities more effective, and reduce the need of backup.[158] Lack of suitable orientation, lack of appropriate collector locations, and shading by adjacent buildings and trees made 30 to 50 percent of the housing stock unsuitable for solar application in 1980. However, eighty percent of residential facilities were expected to be suitable by 2025.[159] In some urban areas avoidance of utility company and user electrical costs for new space heating and hot water made low-temperature solar heating very appealing.

Schools were numbered among the major hot water users by M. Ross Adams.[160] Solar energy is now the energy of choice for hot water in many settings. Bill D'Messandro, Editor of Solar Age, noted the prominent influence of relatively simple technology, the right price, federal (40%) and state tax credits, utility company cash rebates, and subsidized loans in promoting the emergence of solar energy use in provision of domestic hot water. He wrote in June, 1981, "Slightly more than 20 percent of all solar collectors manufactured in the United

States are used to heat water for domestic purposes."[161] He further stated, "Competent, experienced solar contractors can now be found everywhere in the country."[162] Solar water heating had become a standard feature in entire subdivisions, an indicator of their economical fit to a common need.

In the same directory, Joe Carter and Robert G. Flower stated, "Nationally, the residential sector uses 3.1 percent of this nation's total energy use (77 Quads in 1979) for domestic hot water."[163] They called for cutting the domestic hot water energy load in half by simple conservation measures prior to determining the size of solar water heating collector to use. Their recommendations included pressure reduction in lines, low flow shower head, faucet flow controls, cold-water laundry for some purposes, reduction in tank temperature from 150°F to 120°F, insulation of tank, habit of use changes, pipe insulation, time clock, stack heat recovery and grey water heat recovery.[164] They also described "the tankless, or point-of-use electric or gas water heater, which is commonly used in Europe and Japan."[165] This latter measure was seen as applicable to "boosting water temperature for dishwashers, which use 140°F water," which compares to the 115°-120°F water useful for most other domestic purposes.[166] Carter and Flower demonstrated these reductions to be "the micro-load", consequently, "the key that liberates solar domestic hot water."[167] This means that conservation reduces the required capital investment, making solar energy more economical and reducing the payback period.

The durability of solar hot water systems promises to become increasingly reliable as reductions in federal subsidies force energy systems to compete on their merits. "The Solar Age Domestic Hot Water Directory" of June, 1981 reported a warranty period varying from one to twenty years for the various products.[168] Limitations on items covered in the warranty varied widely. A five year warranty appeared likely to become the accepted standard for at least the collector and tank if not the system as a whole. "A Seller's Guide to Solar Domestic Hot Water"[169] was quite optimistic in reference to durability of the major components of solar hot water systems, certainly competitive with other systems. The dialogue included these remarks:

> A collector built with durable parts (glass, copper absorber, aluminum frame) should last 20 years if engineered and installed intelligently. If an installer can't get the manufacturer to provide engineering data on the collector, the manufacturer should be dumped quickly.[170]

Other solar collectors which utilize fluids for heat distribution would be expected to exhibit similar standards.

Solar Electricity Generation

Solar energy can provide electricity to education facilities through use of several technologies which can be scaled to demand or developed to sell to other users by cooperation with utilities, political jurisdictions or other users of electricity. The cheapest energy is achieved by working with nature to avoid costs rather than by wasting additional energy to recover natural resources for use at the cost of still further energy expenditure for transportation, conversion

processes and extensive transmission lines. Small-scale solar electricity production works with nature for use of energy with minimal distance between energy production processes and end-use processes.

Some promising solar electric technologies are being demonstrated by both public utilities and schools and colleges, often in cooperative efforts. Among these solar technologies are large-scale solar plants, concentrating solar power to generate high temperatures to run turbines, solar salt ponds and photovoltaic units. Energy offices in New York, New Mexico, Rhode Island, the District of Columbia, Michigan, Massachusetts, and California have reported use of some solar electricity generation in educational facilities.

Photovoltaic (PV) Production of Electricity

Photovoltaic cells have consisted most commonly of silicon crystals which act as batteries to convert sunlight shining on them directly into electricity. Solar cells have no moving parts. In facilities a photovoltaic array is usually mounted on the southern slope of the roof. The useful life of solar cells is expected to be about thirty years.

Although the photovoltaic effect was discovered in 1839, the technology was not adequately developed for economical use until the 1950's, with practical applications in satellites.[171] That technology has recently been modified for practical applications in facilities and other uses. The development of the technology for direct solar energy production of electricity by a variety of roof top solar cells has been heavily subsidized by government grants. Consequently, the Renewable

Energy Institute (REI) was able to report in November, 1984 that photovoltaic (PV) energy systems have increased in efficiency by more than 400% over the past decade, while during the same time module costs decreased five fold.[172] Today reported PV efficiency percentages are commonly in the teens and twenties where concentrator lenses are employed.

In 1981 Amory B. Lovins and others were optimistic about the prospects of rapid cost reductions and increased efficiency in PV technology to produce electricity, "based on successful laboratory and pilot experiments" then in existence.[173] Lovins used several sources to support the U.S. Department of Energy expectation that photovoltaics would "compete on US utility grids by 1986" without a credit for cogeneration of heat while generating the electrical energy.[174] Special cause for optimism was seen in the pace of development of amorphous cells in experiments being conducted in 1981 in the US, Europe, and Japan.[175]

Miles C. Russell described the components of "the generic residential PV system."[176] In residential application this "system will use a 50-square meter (555 sq. ft.) roof-mounted PV array."[177] This unit generates direct current (dc) electric power which must be converted for residential use to alternating current (ac). This conversion is consistent with the design requirements of all residential wiring and appliances. A power inverter, similar in size to a large household appliance, accomplishes the conversion and is "a fundamental

component of the generic system."[178] Russell summarized the components of a dc-to-ac system. He said,

> The generic residential system then will consist simply of two principal components: a PV array and a dc-to-ac power inverter that produces utility-compatible ac power. Bidirectional power flow between the residence and the utility is a key feature of such a system.[179]

The less attractive alternative is to convert the appliances to dc electrical power. The latter alternative makes little sense in the context of peak load demands which exceed the output of the generic system, but which, at other times, feed excess power into the utility grid.

Russell estimated that the typical PV system he described would provide "5 kW peak rated PV output." This capacity for the 50-square-meter roof-mounted PV array was arrived at by "combining the nominal 10 percent solar-to-electric conversion efficiency of a typical PV array and the nominal peak solar insolation of 1 kilowatt (kW) per square meter."[180]

Power is lost in the dc-to-ac conversion process. Russell said, "An 85 to 90 percent efficiency for converting the dc power from the array into residential ac power is typical of modern inverters."[181]

Russell said the resulting residential power would be "sufficient to meet 50 to 100 percent of projected annual electrial needs of a residence, depending on whether the hot water and space heating demands are met electrically."[182] He said the peak power demand of a residence "can range from 10 to 20 kW."[183] Therefore, the true potential value of a PV system in residential use must be evaluated in

terms of annual output rather than its ability to satisfy peak load requirements of a particular building. Russell said, "However, the annual electrical energy output for a 5 kW system will be approximately 6,400 kilowatt hours (kWh) in Boston, or 11,000 kWh in Phoenix."[184] The data indicate a need to mix technologies to match energy needs, with PV systems being suitable for electricity generation for purposes other than low temperature heat.

In July, 1981 Russell estimated the cost of such a system. He said,

> The cost goal for a residential PV system of this generic size and type is $8,000 to $11,000 (1980 dollars) by the mid-1980s, and the life cycle cost of electricity produced by this PV system is projected to be approximately 8.5 cents per kWh. Present work by DOE continues to progress toward this goal.[185]

The problem with PV production of electricity is that under ideal solar conditions excessive power is generated, while there are also times of power shortage. Since research in the area of on-site electrical storage indicated "that a technically and economically feasible system will probably not be available until the early 1990s—well after the generation of PV systems is in place," Russell saw the importance of a working partnership between the private PV producer and the public utility company.[186] The Public Utility Regulatory Policies Act of 1978 (PURPA) offered the opportunity to reverse excessive PV power flow to the utility company.[187] Russell said, "This act requires utilities not only to accept power from distributed producers, but also to pay for such power at a rate based on marginal utility production costs."[188]

Many specific requirements must be considered in the design of the PV array and its mounting system to make it both practically serviceable and economically attractive. Russell dealt with several of these. First, a simple, safe way to originally install and to replace damaged modules of the array is a high priority. Second, physical access for maintenance, to wash away dirt and soiling agents which require detergents for removal, and to remove debris such as leaves, ice or twigs, is important although rainstorms accomplish some of this maintenance activity with glass-covered equipment. Third, Russell called for weathersealing which will "insure the leak-proof integrity of the structure for a minimum 20-year system lifetime," regardless of the roof-mounting method--"integrated into the roof-structure . . . , stand-off, direct, and track."[189] The fourth requirement deals with the efficiency of the cells; namely, photovoltaic array cooling is necessary due to the fact that "a solar cell's sunlight-to-electricity conversion efficiency typically increases linearly with decreasing operating temperature--about 0.5 percent (relative) per centigrade degree."[190] Since "it is not economical to cool the PV modules with fans" to achieve the desired low operating temperature, efforts must be made to "improve the array's passive heat transfer characteristics and economically enhance the system's energy production."[191] This requirement identifies the importance of cogeneration of heat to increase the efficiency of electricity production and general economic feasibility. Russell acknowledged that the fifth requirement, aesthetics, has only been

approximated. The sixth factor is the cost effectiveness of the PV array-mounting system.[192]

Other aspects of the PV system which he dealt with included the requirements of the power inverter and electrical design.[193] Some of the concerns relative to the power inverter have to do with automatic turn-on and turn-off under variable conditions, automatic disconnection under emergency conditions for safety reasons, and power quality which may have detrimental effects on "both residential appliances and utility transformers, primarily due to overheating."[194]

Among the interesting items discussed relative to electrical design was a diagram of "protection features required to insure that a residential PV system is in compliance with electrical code."[195] It was anticipated that the 1984 National Electrical Code (NEC) would include new photovoltaic installation codes. Russell described the reasons for several possible codes. He foresaw "safe, reliable, and economical residential photovoltaic systems" governed by codes adequate to protect the interest of both the utility and the home owner.[196]

He also included photographs and descriptions of four PV mounting methods, namely, direct, integral, stand-off, and rack. Each system has its merits. However, it should be noted that the direct-mounting method leads to higher temperatures, "as much as 20°C hotter," and lower efficiency than the other methods under full sunlight.[197]

Photovoltaic technology advances: California. In June, 1981, the "Solar Business Review" section of Solar Age described two prototype photovoltaic modules for potential production of both electricity and

thermal energy. The conversion efficiency of sunlight-to-electricity was reported to be 16.4 percent and 20.5 percent for the two inventions.[198] In the first invention use was made of the Fresnel lenses and "the cells themselves, 12 to the module," were made of aluminum-gallium-arsenide (AlGaAs)."[199]

In the second prototype module "the solar beam was split into red and blue spectra," with the red being concentrated by Fresnel lenses onto the 10 silicon cells and the blue onto the 10 AlGaAs cells of the module. Varian of Palo Alto, California, developed the modules "under contract to Sandia National Laboratories in Albuquerque."[200] It was reported, as of June, 1981, ". . . Varian claims that the split-beam module's efficiency measured at 20.5 percent--is 71 percent greater than any single cell concentrator module currently available."[201]

The merits of these PV prototypes include not only direct production of dc power but also heat energy. The report said,

> Both of these prototypes are liquid-cooled and offer a potential additional benefit of thermal energy recovery from the cell coolant. Project technicians believe that use of the waste heat could effectively double the value of the energy produced from the modules.[202]

Projected efficiency of 30% in PV generation. In August, 1984 Solar Utilization News reported records being set in experimental silicon PV modules at Sandia National Laboratories, Albuquerque, New Mexico. Silicon solar cell modules designed there had achieved "a peak solar-to-electric conversion efficiency of 17 percent."[203] The concentration of solar energy was described as follows:

> The module consists of 12 individual solar cells, set up as a 2x6 array; each cell has a Fresnel lens that concentrates sunlight from a 12.5 centimeter square area and focuses it down to the one centimeter diameter area of the cell. Additionally, each cell has a cone-shaped secondary reflector to catch stray light that spills beyond the cell edges.[204]

Dan Arvizu looked forward to increasing the practical efficiency limits of silicon cells to 25 percent in the near future.

Arvizu expected even higher efficiencies to be achieved in multijunction experiments at Sandia. He described the bonding of a thin AlGaAs cell to the top of a silicon cell. He said,

> "Although they are relatively new, multijunction structures have a potential for achieving greater than 30 percent efficiency, eventually, and probably high twenty percent efficiency in the near future."[205]

The technology would require the "illumination level equivalent of 150 suns," achieved by concentrating optical devices and reflecting cones to redirect any light spillage to the silicon cells.[206] Unfortunately the technology is not commercially feasible.

Amorphous silicon cells are expected to be used in the future in conjunction with less expensive optical devices for solar concentration to provide high efficiency, financially feasible PV electricity production. Movement in this direction is seen in Australian scientists' development of a solar energy concentrator that increases the output of standard solar cells up to three times which could enable halving the cost. Solar Utilization News described the concentrator.

> The concentrator consists of a V-shaped plastic trough filled with water. Sunlight falling upon the system is reflected internally, and concentrated onto the solar cells by means of a cylindrical water lens.[207]

Pacific Valley School: Big Sur, California. A remote area with no utility power available is one appropriate school setting for use of a photovoltaic (PV) system to generate electrical energy to meet a number of needs. In June 1984 a one-room schoolhouse addition offered the opportunity for Pacific Valley School, 60 miles south of Monterey, to become "the first solar powered school in California."[208] Sixteen kilowatt-hours (kW) per day of PV electricity are now available instead of the former seven kW propane generator. The roof-mounted solar modules, ac to dc power inverter, battery charger and batteries "meet about 90 percent of the school's electricity needs," including "lighting, five home computers, a television, a satellite dish receiver, projectors, C.B. radio and various other appliances."[209] Natural lighting through skylights and clerestory windows, designed to avoid potential glare problems, helped reduce the primary electrical demand in the classroom. The project architect said, "'The savings in fuel and maintenance over the next eight years will equal the initial cost of the PV system.'"[210]

Solar Salt Ponds Planned to Provide Electricity: Six U.S. States

Solar salt ponds go beyond the collection and storage of the sun's energy to provide space heating, the characteristic feature of solar ponds. Stratification or layering in solar-salt ponds, with greater concentration of salt water, or brine, in lower layers, below a shallow surface layer of fresh, lighter water, enables the sun to heat the brine a few feet below the surface to near boiling temperatures.

The temperature, "sometimes more than 220 degrees Fahrenheit" in these ponds, is "more than enough to drive special turbines" to generate electricity.[211] The top layer of fresh water insulates the brine layer. Wilson Clark explained the process in October, 1984 in Smithsonian. The heated brine is "still too heavy to rise to the top--as warm water would ordinarily do--where heat would be lost by convection, evaporation and reradiation."[212] Some details were offered concerning windbreaks and operation of the turbine itself. He indicated, "The brine holds heat for long periods of time, and generating stations can run day and night, good weather and bad."[213] Furthermore, such facilities are a natural ally of efforts to reduce the salinity of water.[214]

This technology for generating electrical energy was expected to be financially competitive. In October of 1980 plans were underway to build such facilities in six U.S. states, including California, Utah and Washington. The expected beginning of construction of a "full-scale 600-megawatt plant--using a total of 46 square miles"--was 1985.[215] Engineers working on prototypes of the Ormat Turbines expected the cost to be "about the same as a coal-fired plant."[216] Clark reported estimates by Ormat scientists that solar salt ponds could produce "more than 20,000 megawatts" in the western United States.[217]

Lucien Bronicki, an Israeli engineer, hoped in 1980 that Israel would receive one-third of its energy from solar salt ponds by the year 2000.[218] Ein Bokek, on the Dead Sea, was then the setting of the largest solar pond, a research pond covering 70,000 square feet.[219] This technology is adaptable in size, according to need.

Clark made a distinction between solar salt ponds and solar ponds. He said,

> Solar salt ponds . . . are not to be confused with solar ponds, which simply collect and store the sun's energy for space heating. Salt ponds can be stratified, and the brine a few feet below the surface can reach temperatures near boiling, more than high enough to drive special turbines.[220]

The distinction was between the collection of heat energy and the ability of the salt gradient to transfer heat energy in quantities adequate to generate electricity. The article described an exciting installation in Israel and planned installation in California and Utah of electric power generation plants.[221]

Many solar technologies can satisfy multiple uses in schools. For example, when Jacques Constans dealt with the concept of the solar pond, he included hot water, space heating, fresh water, electricity production and aquafarming among the potential uses.[222]

Solar salt ponds to generate electricity: utility company: California. Southern California Edison Co., an innovative electric utility company, was planning to develop four solar ponds in January, 1984 to produce enough electricity to meet power needs of 30,000 people.[223] These solar ponds were to be built on a dry lake site in Southern California, "Lake Danby, about 50 miles west of the Arizona border."[224] The first one was expected to be completed "by late 1985 and . . . to deliver about 15 million kilowatt hours a year of electric energy."[225] Construction was to be handled by an Israeli firm, Ormut Turbines Ltd.

The basic principles of operation of solar ponds can be used on a varied scale of operation to provide hot water, space heat and/or electricity. The utility's electrical principles are briefly explained as follows: "Solar ponds use varying layers of salt water to trap heat in lakes. Heat is then extracted from the lake by heat exchangers and pumps to drive specially designed generators."[226]

Solar pond: Utah State University. In describing an electricity generating facility at Utah State University, the author explained,

> The heat exchangers would transfer heat energy to fluids such as ammonia, propane, or halogenated hydrocarbon. The heat energy vaporizes the fluid and drives a turbine to generate electricity. The brine is circulated back into the pond to repeat the cycle. The warmed brine can also be used to create steam for space heating or heating greenhouses.[227]

Already in service in the summer of 1982 was a "50 square foot test pond" which "is 12 feet deep and collects and stores approximately 100 billion Btu's per year . . . . roughly the energy equivalent of five or six tons of coal."[228] This and another planned test pond were both intended for use in heating agricultural research areas.

An engineering professor expressed hope of much larger-scaled utilization of this resource in spite of high initial capital costs. Dr. J. Clair Batty hoped to see "the largest solar pond in the world" built with future assistance from the US Department of Energy by diking a 10-acre portion of the Great Salt Lake.[229]

Large-Scale, High-Temperature Plants

Large-scale, high-temperature plants, such as one developed in the early 1980s in the Mojave Desert near Daggett, Calif., need not be limited to use by public utilities like Southern California Edison.[230] Such high-technology projects may be a natural ally of the University setting, designing technology for a world which is depleting its fossil fuel supplies. Essentially, heliostats are computer controlled mirrors which receive the suns's energy and are constantly aligned with a focal point of reflection to focus sunlight on a tank of liquid to create temperatures sufficient to generate steam to drive conventional turbines. Such systems can be arranged in various configurations and vary widely in size. In some settings mirrors track the sun to focus on towers. In others horizontal, parabolic troughs track the sun. More recently, a parabolic trough collector has been designed to utilize an inverted geodesic dome design as a dish to permit tracking the sun and focusing the sun's energy on a central tank to generate steam.[231] The combination of heliostats, controlled by computers, to concentrate sunlight, and a new generation of conventional turbines may even overcome environmentalists' concerns in a limited number of settings.[232]

Hybrid Solar Energy Systems

Active and Passive Solar and Wind: Office: Florida

Paula Lippin briefly described the use of renewable energy resource design features in the "new energy-efficient Times Publish Co. in Clearwater, Fla."[233] The goal of the design was to demonstrate the

feasibility of solar and wind energy as power sources.[234] The sloped or wedged side of the roof optimized the angle of solar insolation and surface available for collection of energy by 240 flat plate solar collectors. Lippin indicated the solar panels provided "43 percent of the air conditioning and 100 perecent of the heating."[235] Passive solar energy features of the building included the insulation provided by the 13-feet earthen berm and seven feet of airspace between two complete roofs, both of which provide shade and prevent heat buildup. In 1979 they were expecting a 10-year payback on the combined passive and active solar systems.

Three 15-feet-by-15-feet wind foils were described as resembling egg beaters to utilize the indirect solar energy of the Florida wind. Winds as low as six miles per hour were adequate to generate electricity. The 115-feet wind tower was based on the roof of the facility.[236]

Agriculture, Aquaculture and Heating

Greenhouses have traditionally been high energy consumers, but they are vital in agricultural production. Today, with good design features which reduce loss of heat at night by adequate insulation and use night covers to store heat energy for use as needed, greenhouses make almost no heating demands in some northern climates.[237] Aquaculture, or fish farming, in combination with greenhouses, in some locations is proving to be a valuable energy saving agricultural methodology which is unequalled in production per acre. The water of an indoor pond provides an adequate volume of heat storage for a virtially

self-sufficient, year-around habitat for plants and fish. Agricultural workers can provide the needed controls and farm laborers can be paid as well as or better than traditional farm laborers where the production techniques are energy and capital intensive.

Amory Lovins added this recommendation: Place

> simple, even unglazed, flat-plate collector panels for domestic hot water in the upper part of the greenhouse **where they can never freeze**, thus avoiding the cost and complexity of antifreeze loops, heat exchangers, drain plugs, and other frost precautions.[238]

Lovins used this illustration to emphasize "the powerful synergism between efficiency and cost-effective renewable energy systems."[239] The mixing and matching of energy features in a comprehensive energy system tends to reduce the scale and complexity of component parts.

Solar District Heating: Achieving Efficiency Through Large-Scale Energy Storage

Lovins has demonstrated with convincing statistical data from case studies that passive solar heating and solar district heating are cheaper than any other sources of heat that are widely available. Both of these are distinctly applicable to the heating needs of school facilities.

Lovins recommended solar district heating as a retrofitting system appropriate for urban and historic areas which are less adaptable at a particular site than other locations. Solar district heating permits many facilities to use the same solar heat storage tank. The large volume-to-surface ratio of the storage area reduces the cost of needed equipment, while encouraging desired stratification of

temperature zones in the tank, reducing surface heat losses. Using one large water tank, instead of several small, spacially demanding tanks offers true seasonal storage of heat energy for use when it is needed. Since heat storage is seasonal rather than only adequate for a few days of inclement weather, the full utilization of collectors and the storage tank in summer increases their efficiency. It also reduces the performance penalty of facing the collector east or west rather than south where efficiency is greatest and important when storage is limited. Lovins said,

> . . . The net result is to reduce the total cost per unit of delivered heat by a factor of up to two—to levels competitive with . . . wellhead oil in 1977 . . . , and certainly competitive with electric heat. . . ."[240]

Among the several factors Hooker and others foresaw making a major improvement in the competitive position of solar energy in 1979 was "distributed seasonal storage facilities," which can provide long term cost reductions.[241] They concluded that the credibility of "most present comparative studies" may be limited since they "do not consider such options or indeed substantial storage options of any sort."[242] Hooker and company said,

> . . . Since seasonal storage facilities could be expected to show low maintenance rates, long life times, and to decline sharply in cost with mass development, they could be expected to improve life-cycle costs substantially in the long term.[243]

Level of Usage of Solar Energy

Although reliable statistics may be unavailable, there has been remarkable growth in the use of active solar water and heating systems.

In July, 1981 Frank DeGeorge reported that "the total number of active solar water and heating systems in place in the United States now exceeds the 300,000 mark."[244] It was reported,

> DeGeorge pointed out that in 1974 there were only 20,000 such systems in the country, and fewer than 50 manufacturers employing only about 1,000 people. By contrast, there are some 3,500 solar manufacturers and installers in business today, DeGeorge said, and collector manufacturing is growing at a robust 37 percent annual rate.[245]

A review of statistical data provided by about half of the state energy offices in the summer of 1986 revealed that solar energy was the most widely utilized renewable energy resource among those dealt with in this disseration in educational facilities. The greatest frequency of solar usage was in the area of active solar heating. Passive solar heating, including greenhouses, was second. Solar hot water heating was third. Photovoltaic usage ranked fourth. Very limited use was being made of other solar concentration systems and solar salt ponds. Those who reported usually did so with expressions of concern about the adequacy of their data base. Several of those reporting indicated that efforts were then underway to develop state and regional information. Occasional comments revealed a consensus that passive solar energy, solar hot water and active solar heating, in that order, were the most feasible solar uses in the immediate future.

CHAPTER FIVE ENDNOTES

1. Joe Goodwin and others, eds., Fire of Life: The Smithsonian Book on the Sun (New York: W. W. Norton & Co., 1981), p. 239.

2. Paul Abrecht, ed., Faith, Science and the Future: Preparatory Reading For a World Conference Organized by the World Council of Churches At the Massachusetts Institute of Technology, Cambridge, Mass., USA, July 12-24, 1979) (Geneva, Switzerland: Church and Society, World Council of Churches, 1978), p.79.

3. Ibid.

4. Linda Baine McGown and John O'M. Bockris, How To Obtain Abundant Clean Energy (New York: Plenum Press, 1980), p. 107.

5. Ibid., p. v.

6. Ibid., p. 107.

7. Ibid., p. 109.

8. Ibid.

9. Ibid., p. 110.

10. Ibid., p. 111.

11. P. L. Auer, Renewable Energy Resources (New York: IPC Science and Technology Press, 1978), p. 11. Footnote: "178,000 TW (thermal): Based on a solar flux of 1.35 $kW.m^2$ arriving at the fringes of the earth's atmosphere."

12. Ibid.

13. Ibid.

14. Ibid., pp. 11-12.

15. Ibid., p. 12.

16. Ibid., p. 11.

17. Ibid., p. 12.

18. Ibid., p. 14.

19. Paula Lippin, "Offices Go Solar," Administrative Management, XL:9:35, September, 1979.

20. Ibid.

21. Ken Brotti and John Perlin, A Golden Thread: 2500 Years of Solar Architecture and Technology (Palo Alto, California: Cheshire Books, 1980), pp. 200-202.

22. Ibid., pp. 214-215.

23. Amory B. Lovins and others, Least-Cost Energy: Solving the CO_2 Problem (Andover, Massachusetts: Brick House Publishing Company, 1981), p. 144.

24. Jennifer A. Adams, The Solar Church (New York: The Pilgrim Press, 1982), p. 8.

25. Ibid.

26. Ibid., p. 9.

27. Ibid., p. 10.

28. Ibid., p. 9.

29. Ibid., p. 10.

30. Ibid., p. 9.

31. Ibid., p. 10.

32. Ibid., pp. 10-11.

33. United Press International, "Passive coolness," The Richmond News Leader, March 19, 1985, p. A-10, cols. 3-4.

34. Paula Lippin, "Offices Go Solar," Administrative Management, XL:9:34, September, 1979.

35. Bill Benton, "Solar screens give schools comfort . . . while they save energy!," American School & University, 54:5:42, January, 1982.

36. Ibid.

37. Ibid.

38. Ibid.

39. Ibid.

40. Architectural Portfolio, American School & University, November, 1983, p. 65.

41. Marcia Wallach and Frank K. Coleman, "Solar Oriented System," Library Journal, 108:21:2206, December 1, 1983.

42. Elizabeth Holland, "An Airy Office Complex," Solar Age, 6:7:28-31, July, 1981.

43. Ibid., p. 30.

44. Ibid.

45. Ibid., pp. 30-31.

46. Ibid., p. 31.

47. Ibid.

48. Architectural Portfolio, op. cit., p. 103.

49. "Passive solar energy," Richmond Times-Dispatch, March 14, 1982, p. K-11.

50. Ibid.

51. Ibid.

52. Ibid.

53. Stephen Mitchell, "University of Minnesota builds subterranean skyscraper," SUN (Solar Utilization News), June, 1984, p. 8.

54. Wallach and Coleman, op. cit., pp. 2205-2208.

55. Ibid., p. 2206.

56. Ibid., p. 2208.

57. Ibid., pp. 2205-2206.

58. Ibid., p. 2206.

59. Ibid.

60. Ibid.

61. David Godolphin, "Simplicity in Adobe," Solar Age, 6:6:27, June, 1981.

62. Ibid., p. 28.

63. Ibid.

64. Ibid., p. 29.

65. Ibid.

66. Ibid., pp. 27 & 29.

67. Architectural Portfolio, op. cit., pp. 85 and 102-103.

68. Ibid., p. 85.

69. Ibid.

70. Ibid., pp. 102-103.

71. Elizabeth Holland, op. cit., pp. 29-31.

72. Ibid.

73. Ibid.

74. Ibid.

75. Ibid.

76. Ibid.

77. "Underground research right at home," American School & University, 52:9:52-53, May, 1980.

78. Mitchell, op. cit., p. 8.

79. Jamie James, "Earthscraper," Discover, 5:2:74, February, 1984.

80. Mitchell, op. cit., p. 9.

81. James, op. cit., p. 74.

82. Ibid.

83. Ibid., p. 77.

84. Mitchell, op. cit., p. 8.

85. Ibid.

86. James, op. cit., p. 76.

87. Ibid.

88. Ibid.

89. Ibid.

90. Ibid.

91. Ibid.

92. Ibid., p. 77.

93. Mitchell, op. cit., p. 8.

94. Ibid.

95. Ibid.

96. Ibid.

97. Architectural Portfolio, op. cit., p. 18.

98. Gerald B. Wellner, "Underground building cuts energy costs in half," American School & University, 54:5:52, January, 1982.

99. Ibid.

100. "Passive solar down east," American School & University, 55:4:29, December, 1982.

101. Ibid.

102. Thomas R. Morris, "Solar Design Seems to Work," Richmond [Virginia] Times-Dispatch, p. E-4, February 10, 1980.

103. Ibid., p. E-1.

104. Ibid., pp. E-1 & E-4.

105. Ibid., p. E-4.

106. Rita Robison, "Solar Energy Now?," American School & University, 52:9:43, May, 1980.

107. Ibid.

108. Ibid.

109. Auer., op. cit., p. 27.

110. C. A. Hooker and others, Energy and the Quality of Life: Understanding Energy Policy (Toronto: University of Toronto Press, 1981), p. 137.

111. Ibid.

112. Amory B. Lovins and others, Least-Cost Energy, 1981, op. cit., p. 119.

113. Ibid.

114. Ibid., p. 110.

115. Ibid.

116. Ibid., pp. 110-111.

117. Ibid., p. 111.

118. David J. Rose, "Towards a Sustainable Energy Future," Faith and Science in an Unjust World: Report of the World Council of Churches' Conference on Faith Science and the Future, Volume 1: Plenary Presentations, ed. Roger L. Shinn (Geneva, Switzerland: Church and Society, World Council of Churches, 1980), p. 246.

119. C. A. Hooker and others, op. cit., p. 137.

120. Ibid., p. 10.

121. Auer, op. cit., p. 22.

122. S. V. Szokolay, World solar architecture (London: The Architectural Press, 1980), p. 126.

123. Ibid.

124. Kathleen Courrier and others, eds., Shining Examples: Model Projects Using Renewable Resources (Washington, D.C.: Center for Renewable Energy Resources, 1980), p. 181.

125. Ibid., p. 182.

126. Ibid., p. 181.

127. Szokolay, p. 126.

128. Courrier, op. cit., p. 182.

129. "Atlanta says yes to solar power," American School & University, 52:9:48, May, 1980. Extensive details were given in the article regarding collectors, reflectors, hot and cold storage, cooling system, backup, savings (75% savings in fossil fuel) and other conservation measures employed in the 1,000 population school.

130. "This Pond Is Not for Ducks," American School & University, 53:3:24, December, 1980.

131. Ibid.

132. Ibid.

133. Ibid.

134. Ibid.

135. Ibid.

136. Ibid.

137. Ibid.

138. Ibid. This is an abstract from Solar Ponds.

139. New York State, Energy Research and Development Authority, "Energy Authority and SUNY/Buffalo to Build Solar Pond," New York State Energy Review, chairman, William D. Cotter (Albany, N.Y.: Department of Communications, Summer, 1983), p. 8.

140. "Pendleton Junior High," Architectural Portfolio, American School & University, 56:3:65, November, 1983.

141. "Solar in the snow belt," American School & University, 54:2:54 & 55, October, 1981.

142. Ibid.

143. Ibid., p. 55.

144. Stewart Jones, "Energy saving interest wavers," Richmond (Va.) News Leader, July 27, 1983, p. 4, cols. 1 & 2.

145. "Solar Water Heating Comes out on Top," Solar Utilization News, 8:6:13, December, 1983.

146. Ibid.

147. Ibid.

148. Ibid.

149. Ibid.

150. Hooker, op. cit., pp. 138-139.

151. Lovins, op. cit., pp. 117-118.

152. Ibid.

153. Ibid., pp. 114-115.

154. Ibid., pp. 115-116.

155. Hooker, op. cit., p. 139.

156. Ibid.

157. Ibid.

158. Ibid., p. 137.

159. Ibid., p. 138.

160. M. Ross Adams, "Tax Study Enhances Prospects for Commercial Solar Sales," Solar Age, 6:6:15, June, 1981.

161. "The Solar Age Domestic Hot Water Directory," Solar Age, 6:6:1, June, 1981.

162. Ibid.

163. Ibid., p. 9.

164. Ibid., pp. 2-9.

165. Ibid., p. 9.

166. Ibid., pp. 8-9.

167. Ibid., p. 2.

168. "The Solar Age Domestic Hot Water Directory," op. cit., p. 31.

169. Ibid., pp. 35-36.

170. Ibid., p. 35.

171. "Solar Cells: 30 year anniversary of modern photovoltaics," Solar Utilization News, 9:4:10, October, 1984.

172. "Solar Cells," Solar Utilization News, 9:5:10, November, 1984.

173. Lovins, op. cit., pp. 109-110.

174. Ibid., p. 110.

175. Ibid.

176. Miles C. Russell, "An Apprentice's Guide to Photovoltaics," Solar Age, 6:7:32, July, 1981.

177. Ibid.

178. Ibid.

179. Ibid.

180. Ibid.

181. Ibid.

182. Ibid.

183. Ibid.

184. Ibid.

185. Ibid.

186. Ibid.

187. Ibid.

188. Ibid.

189. Ibid., p. 33.

190. Ibid.

191. Ibid.

192. Ibid., pp. 32-33 & 35.

193. Ibid., pp. 33-34.

194. Ibid., p. 34.

195. Ibid.

196. Ibid., p. 36.

197. Ibid., p. 35.

198. "Solar Business Review: New PV Prototypes Receive High Marks," Solar Age, 6:6:45, June, 1981.

199. Ibid.

200. Ibid.

201. Ibid.

202. Ibid.

203. "Research: Experimental PV module setting records," Solar Utilization News, 9:2:13, August, 1984.

204. Ibid.

205. Ibid.

206. Ibid.

207. "Solar Cells," November, 1984, op. cit.

208. "PV for PV School," ARCO Solar News, 5:2:12, Autumn, 1985.

209. Ibid.

210. Ibid., p. 13.

211. Wilson Clark, "Take sun and salt, add some water--the results is energy," Smithsonian, 11:7:144-145, October, 1980.

212. Ibid., p. 145.

213. Ibid.

214. Ibid., p. 143.

215. Ibid., p. 146.

216. Ibid.

217. Ibid.

218. Ibid., pp. 143 & 146.

219. Ibid., pp. 143 & 145.

220. Ibid., pp. 143-144.

221. Ibid., p. 143.

222. Jacques Constans, Marine Sources of Energy (New York: Pergamon Press, 1979, United Nations), p. 82.

223. "Thermal," Solar Utilization News, 8:7:13, January, 1984.

224. Ibid.

225. Ibid.

226. Ibid.

227. Carl L. Laurella, "Solar ponds: Wave of future?," Utah Energy News, II:4:1, ed. Maggie Wilde (Salt Lake City, Utah: Utah Engineering Experiment Station, Summer, 1982).

228. Ibid.

229. Ibid., p. 2.

230. William D. Marbach and Ron LaBrecque, "Steam From the Sunshine," Newsweek, C:24:92, December 13, 1982.

231. Sandra L. Cole, A Solar Collection: Projects Funded by the Appropriate Technology Small Grants Program, Publication No. WAOENG-84-42 (Olympia, Washington: Washington State Energy Office, August, 1984), pp. 2-5.

232. Ibid., p. 93.

233. Paula Lippin, "Offices Go Solar," Administrative Management, XL:9:34, September, 1979.

234. Ibid.

235. Ibid.

236. Ibid.

237. Donald R. Price, "A New Energy Ethic for Farmers," Vocational Education, 54:1:50, January, 1979.

238. Lovins, op. cit., p. 116.

239. Ibid.

240. Ibid., p. 116.

241. Hooker, op. cit., p. 140.

242. Ibid.

243. Ibid.

244. "Solar Business Review," Solar Age, 6:7:51, July, 1981.

245. Ibid.

Chapter 6

WIND POWER

Wind energy is renewable, indigenous, non-polluting, and, when available in adequate quantity, often a more appropriate energy technology for use in the production of electricity than the traditional energy resource base. As such, it can become part of a just and sustainable energy resource base for the Twenty-first Century.[1] Lester R. Brown said, "Embodying an estimated 2 percent of the solar radiation the earth receives, the kinetic energy in the movement of air along the earth's surface is enormous."[2] This indirect or derived source of solar energy, although less generally available than direct solar energy, has proven its ability to compete on the utility company grids under the the provisions of the Public Utility Regulatory Act (PURPA) of 1978.

Wind Energy Available

The indirect energy of the wind is created by the differential heating of various portions of the planet by the sun. Frank Carrol explained the energy of the wind this way:

> . . . For example, oceans can absorb large amounts of radiant energy and stay cool, whereas the land can't, so the land heats up and sends hot air rising above it. Cooler air from the ocean moves in over the land to replace the rising warm air, and that movement generates the sea breezes at the seashore. This type of air movement is what we call the wind. Wind energy is in the velocity of a mass of air. In fact, the energy of the wind triples with the increase of the wind velocity. This accounts for the destructiveness of storm winds like tornadoes, hurricanes, and typhoons. Most areas have an average wind speed of 10 to 17 miles per hour. To tap that power, some means of

> transforming the kinetic (energy of motion) energy of the moving mass of air to our wind energy system must be found.[3]

Janet L. Hopson illustrated the availability of wind energy in Altamont Pass, California, on a wind farm. The Altamont area was described as follows:

> . . . a zone of dry, grassy hills east of the Coast Range, surrounding San Francisco Bay, and west of California's Central Valley. Eight months of the year, the temperature difference between the cool coast and the hot valley is so great that a powerful pressure difference is created and air surges inland, funneled through natural gaps like the Altamont. The annual average wind speed amounts to 17 miles per hour, including the four calm winter months.[4]

The wind available at different sites is highly variable. In contrast to the Altamont area, a wind energy site in North Carolina was reported as having adequate wind energy to keep "batteries charged from late September through May of each year."[5] The season of adequate available wind energy varies with the site characteristics. The topography and vegetation at a particular site can dramatically alter the estimates of a weather station in an area regarding the expected availability of "regular power-producing breezes."[6] Potential windpower users are advised to use an anemometer to measure the force or velocity of the winds at the site of intended use for at least a year. The measurements should be taken "at the elevation at which the blades of the plant will be located."[7]

Wind energy can be converted to mechanical and electrical energy. It can be stored and coverted to other uses. Its most practical use is in the generation of electricity in the school setting. Mechanical tasks of agrarian settings or educational programs for tasks

such as pumping water for irrigation and animal use are also appropriate applications of wind energy. Remote sites which experience relatively high and consistent wind velocities are particularly suited to this form of energy. Wind power may also be used to provide electrolysis of water for direct use of hydrogen gas as a fuel.[8]

Two suggested strategies are available for those times when the wind speed is too slow for effective utilization in electricity generation. First, wind energy can be stored for later use in a variety of ways, some of which are far less costly than others. Among the more economical ways to store wind energy are these: the use of batteries, fuel cells, converting the wind energy to heat energy in water, and using the wind energy to pump water behind dams for use of the power of falling water as needed.[9] The storage strategy tends to be more appropriate in a remote setting. The alternative strategy is to depend on the cooperation of the public utility companies to allow schools to cogenerate excess wind-generated electricity for sale to the utility company, while relying on the utility company to provide electricity in times of low wind velocity.

Auer and others estimated that the combined wind, waves, convection, and current indirect use of solar energy is more than nine times the solar energy used in photosynthesis, the origin of fossil fuels.[10] In 1978 the state of knowledge of wind energy was quite limited when they tried to assess world energy resources for 1985-2020. They stated, "Wind energy is known with the least precision, since it is most geographically variable of the solar energy forms and because there

has been little need for wind energy maps.[11] Scattered measurements of wind energy offered only preliminary estimates of the potential worldwide production of energy from this secondary solar energy resource.

In 1981, when C. A. Hooker and others evaluated Canadian wind energy potential, they found that

> . . . The National Research Council estimates that full-scale development of windmills over the parts of Canada with reasonably high wind densities could supply sufficient electricity to meet all of Canada's projected electricity needs up to about the year 2000, even with rapid growth in demand.[12]

The most vital role of wind-electrical technology was seen as being in remote areas.

Frank Carrol reported on the U.S government's published estimates of wind power which can be harnessed in the U.S. at low altitudes. The practically available wind power was seen as being "30 times greater than present electrical power generation."[13] Professor Stan H. Lowy offered additional details, as follows:

> In 1972, the Solar Energy Panel of the NSF and NASA estimated the power available from surface winds over continental USA, the Aleutian Arc and the Eastern Seaboard is equivalent to approximately 10^5 gigawatts of electricity. This is over 30 times more than the estimated total power consumption in the US by 1980 and more than 100 times the estimated electrical generating capacity in the US by that time.[14]

In the U.S. new firms have taken advantage of a promising market for more economical wind energy products to replace increasingly expensive nuclear and coal energy resources. In February 1980 Lester Brown reported,

> . . . Sensing this new potential, Congress passed the Wind Energy Research, Demonstration, and Utilization Act of 1980, a

> bill that would provide strong market support for wind generators through 1985, by which time the industry should be mass producing wind generators. Support for the bill stemmed from the conviction that wind could supply 2 to 4 percent of national electrical power demand in the year 2000. It now seems likely, however, that the ambitious timetable for wind energy development embodied in the Wind Energy Act will be altered by the budget cuts of the Reagan Administration.[15]

States with high wind-energy potential have led the way. As early as 1981, Amory B. Lovins reported, "Hawaii plans to get 9% of its electricity from wind by 1985."[16] In 1984 Senator Alan Cranston of California recommended the goal of "3.4 percent of the nation's energy needs in the year 2000" as the wind energy contribution.[17] At the same time California, the world's wind-energy leader, was hoping "as much as 10 percent" of the state's "projected demand of 52,000 megawatts of electricity" would be supplied by wind turbines.[18] An "estimated 3,340 wind turbines were producing 341 megawatts" of electricity in California on January 1, 1984.[19] By July 1985 wind energy was growing faster than all other renewable energy sources. Harry Bacas stated,

> . . . The heaviest development has been in California, where more than 8,000 wind turbines, erected in the last three years in windy mountain passes, generate 600 megawatts of electricity, enough to serve 200,000 homes.[20]

Wind-aerogenerators over the oceans and seas offer a remote production facility possibility. As McGown and Bockris reported, the engineering principles are already known.[21] Such possibilities make it interesting to speculate about the likelihood of sea-going, cruiser universities or schools of the future. The potential educational experiences which could emerge from this and other uses of energy resources demonstrate the reality that "energy shapes the future."

Methods of Harnessing Wind Power

The orientation of openings, contours, overhangs, and materials used in buildings can facilitate the use of both direct solar energy and the indirect energy of the wind. For much of the year desirable climate control can be achieved without resorting to use of electrical energy to provide ventilation and cooling. User interaction with natural wind energy application in facilities is required when natural ventilation is used. In some locations school officials would raise concerns about additional openings contributing to possible vandalism and theft. However, few would disagree with the merits of a cool, gentle breeze relative to the hum of cooling systems which frequently provide too little fresh air for comfort.

The spaces utilized by the welding and industrial machining programs of a new building at Texas State Technical Institute at Harlingen, Texas, have demonstrated the values of natural ventilation as a use of wind energy in an educational setting. In a setting where the climate makes large energy demands for air conditioning, the design firm provided a facility offering "a raised roof bay running through the center of the building" which "allows natural light to penetrate into the shop areas through operable clerestory windows that also aid ventilation."[22] The importance of ventilating the shop areas heavily influenced the building design. Louvers for exhaust and air intake assume the character of "interesting features on the exterior of the building."[23] Much of the heat generated by the shop equipment is released as a result of the combination of operable windows on the south

wall, north wall, and the high clerestory. In addition to these natural ventilation features, "The brightly colored manifolded ventilation for the welding shop provides fresh air and exhaust for each booth."[24] The total effect is a pleasing exterior appearance which makes optimum use of naturally occurring wind energy for interior ventilation.

Moving beyond natural ventilation to other uses of wind energy, wind energy is free and widely available to those who choose to use the intermediate technology already available, with improvements being made daily. The technology is significantly less complex than that of the automobile. The kinetic energy of air currents is used to rotate a propeller, airfoil or other driving device known as a turbine. The driving mechanism can be used to produce mechanical energy or to drive a generator to produce electricity which may be used directly or stored for later use by a number of methods.

In 1980 Frank Carrol described three primary methods of collecting wind energy for practical use. These were the drag method, the lift method, and a new experimental method described as the tornado-type wind turbine tower.[25] Figure 4 is a representation of some typical windmill configurations of the airfoil which catches the wind to generate usable power.

The traditional Dutch windmill used four arms to trap about 15-20% of the total kinetic energy of the passing wind.[26] It illustrates the **drag method** of collecting power which uses the wind to push an object.

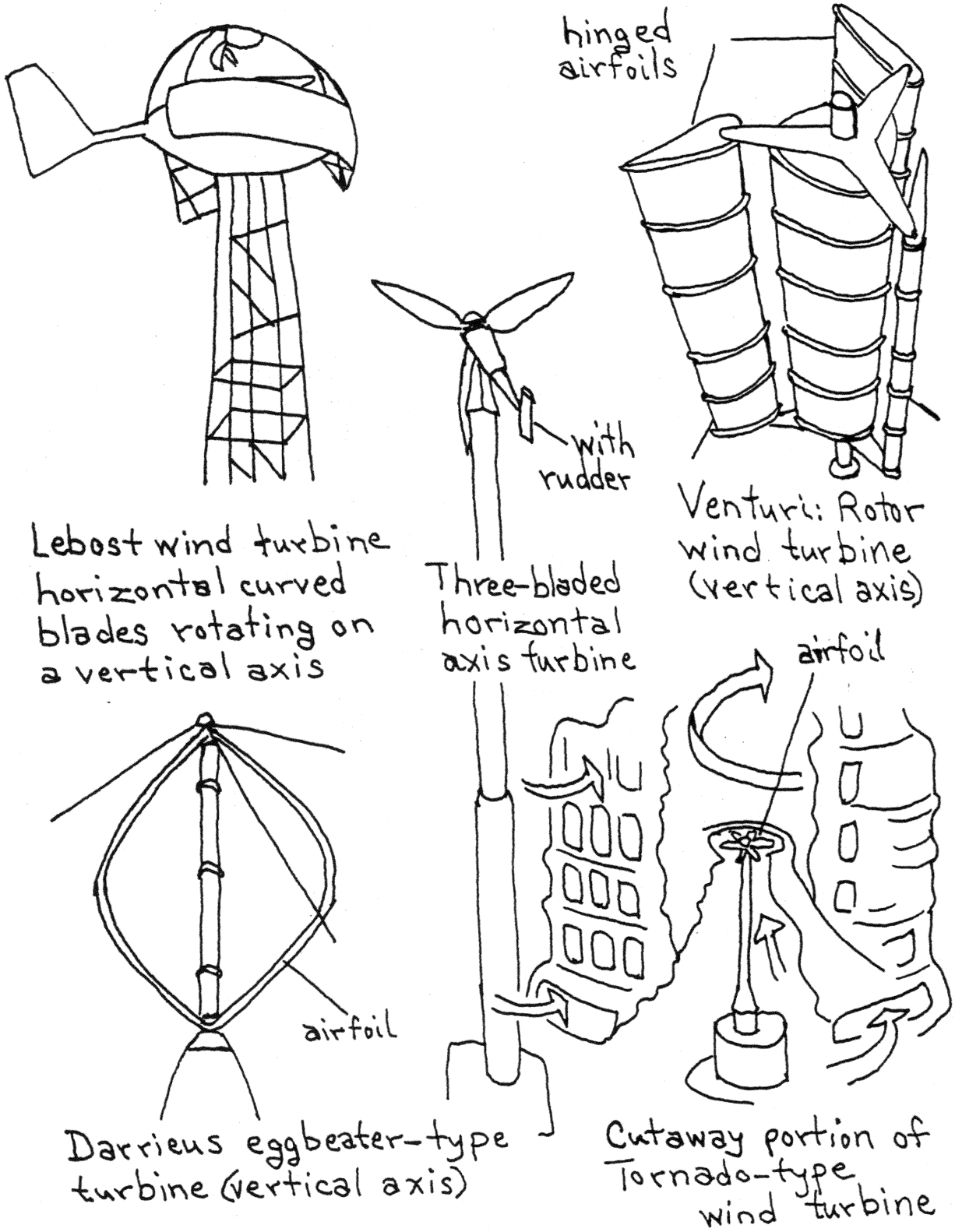


Figure 4

Windmill Configurations

The aircraft wing offers the basic design principles of the **lift method** used in modern wind turbine design. Carrol offered this description:

> . . . With the lift method, the sail turns into a wing section and is not pushed by the wind, but is driven by the lift generated by the airfoil section placed in the wind stream. With this lift, the airfoil typically rotates at three to six times the velocity of the wind and is correspondingly much more efficient, taking-out approximately 30-40% of the total wind energy.[27]

Both horizontal axis and vertical axis wind turbines belong to the lift method of harnessing wind energy. In the horizontal axis design the propeller or airfoil always faces into the wind like the traditional Dutch windmill. The rotating propeller blades go up and down relative to gravity. Carrol distinguished the vertical axis wind machine in this way.

> . . . The airfoil is like a barrel hoop spinning like a top around its vertical axis. The vertical axis machine can take the wind from any direction, without any special positioning, whereas the horizontal axis type must either be moved manually or by automatic servos or by the wind (through a tail vane).[28]

Carrol saw in both horizontal and vertical axis systems, both of which are commonly used in wind farm sites, the potential for serious structural problems and consequent uncertainties about the lifetime and maintenance requirements of the very large blades required to produce electricity in the large quanties desired by the public utilities from alternative energy resources. He indicated that ". . . 300-foot blades at 30 m.p.h. high wind generate only three megawatts. . ."[29] This is about one-hundredth of the power generated by a traditional coal, oil,

or nuclear power plant. Furthermore, technology on this scale in the lift method of wind technology had not been proven.

If schools elect to use wind energy, they may be ill-advised to follow the practices of large-scale developers of wind energy in the private sector. By January 1984 Solar Utilization News was reporting serious manufacturer reservations about the use of very large-propellor driven wind turbines.[30] Federal subsidies were apparently exercising some restraints on the wind industry by modeling this alternative with machines of excessive size. Even General Electric Co. (GE) found reasons to cancel a contract to assist in building an unprecedented 7.3 kilowatt wind turbine on the north shore of the island of Oahu, Hawaii.[31] This wind turbine generator was to be the world's largest.[32] GE intended to honor its commitments to NASA and DOE to complete the design and development of the MOD-5A, which was to "feature a 400-foot rotor mounted on a tower 240 feet high."[33] The electrical capacity would serve 3,500 homes. The project called into serious question the economics of scale in this renewable energy technology and the appropriateness of this federal subsidy. Some of the factors GE officials considered in the cancellation decision were of a more general nature, including "the declining price of oil, lower utility forecasts for load growth, the planned expiration of alternative energy credits and an apparent decrease in consumer interest in renewable energy."[34] While it is theoretically possible that such a machine could meet the electrical needs of a college, some perspective regarding the scale is

suggested by the fact that such a rotor is more than 100 feet wider than the "wingspan of a Boeing 747 jumbo jet."[35]

One of the wind farm developers working in California's Altamont Pass at the time was using 50 significantly smaller 200-kilowatt wind systems. The Belgian-made turbines used fiberglass blades to "produce an estimated 450,000-500,000 kilowatt-hours a year at an average wind speed of 16 miles per hour."[36]

The European Wind Energy Association (EWEA) newsletter reported that about three wind energy installations per week were being added to "a total of 730 small wind systems in Denmark as of January 1983."[37] The Danish goverment was providing small wind machine purchasers a 30 percent subsidy.

Cathy Stone described a vertical turbine which can be horizontally site assembled and positioned with an hydraulic jack and is designed to withstand 200-mph winds. Stone stated, "The modified eggbeater, developed by Flowind Corp, (Kent, Wash. 98031), can generate enough energy annually to power 20 homes."[38] The slender tower and curved airfoils, a 55-foot diameter rotor, are braced by cables. The system is controlled by computer to permit safe shutdown. The machine had "produced 120 kilowatts in 36-mph winds."[39] The goal was "to raise the windmill's peak output to 170 kilowatts."[40]

The project manager saw this machine as appropriate "where power could be sold at from five to seven cents per kilowatt-hour."[41] The real economic sense was made when Tom Hiester said, "The turbine is even

more attractive for remote areas in Alaska, where diesel-generated power costs 40 cents a kilowatt."[42]

In 1980 the wind technology which Carrol saw as offering more promise of providing a large quantity of wind energy efficiently was the **tornado-type wind turbine towers.** Dr. James Yen, a Grumman Aerospace Corp. research scientist, invented the machine which was still being tested. The Federal government had funded four years of development work on an 18-foot model which still needed to undergo full-sized wind tunnel testing.[43] The "Tornado Wind Energy System" was described as follows:

> . . . This system operates on the basis of capturing the wind in a stationary and slotted tall cylinder and forcing it to whirl around like a tornado inside. The vortex is then pulled out by the wind over the top of the cylinder. No large propellers are involved. The power is obtained by using a low-pressure turbine, similar to a jet engine gas turbine, to be spun by the pressure difference between the center of the tornado and the normal outside pressure.[44]

The risks associated with this technology were seen as being significantly smaller than those associated with lift method wind machines. Carrol saw real promise of development of this technology for various scales of use, ranging from powering a home to 100 megawatts to energize a city. A 10 kilowatt prototype of this system was installed on a New York State University campus in 1981.

Amory B. Lovins and others offered a useful critique pointing out the varieties of wind energy technology available and the bearing technology selection can have on the conclusions likely to be reached about the viability of this energy resource. They stated a truism which is sometimes more important than obvious in practice, "Overengineered,

highly instrumented wind machines can easily cost ten times as much per kW as elegantly simple designs that are probably a good deal more durable and reliable."[45]

On the world scale there are many opportunities for appropriate, non-electrical uses of wind power. International education, trading relationships, and the economics, ecology, and politics of global survival make increasing demands that educators and their students be sensitive to global needs. In 1981 George McRobie described a number of intermediate technological developments which were being applied to such tasks as mechanical power and low-lift pumping for irrigation in several Third World countries subject to seasonal droughts.[46] The large windmills being developed in Australia and the U.S. at the time were seen as excessively complex and inapplicable to the needs of developing countries. With growing imbalance in international trade, the U.S. today needs to reevaluate the scale and potential uses of its technology. Appropriate demonstration of non-electrical uses of wind power could be made in vocational facilities and equipment.

Descriptions of U.S. windpower practices, largely for sale of power to public utilities, may be erroneously perceived in general as the appropriate uses of wind energy. On December 29, 1985 the Associated Press reported, "California produces 95 percent of the wind energy generated in the United States."[47] The most commonly used wind equipment in Altamont Pass, site of more than half that total, was described this way:

> Row upon row of windmills stretch over the pass; they are set atop tripods and tubular or lattice towers. Most of the

> windmills have three rotors, although a two-bladed machine and one vertical axis model resembling an eggbeater also are used.
>
> The machines are mostly U.S.-made, but Danish, Scottish, Dutch and Belgian windmills also can be found at the pass.
>
> U.S. Windpower Inc. of San Francisco operates about 40 percent of the windmills at the pass. The company's machines have three blades, a rotor diameter of 56 feet and rise 60 feet above the dry vegetation that is dotted with grazing cows.[48]

Other smaller scale uses of wind energy might less likely seem to be spacially demanding, visually distressing and noisy.

In June 1985 Mayo Mohs noted both the rugged quality and distinctiveness of design of Danish windmills. Furthermore, Denmark, the "number two country in wind power,"[49] tended to use windmills "singly or in small clusters," contrasting sharply with the massive US wind farms.[50] About 4,000 of the Danish built windmills were expected to be exported to the U.S. by the end of 1985. Nearly all Danish machines are designed for upwind operation. Yaw motors do the work of keeping the machine facing into the wind rather than the traditional, large tail vane. The upwind position avoids the turbulence created by the tower.[51]

Mohs also reported an interesting contrast between the US subsidy of development of ever larger horizontal axis wind turbines and Canada's heavy support of the development of the vertical-axis wind turbine. The design was characterized as resembling a "graceful egg-beater." The principal U.S. maker of these machines noted the avoidance of the upwind-downwind choice in this equipment. These machines provide higher efficiency at lower cost per kilowatt-hour. With a twelve miles per hour cut-in speed and "a conservatively projected 15-year life," the

most recent model was expected to provide electricity at "a mere 5.4 cents per kilowatt-hour."[52]

In July 1985 Harry Bacas reported that research continued to be aimed at using larger machines in hopes of achieving efficiency although significant damage reports and frequent maintenance problems had occurred. Bacas found large turbines being manufactured by 20 U.S. companies. Smaller wind machines for individual use at remote sites were being produced by 25 companies.[53]

A 1984 survey of 44 wind generation systems in Washington state revealed frequent user failure to adequately assess the average annual wind speed prior to installation of wind energy equipment. Many sites proved to be uneconomical due to less than 10 mph average windspeeds. In one instance a horizontal axis, downwind, fixed pitch motor with three blades was moved from a 6.9 mph site to the Port Townsend High School where the wind was better and where it could serve an educational purpose. The cut-in wind speed was nine mph. The cut-out wind speed was 40 mph. In the former poor wind site the estimated cost of wind-generated electricity was a very high 26 cents per kilowatt-hour.[54] By comparison, a horizontal axis, upwind with tail vane, wind generator, in a more favorable residential wind site, with a cut-in wind speed of seven mph and no cut-out wind speed, was expected to provide electricity at five cents per kilowatt-hour.[55] The upwind configuration to keep the turbine pointed into the wind was most commonly used in Washington.[56]

Only one "vertical axis, Darrieus style (egg beater type

blades)" installation was reported in the Washington state survey. It had a cut-in wind speed of 11 mph and a cut-out wind speed of 60 mph.[57]

Wind Energy Problems

High initial costs, technical problems, financial uncertainties, storage problems, and environmental problems are among the inhibitors of development of wind energy systems. Mass production and marketing can help reduce costs. In most locations cooperation with the public utility company can deal with storage problems. Opinions differ about the seriousness of concerns related to ". . . noise from the rotors, interference with television reception, blade-and-tower failure and 'visual pollution.'"[58]

High Initial Costs

The resurgence of use of wind machines in the U.S. has been based on federal legislation which contributed to the economic feasibility of wind energy by dealing with the storage problem and by tax incentives which have helped underwrite the high initial costs associated with an emerging technology. The Public Utility Regulatory Act (PURPA) was passed by Congress in 1978. Section 210 required utilities to buy from and sell power to "independent producers of electricity who utilize renewable sources of energy."[59] PURPA effectively eliminated both the problem of excess wind energy production and the need of storage batteries and backup generators for extended periods of inadequate wind to generate electricity, except, of course, in remote sites which are not served by public utilities.

PURPA requires utilities to pay qualified independent producers for the excess electricity produced based on utility company cost avoided rates. Russ Ramsey explained the rates as follows:

> . . . This figure is determined by what it would cost the utility to produce the electricity. Because there's tremendous variation in the actual avoided costs of different power companies, and because there are a number of different ways to go about calculating them, buy-back rates vary from about 1¢ per kilowatt-hour (kwh) in some midwestern states to as much as 10¢ per kwh in California and parts of the Northeast.
>
> However, regardless of your location, you'll never get rich by selling power from your home-size wind machine to a utility. Because the power company pays less than retail for power it buys, your best bet is to use as much of your home-generated electricity as possible. Unfortunately, some utilities require that **all** generated power be sold directly to them (at buy-back rates, of course) and that all power consumed at the site be purchased from the utility at **retail** rates. This provision--which is often called parallel (as opposed to series) interconnection--can make tying into the utility's grid a financial bust![60]

Former Federal tax credit incentives for domestic and business applications of renewable energy offered the other major impetus to development and use of wind energy resources. Federal research and development funds for wind energy were quite high during the Carter administration. The tax credits passed by Congress to help develop this approach to dealing with the energy crisis enabled homeowners to recover 40% or more of the initial cost and businesses to recover as much as 90% of the initial costs, through the combination of a 15% renewable-energy tax credit, being a business producing electricity, a 10% investment tax credit, and depreciation over a five-year period.[61]

In November 1982 Janet Hopson expressed concern about economic challenges to the viability of the wind industry. She said,

> . . . These include the general recession and high interest rates, the temporary glut and drop in oil prices and Reagan administration budget cuts. Since 1980, federal support for wind-energy projects has been cut by more than 90 percent, and many of the large machines may have to be crated and stored unless taken over by utilities.[62]

A high level of uncertainty surrounds the federal government's likelihood of continuing to provide various tax incentives to residential and business users of wind energy to encourage the development of more economical and mass-produced wind machines.

Many factors are important in evaluating the cost-effectiveness of wind energy. If all energy systems were equally and fairly subsidized by government, a more accurate analysis would be possible. Wind power feasibility considerations vary from those of private enterprise. As desirable as tax incentives may be for developing economical wind energy systems, schools must rely on school and hospital related grants for subsidies from the federal government rather than tax incentives unless they operate in the private sector. However, the reduction of appropriately applied tax incentives in the private sector may tend to delay the development of more competitive wind technologies available for use in the public sector. Competing fuels and energy systems, suitability of site for wind energy, initial cost of wind turbines, cut-in and cut-out speed of the wind equipment, productive capacity of the equipment at the site, towers, method of storage (if applicable), maintenance, tying in with the utility, wiring, labor, and insurance are among the cost factors to be analyzed.[63]

Technical Problems

Hopson reported a number of technical failures in wind turbines of various sizes and types. Developing technology can solve many of these problems. Problems such as rotating blades coming loose, consequent damage to the supporting structure, the launching of rotor blades into flight, hydraulic problems, and maintenance in high winds can be solved with adequate funding to redesign the equipment.[64]

When comparing "the products of several different manufacturers of wind generators" in 1978, D. F. Warne acknowledged that there was no fair way to do so "even with ERA's extensive network of contacts throughout the world."[65] Among the difficult factors to analyze were the operational experience, the objectivity of reports, the skills of the construction crews, the skills of the maintenance engineers, and the statistical importance of occasional failures even in older established firms several of which had been in the business for nearly fifty years.

Robert D. Kahn reported high failure rates of wind energy machines in the period from 1981 through early 1983, with "high maintenance costs, considerable downtime, and poor energy production."[66] Since that time, industry competition has increased and better wind energy products have been produced due to field experience and redesign of equipment. At the end of 1984 Kahn reported that wind machines averaged 15 percent downtime, with as little as 5 percent downtime for some machines. He reported five-year guarantees of 90 percent of the time by some manufacturers.[67]

Kahn emphasized reliability as a criterion in wind turbine selection. Complexity to achieve maximal performance was seen as often causing trouble. Too much complexity has been built into the 2.5 megawatt MOD-2 machines built by Boeing Co. They stand "350 feet tall . . . with a 300-foot rotor."[68] In the U.S. in 1984 the emerging expectation appeared to be that a more optimal size for wind turbines generating electricity might be somewhere in the range of 200 kilowatts to 1 megawatts. By contrast to excessively complex technology, sturdy, simple machines, especially those manufactured by Danish companies, were seen to be reliable and durable. The American Wind Energy Association reported that 10 percent of the wind machines purchased in the U.S. in 1983 were of Danish origin. The competition was expected to lead to a tripling of that figure by the end of 1984.[69]

Very durable wind machines can be built. The Center for Renewable Resources reported on a wind-powered farm in Woodward, Iowa, which had found adequate electricity generated by two small windmills and stored by batteries which had lasted for more than 75 years. A homemade ac-dc inverter was also included among the equipment used.[70]

More typical estimates of the durable life of wind machines being sold in the 1970s and 1980s were 15 to 30 years.[71] These estimates assume regular maintenance.

Storage

Since the wind energy needs and the time the wind is blowing do not always occur together, some provision must be made for an energy storage system or a backup system. Although using wind energy to charge

batteries is usually adequate in a residential setting for electricity, the high initial cost of providing wind power collectors, storage, and transformation controls, plus unpredictable maintenance problems, is high. In 1980 Carrol found these economic obstacles making the present generation of wind energy systems unable to compete successfully with utility-provided electricity.[72]

Carrol offered several ways to reduce the problems of high initial costs and storage for low wind energy periods. He suggested,

> . . . Some of the emerging means for reducing initial costs include not using wind power to generate electricity, but to generate heat, which is easier to store. For example, heated water can be stored in insulated hot water tanks. Another method is using a larger wind generator and sharing the load between several houses. Still another method is to not store it, but to use the electric utility to provide electricity as a back-up when there is no wind and sell the excess power back to the utility when you have too much power.
>
> Future technological development should be aimed at reducing the costs of energy storage. One type of storage device could be a flywheel, which is now being used on subway trains and some heavy trucks to take the energy absorbed from stopping a vehicle and using it to start it again. . .
>
> Hydrogen generation, through the electrolysis of water, and the subsequent storage and use of hydrogen as a direct fuel or through electrical conversion by fuel cells are other ways of storing energy from wind power. One overwhelming advantage hydrogen has over hydrocarbon fuels like oil, coal, wood, and gas is that the only product of its combustion is water and not carbon dioxide.[73]

Statistical observations of Stan H. Lowy in 1978 suggested that storing energy in batteries or fuel cells and storing energy in the form of hot water or water pumped behind a dam were more economical than other alternatives.[74]

Since short-term output of wind generators is not nearly as predictable as long-term output, D. F. Warne suggested that, whether

storage is electrial, thermal, or pumped, provision of storage should be site specific. Although five days of storage is frequently sufficient, practice must be more specific. Such factors as varied wind patterns, changing load profiles, cut-in speeds of wind machines, excessive wind speeds, and excessive power must be evaluated. Warne stated, "Storage capacity is determined by the peak surplus or deficit level, and making due allowance for a minimum state of charge that may be tolerable (particularly in electrolytic batteries)."[75]

Not all wind energy dealers and distributors are reliable. Remote sites can ill afford to be served by incompetent suppliers who supply equipment which is poorly matched to storage and the usage requirements. Batteries, voltage regulators and inverters to deal with ac-dc requirements must be appropriately matched.[76]

Environmental Problems

One way to overcome some of the environmental complaints associated with wind energy use is to restrict the range of wind speeds within which the turbines are permitted to operate in populated settings. The largest totally wind-powered farm in 1980 in New Jersey, located at Clarksboro, had to secure a zoning variance to operate a windmill which operated only in wind speeds ranging from seven to twenty mph. The 60-foot wind machine, using six aluminum blades, and installed on a tubular tower 36 inches in diameter, could "produce between 45,000 and 60,000 KWH annually."[77] The wind user experienced the advantage of reduced wear and tear due to shut down during high winds. Operating at about 60 revolutions per minute, the windmill was expected to be

relatively quiet and not interfere with radio and television reception. When television reception is interfered with, the addition of cable installation is required to permit communication technology to work. Such environmental problems and the cost of the technical fix led Robert Teitelman to the conclusion that large wind turbines would not prove to be cost effective in electricity production.[78]

In June, 1985 Ellen Paris described environmental complaints against the manner of development of wind power in the Palm Springs, California area. Numbered among the complaints of the Mayor and other citizens against the wind energy development in that setting were birds killed by the machines, noise and visual pollution, a threat to the tourist industry, and possible injury by machines sited too close to traffic arteries.[79] Threats to human safety from potential broken windmill blades being propelled hundreds of feet through the air were not without precedent since one blade had been thrown 400 feet.[80]

The consequence of such complaints was that the city government took "seven wind-park developers and the U.S. Department of the Interior's Bureau of Land Management" to federal court.[81] Failure to follow their 1982 environmental impact study, surreptitious changes without consultation, excessive development, interference with TV reception, highly irritating whirring and humming, interference with the path of migratory birds, and visually offensive colors used in the wind turbines in the desert environment were numbered among the specific complaints.

Varied Settings of Wind Energy Usage

Wind energy has been used in varied tasks and settings. They range from rural pumping of water and crude oil to generation of electricity on urban university campuses. While schools are unlikely to pump crude oil, those who doubt the merit of using renewable energy resources instead of traditional energy systems must find it interesting to learn that energy savings have paid for wind energy equipment to pump crude oil in as little as one year.[82]

Office Wind Energy: Florida

In 1979 Paula Lippin described the solar and wind energy features of an office building, the Times Publishing Co. in Clearwater, Fla. Wind energy was providing "an uninterrupted power source" for about 10 percent of the electrical needs. The wind energy source was described as follows:

> A 115-foot wind tower stretches 100 feet from the base on the roof of the building. . . . It has three egg beater-like sections--each measuring 15 feet by 15 feet--that catch the wind. The moving blades turn a generator to produce electricity. For the turbine to work, the prevailing wind has to be at least six to eight miles per hour.[83]

Farm Usage of Wind Energy

Donald R. Price reported a significant level of use of wind power in agriculture in the middle west. A common use was pumping water for animals in remote locations. He saw the likelihood of improvements in wind energy design techniques and the economics of manufacture, distribution and maintenance with growing interest based on the energy

crisis. Price recommended that vocational training of future farmers include a unit on "the basic operation of wind turbines."[84]

Virginia Polytechnic Institute and State University (VPI&SU) in Blacksburg, Virginia, used a windmill to help solve the orchard owner's and grower's problem of keeping Virginia apples in cool storage in 1980. The project was funded by the Energy Research and Development Administration through the United States Department of Agriculture with the specification that commercially available components be used.

VPI&SU used a Swiss windmill which "has three steel-impregnated wooden blades that turn in a circle 21 1/2 ft in diameter."[85] The wind energy system uses energy in two ways:

> . . . The first part uses a direct drive arrangement to blow air over the stored apples. The second phase uses a compressor to convert wind energy into electricity which is stored in batteries until needed. Stored electricity can be used to cool the apples by refrigeration on a low wind day or to power other equipment in the building.[86]

Based on wind tunnel experiments with a scale model, the windmill was supported by a "slender, 90 ft microwave tower made of tubular steel vertical members reinforced with solid steel cross members."[87] The height of the tower was designed to take advantage of fairly steady winds.

Heating Water by Friction: New York University's Applied Science Building

An unconventional, experimental windmill, invented by Barry Lebost of Yonkers, provides mechanical energy to heat water by friction. The strange sculptured wind machine seems to be a hodgepodge of kite,

airplane, helicopter, dome, and snow plow. However, the strange windmill has demonstrated impressive results. While it has demonstrated its ability to heat ". . . water to 180F needed to heat buildings," it could be ". . . used for other purposes such as irrigation or the powering of oil rig pumps."[88]

The siting of the patented "Lebost Wind Turbine" is equally remarkable. It stands on a tower on top of New York University's Applied Science Building. It was described this way:

> . . . a silver domed silo shell 21 ft in diameter that houses four 5 ft long dynamically curved blades resembling snowplows. Unlike conventional windmills, the blades inside the dome are horizontal. They rotate on a fixed vertical axis, driving a shaft which penetrates the roof 40 ft below. In a laboratory on the sixth floor the torque spins a water twister or paddle wheel that, by churning away, heats water by friction in a 52 gal. storage tank.
>
> The peculiar aircraft design feature of the wind turbine is a set of twin fins which steer the free spinning dome keeping its opening always in the face of the prevailing wind. The wind is channeled and concentrated by the structural elements of the dome and the shield that skirts the opening. It multiplies the wind's force four fold. This increases air flow through the turbine and allows the heat brake to be driven at peak efficiency at all wind speeds. A wind of 15 mph can make the mill produce 9,000 Btu's each hour compared to a conventional wind turbine which produces 7,300 Btu's.[89]

Funding sources for this experimental windmill included the New York State Energy Research and Development Authority.

Water and Utility Power: Department of Water Resources Wind Project at Pacheco Pass, California

Among the uses of wind power is the pumping of water to storage for domestic use and also to permit use of the energy of hydropower when wind is not adequate to provide wind power. The Center for Renewable

Resources described the Pacheco Pass Wind Project which included "three demonstration projects to utilize prototype wind machines in pumping water into the San Luis Reservoir from the aquaduct of the State Water Project."[90] The projects involved cooperative agreements between the Department of Water Resources (DRW), the Department of Energy (DOE), the utility company, and a private firm related to funding, installation, maintenance, ownership, and purchase of power. The wind turbines involved ranged in size from 50 KW to 2.5 MW. The private firm agreed to "build a first array of about 10 machines (50 KW) totaling .5 MW of power" for purchase by DRW.[91] This aspect of the project was expected to expand to as many as 1,000 wind machines.

DOE was providing an educational model and testing the public's reaction to a 14-stories-high intrusion into the landscape, relative to potential aesthetic offensiveness and noise created by the larger 2.5 MW machines' blades spinning at about 500 mph. Given the possible reactions, the remoteness of the site was appropriate.

Chelsea Middle School: Chelsea, Oklahoma

Numbered among the many model projects using renewable energy resources reported by the Center for Renewable Resources was the Chelsea Middle School in Chelsea, Oklahoma. The school offered practical experiences of wind power, battery storage of electricity, solar energy, water storage of heat, wind velocity and other climatic data. A 20-foot windmill, site assembled by special education students, provided electricity for a 10x30 foot, central greenhouse, for a fan used in the heating system, and to pump water. The project was initially funded as

a two-year program with Title IV-C ESEA money in 1976, "the first federally funded solar grant for a public school system in Oklahoma."[92]

Tornado Wind Energy Conversion System (TWECS): New York University's Westbury Campus

By the fall of 1981 a 10 kW prototype of the tornado-type wind turbine, described earlier, had been installed on the roof of General Applied Sciences Laboratories Inc.'s building at Westbury Campus of New York State University. The New York State Power Authority and Energy Research and Development Authority installed the structure which "stands 30 feet high, measures 15 feet in diameter, and includes a turbine/stator assembly approximately 5 feet in diameter."[93] The TWECS was to be applied in utilities by the end of 1982.[94]

A number of features of the TWECS appear to recommend them for use in educational settings as well as utilities. Relative to conventional wind turbines, they function on a vertical rather than a horizontal axis for safer operation. Much smaller turbines, relative to horizontal-axis equipment, can operate at lower wind speeds to generate comparable amounts of electricity. Furthermore, the lower cut-in speeds permit installation "at or below ground level to reduce structural and maintenance problems."[95]

Wind Energy Potential

The wind energy potential of a specific school setting is primarily a function of average annual wind speeds and seasonal availability. However, the equipment selected can be an equally

important consideration since wind turbines vary significantly in the wind speed required to generate electricity and their capacity to withstand high winds. The cost effectiveness of selection of wind energy systems is a function of these and other factors.

General Assessment of Potential

In 1978 Professor Stan H. Lowy of Texas A & M University offered "conservative estimates of the electrical power output (KWH per year per installed KW) possible at eight different Texas locations."[96] Today wind energy machines can produce useful power at much lower wind speeds, as low as six miles per hour, than those examined by Lowy and can withstand much higher winds than those evident in his data. Environmental considerations in a school setting would tend to restrict the use of high speed winds unless the system is designed with safety and noise control as very high priorities. Lowy's data must be read with the understanding that wind energy efficiency is machine and site specific. Obviously, more useful wind energy is available at Amarillo than at Galveston in a school setting. However, if the cut-in speed of the equipment selected were six miles per hour, as opposed to 13 miles per hour, data may both support wind energy use at all of the locations cited and make this energy alternative quite attractive economically. The data were as follows:

> . . . The basis of the estimates are: Cut-in wind speed of 13 mph, rated wind speed 25 mph, shut-down wind speed of 60 mph, and overall power coefficient of .40.

	Location	Specific output, KWH/yr/KW
1.	Amarillo	5,000
2.	Lubbock	4,800
3.	Corpus Christi	4,500
4.	Brownsville	4,350
5.	Waco	4,300
6.	Wichita Falls	4,250
7.	Dallas-Fort Worth	4,050
8.	Galveston	3,950

> A 1000 KW generator installed in the Dallas-Fort Worth area would then produce approximately 4 x 10^6 KWH per year, or enough to satisfy the requirements of about 500 homes. A similar installation in the Amarillo area could probably take care of 615 homes. About 300 wind-driven generators of 3,000 KW capacity should be sufficient to satisfy the residential electrical requirements of the Dallas-Fort Worth area. These could be installed on various "farms" surrounding the metropolitan area.[97]

Based on his study of the technology available and the escalating cost of fossil fuels in 1978, Lowy concluded, ". . . When the overall cost per KWH is considered, the wind-driven generator becomes a highly competitive method of electrical power generation. . . ."[98]

Wind of adequate speed to generate electricity is widely available. M. R. Gustavson offered a technical analysis of reasonable limits to be applied in tapping the vast wind energy potential in a manner which would minimize environmental consequences.[99] Gustavson concluded, "As a potential source of energy it exceeds in magnitude many other self-renewing sources such as tidal energy capture, geothermal energy, or hydropower."[100] The estimated ". . . global average wind velocity was 11 meters per second . . . ."[101] By contrast, ". . . An average wind speed of 7 m per second (25 km per hour) . . . is quite adequate to achieve good operating efficiencies."[102] Gustavson found the usable energy potential on a global basis for wind to be 45 times

greater than hydropower, 975 times greater than geothermal power, and 2053 times greater than usable tidal energy.[103] The extraction rate limit for use of wind for the United States was reportedly "roughly 75 percent of the current national total energy consumption rate, whereas the global limit . . . is about 20 times the worldwide energy consumption rate."[104]

The California Energy Commission expected that state's wind generation capacity to reach 740 megawatts by the end of 1984, with the possibility of 1,250 megawatts by the end of 1985.[105] The projection of wind farm production of California electricity for the year 2000 was 8 percent.

New Hampshire, Montana, Oregon, Kansas, Hawaii, and New York were among other states where developers were actively developing wind power. The American Wind Energy Associations projection of on-line wind energy generating capacity by the end of 1984 was 900 megawatts for the nation. In an even longer ranged forecast, Kahn stated, ". . . The Worldwatch Institute in Washington, D.C., recently reported that wind could provide 14 percent of the nation's projected demand for electricity by the turn of the century."[106]

Specific Site Selection

D. F. Warne described the importance of site selection in the determination of the feasibility of wind energy at various typical sites in the United Kingdom. Warne's data indicated the effects of changes in meters per second (m/s) of wind speed on the potential electrical output in Watts of wind turbines of various diameters. Doubling the wind speed

is accompanied by vastly more than doubling of the power produced. The effect of apparently small variations in the mean annual wind speed on electrical power output is abundantly clear in the figures in Warne's Table 1, offered here:

Influence of wind speed on output of turbines of various diameters.

Turbine diameter (m)	Electrical power output (W) Wind speed		
	3 m/s	7 m/s	12 m/s
1	3	43	217
5	85	1080	5420
10	340	4310	21700[107]

Warne illustrated the average annual wind speed in meters per second in three characteristic locations in the UK which were described as follows:

3 m/s - fairly commonly over inland areas
7 m/s - only with careful siting and usually near the coast
17 m/s - only at a few of the windiest coastal hilltop sites[108]

Robert D. Kahn emphasized the importance of appropriate site selection for wind-generated electricity. Proximity of the site to the needed users was emphasized less than the available winds. Kahn said,

> . . . In technical parlance, the power in wind is proportional to the cube of its speed. This means that as wind speed doubles, available power increases by a factor of eight. Therefore, a 3 percent difference in average wind speed can alter power production by almost 10 percent.[109]

Hopson listed some of the probable sites of a high level of wind energy use. She listed some of the current and potential wind farm developments in the Altamont Pass area, east of San Francisco. Marginal grazing land became wind farms, while maintaining the grazing value.[110] Other sites included the following:

> . . . wind swept mountain passes of San Diego, Los Angeles, Santa Barbara, Monterey; windy areas off the coasts of New England and the Pacific Northwest (islands generally are very good locations for wind turbines); the northern Great Plains; and parts of Wyoming, Colorado, Montana, Hawaii and a few other states.[111]

Writing in a more global perspective, Lester R. Brown stated:

> . . . Much of the economically harnessable wind energy is concentrated along coastlines and in mountain passes. Among the promising coastal sites now being considered for wind generation are the northern coast of the United Kingdom, the southern and western coasts of Australia, the Soviet Union's extensive Arctic coastline, and the Caribbean Third-World countries astride the trade winds belt. The coastal and mountain regions of the United States are also richly endowed with wind power.[112]

It is not enough to know in general that winds are greatest where air streams are unobstructed by the changing contours of the landscape. While shorelines, open plains, and mountain passes are generally recognized as favorable wind energy sites, other less favorable sites may provide useful wind energy. The wind accelerates as it passes over hilltops.

Trees and buildings obstruct air flow. Jeanne MeCermott said,

> The wind picks up speed with altitude . . . . A rule of thumb says that velocity increases as the one-seventh power of the distance from the earth's surface. This increase is related to turbulence: At greater distance from the ground, the hindering effect of obstructions is minimized.[113]

Since school buildings are surrounded by a wide variety of obstructions and are an obstruction themselves, McDermott's statement of some general guidelines is helpful. Both monitoring equipment and the eventual wind energy generators should be placed a significant distance away from or above buildings and other obstructions. While upwind sites call for raising the equipment "twice the building's height," downwind

sites should be "at least 10 times the building's height" and, if mounted close to or on the building, an appropriate height would be "three times the building's height."[114]

About five years later, in 1985, another wind site assessment, reflecting changing technology used a different criterion. The rule was to monitor the wind at a distance of at least 15 times the height of obstructing objects, with potential wind sites requiring an average annual wind speed of at least 8 mph.[115]

The Office of Energy Policy in South Dakota recommended a careful wind survey of sites under consideration, with "an average annual wind speed of 10-12 mph" as the minimum velocity affording economic use of wind machines.[116] This is consistent with McDermott's generalization about feasible sites, namely: "For a wind machine to be cost-effective today, you probably require annual average windspeeds of at least 10 mph."[117] South Dakota reported that high elevations and ridge crest sites tend to offer the highest quality wind energy. The seasonal differences in wind energy availability in South Dakota vary widely with spring, winter, autumn and summer offering greatest to least seasonal average wind power, in that order. Consistent diurnal or daily wind speed patterns were observed throughout the state. Maximum wind speeds were reported "in the afternoon from noon to 5:00 p.m., earlier in the winter than in spring and summer."[118] The data reported were all gathered about 2:00 p.m. for maps of wind power density. The majority of the state showed class 4 (16.8 mph or 7.5 meters per second)[119] or above for average annual wind power, with the vast majority of the state

offering these desirable wind velocities in the spring and winter seasons. Steve Wegman reported unfortunately, "Almost all of South Dakota is estimated to have class 2 or lower wind power in the summer."[120] However, class one wind power is 5.6 meters per second or 12.5 mph and class 2 wind power is 6.4 m/s or 14.3 mph, both of which fall within the minimal area to be considered economical.[121] The low degree of certainty regarding specific sites demands the use of wind measurement equipment, preferably with observations more representative than only 2:00 p.m. readings.

Individual and public users of wind energy need a practical means of determining whether a specific planned site offers a wind resource which is adequate to harvest. The required information ideally involves the monitoring of wind speeds for at least a year in a site of intended use. Furthermore, data from the weather stations should be correlated with this data to arrive at a reasonable estimate of wind energy available. McDermott suggested sources of data regarding "local wind characteristics," specifically, "airports, the national weather service, the park service, military bases, air-pollution testing stations, and universities."[122] If other weather data were gathered in a similar landscape nearby, McDermott added this counsel from a member of the American Wind Energy Association: "'If the reading from the local weather station shows anything above 12 mph, you probably don't even need to mess with monitoring.'"[123]

When area wind speeds are reported between 10 and 12 mph, accurate monitoring is critical because the available wind power varies

with the cube of the speed of the wind. The effect on feasibility is clearly stated by McDermott as follows: "A wind machine on a site with 12.5-mph windspeeds produces **twice** as much power as a windmill on a site with 10-mph winds."[124]

Measuring wind speeds can be accomplished by an inexpensive anemometer, mounted on a pole, with an attached odometer for readouts on the ground level. Accurate, at least twice-daily, recordings of data for at least a year provide a basis for determining monthly and annual average wind speeds which are important in selecting wind energy machinery. While the daily availability of wind energy is somewhat unpredictable, wind energy users can draw some confidence from Lowy's conclusion that the ". . . average annual wind speed . . . does not vary at a given site by more than about 20%."[125]

Before shopping for energy equipment, McDermott suggested the kinds of preliminary data needed. Wind energy equipment suppliers need a map of the site. Obstructions, elevations and distances should be recorded. This general statement covers the site analysis needs:

> Once you've analyzed your energy needs, calculated your annual average windspeeds, obtained a year's worth of data from the nearby weather station, and mapped the site, you are ready to shop for a wind-energy conversion system.[126]

Development of Wind Energy

While complaints have been raised about the low level of government subsidy to the young wind energy industry in the U.S., the investment and progress have been substantial. According to Lester Brown, "Between 1973 and 1980, the Department of Energy (DOE) spent

nearly $200 million studying and developing wind turbine generators."[127]

There is room for serious debate about the appropriate scale of wind energy technology. In fact, Brown indicated that most of the DOE money

> . . . went into the development of large- and middle-sized turbines, but roughly a quarter of the budget underwrote the development of generators of the two- to ten-kilowatt variety--machines small enough for use by individual homeowners, farmers, and ranchers.[128]

Brown outlined the DOE-subsidized development steps in the area of wind energy as follows:

> DOE's early wind-generator prototypes, erected at a variety of sites around the country, were medium-sized machines designed to produce a flow of 200 kilowatts. The second generation of wind turbines is much larger, mostly in the 2.0 to 2.5 megawatt range, a size that some engineers believe will be economically optimal. The next step in the DOE program was to construct three 2.5-megawatt wind turbines in Washington State near the border it shares with Oregon. Each of the propeller blades of these Boeing-built prototypes spans over 300 feet--more than the wingspan of a Boeing 747 jumbo jet. The machines will stand in a windy gorge of the Columbia River and feed electricity into Bonneville Power, the local utility. At full power, this cluster of three wind turbines will provide enough electricity for 2,500 average American homes. (Four hundred such machines could produce as much power as a large nuclear- or coal-fired generating plant.)[129]

On October 17, 1983, Suzanne Zwarun reported wind farm plans underway in Calgary, Alberta, in Canada by the Abax Energy Service's wind power development program.[130] She described use of a prototype wind turbine with "delta-winged vanes measuring 52 feet in diameter," on a thirteen-story tower.[131] While traditional Canadian windmills were 30 feet high, the president of Abax reported plans to develop "wind turbines with diameters of as much as 150 feet."[132] The wind turbines

which Abax planned to develop were expected to range in "cost from $150,000 to $1 million."[133]

In Canada also the movement was toward selling excess electrical power to public utilities rather than the limited traditional use of wind energy in remote sites for irrigation and other uses.[134] Two utilities had agreed in principle to buy power from Abax, but had not agreed on rates. Abax expected to build the first Alberta, Canada wind farm which would consist of "a series of five 100-foot-diameter machines working in tandem on an 80-acre site to produce an output of one megawatt, enough to power 1,000 homes."[135]

Mohs quoted an industry estimate that there would be 6,000 to 8,000 new wind turbines installed in the Altamont, Tehachapi, and San Gorgonio passes by the end of 1985, bringing the total generating output of wind farms in California to more than 1,000 megawatts.[136] The wind-generated electricity could meet the needs of about 400,000 households. It could displace the development of "one nuclear reactor the size that failed at Three Mile Island" or "save 3.7 million barrels of oil a year."[137]

Relative Cost of Wind Energy

Reports and estimates of the cost of wind-generated electricity ranged from as low as four cents per kilowatt hour to seventeen cents in 1985 and 1986. Mohs reported an estimate of the ability of the vertical-axis wind turbine to provide electricity at 5.4 cents per kWh.[138] Until the useful life and quality of wind machines can be appraised accurately, the cost effectiveness of wind energy relative to

other renewable and conventional technologies will remain somewhat speculative. It seemed probable in 1986 that new vertical-axis wind turbines of various configurations would be able to provide electricity at four to six cents per kilowatt hour, far lower than more common reports of about seven to nine cents per kWh. Tax subsidies to wind energy developers and other energy developers and varied implementation of PURPA regulations distort the effort to make economic comparisons. In 1984 Robert D. Kahn reported the range of estimates of the cost of wind-generated electricity to be from as low as seven cents per kilowatt hour to seventeen cents per kilowatt hour, making "wind competitive with the more expensive nuclear plants coming on line."[139] Furthermore, Kahn reported,

> . . . And researchers at Battelle Laboratories report that wind should be able to compete with conventional fuels by 1990 and perhaps even within the next several years. By comparison, they predict that photovoltaic cells won't be competitive until the mid-1990s.[140]

Court actions like those of Palm Springs, California offer a serious threat to the wind industry and may represent future hidden costs of wind energy. The zeal for quick profits by energy entrepreneurs may need to be checked by such balances. There are obviously inappropriate wind energy sites for reasons of human habitation. Ellen Paris raised important questions about the parties who would bear the cost of reclamation of land and moving machines which are inappropriately sited if the wind energy industry proved to be uneconomical at some point in time. This is particularly true for wind

energy machines and their supporting structures which, taken together, may weigh 90 tons.

Paris found the cost of wind energy to produce electricity, relative to other available resources, to be excessive. She reported in June of 1985 that Southern California Edison (SCE) paid an average of "7.6 cents per kilowatt-hour for wind power, vs. 6.3 cents for hydropower and 5.8 cents per kwh for cogeneration power."[141] However, SCE "bought 14,932 metawatt-hours of wind power (roughly 0.2% of all its purchased power)" in the first quarter of 1985.[142]

Mohs reported increasing efficiencies in vertical-axis machines which may help make the California forecast believable. Mohs stated,

> . . . Last year the California Energy Commission estimated that the **retail** cost of wind power could be between 7.5 cents and 11 cents per kilowatt-hour by 1990—competitive with hydroelectric power and cheaper than any other form of electricity now available.[143]

The growth of wind energy in the production of electricity in the Southern California Edison (SCE) area has been remarkable since December of 1981.[144] This was in part the result of the California Energy Commission's effort to make "alternative and renewable energy its number-one priority."[145]

Cost Effectiveness of Wind Energy

When D. F. Warne evaluated the economics of wind energy in 1978, the assessment was unfavorable in terms of savings through quick payback of capital costs. An acceptable capital recovery period is influenced by installed costs, the power output of the specific machine in its setting, the level of inflation, the cost of other energy resources,

maintenance and other factors. Warne's conclusion, although seen as being in need of continuous review, was as follows:

> Although prices of other units are different (and the calculations for thermal output machines must be based on different energy values) the broad conclusion is nevertheless that on a hard accounting basis it will usually be difficult to justify a wind generator against grid-produced electricity. This is not to say that many viable applications do not exist, particularly for remote autonomous power supplies where effective alternate energy costs are often extremely high, or where a substantial charge for electricity connection can be offset against the capital for the wind generator, or where the user may be concerned with energy independence regardless of cost.[146]

Some of the United Kingdom scholars who responded to Warne's position found a five year capital recovery acceptable. One concluded, "When considering windmills which will last for 15 years, we must evaluate the financial returns over that period and certainly not over much shorter periods such as 5 years."[147] Suggested uses were in remote areas to "supply energy for domestic or district heating systems, for agriculture, or for desalination systems."[148] Others suggested alternatives such as pumped water storage or following the emerging practice in the United States of relying on the utility company to provide storage rather than deal with this additional cost factor.

A December 1985 Associated Press article from Livermore, California, indicated that the largest supplier of wind power at Altamont Pass expected the cost of wind-generated electricity to be about nine cents per kilowatt over the life of the machine. In the context of fossil fuels, the article stated,

> While that is still a little higher than the 7 cents to 8 cents it costs to produce electricity with oil, the gap is

closing. Coal still remains the cheapest form of energy, costing about 4 cents per kilowatt hour at an existing plant.[149]

In December 1985 David Pate, director of government relations for the American Wind Energy Association, reported very little carry over from large-scale private developers of wind energy to individual-scale operations. Both battery storage of electricity and equipment required to transfer energy to a utility company were regarded as prohibitively expensive on a small scale. Pate found only a number of farm applications and use in remote settings cost effective for small users.[150]

Future Wind Energy Systems

Some writers complain of the limited level of innovation in wind technology for the federal investment to date. Scaling up of existing equipment has seemed to be an inadequate substitute for the creative genius of better ideas. However, there are promising exceptions on the horizon to the scale-up of existing technology, such as those cited here.

Push-Pull Windmill

Christian Herrmann invented and patented an exciting new vertical-axis wind turbine which has been characterized as a "push-pull windmill."[151] Three hinged airfoils of "the Venturi Rotor wind turbine" swing out to catch the wind. Herrmann said his design is more efficient than propeller-driven windmills. A partial explanation of the greater efficiency is "a clever narrowing air-gap arrangement that creates a

low-pressure zone behind each wing to help pull the rotor around," according to Robert Gannon.[152]

The air-gaps are created by the arrangement of the three main components. They are ". . . a rounded triangular central core--a barrier redirecting the wind to its perimeter--with three sets of airfoils swinging in the breeze on a trio of supports."[153] The unique capacity of this machine to catch the wind enables it to begin revolving in a 1.3 mph wind and the generator to start at 6 mph. At very high wind speeds (about 80 mph) centrifugal forces provide a safety margin by opening the wings against the wind and slowing its motion. The prototype machine operated successfully in high winds and ice in Oronogo, Missouri, before Herrmann dismantled it due to vandalism.

An impressive aspect of this machine's potential use is the possibility of assembling several of them vertically in towers rather than spreading them out over the landscape. Herrmann anticipated the possibility of a tower being built which could pay for itself in three years in energy savings. He indicated that "a one-megawatt 170-foot-high tower" would be "built into an apartment building near Boulder, Colorado."[154] Gannon reported that "Such a tower is expected to produce 50 kW at 10 mph, 440 kW at 20 mph, and 3.5 MW at 40 mph."[155] However, he was not precise about the anticipated costs.

The cost of electricity over the projected life of about 30 years for such machines is certainly competitive. A 1986 project for a turkey farmer, a 16-foot-high, 50 kW unit, was expected to provide

electricity at the rate of "about four cents per kW."[156] This cost is significantly lower than commonly used, horizontal-axis wind turbines.

Tethered Windmills

Mark Kindley summarized a number of theoretical concepts for using tethered kites of various kinds to harness the wind. The basic value of a tethered windmill would be its ability to reach higher to take advantage of the wind velocities of high altitudes. Kindley explained, "The wind blows hardest (more than 100 miles per hour) about 30,000 feet above the ground in the jet stream."[157] He gave examples of potential technology which might demonstrate that it is not absurd to locate a windmill in the jet stream.

For those who think that such ideas lack credibility, Kindley described at some length the research in kite design to generate electricity being done by Miles Loyd, a nuclear engineer at the Lawrence Livermore National Laboratory in Livermore, California.[158] He expained,

> . . . A kite flying across the wind will fly faster than the speed of the wind. If the lift-to-drag ratio is ten to one, . . . the kite theoretically can go ten times as fast as the velocity of the wind.
>
> The energy captured by a kite flying in endless circles hundreds of yards off the ground, Loyd figures, can be converted to electricity three ways . . .: 1) Rotors could be mounted on the wings of the kite that would turn generators on board. They would work like conventional wind turbines on towers, but turn much faster. 2) The tether from the kite could be secured to a pump. Loyd visualizes something similar to the classic "horsehead" pump used in the oil fields, except that the pump would be worked from above by the tether pulsing as the kite surges across the wind in circles. The kite would pull hardest on the tether near the bottom of each circle, slacking off as it reaches the top. 3) A turbine at the front of the kite could turn a crankshaft within. Separate lines from the crankshaft to the ground would act as connecting rods, producing rotary motion.

> Loyd estimates that a generating system based on a kite the size of the C5 transport plane could produce as much as 13 megawatts of electricity, enough to power a community of thousands.[159]

Prototypes large enough to demonstrate the principles used in five years of kite studies had yet to be built. Sketches of the "kites" resemble tethered glider planes. It was anticipated that such a system could "generate electricity for 8.4 cents per kilowatt hour."[160] This is similar to the cost with conventional turbines. However, congested airways were expected to create problems since the jet stream is strongest over the northeastern United States where renewable energy systems may be in greatest demand. Neither private industry nor government seemed to be interested in funding research on tethered windmills in June of 1982.

Conclusions

Wind energy systems are available for schools and universities to use in a wide variety of ways, including the training of future engineers and technicians. In 1985 it appeared likely that private developers would employ about 100,000 people in wind-energy jobs in the U.S. by the year 2000, with California alone employing 55,000.[161] The vocational implications alone suggest that many schools and colleges should employ wind energy systems. As more efficient and less environmentally disruptive equipment is designed and developed, wind energy promises to be a cost effective technology in a wide variety of settings in the 1990s. Today its most approriate use in educational facilities appears to be in remote settings to generate electricity.

For safety reasons the public should not be admitted to areas in the immediate vicinity of wind turbine sites. However, heating water, providing mechanical energy for pumping water for irrigation, and other mechanical uses would be approrpiate in some settings. Vertical-axis wind machines appear to have a leading edge in cost effectiveness. Although wind energy may contribute all of the energy needed in some educational facilities, with adequate storage, the school administrator who seeks renewable energy self-sufficiency would be wiser to utilize a mix of renewable energy resources, especially, including primary solar energy.

CHAPTER 6 ENDNOTES

1. Paul Abrecht, ed., Faith and Science in an Unjust World: Report of the World Council of Churches' Conference on Faith, Science and the Future, Volume 2: Reports and Recommendations (Geneva, Switzerland: Church and Society, World Council of Churches, 1980), p. 96.

2. Lester R. Brown, "The Coming Solar Age," Natural History, 91:2:48, February, 1982.

3. Frank Carrol, "The Muzzled Wind," USA Today, 108:2416:44, January, 1980.

4. Janet L. Hopson, "They're harvesting a new cash crop in California hills," Smithsonian, 13:8:123, November, 1982.

5. "A Windpower Update from Mother's Eco-Village," Mother Earth News, 86:151, March/April, 1984.

6. Ibid.

7. Ibid.

8. Paul Abrecht, ed., Faith, Science and the Future: Preparatory Readings for a World Conference Organized by the World Council of Churches at the Massachusetts Institute of Technology, Cambridge, Mass, USA, July 12-24, 1979 (Geneva, Switzerland: Church and Society, World Council of Churches, 1978), p. 102.

9. Stan H. Lowy, "Wind Power as a Viable Energy Source," Solar Architecture, eds., Gregory E. Franta and Kenneth R. Olson (Michigan: Ann Arbor Science Publishers, Inc., 1978), p. 231.

10. P. L. Auer, Renewable Energy Resources (IPC Science and Technology Press, IPC House, 32 High Street, Guildford, UK, GU1 3EW; copyright: The World Energy Conference 1978), p. 14.

11. Ibid., p. 20.

12. C. A. Hooker and others, Energy and the Quality of Life: Understanding Energy Policy (Toronto: University of Toronto Press, 1981), p. 157.

13. Frank Carrol, op. cit., p. 44.

14. Stan H. Lowy, loc. cit.

15. Lester Brown, op. cit., p. 50.

16. Amory B. Lovins and others, Least-Cost Energy: Solving the CO_2 Problem (Andover, Massachusetts: Brick House Publishing Company, 1981), pp. 144-145.

17. Senator Alan Cranston, "The Cranston Energy Plan," Solar Utilization News, 8:7:7, January, 1984.

18. "Investors discover profit in the wind," Richmond [Virginia] Times-Dispatch, p. D4, January 1, 1984.

19. Ibid.

20. Harry Bacas, "Energy: A Promise Renewed," Nation's Business (A U.S. Chamber of Commerce Publication), 73:7:35R, July, 1985.

21. Linda Baine McGown and John O'M. Bockris, How To Obtain Abundant Clean Energy (New York: Plenum Press, 1980), p. 105.

22. Architectural Portfolio, American School & University, 56:3:100, November, 1983.

23. Ibid.

24. Ibid.

25. Carrol, op. cit., pp. 43-44.

26. Ibid., p. 44.

27. Ibid.

28. Ibid.

29. Ibid.

30. "Wind," Solar Utilization News, 8:7:11, January, 1984.

31. Ibid.

32. Ibid.

33. Ibid.

34. Ibid.

35. Mayo Mohs, "Blowin' in the Wind," Discover, 6:6:73, June, 1985.

36. "Wind," op. cit., p. 11.

37. Ibid.

38. Cathy Stone, "Knockdown turbine for remote sites," Popular Science, 224:52, June, 1984, p. 52.

39. Ibid.

40. Ibid.

41. Ibid.

42. Ibid.

43. Carrol, op. cit. , p. 45.

44. Ibid., p. 44.

45. Lovins, op. cit., p. 117.

46. George McRobie, Small Is Possible (New York: Harper & Row, 1981), pp. 51-51.

47. Associated Press, "Wind energy industry may find growth no longer a breeze in '86," Richmond [Virginia] Times-Dispatch, p. E-2, col. 1, December 29, 1985.

48. Ibid.

49. Mayo Mohs, "Blowin' in the Wind," Discover, 6:6:70, June, 1985.

50. Ibid., p. 71.

51. Ibid., p. 73.

52. Ibid., p. 73.

53. Harry Bacas, "Energy: A Promise Renewed," Nation's Business, 73:7:35R, July, 1985.

54. Priscilla J. Pierce, Jeffrey W. James, and Nancy Kinnear, A Preliminary Survey of Wind Generation in Washington (Olymbia, Washington: Washington State Energy Office, September 1984), pp. 16-17.

55. Ibid., p. 78.

56. Ibid., p. 92.

57. Ibid., p. 59.

58. Hopson, op. cit., p. 126.

59. Russ Ramsey, "Hook Your Wind Machine to the Grid," Mother Earth News, 89:173, September/October, 1984.

60. Ibid.

61. Ibid.

62. Ibid.

63. Jeanne McDermott, "How to make a wind-site analysis," Popular Science, 217:1:102, July, 1980.

64. Ibid., p. 125.

65. D. F. Warne, "Usable Energy from Wind," Ambient Energy and Building Design, ed. J. E. Randell (New York: Construction Press, 1978), p. 43.

66. Robert D. Kahn, op. cit., p. 58.

67. Ibid.

68. Ibid., p. 61.

69. Ibid., p. 58.

70. Kathleen Courrier and others, eds., Shining Examples: Model Projects Using Renewable Resources (Washington, D.C.: Center for Renewable Resources, 1980), p. 5.

71. Ibid., pp. 13-14.

72. Carrol, op. cit., p. 44.

73. Ibid., pp. 44-45.

74. Lowy, op. cit., p. 231.

75. D. F. Warne, op. cit., p. 45.

76. Windy Dankoff, "Ask Our Experts," Mother Earth News, 97:121, January/February, 1986.

77. K. Courrier and others, eds., op. cit., p. 13.

78. Robert Teitelman, "Tilting at windmills," Forbes, 132:1:134, July 18, 1983.

79. Ellen Paris, "Palm Springs and the wind people," Forbes, 135:12:170-171, June, 1985.

80. Ibid., p. 171.

81. Ibid.

82. K. Courrier and others, eds., op. cit., p. 92.

83. Paula Lippin, "Offices Go Solar," Administrative Management, XL:9:34, September, 1979.

84. Donald R. Price, "A New Energy Ethic for Farmers," VocEd, 54:1:49, January, 1979.

85. "Can We Reap the Wind?," American School & University, 53:2:56 & 58s, October, 1980.

86. Ibid.

87. Ibid.

88. "Can We Reap the Wind?," op. cit., p. 58s.

89. Ibid.

90. Kathleen Courrier and others, op. cit., p. 184.

91. Ibid.

92. Ibid., p. 127.

93. New York State Energy Research and Development Authority, "Long Island Campus Is Site of Wind Machine Test," New york State ERDA Review, ed. Mary Ann Lynch (Albany, N.Y.: New York State ERDA, Department of Communications, Fall, 1981), p. 8.

94. Ibid.

95. Ibid.

96. Lowy, op. cit., p. 233.

97. Ibid., pp. 233-234.

98. Ibid., p. 238.

99. M. R. Gustavson, "Limits to Wind Power Utilization," Science, 204:4388:13-17, April, 1979.

100. Ibid., p. 13.

101. Ibid., p. 14.

102. Ibid., p. 16.

103. Ibid.

104. Ibid., p. 17.

105. Robert D. Kahn, "Harvesting the Wind," Technology Review, 87:8:56-57, November/December, 1984.

106. Ibid., p. 57.

107. D. F. Warne, op. cit., p. 41.

108. Ibid.

109. Robert D. Kahn, op. cit., p. 57.

110. Hopson, op. cit., p. 123.

111. Ibid.

112. L. Brown, op. cit., p. 48.

113. Jeanne McDermott, "How to make a wind-site analysis," Popular Science, 217:1:100, July, 1980.

114. Ibid.

115. "Site Assessment for Alternative Energy," Mother Earth News, 96:64, November/December, 1985.

116. Steve Wegman, "Wind Energy," South Dakota Energy: Production, Consumption, and Policy (South Dakota: Bureau of Intergovernmental Relations, Office of Energy Policy, June, 1982), p. 163.

117. McDermott, op. cit., p. 100.

118. Wegman, op. cit., p. 173.

119. Ibid., p. 165.

120. Ibid., p. 171.

121. Ibid., p. 165.

122. Ibid., p. 101.

123. Ibid.

124. Ibid.

125. Lowy, op. cit., p. 232.

126. McDermott, op. cit., p. 102.

127. Ibid.

128. Ibid.

129. Ibid.

130. Suzanne Zwarun, "Wind power in the West," Macleans, 96:42:72, October 17, 1983.

131. Ibid.

132. Ibid.

133. Ibid.

134. Ibid.

135. Ibid.

136. Mohs, op. cit., p. 70.

137. Ibid.

138. Mohs, op. cit., p. 73.

139. Robert D. Kahn, op. cit., p. 57.

140. Ibid.

141. Ellen Paris, op. cit., p. 171.

142. Ibid.

143. Mohs, op. cit., p. 73.

144. Jessica Maxwell, "Wind: The Next Multibillion-Dollar Business," Esquire, 99:4:121, April, 1983.

145. Ibid.

146. D. F. Warne, op. cit., p. 47.

147. Ibid., p. 48. The opinion was that of Dr. J. C. McVeigh (Brighton Polytechnic).

148. Ibid.

149. Associated Press, "Wind energy industry may find growth no longer a breeze in '86," Richmond [Virginia] Times-Dispatch, p. E-2, col. 4, December 29, 1985.

150. Ibid., p. E-2, cols. 3 & 4.

151. Robert Gannon, "Push-pull windmill," Popular Science, 228:5:85-87 & 118, May, 1986.

152. Ibid., p. 85.

153. Ibid.

154. Ibid., p. 118.

155. Ibid.

156. Ibid.

157. Mark Kindley, "For eye-in-the-sky inventors, kites can be much more than toys," Smithsonian, 13:3:58, June, 1982.

158. Ibid., p. 57.

159. Ibid., pp. 57-58.

160. Ibid., p. 60.

161. "Wind," Solar Utilization News, 9:9:13, March, 1985.

Chapter 7

BIOMASS ENERGY USES

Plants collect the sun's energy by means of photosynthesis and by their growth processes store solar power. Biomass energy resources potentially include living matter and the by-products of living things. Fossil fuels are a derivate of solar energy and biomass energy resources. Moving toward a more practical definition, Harry Bacas said, "**Biomass energy** . . . is the conversion of organic material . . . into heat through burning or the conversion of various crops into gas or liquid fuel."[1] While scientists say life first emerged from the primordial sea about 3.8 billion years ago, the human use of this energy resource began with the use of food and took a giant leap forward in primitive man's use of fire. Since organic matter in some form is available on a worldwide basis, the potential uses of the various resources make it the "largest alternative technology," according to Bacas.[2] The resource consists mainly of wood, increasingly involves the organic wastes of cities, and includes farm, industrial and forest residues, and a number of plants cultivated specifically to produce energy, even including microscopic algae and bacteria and seaweed.

The conversion products of this resource base include methane, alcohols, hydrocarbons, hydrogen, nitrogenous fertilizer, and other chemicals. Edward J. Philips said, "This conversion can be very efficient; up to 75 percent of the biomass can become usable energy."[3]

However, the resource base has real limits which require careful management of its uses. Gene Bylinsky reported that U.S. " . . . trees and plants, nature's green solar collectors, contain more than 300 quads (quadrillion British Thermal units) of energy . . . and nearly four times the 78 quads of total energy we use each year."[4] A 1983 United Nations (UN) report indicated that the theoretical, annual, global biomass ". . . productivity adds enough energy to meet at least 10 times all the world's commercial energy demands."[5] Realistically, the UN report indicated a great many practical limits on its availability and use and, also, the fact that it is being used faster than it can be replaced with devastating consequences at many places on the globe.

D. Pimentel and others, in reviewing the environmental and social costs of biomass energy, reminded their readers of the land and water resource demands of a major biomass energy production program. The reported uses of US land in the early 1980s were as follows:

> . . . Of a total land area in the United States of 917 million hectares, agriculture uses 503 million hectares and forests occupy 218 million hectares (ERAB 1981, USDA 1980a). Combined, they constitute 80% of the total US land area. Another 8% is used for cities, roadways, recreation, and public installations, and the remaining 12% is deserts, marshes, and tundra.[6]

These data, combined with "a projected 60-85% rise in the demand for agricultural products" by 2000, help to define the limits of biomass energy potential.[7] The productivity of agricultural land has leveled in recent years suggesting that forests, range, and pasture uses will show substantial declines, with the largest impact on biomass availability being evident in wood resources.

The statistical data on the proportion of biomass resources used and potentially available for energy uses provide a context for thinking about this resource. The United States now derives more than five percent of its energy from biomass resources. This represents almost twice as much use as in 1975 according to Bacas.[8] In 1979 Gene Bylinsky saw the plausibility of using biomass to meet fifteen percent of U.S. energy needs by the end of the century.[9] In 1980 the U.S. Office of Technology Assessment (OTA) projected the possibility that biomass energy could supply twenty percent of U.S. energy needs by the year 2000.[10] The OTA prediction that "as many as 17 quadrillion Btu (quads) could come from bioenergy" contrasted sharply with the Department of Energy plan to derive "only 3 quads from biomass by 2000."[11] Apparently splitting the difference, in 1981 The Energy Research Advisory Board Panel on Biomass (ERAB) of the Department of Energy projected that eleven percent of U.S. energy could be provided by biomass by the year 2000.[12] The potential resource base, described by ERAB, was to come primarily from agriculture and forestry (80%), with only 20% coming from "municipal solid wastes (MSW), sewage,and aquatic plants."[13] Philip H. Abelson said, "Ultimately, perhaps half of the nation's energy will be provided via photosynthesis and subsequent conversion of its products."[14] Wallace E. Tyner's 1981 statement of a range of "9 to 20 percent of 1979 US energy consumption" potentially available from biomass resources seemed more realistic than precise quantification.[15]

Increasing global interest in use of biomass energy resources has developed in the last decade. In 1980 most Brazilian automobiles

were burning gasohol containing 20 percent ethanol derived from biomass resources. New Brazilian cars were being built to burn only ethyl alcohol. Many older cars were being converted to run on ethanol. Distilleries were fermenting sugar from sugarcane to produce the ethanol and plans were being made to use cassava roots and eucalyptus trees for the same purpose.[16]

Wood bark and pulp residues were providing eight percent of Sweden's energy supply in 1980.[17] Sweden was evaluating the use of birch and willow trees as a fast-rotation crop to be harvested every three to five years. However, to avoid damaging forestry practices the plan called for mowing and collecting the wood in winter, and leaving the stumps and root systems undisturbed to produce new shoots.[18]

In May, 1980 R. Jeffrey Smith reported "an estimated 30 million peasants in China" were using agricultural wastes as a biomass resource for anerobic digestion to produce methane for heating.[19] The use of methane (biogas) was providing some lead time to permit reforestation where forests had been destroyed and soil was being eroded to provide cooking fuel.

Methods of Using Biomass Energy

An effort was made here to review a significant portion of the biomass conversion methods now in use and potentially available before the year 2000. Some of them are more appropriately used in transportation than in a school facility. However, all of them would

appropriately be modeled in some school settings for educational purposes.

In 1980 the United States was conducting 600 or 700 research and development projects to develop technology and bring about appropriate increases in the use of biomass energy. Philip H. Abelson was impressed by ". . . a machine that could reduce a sizeable tree, branches and all, into chips, each about the size of a dollar, in about 30 seconds."[20] Other equipment was designed to collect and process biomass, especially for the production of ethanol. The U.S. emphasis has been on wood and ethanol as biomass fuels.

A wide variety of biomass energy systems is currently available. Many others bio-conversion processes are being researched for future development, including hydrogenation or chemical reduction.[21] Among the many energy conversion processes available are the following:

municipal wastes	----->	incineration
	----->	ethanol
wood and wood wastes	----->	incineration
	----->	charcoal
	----->	gasification
	----->	methanol
	----->	diesel fuel
corn	----->	ethanol
sugarcane	----->	ethanol
euphorbia	----->	oil
giant kelp (seaweed)	----->	methane
water hyacinths	----->	methane & fertilizer
sewage	----->	methane & feedstock for other energy processes
livestock manure	----->	methane & fertilizer

Direct Combustion

The traditional method of use of wood and other biomass products was burning or incineration. The specific methods of burning biomass to provide useful heat energy range from ". . . 5% to 80% in conversion efficiency," suggesting significant room for conservation measures.[22] More than half the world's population still burns wood for cooking, which is the most important use of energy in developing countries.[23] The primary materials being burned directly in the U.S. are wood, wood wastes, solid municipal wastes, and fibrous by-products of industrial processes which are used to fuel the industrial processes themselves.

Wood. The use of wood energy increased steadily until 1985 by which time Alberto Goetzl of the National Forest Products Association was of the impression that wood had peaked as a source of residential heat.[24] Lester R. Brown reported that in 1980 more energy in the United States was being delivered by wood (2.6 percent) than nuclear energy (1.2 percent).[25] After having been almost abandoned due to cheap oil, urbanization, large-scale agriculture, and concern about deforestation, especially in the Third World, the reemergence of wood for fuel was very rapid. Wood had become the primary or secondary source of heat in about 10 percent of U.S. residences by 1981. In 1981 Lovins and others reported a more than sixfold increase in private wood-burning in recent years, while stove foundaries had grown "from a handful to more than 400."[26] By 1983 wood "accounted for only 3.6 percent of the energy used in the United States."[27] In 1985 the price of wood was still favorable in Virginia, with statistics reported, as follows: "Wood energy costs

about half of an equivalent amount of energy from natural gas, 40 percent of industrial fuel oil energy and only 14 percent of electrical energy."[28]

The shift to use of wood was most rapid where the price of oil was highest and wood was more plentiful. In 1979 the reported level of dependence on more expensive, imported oil was 80 percent in New England, compared with a U.S. average of 47 percent.[29] In these settings wood can produce heat for home cooking and heating, for industrial processes, and for electricity generation. Lester R. Brown gave this summary of residential usage:

> The shift to wood use was most dramatic in New England, although it was plainly evident in Appalachia, the Great Lakes states, the Northwest, and other heavily wooded areas. In Vermont, New Hampshire, and Maine, 20 percent of all homes were burning wood as the primary source of heat by 1980. In two-thirds of the remaining homes in the region, wood provided a secondary source of heat. So swift was the conversion that the revived stove- and furnace-manufacturing industry was swamped by demand.[30]

In 1984 the College of St. Scholastica, Duluth, Minnesota, expected to save more than $50,000 annually by pulverizing waste wood pellets and using them for fuel in burners which have a capacity to use either wood or gas as fuel. Heat is needed in this northern Minnesota college which deals with a mean annual temperature of 37.8°F. In a refractory fire chamber, capable of operating at high temperatures, air is injected and the suspended, pulverized fuel is gasified and ignited. Secondary air is injected to complete the combustion process and to achieve a 75-80% efficiency rating. The air used to achieve the high efficiency is held to a maximum excess of 25%. Secondary air is

injected to complete the combustion. The combustion efficiency provided by the system was ". . . comparable to that of new gas and oil burners."[31] This system was recommended as appropriate for schools located in wood producing areas where costly shipping charges can be avoided.

Bacas offered two illustrations of large-scale use of wood to generate energy, one in industry, the other in a utility company.[32] Two years ago Procter & Gamble converted from oil to wood fuel at a Staten Island, N.Y., plant. The cost was $30 million. The Burlington (Vermont) Electric Company completed a 62-megawatt plant fired by wood. The cost of the electric power plant completed in 1984 was $76 million.

While most American's reflect on residential wood stoves and fireplaces which require a lot of attention and work on the part of the user, Bylinsky reminded his readers of large automatic boilers and furnaces designed to burn wood chips and wastes. Bylinsky saw these systems which cost "50,000 and up" as being suitable for schools and other large installations, but only where wood is plentiful.[33]

Many states and localities have found in wood gasification and incineration a neglected renewable technology for displacing dependence on oil and natural gas. Washington state, New York, Idaho, Missouri, Alabama, North Carolina, Minnesota, Georgia, and Michigan are numbered among the states where some school systems have turned to wood and other biomass incineration and for energy. Even populous states like New York and Michigan which rely heavily on imported energy resources have identified industrial scale wood combustion as a feasible energy

resource. St. Lawrence County in northern New York, with the assistance of the Clarkson College of Technology at Potsdam, found that whole trees in a 20-year rotation cycle could be economically turned into wood chips for use as a fuel. An annual area of "demand of more than 40,000 tons" was necessary in October of 1979 to achieve economic feasibility of whole tree chipping operations.[34] Evaluation of the various factors involved demonstrated the feasibility of converting oil- and gas-fired heating plants of Clarkson College to wood chip incineration. However, the high capital costs involved in additional conversion measures to use the wood-generated energy for cogeneration of electricity was not economically feasible. Feng-Bor Lin and others stated, "For Clarkson College, the most desirable mode of wood energy utilization is to install a 10,000 lbs/hr wood fired steam production system without a cogeneration capability."[35] The savings were expected to pay for the system in about five years. One of the several factors making cost effective use of cogeneration difficult was the mismatch of steam and electricity demands. Large spacial demands for fuel storage and large labor demands for handling were seen as inhibiting factors in use of wood for fuel. Commercial forest lands were capable of producing from five to nine times the anticipated demand of industrial firms and educational institutions in St. Lawrence County.

The Michigan Department of Natural Resources compared the combustion efficiency and cost of various biomass resources in 1986. The combustion efficiency of wet wood residue and wood chips was the same, namely, 67%, while wet wood pellets were 78% efficient, and

municipal solid wastes offered a low 60% efficiency, but also the lowest cost per million Btus ($1.85). The highest cost per million Btus was $5.34 for wood pellets.[36] The estimated wood energy consumption in Michigan approximately doubled from 1960 through 1983 to an estimated 69.75 trillion Btus in combined sectors of the state's economy.

Bacas demonstrated another contribution that wood as a renewable energy resource can make during the transition from fossil fuels to sustainable resources. Improved burning of coal in some of the emerging technologies is achieved by mixing in a little wood to absorb "90 percent of coal's sulfur emissions."[37]

When Peter Bacqué evaluated the cost, availability, and usage of wood in Virginia, he stated or implied a number of criteria for the use of wood as fuel. First, a conversion investment payback within three years was seen as appropriate for those converting from the use of oil, gas or coal to wood. Second, temporary transportation and storage space demands made it imperative that land values permit the purchase of an "extra half-acre to an acre of open ground."[38] Third, the specific energy use has need of a relatively constant level of energy. Fourth, the market indicates a continuing high price of fossil fuels, especially crude oil.[39] Given declining crude oil prices and the other criteria, Bacqué believed only a few rural settings were likely to satisfy all of the implied criteria for conversion to wood as fuel.

Municipal waste. While wood is the largest biomass material in use, Bacas reported, "Burning municipal waste is the fastest growing use of biomass energy."[40] Approximately 75 percent of the refuse which has

traditionally been put in landfills can be recycled, with a large portion capable of providing useful energy.[41] Bacas provided a cutaway drawing of a trash-into-energy plant in Harrisburg, Pennsylvania, which ". . . uses the Martin process, one of the two leading technologies, both developed in Germany."[42] The brief description, accompanying the drawing, follows:

> . . . Trucks dump refuse into the pit at left. An overhead crane picks it up in chunks and drops it into the hopper, where it travels to the inclined grate. The burning mass is continuously agitated and subjected to blasts of air from underneath. Air jets above promote further combustion in the exhaust gases. The heat produces superheated steam in boiler chambers above the grate. Then electrostatic scrubbers clean and deodorize the gas before it is released through the chimney. Residual ash is discharged onto the track under the grate. The steam drives electric generating turbines.[43]

For several years the Richmond, Virginia, region has studied its growing solid waste or trash and sludge problem. While landfills have been the cheapest alternative, many others have been evaluated, including incineration, composting and others. Methane gas leaks from urban landfills have required federal grants to make use of the natural methane. The size of the problem is suggested by the 1983 study which indicated that "By 1990, each person in the Richmond region will be generating roughly 8.5 pounds of trash daily."[44] By August 1984 Richmond joined many other cities in giving serious consideration to an underutilized renewable resource which can be converted to useful energy and other by-products by using currently available technologies.[45]

European cities began using urban garbage to generate electricity almost twenty-five years ago. Damp fuel, in the form of lignite or brown coal, was burned by the Germans in World War II. The

lignite-burning technology was readily adapted to urban waste incineration to produce electricity. Lester R. Brown summarized the usage of urban waste for energy, stating,

> . . . As a result, a 1978 survey found that three-fourths of the 262 plants that were converting urban garbage into energy were located in Europe. Most of the remainder were in Japan, while only six were in service in the United States: in Chicago; Franklin, Ohio; Harrisburg, Pennsylvania; Nashville, Tennessee; and Norfolk and Portsmoth, Virginia. (More recently, other plants have begun operating in the United States, and many more are now being planned and built.)[46]

Munich, Paris, and Rotterdam were among the European cities deriving a significant portion of their electricity from garbage and other local wastes. Both electricity and building heat were being provided by waste-produced steam on the outskirts of Paris at several generating plants. In 1982 Rotterdam claimed "the world's largest single waste-burning facility . . . a 55-megawatt electrical generating plant."[47]

A recent example of use of solid municipal waste to save on energy expenses in facilities was offered by the Ida Barbour Park development, a 663-unit housing project, in Portsmouth, Virginia.[48] In this instance a Colorado company, Bio-Mass Energy Inc., in a 10-year contract with the Portsmouth Redevelopment and Housing Authority, was to furnish the burner-boiler system without cost to provide heat and hot water. The private company planned to buy odorless garbage pellets, consisting mainly of paper products, from a private waste reclamation facility in Chesterfield County, Virginia. The expected savings when the plant goes on line in October 1986 will be achieved due to the lower fuel bill. The contract guaranteed the bill to be twenty percent lower

than the cost of using natural gas. The housing authority was expecting to save $50,000 a year on heating and hot water in this housing project.[49]

On a much larger scale, Baltimore, Maryland, recently started operation of a waste-to-energy plant which was described as the "cathedral of garbage plants" because its design and combustion efficiency eliminated many of the usual complaints about waste disposal sites.[50] In 1986 it was accepting about 1,800 tons of trash per day in an enclosed receiving pit from Philadelphia, Pennsylvania. Three boilers incinerate the garbage at temperatures above 2,500°F. In winter most of the steam generated by the plant is sold to heat downtown buildings. When the weather is warm, a turbine generates 50,000 kilowatts of electricity per hour for sale to the local utility company.

If school officials were to support other government agencies and private investors in the development of such a plant as a source of their energy, they would have to evaluate environmental questions. The plant was described as being "clean and odor-free," but there were some complaints from neighbors about the trucking involved in receiving the wastes and removing the residual ash.[51] The plant was not a noise problem.

Contradictory opinions were offered about the environmental effects, specifically, threats to health. While federal and state officials foresaw no threats to the health of community residents, environmentalists had very serious reservations. Among the unacceptable

levels of emissions reported from waste-to-energy plants were the following:

> . . . dioxin and furans--carcinogenic organic particles created during combustion.
> . . . invisible particles of hydrochloric acid, arsenic and other toxic substances.
> . . . The group also is worried about the disposal of the plant's fly ash--a powder-fine dust that contains dioxin and such toxic elements as lead, arsenic and cadmium.[52]

The residual ash was being disposed of at hazardous waste sites. Evidently, school and community leaders must deal intelligently with questions about how to identify and minimize acceptable risks.

In November 1984 Consumat Systems, Inc., a Virginia business which manufactures waste-to-steam equipment, reported having marketed about 4,000 pieces of equipment worldwide.[53] The company found a profitable market for smaller machines, notably for use in hospitals. Medical schools associated with state, county or municipal governments would be appropriate users of such energy equipment. Some potential users would appreciate this particular manufacturer's willingness to enter into a contract not only to sell, but, also, to operate, maintain, lease, and manage such equipment.

Wood and fibrous waste. In addition to municipal waste, wood wastes have been used extensively in the pulp and paper industry and the forest-products industry to generate electricity and/or to produce steam for industrial processes. The industrial application of wood wastes to produce energy for heating and electricity has increased rapidly in the US and Canada. Sugar refineries have been fueled by bagasse, the fibrous residue of sugar cane. In 1974 S. David Freeman wrote,

"Agricultural residues such as straws, shells, hulls, corncobs, etc., could supply about 4 percent of total U.S. energy--as much as all our hydroelectric sources."[54]

Schools using biomass energy resources were numbered among those receiving American School & University's 1983 Energy Conservation Awards. The Miller School of Albemarle, Virginia, was using a sawdust burning unit to save energy in stately rooms with 16 foot ceilings and cool mountain breezes.[55] The 160 students and staff were warmed by thoroughly burned fuel in a pre-combustion process which was so complete as to avoid creosote buildup and visible smoke. The resulting fuel saving was achieved by the difference between $70.36 per eight hour shift for sawdust from a local mill and $512 for oil for the same period. The director of buildings and grounds expected the unit to pay for itself in less than a year at the then existing oil prices.[56]

Another school receiving a 1983 award was the Springcreek School, an elementary school in Piqua, Ohio. It was recognized for the effective use of agricultural waste in the form of corncob pellets. In all fairness the reporter acknowledged, "There are currently more than 90 uses for corncob products ranging from pesticide carriers to small animal bedding."[57] Springcreek replaced fuel oil at significantly less than a third of the cost. The corncob pellets had the added advantage of bringing the temperature of the system up more quickly than fuel oil. After some experience in more efficient use of the stoker, the school officials expected ". . . a savings of 55% over fuel oil . . . ."[58]

Several universities and research centers have demonstrated the cost effectiveness of using corncobs, wood, and other fibrous wastes to generate heat to dry grain. Grain drying consumed thirty percent of the farm fuel dollar in 1983. Crop residue handling, storage, start-up management time, and labor costs were factors limiting widespread application of these biomass resources in agricultural settings.[59]

School trash. Prior to installing a non-polluting, pyrolitic incincerator to burn its "2,500 pounds of trash a day at 500 pounds per hour" the University of North Florida (UNF) in Jacksonville "paid a refuse company $10,000 a year to haul away its trash to a nearby landfill."[60] Annual energy savings, with labor and operational expenses duely considered, based on a brief experience, was expected to be $46,000. Participation in the National Energy Conservation Policy Act enabled the university to buy the incinerator with a $234,000 grant. The payback time seemed to be reasonable.

When fully operational, the system was to include a heat recovery boiler and a separate absorption chiller to provide chilled water and air conditioning. The University planned to use the trash of neighboring institutions to bring the operation up to the optimum ten hours. The trash generated by UNF was adequate for only five hours. No estimates were given relative to the financing of the needed trash supply.

A paper shredder was expected to help solve the residual ash problem occasioned by "old textbooks and computer print-out sheets, which don't burn as efficiently as loose, crumpled paper."[61] More

efficient operation was expected to reduce the daily requirement of sweeping out a cubic yard of residue per day.

The incineration of waste paper may be practical even with the high cost of the incinerator, but less than ideal as an energy conservation strategy. Pimentel and others stated in reference to paper and metals, "The wastes that can be recycled save more energy than if they were converted into fuel."[62]

Conversion of Biomass to Other Fuels

Direct combustion of wood and other forms of biomass is not the only way of converting organic waste to useful energy. Air-blown gasification and oxygen-blown gasification processes burn part of the biomass material to produce gas which can be used in oil-fired or natural gas-fired boilers.[63] Georgia Institute of Technology designed and developed a pyrolitic converter plant for use in Ghana to convert sawdust into "charcoal briquettes, gas, and combustible oil."[64] In pyrolitic processes an external heat brings about changes in the chemical composition of biomass materials. Chemical conversion processes which have required fossil fuels can be replaced by biological conversion systems. Waste and other biomass products can be converted into methane, methanol, ethanol, and other storable fuels.

Wood gasification. In 1980 Georgia announced plans to derive 25 percent of its energy "from wood by 1995, with small additional amounts supplied by the production of liquid fuel from kudzu and kelp

farming."[65] The ambitious plan involved schools, as reported by R. Jeffrey Smith:

> . . . The state forestry commission, in cooperation with the Georgia Institute of Technology (GIT), plans to install demonstration projects that convert wood chips into wood gas at a state hospital, several schools, and possibly a textile mill and a carpet factory. William Bulpitt of GIT says the projects will recoup their initial costs in less than 5 years through savings over oil and natural gas.[66]

Paul Burks, Director of the Office of Energy Resources, reported on June 26, 1986, that at least four Georgia schools were, in fact, using wood or other biomass fuel, and that two schools were using biomass conversion.[67]

Ethanol. An area of biomass energy use which has received heavy federal government subsidies is the use of a variety of crops and crop wastes to produce ethanol (ethyl alcohol) for use in liquid fuels. In 1980 the American Petroleum Institute found the four major ethanol distillers in the United States using "cornstarch, local waste, cheese whey and wheat" to produce ethanol.[68] Various byproducts of food-processing companies, especially, fruit and vegetable wastes, can be converted to fuel-grade alcohol. Lester R. Brown stated in 1982,

> . . . By U.S. Department of Energy estimates, it is now economically feasible to convert four-fifths of all such U.S. wastes into alcohol for a net gain of 500 million gallons of ethanol per year, or 0.5 percent of gasoline consumption in 1980.[69]

The blending of ethanol and gasoline to provide gasohol was widely reported during the 1979 energy crisis. Gasohol dates from the 1920s when the 90 percent gasoline and 10 percent ethanol blend was variously referred to as agrifuel, agrol or alky-gas.[70] The first

automobiles in the 1880s were fueled entirely by ethanol.[71] However, US production of ethanol for use in gasohol in 1980 was only 3,250 barrels a day, enough to supply 32,500 barrels a day of gasohol, with an equivalent amount being produced for other industrial purposes.[72]

José M. Miccolis stated some of the useful properties of ethyl alcohol as a gasoline additive.

> . . . Blended with gasoline, it increases the octane rating of the fuel, thus reducing the need for cyclic hydrocarbons. Also, as an anti-knock additive, ethanol makes the use of lead unnecessary. . . . It should also be noted that an ethanol-fueled engine drastically reduces the emission of pollutants such as nitrogen oxides, carbon monoxide, and cyclic hydrocarbons.[73]

Not all of the press regarding use of ethanol as fuel was favorable. Paul B. Weisz and John F. Marshall reported that "Ethanol contains 0.67 times the fuel energy of an equal volume of gasoline."[74] Simply put, the problem is to avoid a fuel production process which is a "net fuel consumer."[75] Gene Bylinsky foresaw neither available acreage for crops for this purpose nor avoidance of oil imports. He explained,

> This is because distilling a gallon of pure ethanol from corn consumes 1.6 BTU's of energy for every BTU of energy in the end product. If the energy used to fertilize and transport the corn is considered, too, the ratio drops to a depressing 2.7 BTU's of energy input to 1 BTU of energy output.[76]

Bylinsky concluded that exemption of gasohol from state and federal gasoline taxes was a wasteful subsidy of ethanol as an alternative fuel. Writing in 1983, D. Pimentel and others used USDA and ERAB data regarding land requirements to raise corn for conversion to ethanol to support their conclusion that providing fuel for one US automobile would require "more than eight times more cropland" than feeding one person.[77]

Grain and other starches do not appear to be an appropriate large-scale source of biomass for ethanol production.

However, garbage offers another potential feedstock for ethanol production. Bylinsky reported in 1979,

> . . . A Department of Energy study calculates that municipal waste can potentially provide a larger source of feedstock for ethanol production than all agricultural wastes and surplus crops combined.[78]

By September 24, 1979 twenty U.S. localities had used some conversion process, not necessarily ethanol production, to extract energy from municipal solid waste with varying degrees of success.[79] In 1980 the American Petroleum Institute estimated that only about one percent of the "150 million tons of garbage" Americans throw away annually was being used to generate energy.[80] At the same time Sweden, the Netherlands and Denmark were converting "40 percent of their municipal waste into energy."[81] A General Accounting Office study (February, 1979) estimated that "by 1985 the United States could process 18 percent of the nation's garbage into energy."[82]

On the frontier of ethanol production scientists have used genetic engineering to produce bacteria capable of converting cellulose to glucose. This is a needed step in the biological conversion of cellulose to ethanol. Cornell University scientists isolated a gene responsible for producing an enzyme called cellulase which can covert celluose to glucose so that fermentation and distillation can accomplish the production of ethanol. The gene was transferred from the inefficient donor bacterium to the common **E. coli** bacterium. Following other modifications, the bacterium was able to deliver a 50-fold

increase in cellulase production. When the research of David Wilson and Dexter Bellamy was reported in September, 1983, they were seeking improved efficiency in cellulase production to make the process efficient enough to compete with petroleum. Since cellulose is much more plentiful than glucose, the scientists looked forward to an energy resource base of the future which included ". . . leftover cornstalks, wood, sawdust, straw and wastepaper--the world's largest renewable resource and only one-fourth as expensive as starches."[83]

Methanol. In 1980 the Office of Technology Assessment considered methanol, derived from wood and plants, to be the least expensive short-term biomass option for liquid fuel. The failure of the product to mix well with gasoline led OTA to recommend straight rather than blended use of methanol.[84]

Bylinsky offered a mixed review concerning the feasibility of using wood as a raw material for the production of methanol as a fuel for either transportation or stationary turbines to generate electricity. In 1979 this alcohol was expected to "cost only about 65 cents a gallon to distill it from wood, compared with the $1.25-per-gallon cost of extracting ethanol from corn."[85]

While methanol can be used as a blend with gasoline to provide energy in gasohol, its high toxicity and other properties make it less attractive for use in transportation fuel systems than in stationary electric power plants. If used in more than one part methanol to nine parts gasoline blends, rubber and plastic parts of fuel systems would need replacement.

Bylinsky also raised serious questions about the abiliity to secure investment capital needed to build the capital-intensive distillation plants. Bylinsky indicated that efficient plants would require an investment of "anywhere from $500 million to more than $1 billion per plant."[86]

Methane and sludge: energy, fertilizer and humus. One of the most appropriate renewable energy technologies in the field of biomass conversion is the use of livestock manure and other agricultural wastes to produce methane (natural gas) for energy and sludge for agricultural crop production. The process is called anerobic (oxygen-free) digestion. In a large-scale application this usually involves either batch or continuous processing of these biomass materials in airtight digesters which utilize naturally occurring bacteria to break down the materials into the desired products in less than a month.

In deforested parts of the Third World which have used cow dung for cooking for generations, this relatively simple technology is particularly appropriate since it not only is more efficient in energy production, but also preserves needed fertilizer and humus for soil enrichment. The use of manure to provide both methane and sludge was pioneered on a large scale in China. The level of usage in China suggests the rapid growth potential of this energy resource in a variety of settings. According to Lester R. Brown, China was expected to expand its usage of methane digesters from seven million in 1978 to seventy million nationally in 1985.[87]

Waste digesters operate more efficiently when the appropriate mixture of ingredients is combined and temperatures maintained to encourage bacterial action. Many different combinations are used, depending on local waste materials available. Brown reported concerning usage in China, "One widely used combination for digester loading consists of 10 percent human waste, 30 percent animal waste, 10 percent straw and grass, and 50 percent water."[88] Waste digesters deals with unavoidable, indigenous wastes efficiently, thereby, conserving needed soil nutrients and providing a clean burning fuel which has many applications capable of displacing some fossil fuel uses.

Agricultural schools provide an appropriate setting for use of livestock manure to generate methane and liquid fertilizer. A number of federal, state and privately funded projects have demonstrated the feasibility of providing these resources at reasonable costs. A poultry farm in Iowa used an agricultural waste-digestion system to handle the waste from 160,000 laying hens. The methane gas produced by the anerobic digestion process powered 100-kilowatt engine/generator equipment while the liquid fertilizer replaced commercial fertilizers used on nearby fields. The estimated savings/earnings from electric power generation and the fertilizer by-products were expected to pay for the $160,000 worth of equipment in six years or less.[89]

A similar payback period of five to seven years was expected in Michigan in a smaller operation using cow manure and a $40,000 digester. The equipment dealt with waste produced by 350 head of cattle. The decomposition was catalyzed by heating the digester to 95°F with the

exhaust of the internal combustion engine used to run an electric generator. Decomposition occurred in seven to twenty days and produced gas which was sixty percent methane. The consequent cost of electricity was about "4.5 to 5 cents per kWh."[90]

Bio-Gas of Colorado, Inc. has developed "an education and training program in bio-energy technology and in the construction of small bioconversion projects."[91] Schools, government-sponsored conferences, and private firms in a five-state area have profited by the demonstration of a small anerobic digestion unit capable of dealing with the waste of 12 to 50 cows to produce methane. This is one of four different sizes of digestors whose designs are made available for purchase by potential users of bioconversion technology.

In 1977 C. E. Tomson, Jr. and W. W. Marlatt cited dollar costs per million Btu and conversion efficiencies of other processes to support their conclusion that "Methane production from organic material is the cheapest and most efficient source of heat energy."[92] The 20-year cost of methane was expected to be less than half the cost of natural gas and less than a third the cost of propane. Although the conversion efficiencies of some of the technologies have been improved somewhat since 1977, Tomson and Marlatt's efficiency comparisons were interesting, namely, methane production (90 to 96%), solar received to collected (60 to 65%), wind to electricity (33%), geothermal conversion to electricity (30 to 40%).[93]

Methane is not appropriate to all energy uses. It is not practical as a vehicular fuel since it is spacially demanding, hazardous

to transport in gaseous form, and very low temperatures are required to liquefy methane. However, in stationary use it offers an excellent source of heating and electricity generation with relatively nonpolluting combustion yields of carbon dioxide and water vapor.[94]

Methane: marine resources. The seas contribute a little less than half of the earth's biomass.[95] Giant kelp and water hyacinths are numbered among the plant resources which can provide energy without making significant additional demands on land resources. A United Nations report indicated that as much as 50 tons of dry matter per hectare and 90 tons per hectare per year of water hyacinths and seaweeds, respectively, can be grown under ideal conditions.[96]. One estimate indicated that ". . . the full exploitation of West Coast kelp could satisfy 20 percent of the United States' energy needs by the year 2000."[97] In December of 1978 experimental farming of giant kelp, a rapidly growing variety of seaweed, was begun about five miles off the coast of southern California. Sometimes growing as much as two feet a day, the kelp promised to provide a rich source of biomass for conversion to methane gas as a substitute for natural gas. The researchers were experimenting with anchoring devices and concerned about potential damage from winter storms.[98] A May of 1983 update indicated the prospect that by 2000 the California Ocean Farm Project would cover 40,000 hectares, with a kelp yield per cultivated hectare of "about 10 million kilocalories of food and nearly a hundred million kilocalories of methane energy a year."[99]

Water hyacinth, another fast-growing, marine plant, promises a number of energy conserving uses. Four years of experimentation by the National Aeronautics and Space Administration have demonstrated their usefulness in cleaning "domestic waste water and some chemical wastes."[100] When the hyacinths are harvested and converted, methane and fertilizer can satisfy energy and agricultural needs.

Converting carbon dioxide to fuel: future microbial oil? On January 17, 1981 Science News reported that bacterial blubber may be a biomass fuel of the future. Morris Wayman and his University of Toronto colleagues had discovered two bacteria, **Chromatium warmingii** and **Desulforistella**, in purple blossoms on a Saskatchewan salt lake which by working in partnership "can convert carbon dioxide to chains of hydrocarbons--the components of crude oil."[101] The process was explained as follows:

> The bacterial oil is the end-product of an extended version of photosynthesis. The process consists of a light-driven splitting of water and a second step that uses the energy gained from the splitting water to convert carbon dioxide to energy in the form of organic compounds, such as the simple sugar glucose. But the bacteria pair takes photosynthesis one step further. After one bacterium converts carbon dioxide to the energy-rich organic compounds, the other bacterium feeds on those compounds and accumulates very high concentrations of oily material.[102]

The research team has since made discoveries of more efficient partnerships to perform the job. A more efficient algae-bacteria combination could provide the microbal oil equivalent of 50,000 barrels of crude oil annually on one hectare (2.47 acres) of sea surface, reducing the food versus fuel conflict involved in less efficient production of ethanol for use of gasohol. The ability of some bacteria

to utilize weak light in energy conversion processes helps explain the more efficient marine energy conversion of carbon dioxide to oil.[103]

Biomass diesel fuel. In 1984 Science News reported plans to harvest "the dense tangle of scrubby trees and brush" of the arid chaparral of the southwestern United States to produce a high-quality diesel fuel.[104] Research was cooperatively sponsored by the Arizona State University in Tempe, the U.S. Forest Service, and the U.S. Department of Agriculture to grind the biomass into sawdust and convert it into liquid fuels. To be economical the processing equipment would have to be small enough to be portable since transportation is also wasteful of energy.

James L. Kuester, a chemical engineer, described the two steps involved in the biomass conversion process called indirect liquefaction.

> . . . First the feedstock (for example, plant material), is converted to "synthesis gas," a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and olefins like ethylene. This gas mixture is exposed to a catalyst that aids in the formation of a high-quality product similar to diesel fuel. The process yields about 40 to 50 gallons of liquid fuel for every ton of feedstock. "The yields will vary," Kuester says, "depending on what the synthesis-gas potential of the various feedstocks is, but within broad limits they react the same."[105]

The process is seen as being applicable to all kinds of biomass waste, not only on the chaparral, but, also, in industrial settings.

The ecological community of the chaparral which is adapted to moist winters and dry summers may experience both favorable and unfavorable consequences. Soil and the habitat of some species would apparently suffer. However, the researchers with the U.S. Forest Service were interested in positive effects, with the harvest expected

> . . . to increase water flow into reservoirs, augment forage for grazing, improve deer habitat and reduce the spread of wildfires, it often must control by controlled burning or chemical treatment.[106]

The root systems of the plants would be left intact to provide a partial answer to environmental concerns while maintaining the energy resource which would probably be sacrificed by tillage.

Biophotolysis: hydrogen from water. Biophotolysis is the "biological disassociation of water into its constitutent hydrogen and oxygen molecules."[107] In 1981 a scientist at Oak Ridge National Laboratory reported "the first experimental data on simultaneous light-activated oxygen and hydrogen production from water using a cell-free system based on green plant photosynthesis."[108] In other words, the splitting of water molecules to provide free oxygen and free hydrogen has been achieved by use of biomass materials in the presence of sunlight. Although only partial laboratory success had been achieved, the goal of this research was to eventually develop hydrogen as a renewable, non-polluting energy resource on a commercial basis.

Microbial hydrogen production. After decades of little attention to the 1942 discovery that "certain microorganisms were capable of using solar energy to drive a hydrogen-producing reaction," the search for new biomass forms of energy led to new research.[109] By 1982 Akira Mitsui and John Benneman had discovered that

> . . . a number of algae and photosynthetic bacteria are capable of producing hydrogen gas at very high rates. It has been estimated that blue-green algae in a chamber 20 feet square and 3 feet deep could produce enough hydrogen to yield 1,000

> kilowatt-hours per month, energy sufficient to supply the needs of an average three-bedroom home.[110]

The systems were too expensive to market in 1982, but Edward J. Philips expected such systems to eventually enter the energy market.

Transfer of Body Heat

Although human and other animals' body heat may not be the most exotic forms of energy, this natural heat serves useful purposes in schools and other facilities and in dairy farming operations. The management of waste heat by use of heat transfer is a useful conservation strategy since body heat, along with lights, can supply a significant portion of the heating needs of school buildings.

In dairy farm operations heat exchangers are now being used to recover the heat extracted from milk in the cooling process. The heat is needed to heat water to wash the milk handling equipment to assist in maintaining a sanitary environment for food processing.[111] Model operations of such technology would certainly be appropriate in agricultural school laboratory areas.

Bringing Energy Production Elements Together

Total energy integration and management in a facility or production setting can provide an economical return on capital expenditures for energy-related equipment, engineering and architecture. In 1982 a Warrenton, Virginia, farmer demonstrated the feasibility of producing corn, steers, ethanol, methane, heat, electricity, fertilizer, and cattle feed in an integrated system. The movement towards energy,

fertilizer and feed grain self-sufficiency proved to be both profitable and capable of providing some protection from the price swings in agriculture and energy. The fertilizer, rich in nitrogen, phosphorus and potash, was a by-product of an underground digester of cattle manure which produced methane gas to generate steam and electricity and to dry corn. The cattle feed was the high-protein by-product of the production of ethanol from corn to mix with gasoline to provide higher octane fuel for farm machinery and for sale to the ethanol market. The marketing of excess ethanol alone was expected to pay for the capital equipment investment in these energy systems within five years. A commonwealth Department of Agriculture executive reported that ". . . MacWelch remains the first to bring potential elements of farm energy production together into a system in Virginia and one of the few in the country to do so . . . ."[112]

Producing Energy Crops

Ecological problems associated with the use of fossil fuels, especially, those related to vehicle exhaust and coal combustion, have a direct effect on forest and agricultural productivity and the supply of biomass available for fuel, food, building materials and other uses. Many small biomass resources, if examined separately seem insignificant, except in a local context. However, their combined potential addresses the need to replace diminishing fossil fuels with renewable resources. Consequently, the potential energy resources must be viewed together. Sulfates and nitrogen oxides are products of fossil fuel combustion

which contribute to acid rain and ozone inhibitors of plant and animal growth and may be endangering the survival of some species of plants and animals. The accelerating ecological damage requires global action to maintain and assure the biological productivity of the planet.[113]

The growing demand for wood as fuel and for other plant products to produce liquid and gaseous fuels calls for new levels of forest and agricultural resource management to avoid damaging consequences of competing uses of land. Food for man, feed for animals, fiber, and fuel make heavy demands on land. Therefore, use of marginal agricultural land for energy crops to avoid conflicts with food needs and inflationary pressures on food prices is preferable to competing uses. One of the recommendations of the 1982 International Energy Symposium was that there be ". . . minimal (preferrably no) conversion of crop land from food to energy production."[114]

In areas of the world where more than a third of the world's poor live, whole ecological systems are in danger due to acute scarcity of wood. Only a very high level of government planning and development can return many of these areas to sustainable yields of nitrogen-fixing trees and other needed biomass products.[115]

The land demands for ethanol production from corn suggest the difficulty of providing adequate fuel from fermentation and distillation processes using grains. Abelson stated in 1979, "Even if the total harvest of corn grains were fermented to alcohol, the liquid would provide only one-eighth of current gasoline demand."[116]

Sugarcane, cassava and pineapple are numbered among the plants that have been studied for alcohol production in tropical environments. A study by D. L. Marzola and D. P. Bartholomew in Hawaii indicated that "Pineapple is well adapted to the subhumid or semiarid tropics and thus is particularly well suited for exploiting large areas not now under cultivation with any crop of commercial value."[117] The amount of water required for commercial yields of pineapple is much lower than for sugarcane. Pineapple makes efficient use of CO_2 at night while "cassava and sugarcane assimilate CO_2 only in the light."[118] This is to point out the fact that specific species charateristics and local environmental characteristics must be well understood to determine suitable biomass resources to propagate for their energy potential.

Since the majority of all students now live in cities and many of them experience urban poverty, including inadequate food, schools and universities can profitably model efficient biomass production where land is limited. The mix of productive techniques is very efficient when intensive organic agriculture, aquaculture, greenhouses, recycled materials, small windmills, plant and animal wastes, composting and other labor intensive cultivation are brought together. The New Alchemy Institute at Cape Cod, Massachusetts, has modeled 100 percent self-sufficiency in energy, along with very high garden and fish yields, in "bio-shelters."[119]

A Palo Alto, California, urban model uses the French bio-dynamic system of gardening to achieve an estimated, eventual $20,000 annual income from plant sales on one tenth of an acre. A U-bar, a

long-necked watering can, a miniature movable greenhouse, and a forty-hour week of labor are numbered among the relatively simple cultivation requirements.[120] Human labor is a biomass energy form.

Biomass energy resources seem certain to experience continued growth as research and development continue in various areas related to plants for energy production. These include improvement of plants by genetic engineering, more appropriate selection of species for use in a specific area, identification and propagation of vegetation yielding hydrocarbons as oil substitutes, and more effective use of currently undeveloped land and marine resources.[121]

A number of different plants have been evaluated for their ability to produce hydrocarbons. These include oleoresins for turpentine, the desert plant guayule for latex production, rubber trees, the desert plant jojoba for nuts containing oil, and euphorbia for oil.[122]

Melvin Calvin, a Nobel Prize-winner and professor of chemistry at the University of California, Berkeley, described as "America's foremost advocate of energy farms," was very impressed by the diesel fuel being harvested in Brazil. Fuel was provided directly to the tank of diesel engines without further processing by tapping the **Copaiba** (**Copaifera**[123]) tree's truck every six months. The yield per tree was 20 to 30 liters of oil.[124] Peter Ognibene said, "The **Capaiba** is probably the best direct source of biocrude oil in the world."[125] The quality and yield of these and other plants was expected to improve with the use of "improved genetic engineering techniques."[126]

In 1983 a researcher in Southern California was evaluating "several of the more than 700 known species of eucalyptus that could grow well on California's poor or marginal cropland."[127] The combustion properties of the tree, namely, "clean burning, low ash and high heat content, seemed suitable to the area.[128] According to Keith S. Mayberry, the expected yield of one acre of marginal land was "6 to 12 cords of wood every five years."[129]

Both the University of California and the University of Arizona have conducted studies of the feasibility of using the **Euphorbia lathris**, or gopher plant, as a biomass source of a material which functions like crude oil. The plant material is harvested, dried, pulverized, and exposed to a solvent in the oil producton process. In 1981 Jack Johnson of the University of Arizona, based on experience with a prototype processing plant, was estimating that ". . . in 10 years commercial extractors will be able to convert 1,000 tons of biomass a day into 1,500 barrels of biocrude and 40,000 gallons of ethanol."[130] Furthermore, "The remaining dried pulp would be burned to generate 25 megawatts of electric power."[131]

The proposed source of the gopher plants was about 35,000 acres of underdeveloped arid land, the equivalent landmass of Pittsburgh. To farm gopher plants on a scale equal to needed raw material of a small oil refinery, producing 50,000 barrels of oil a day, would require the equivalent landmass of Rhode Island, 671,360 acres. Obnibene reported that the combined federal landholdings in Arizona, Nevada, and New Mexico were more than 175 times that size.[132]

A great many different species of photosynthetic bacteria and microalgae have been studied to determine the feasibility of their massive culture in artificial ponds. Edwards J. Philips reported,

> . . . Species that can double their weight in less than two hours have been found. Recent improvement in pond-culture techniques has generated growth yields of up to twice those obtained in conventional agriculture.[133]

However, in 1982 Philips indicated no significant industrial-scale applications of algae or bacteria for energy purposes had been made.

Mariculture or ocean farming of red and brown (example, giant kelp or seaweed) algae and other marine plants has been heavily researched. In 1980 harvesting of wild seaweed beds had already been practiced for many years and the results of experimental, artificial anchoring of giant kelp was being reported. Susan Walton's review of a report from the Office of Technology Assessment indicated that the data were too sparse to support or reject ocean energy farms.[134]

Risks Associated with the Use of Biomass

Environmentalists have identified risks associated with excessive use of firewood and other biomass products. Among the potential consequences of greater use of land and water based biomass are increased degradation of soil and water and flooding. Warmth, power and building materials make heavy demands for firewood which could lead to deforestation and devastating climatic and agricultural results in arid regions of the US and the world. The use of wood as fuel consumes 80 percent of the forest products used in poor countries. In 1981

Kenneth R. Stunkel reported a study indicating that ". . . heavily forested regions, consisting of some 20 percent of the earth's land area, are vanishing at a rate of 11 million hectares a year (1.2 percent of the total), an area about the size of Cuba."[135]

In reviewing the Worldwatch Institute's State of the World 1984, Stephen Mitchell called attention to acid rain, the continuing population explosion, and deforestation. Specifically, Mitchell reported that 7.5 million hectares of forest and woodland in the tropics were ". . . disappearing each year—an annual loss the size of Austria and Albania combined."[136]

The world can take a lesson from those who exhausted the biomass of central Africa and elsewhere and who experienced spreading deserts and consequent dependence upon the burning of cow dung for fuel which deprived the land of this declining base of fertilizer and humus also. This is a worst case scenario of the current connection and potential conflict between "the world energy problem and the world food problem."[137]

Risks associated with the use of firewood can be minimized, while creating needed employment and increasing the commercial value of forests, by managing forests to achieve sustainable yields.[138] Rapid growth and harvesting in intensively managed energy plantations appear certain to eventually deplete the soil, especially where use of wood waste and cultivation expose the soil to the ravages of wind and water runoff. Pimentel and others said, "The removal of forest and crop biomass on slopes can increase water runoff 10-25 times."[139] Continued

harvesting of virgin forests and spreading deserts indicate that tree-planting efforts have not yet matched the energy demand for a sustainable yield of wood which avoids unacceptable environmental risks. Environmentally sensitive management of energy plantations can maintain the soil humus and fertility.

In 1983 Patrick Barry warned of environmental damage being done by indiscriminate use of wood-fired stoves and industrial furnaces in urban areas. Trucking valuable hardwood lumber hundreds of miles for use as firewood when the surrounding land has been stripped of trees made no sense. Not only were forests being cut, sometimes clear-cut, and soil degraded, but the atmosphere was being filled with "carbon monoxide and tons of carcinogenic particulates."[140] Barry doubted that scattered millions of individual users would deal with the air pollution caused by the incineration of wood products in inefficient stoves and fireplaces. He expected the lung and skin cancer, asthma, emphysema, and bronchitis problems to become more severe with wood burning. Energy plantations were not certain to balance out the greenhouse effect of carbon dioxide by adequate forest replacement. Atmospheric inversions in winter and the consequent pollution alerts were on the increase in winter where wood use was accelerating. More efficient burning techniques and catalytic converters to clean emissions were expected to add hundreds or thousands of dollars to the expense of burning wood.[141]

The growing air pollution problem associated with use of wood-burning stoves and fireplaces is graphically illustrated by various studies. Peter Coy offered these threatening details:

> A modern wood stove produces 500 times as much carbon monoxide, 1,500 times as much particulate matter and 750 times as many hydrocarbons as an oil furnace to heat the same space, according to a 1980 study at Long Island's Brookhaven National Laboratory.
>
> Wood smoke has more than 100 pollutants, including hydrochloric acid, benzolate pyrene (an ingredient of cigarette smoke), sulfur oxides and polycyclic organic compounds. The polycyclic compounds have been found to cause cancer in laboratory animals.[142]

The long term effects of exhaustive use of wood wastes for energy potentially include the depletion of humus needed for soil fertility, for the holding of moisture for future crops, and to prevent erosion. To exhaust soil nutrients and, consequently, be forced to use energy intensive fertilization and cultivation techniques to reclaim the land is unreasonable. Furthermore, use of the energy stored in forest and agricultural humus adds to the size of the CO_2 problem.

Pimentel and others have illustrated the potential damage to existing agricultural land by excessive and inappropriate energy uses of crop residues and animal wastes which have traditionally been important in maintaining soil quality and avoiding erosion. Writing in 1983, they found very significant increases in erosion, even with conservation tillage practices, where increasing levels of crop residue were removed.[143] Failure to apply animal wastes to agricultural land results in soil which has less organic matter, loses some of its bulk density, and distributes water and gases less effectively.[144] Use of energy-intensive fertilizers and pesticides to maintain the yield of one crop, replacing diverse vegetation, does not offer an adequate long-term alternative replacement of biomass. Wildlife habitats are damaged.

Monoculture in agriculture and forestry may yield a profitable biomass which proves to be environmentally unsustaniable.

Increased use of biomass energy resources requires weighing the outcomes. Even the desirable social impact of providing needed jobs and some shifting of the burden of cities has both desirable and undesirable consequences. Susan Walton summarized the employment potential, especially in rural areas, this way:

> . . . Bioenergy conversion would create new jobs in resource harvesting (forestry and agriculture); manufacture, distribution, and servicing of conversion equipment; and the construction and operation of large-scale conversion facilities.[145]

However, occupational injuries and illnesses are greater in agriculture and forestry than in coal, oil, and gas production.[146]

Conclusions

Reporting on a conference sponsored by the World Resources Institute and the Rockefeller Brothers Fund, Constance Holden stated, "Biomass energy systems, to be economic, must be multipurpose, combined with food, fodder, fuel, fiber, or fertilizer production."[147] Although not all the dimensions of biomass products usage outlined by Constance Holden are likely to be present in most school settings, multiple and interacting uses make more appropriate response to the needs to conserve energy and the need to act in a manner which acknowledges social and environmental consequences of energy systems.

Schools and universities which take adequately into account their local situation often have access to a variety of biomass energy

resources, some of which are much more readily available and economical than others. Biomass energy system feasibility usually requires local availability of a plentiful supply of the energy resource. Rural areas often have an adequate supply of wood, wood wastes, or crop residues to make effective use of these resources. Animal wastes in rural areas would be better left to meet the needs of the farmer or sold to private distributors of methane and fertilizer, except, of course, in agricultural schools for the purpose of demonstrating the technology.

Urban schools and other public facilities could in many instances be natural allies of regional planning commissions seeking appropriate strategies to utilize incinceration or other biomass conversion methods to deal with landfills or solid waste associated with trash disposal and sewage. A number of major cities and urban counties were already providing energy from shredded and compacted garbage in 1981, with other large-scale plants planned.[148] Cogeneration of heat and electricity is a highly appropriate use of urban biomass wastes.

Since Third World markets have such great need of many of the products associated with utilization of energy and often lack the resource base to purchase processed goods, American students can profit by energy models for transportation, industrial production, and facilities which are adaptable to village level needs. Intermediate technological initiatives of the present and future promise the possibility of solving many age-old needs. If for no other reason than this, students in American schools and universities will profit by exposure to working energy systems which integrate biomass resources

with solar, wind and small-scale hydro projects to permit sustainable food, fuel, fiber, fodder, fertilizer, and building materials.

Ultimately this energy resource in the United States has very serious natural limits. These limits are best suggested by the fact that ". . . agriculture and forests occupy 80% of total land area and use 83% of the total water consumed by society."[149] To the extent that monoculture production of energy crops may tend to reduce biological diversity and destroy ecosystems, large-scale biomass production risks becoming as damaging to nonrenewable resources as the use of fossil fuels.[150] Inappropriate use of limited resources places real limits on the sustainability of the biosphere.

When sustainable-yield biomass resources can replace use of fossil fuels in environmentally appropriate ways, they offer real potential for reducing the anticipated "greenhouse effect" of atmospheric CO_2 buildup. Consequently, advocates of use of biomass energy resources are encouraged to select biomass energy systems "with a recognition of the need for carbon retention."[151]

A lesson which still needs to be taught in schools and universities is that the biomass of man power can also displace the use of fossil fuels. Often quite limited user orientation and labor can reduce the cost of energy systems. Walking to school, physical labor to replace unnecessary energy using devices, user involvement in energy processes, and riding a bicycle may well be Third World advantages in the Twenty-first Century.

CHAPTER SEVEN ENDNOTES

1. Harry Bacas, "Energy: A Promise Renewed," Nation's Business (A U.S. Chamber of Commerce Publication), 73:7:34R, July, 1985.

2. Ibid.

3. Edward J. Philips, "Biological Sources of Energy from the Sea," Sea Frontiers, 28:1:38, January/February, 1982.

4. Gene Bylinsky, "Biomass: the Self-Replacing Energy Resource," Fortune, 100:6:78, September 24, 1979.

5. "Environmental Aspects of Energy Farms," UN Chronicle, 20:5:43, May, 1983.

6. D. Pimentel and others, "Environmental and Social Costs of Biomass Energy," BioScience, 34:2:89, February, 1984.

7. Ibid.

8. Bacas, op. cit., pp. 34R & 35R.

9. Bylinsky, loc. cit.

10. Patrick Barry, "Snags in the Biomass Revolution," Environment, 25:1:2-4, January/February, 1983.

11. "Energy potential from biomass high, OTA says," Chemical and Engineering News, 58:30:11, July 28, 1980.

12. D. Pimentel and others, op. cit., p. 89.

13. Ibid.

14. Philip H. Abelson, "Bio-Energy," Science, 204:4398:1161, June 15, 1979.

15. Wallace E. Tyner, "The Potential of Using Biomass for Energy in the United States," International Energy Options: An Agenda for the 1980s, ed. Paul Tempest (Cambridge: Oelgeschlager, Gunn & Hain, Publishers, Inc., 1981), p. 166.

16. Philip H. Abelson, "Energy from Biomass," Science, 208:4450:1325, June 20, 1980.

17. R. Jeffrey Smith, "Experts Endorse Biomass Energy," Science, 208:4447:1018, May 30, 1980.

18. Philip H. Abelson, op. cit., p. 1325.

19. R. Jeffrey Smith, op. cit., p. 1018.

20. Ibid.

21. Herman Kahn, William Brown and Leon Martel, "Energy Exhaustible to Inexhaustible," The Next 200 Years: A Scenario for America and the World (New York: William Marrow and Company, Inc., 1976), p. 71.

22. Pimentel and others, op. cit., p. 91.

23. "Environmental Aspects of Energy Farms," UN Chronicle, 20:5:43, May, 1983.

24. Peter Bacqué, "Millions of acres of energy cover state, and price is right," Richmond [Virginia] Times-Dispatch, February 3, 1985, p. D-4, col. 3.

25. Lester R. Brown, "The Coming Solar Age," Natural History, 91:2:42, February, 1982.

26. Amory B. Lovins and others, Least-Cost Energy: Solving the CO_2 Problem (Andover, Massachusetts: Brick House Publishing Company, 1981), p. 144.

27. Peter Bacqué, op. cit., p. D-4, col. 2.

28. Ibid., p. D-4, col. 1.

29. Bylinsky, op. cit., p. 79.

30. Ibid.

31. "Exemplary!," American School & University, 56:7:65, March, 1984.

32. Bacas, op. cit., p. 35R.

33. Bylinksy, op. cit., p. 81.

34. Feng-Bor Lin, Norbert L. Ackermann, and Edward B. Kear, Jr., Potential of Industrial Scale Wood Combustion in St. Lawrence County, prepared for New York State Energy Research and Development Authority (Potsdam, N.Y.: Clarkson College of Technology, October, 1979), p. ix.

35. Ibid., p. x.

36. Michigan Department of Natural Resources, Michigan Wood Energy Development Plan (Lansing, Michigan: Michigan Department of Commerce, Department of Natural Resources, Forest Management Division, March, 1986), p. 12.

37. Bacas, op. cit., p. 35R.

38. Bacqué, op. cit., p. D-4, cols. 2-3.

39. Ibid.

40. Bacas, op. cit., p. 35R.

41. "Henrico aims to convert landfill garbage into fuel," The Richmond [Virginia] News Leader, p. 15, June 25, 1984.

42. Ibid.

43. Ibid.

44. Ray Filegar, "Trash, waste worries keep growing," Richmond [Virginia] Times-Dispatch, p. C-4, December 25, 1983.

45. William Ruberry, "Conversion of trash is studied," Richmond [Virginia] Times-Dispatch, p. D-10, col. 1, August 12, 1984.

46. Lester R. Brown, op. cit., p. 44.

47. Ibid.

48. Associate Press, "Housing project in Portsmouth to get heat from burning trash," The Richmond [Virginia] News Leader, p. 21, June 12, 1986.

49. Ibid.

50. Pamela Porter, "No one's steamed by this incinerator," Montgomery [County, Maryland] Journal, p. A-1, June 6, 1986.

51. Ibid., p. A-10.

52. Ibid.

53. Steve Row, "Two energy-related firms change focus," The Richmond [Virginia] News Leader, p. 1, col. 2, November 5, 1984.

54. S. David Freeman, "Tapping the Eternal Energy Supplies," Energy: The New Era (New York: Walker and Company, 1974), p. 266.

55. "Exemplary!," op. cit., p. 63.

56. Ibid.

57. Ibid., p. 69.

58. Ibid.

59. Alan Guebert, "Cobs, cords and stover fuels new biomass grain dryers," Successful Farming, 81:11:10, October, 1983.

60. Diane Kortus, "Rubbish!," American School & University, 56:1:60, September, 1983.

61. Ibid.

62. Pimentel and others, op. cit., p. 89.

63. Steven E. Plotkin, "Energy from Biomass: The environmental effects," Environment, 22:9:7, November, 1980.

64. George McRobie, Small Is Possible (New York: Harper & Row, 1981), p. 228.

65. R. Jeffrey Smith, op. cit., p. 1018.

66. Ibid.

67. Based on personal correspondence between Paul Burks, Director of the Office of Energy Resources, Georgia, and Glenn Thomason, June 18, 1986 and June 26, 1986. See Appendix C.

68. American Petroleum Institute, Two Energy Futures: A National Choice for the 80s (Washington: American Petroleum Institute, 1980), p. 100.

69. Lester R. Brown, op. cit., p. 44.

70. American Petroleum Institute, loc. cit.

71. Ibid.

72. Ibid.

73. José M. Miccolis, "Alternative Energy Technologies in Brazil," Renewable Energy Resources and Rural Applications in the Developing World, ed. Norman L. Brown (Boulder, Colorado: Westview Press for the American Association for the Advancement of Science, 1978), p. 62.

74. Paul B. Weisz and John F. Marshall, "High-Grade Fuels from Biomass Farming: Potentials and Constraints," Science, 206:4414:25, October 5, 1979.

75. Ibid.

76. Bylinsky, op. cit., p. 78.

77. Pimentel and others, op. cit., p. 90.

78. Ibid., p. 81.

79. Ibid.

80. American Petroleum Institute, op. cit., p. 101.

81. Ibid.

82. Ibid.

83. "Replacing Petroleum with Plants," Science Digest, 91:9:36, September, 1983.

84. "Energy potential from biomass high, OTA says," op. cit., p. 11.

85. Bylinsky, op. cit., p. 81.

86. Ibid.

87. Lester R. Brown, op. cit., pp. 44-45.

88. Ibid., p. 45.

89. Kathleen Courrier and others, eds., Shining Examples: Model Projects Using Renewable Resources (Washington, D.C.: Center for Renewable Energy Resources, 1980), p. 3.

90. Ibid., p. 6.

91. Ibid., p. 104.

92. C. E. Tomson, Jr. and W. W. Marlott, "Energy Independence through Methane," Solar Architecture, eds. George E. Franta and Kenneth R. Olson (Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., 1978, p. 255.

93. Ibid.

94. Ibid., p. 262.

95. Edward J. Philips, op. cit., p. 39.

96. "Environmental Aspects of Energy Farms," UN Chronicle, 20:5:45, May, 1983.

97. Edward J. Philips, op. cit., p. 40.

98. Bylinsky, op. cit., p. 81.

99. "Environmental Aspects . . . ," op. cit., pp. 45-46.

100. Ibid.

101. "Bacterial blubber: Fueling the future?," Science News, 119:3:40, January 17, 1981.

102. Ibid.

103. Ibid.

104. "Biomass: Roam on the range," Science News, 125:12:187, March 24, 1984.

105. Ibid.

106. Ibid.

107. G. Lee Salmon, "Solar news & views," Solar Age, 6:7:60, July, 1981.

108. Ibid.

109. Edward J. Philips, op. cit., p. 43.

110. Ibid., pp. 43-44.

111. Donald R. Price, "A New Energy Ethic for Farmers," VocEd, 54:1:48, January, 1979.

112. Jerry Lazarus, "Warrenton farmer is pioneer in farm energy," Richmond [Virginia] Rimes-Dispatch, pp. F-1, cols. 1-4 and F2, cols. 2-5, November 7, 1982.

113. Paul Haskins, "Acid rain, growing problem in Southeast, despoiling forests, crops," The Richmond [Virginia] Newsleader, p. 12, cols. 1-4, April 4, 1986.

114. Carla Carlson, "World's Fair Symposium Stresses Biomass," BioScience, 32:6:492, June, 1982.

115. "Environmental Aspects . . .," op. cit., pp. 42-46.

116. Abelson, 1979, op. cit., p. 1161.

117. D. L. Marzola and D. P. Bartholomew, "Photosynthetic Pathways and Biomass Energy Production," Science, 205:4406:555, August 10, 1979.

118. Ibid., p. 556.

119. McRobie, op. cit., pp. 131-132.

120. Ibid., p. 147.

121. Ibid.

122. Ibid.

123. "Tomorrow's Fuel: Green Plants," International Wildlife, 13:3:24-D, May/June, 1983.

124. Peter Ognibene, "Energy Farmers: Growing Tomorrow's Fuel," Science Digest, 89:7:98, August, 1981.

125. Ibid.

126. "Tomorrow's Fuel: Green Plants," op. cit., p. 24-D.

127. Ibid.

128. Ibid.

129. Ibid.

130. Ibid., pp. 98-100.

131. Ibid., p. 100.

132. Ibid.

133. Edward J. Philips, op. cit., p. 41.

134. Susan Walton, "Oddball Crops May Alleviate Energy Shortages, Says OTA," BioScience, 30:12:806, December, 1980.

135. Kenneth R. Stunkel, ed., National Energy Profiles (New York: Praeger Publisher, 1981), p. 22.

136. Stephen Mitchell, "The State of the World 1984," Solar Utilization News, 9:1:15, July, 1984.

137. Paul Abrecht, ed., Faith, Science and the Future (Geneva, Switzerland: Church and Society, World Council of Churches, 1978), p. 90.

138. Lester R. Brown, op. cit., p.44.

139. Pimentel and others, op. cit., p. 91.

140. Patrick Barry, "Snags in the Biomass Revolution," Environment, 25:1:2, January/February, 1983.

141. Barry, op. cit., pp. 3-4.

142. Peter Coy, "Wood stove smoke is becoming major problem," Richmond [Virginia] Times-Dispatch, p. E-4, cols. 3 & 4.

143. D. Pimentel and others, op. cit., p. 90.

144. Ibid.

145. Susan Walton, "Biomass Could Provide 20% of U.S. Energy by 2000, OTA Says," BioScience, 30:9:631, September, 1980.

146. Pimentel and others, op. cit., p. 92.

147. Constance Holden, "Is Bioenergy Stalled?," Science, 227:4690:1018, March 1, 1985.

148. Alyssa A. Lappen, "Garbage in, garbage out?," Forbes, 127:11:50, 52-53, May 25, 1981.

149. Pimentel and others, op. cit., p. 93.

150. "Plants Our Renewable Resource," USA Today, 111:2457:6, June, 1983.

151. Plotkin, op. cit., p. 39.

Chapter 8

HYDROPOWER

For almost 2,000 years, prior to its current use in generating electricity, hydropower was used to supply mechanical energy. The labor of Greek women in grinding grain was reduced as early as 85 B.C. by the introduction of the water-powered gristmill. Our European ancestors developed the use of water wheels "during the Middle Ages to power mills for grinding flour, sawing wood, and producing textiles."[1] In a very real sense the millwrights were the renewable energy engineers of the 18th and 19th centuries in the United States.

Lester R. Brown reported that shortly after Edison invented the light bulb, "The first central hydrogenerating facility began producing electricity in Appleton, Wisconsin, in 1882."[2] Hydropower to light 350 bulbs was a modest beginning for the rapid worldwide development of hydroelectric power. However, the progress was rapid, given the fact that Edison introduced his incandescent light bulb for marketing on New Year's Day in 1880.[3] The total output of the two generators on this Fox River site was 25 kilowatts.[4]

From this modest beginning, hydropower grew rapidly until cheap oil made smaller hydroelectric plants uneconomical. Consequently, the one third of U.S. electricity supplied by hydropower in the 1920s had declined to only 13 percent in 1978.[5] That year William J. Broad reported, "According to the Federal Power Commission, no fewer than 770 hydro plants have been abandoned since 1940."[6] In 1980 the General

Accounting Office reported that in the last forty years hydroelectricity had declined from providing 40 percent to 15 percent of the nation's electricity.[7]

In 1978 Richard C. Dorf predicted very limited growth in hydropower development. The coupling of geothermal power, which then contributed about 516 megawatts, with hydroelectric (then contributing 60,000 megawatts capacity) was interesting. Dorf stated this projection:

> . . . It is anticipated that hydroelectric and geothermal power plants will grow moderately in capacity over the next decade, but that these sources will continue to provide only about 16 to 18 percent of our total electric energy over the next 20 years.[8]

The Arab oil embargo led to a small-scale hydroelectric renaissance. While utilities added new generators to existing hydroelectric plants, entrepreneurs rapidly bought old dams to retrofit them, and government agencies initiated inventories of dam sites, pilot feasibility studies, and demonstration projects. Manufacturers developed small-hydro turbines and equipment.

In July of 1985 hydropower was second only to biomass as an applied renewable energy resource in the United States. During the same year hydropower relinquished its second place as an energy resource to nuclear power, with coal maintaining first place, as a source of electricity.[9] Developers of small-scale hydroelectric projects were being subjected to strong pressures against both retrofitting old, abandoned sites and new, potential sites.

Both in the United States and around the world the use of falling water to generate electricity is far below the great undeveloped potential. In March, 1982 twenty-five percent of the world's electricity was being provided by hydropower.[10] However, in February, 1982 Lester Brown reported the top three leaders and the megawatts being produced as follows: the United States, 71,000; the Soviet Union, 47,000; Canada, 40,000.[11] In 1982 the U.S.S.R. and Canada, respectively, generated approximately 20% and 70% of their electricity from water power.[12] Improved efficiencies of various kinds led to a 1.9% decline in the use of electricity in the U.S. in 1982 over the previous year.[13] The worldwide, undeveloped, hydropower potential which is three or four times the current operating capacity suggests a need for American educators and business leaders to maintain an active involvement in this development.[14] At that time Brazil was ranked fifth in hydroelectric generation. However, with much of its potential in remote areas where other resources had not been developed, the promise of future development was suggested by the estimate that "only 14 percent of its hydropower potential" had been tapped.[15] The widespread development of small-scale hydropower projects in China and its plans to develop four large-scale dams with a combined 32,000 megawatts generating capacity promised to rank it among the world leaders in this energy technology by the end of the century.[16] The World Bank projected a large growth in demand for electricity and a doubling of hydro capacity in the developing world in the 1980s.[17] The Worldwatch Institute offered a less optimistic assessment, specifically stating,

"In 1980, only 22% of the world's technically usable hydropower was actually producing electricity or was likely to in the near future."[18]

The extremes to which developers may go in harnessing hydropower in the future are suggested by two trivia. First, the world's tallest dam, located on the Dixence River in Switzerland, "contains more than 7,790,000 cubic yards of concrete" and rises "935 feet from the river bed to upper rim, . . . nearly as high as New York City's Chrysler Building . . . ."[19] If a proposed Amazon River Dam is built, it ". . . would flood an area the size of Montana and pour out a whooping 66,000 megawatts."[20] The environmental trade-offs of such projects raise enormous questions about the reasonableness of technology on this scale and the viability of other future technologies which may make more appropriate uses of the resources at hand.

In 1980 the General Accounting Office (GAO) reported a total 60,000-megawatt hydroelectric capacity in the U.S., with the largest amount of hydropower being provided by the Federal Government. The power production control was lodged with the following agencies: Department of Defense (through the Army Corps of Engineers), 16,500 megawatts; Department of the Interior (through the Bureau of Reclamation, the Bureau of Indian Affairs, and the National Park Service), 9,400 megawatts; Tennessee Valley Authority, 3,300 megawatts.[21] The construction and maintenance of dams for river navigability is the vital function of the Army Corps of Engineers, with the hydroelectric power development as a secondary task. The Bureau of Reclamation provides 15 western states with needed irrigation water.

The fact that hydroelectric generation is secondary to other federal responsibilities, including navigation, irrigation, flood control, water storage and recreation, in use of the nation's rivers helps to explain the undeveloped hydroelectric potential.

Opinions varied as to the potential growth and cost of new hydroelectric projects in the United States. Harry Bacas saw the availability of well developed technology, requiring minimal maintenance, as favoring a "modest but steady growth in small projects," even though custom-designing to fit a specific site makes their unit cost higher than large-scale projects.[22]

The vast majority of existing dams are not being used to generate electricity and sites where hydropower is being used are not being used at full capacity. In 1980 the very low level of utilization of hydroelectric potential was evident in the GAO report that

> . . . only 3 percent of the 49,000 dams in the U.S. have power-generating facilities. If the most suitable of the unused 97 percent were to be similarly harnessed, one Department of Energy study suggests, the nation's hydroelectric capacity could be increased by an additional 110,000 megawatts, or the equivalent of more than four million barrels of oil per day.[23]

The very limited use of existing dams helps to account for the difference between "the current 71,000 megawatts of generating capacity (including pumped storage)" and the undeveloped "300,000 megawatts of power, over half of it in Alaska" reported by the Army Corps of Engineers.[24] It also suggests that this energy resource is underutilized in proximity to many educational institutions which could use the resource without the capital cost of new dams.

Evaluating Small-Scale Hydropower

The quantification of power generated can be confusing. These metric equations may assist in comprehension of the descriptions included here: one megawatt = 1,000 kilowatts = 1,000,000 watts.

The definition of small-scale hydropower is variously described in the literature. Marc Reisner said, "Under PURPA, it can be a dam producing as much a eighty megawatts of power."[25] However, very few proposed projects exceed twenty-five megawatts. A working definition offered by William J. Broad is suitable for thinking about use of falling water to generate electricity for use in school facilities. Broad stated:

> . . . Small, "low-head dams are usually less than 65 feet in height and generate less than 15,000-kw of electricity. "Small" may be a deceptive word, however, since even a 5,000-kw hydro plant can serve the needs of several thousand families.[26]

In 1983 Phillip Johnson stated that "any dam generating under 30 megawatts" fell within the "small-scale" classification, as administered by the Federal Energy Regulatory Commission (FERC).[27] For clarification, Johnson illustrated, stating, ". . . That includes some relatively large-scale projects like the Glendo Dam in Wyoming, which is 190 feet high and generates 24 megawatts."[28]

The Public Utilities Regulatory Policies Act of 1978 (PURPA)

The most significant incentive for the development of hydropower following the 1973 Arab oil embargo was Congress' passage of the Public Utilities Regulatory Policies Act of 1978. A key provision required

utilities to buy power from independent producers, including public institutions, at rates based on the avoided costs of the utility. The small-scale hydropower producer was afforded the opportunity to earn an income from small sites equal to "what it would cost a utility to generate that power itself or purchase it from another utility."[29] Although the provisions of this act do not apply exclusively to hydropower, the fact that hydropower, like wind power and photovoltaic power, seldom comes in quantities specificially suited to the user's needs makes it particularly suited to the encouragement of such development. The level of cooperation of the local utility company and the rate of compensation for excess power affects the feasibility of renewable energy projects.

Availability of Falling Water

Hydropower is both renewable and broadly available in the vast majority of the country. In some areas hydropower was still the primary source of electricity in the late 1940s. Peter Kakela and others reported the usage in three of the leading states: "65 percent in Maine, 68 percent in New Hampshire, and 85 percent in Vermont."[30]

Availability of hydropower is not consistent everywhere, as William J. Broad reported, "About 60 percent of the nation's 49,500 dams are on streams that dry up for one week to six months almost every year."[31] The highly variable volume of water flowing in a river is based on seasonal fluctuations of snowmelt and rainfall. In some cases

dams lack sufficient holding capacity to deal with these seasonal changes.

The Army Corps of Engineers (ACE), using a less than fifteen-megawatt capacity definition of small hydro, recently estimated that less than a fourth of the new hydropower potential would come from small-scale sites.[32] As noted above, FERC uses a broader definition of small hydro, including sites with less than a 30-megawatts capacity.

Although many school facilities receive their electric power from hydroelectric plants, large-scale plants are unlikely to be developed by schools and universities. However, very durable, small-scale projects may be developed in the vicinity of some schools and colleges. Brown reported,

> . . . A survey undertaken in 1977 by the Army Corps of Engineers identified more than 50,000 dams--built for water storage, flood control, or recreational purposes--that were not being used to generate electricity. These sites are attractive because the water-impounding structures already exist and require only the installation of electrical generators to tap the energy in the overflow. Small and widely dispersed, such facilities do not require long-distance transmission lines.[33]

Broad reported that less than three percent of the sites identified by ACE produced power. He stated, "The rest were used for flood control, navigation, irrigation, water supply or recreation, and a large number were just old and abandoned."[34] Many of these preclude hydro development. Broad elaborated on the potential 54,600 megawatt resource identified by ACE:

> . . . The Corps estimates that the installation of additional generating capacity at existing dam sites could add to the nation's power pool about 54.6 million kw--the equivalent of 85 good-sized nuclear power plants. Almost half of that power

> would come from tiny, undeveloped dams with capacities of less than 5,000 kw, while the rest would come from installing more powerful and efficient equipment at dams that already produce power.[35]

New hydropower sites have real potential. In December of 1982 Matt Herron reported these data:

> . . . A recent study by the U.S. Army Corps of Engineers suggests that small hydro at 2,000 new sites could add 45,000 megawatts of generating capacity (the equivalent of 45 nuclear power plants) by the turn of the century.[36]

Schools and colleges may find it profitable to consult with the DOE, ACE, or their state energy office regarding potential use of existing dam sites. Small existing sites are less likely to incur the wrath of environmentalists who are appropriately concerned about the loss of cropland, wilderness areas, and migratory fish.

Some states, particularly the midwestern states, suffer not from politicial or environmental opposition to hydropower development, but from a very limited number of suitable sites. For example, Michigan was reported to have a cumulative capacity of 1,000 megawatts.[37] However, even in Michigan a number of low- and medium-head hydro sites, typically having less than thirty feet of head, were abandoned by public utilities. Head refers to the distance the water falls, with high pressure and increasing power being contributed by a similar volume of water in high head sites due to the effects of gravity on falling water. Timothy A. Fausch offered this summary from the Michigan Hydroelectric Research Potential and Site Development Guide:

> . . . According to the guide, of the 2,000 dam sites on Michigan streams, 780 have some potential for hydroelectric operation. Of the 780, 81 are operating hydroelectric facilities and 55 are retired sites, with the balance used for flood control.

> According to the Guide, just 77 sites currently have potential as hydroelectric generating facilities.[38]

The most feasible sites were already developed or under development in 1986. However, the statistics may need reevaluation in terms of the potential multiple uses of existing dam sites, for example, generating electricity at a flood control dam.

Often dams can serve multiple purposes. Broad described the electricity potential at a dam designed to provide flood control on the Genesee River in west central New York.[39] In this case penstocks, meaning conduits or pipes to conduct water to turbines, were built into the dam by the Army Corps of Engineers to enable the dam to serve a dual purpose in the future. Navigation dams can be similarly fitted for dual usage.

In the fall of 1984 Alternative Sources of Energy reported plans by a Wisconsin utility company to use existing dams on the Mississippi River which were built to aid navigation to generate electricity.[40] The utility company planned to begin producing power at these navigation dams in the fall of 1986 without making any major structural changes in the dams. The company's intended method of power production was to use generator-equipped barges which can be attached and removed as necessary to permit "all of the spillway gates to be left open" when the water level in the river is high.[41] Just one dam site affords the opportunity to provide a total of 10 megawatts of power by using single barges which have a generating capacity of about 3.3 megawatts. The estimated total

generating capacity at about 50 dams capable of accommodating these hydrobarges was 1,200 megawatts.[42]

Hydrobarges may have environmental impacts on the Mississippi. Migrating walleys, saugers, and a variety of fish eggs may cause problems. Studies were being made of the potential environmental impact "by the U.S. Fish and Wildlife Service and the River Studies Center at the University of Wisconsin-La Crosse."[43]

New England states already have many small hydroelectric projects in operation and a very large potential for expansion. The estimated 8,200 dam sites, including both current and former sites, offer the possibility of satisfying approximately seven percent of the region's electricity needs.[44]

Matt Herron made a useful distinction between the development of hydropower in the East and the West. Since development of the resource began earlier in the East and was largely completed before economies of scale (the idea that bigger is better), there were far more small scale dams available for renovation in the East. Herron reported that

> . . . By the hundreds, these durable civil works were shut down. Still viable, they rusted away. Weeds grew through powerhouse walls, dams spalled, weirs crumbled, penstocks collapsed, rats nested among the windings of perfectly good generators. Now, many of these old plants are being coaxed to life.[45]

By contrast, most of the development of hydropower in the West was accomplished in this century after "economies of scale made small-generation plants unprofitable, or merely inconvenient."[46] The consequence was that there were fewer small, refurbishing projects available in the West. This distinction accounts for some of the court

actions of environmentalists in the West where promising new sites have not been tapped.

The Federal Energy Regulatory Commission is the primary agency controlling the development of potential sites. This agency has been flooded with applications for permits to reserve development rights since passage of the Public Utilities Regulatory Policies Act (PURPA) of 1978. The largest number of applications (1,856) were submitted in 1981.[47] In June, 1985 licences had been granted for only 315 sites, suggesting something of the complexity of dealing with the maze of agencies and environmental protection groups involved. However, since many generators are small enough to be exempt from the licensing procedures, this statistic does not reflect the much larger number of projects which were being developed.[48]

One interesting strategy for use of falling water to generate electricity is a remarkably practical, if inefficient, way to deal with the problem of peaks and valley in electricity demand. Pumping water into elevated reservoirs during off-peak hours, when power may be purchased more cheaply, permits users to use the pumped storage to generate their own hydroelectricity during peak periods. This sort of facility permits small-scale hydroelectric power even where a continuous stream of adequate water is unavailable.

A new underground hydropower plant in California suggests the kind of possibilities available for pumped storage sites. In April, 1984 this "first underground hydroelectric power plant" in the U.S. was ready for operation.[49] Water from Courtright Lake, high in California's

Sierra Nevada, is drained into Lake Wishon through a three and three-quarter-mile-long tunnel, and fed through a large underground hydroelectric plant, following a vertical plunge of 1,500 feet about four-fifths of the way through the mountain. Turbines are reversed during off-peak hours to pump the water back into Courtright Lake. A large quantity of power is made available for use during peak hours. Where such facililities can avoid construction of new potentially more environmentally damaging plants, the feasibility is suggested by this comment in Environment, ". . . It will provide about half as much electricity as California's Diablo Canyon nuclear power plant for only a quarter of the construction cost."[50]

Environmental Impact

Environmentalists and small-scale hydropower developers have recognized the necessity of evaluating both the environmental impact of a specific site and the cumulative impact of developing many sites on a given river or stream. Ordinarily one or several small-scale dams would be much less destructive to cropland, the watershed, and plant and animal species than one large dam. However, excessive development of small-scale hydropower on some river basins may be even more damaging. In June, 1985 the "more than 700 applications pending for hydropower permits, licenses, and exemptions" in four states in the Pacific Northwest illustrated the concern, according to The Worldwatch Institute.[51]

Various state, regional and federal commissions have studied the potential environmental problems associated with the development of hydropower. The effects on food production, plant and animal habitat, fish migration and breeding, silting or muddying of river bottoms, and recreational uses are among the important concerns. While small-scale hydropower development at existing dams does little to alter existing watersheds, long-term environmental consequences are a valid consideration.

Although the National Wildlife Federation supported the Public Utilities Regulatory Policies Act of 1978 as a means of encouraging the development of renewable energy resources which do not adversely affect the environment, they reacted strongly when the Federal Energy Regulatory Commission implemented the law. Two specific concerns were the giving of financial incentives to the development of new hydroelectric projects and to the failure to examine individual applications in the context of the cumulative impact of the total number of small-scale projects being developed on a particular river basin. The Federation saw these decisions as changing the intent of the law. Although they intervened in specific cases to insure that the environment was protected, the Federation did not object to refurbishing of old, small-scale dams.[52]

The development of many small dams poses a serious threat to anadromous fish. These include salmon, sea-run trout, shad, and sturgeon, among others. Any threat to depletion of the run of these

fish tends to lead conservation groups to file intervenor petitions with FERC.[53]

A worst hassle scenario illustrates the importance of potential school hydropower users dealing appropriately with environmental concerns. In developing a hydropower project at the Winchester Dam in Oregon Dixon Collins tried to protect the Umpqua fishrey from harm. According to Marc Reisner, Collins made exhaustive efforts to anticipate any potential criticism and effectively address them ahead of time:

> . . . He proposed to do this by installing the last word in state-of-the-art fish protection features: a state-of-the-art fish screen, a state-of-the-art fish ladder, a state-of-the-art tailrace flume and attraction channel. He also proposed to move the power plant to the north side of the river and install the fish ladder on the south side, where the migrating adult fish tend to move. He would settle for one and a half megawatts instead of the historical four, which would result in lower flows through the turbines--such flows being the prime cause of mortality among young fry and smolts, which either enter the turbine and are killed by depressurization or are impinged by suction on the fish screens designed to prevent them from going in. He would increase flows down the fish ladder by 700 percent in order to create a greater attraction to the upriver-migrating adult fish. He would also commit half a million dollars to modifying the sheer downstream wall of the spillway, which would help flush the helpless young fish out of rockpile and a vicious hydraulic hole at the base of the dam.[54]

Although Collins was able to secure an exemption from its normal licensing process by FERC, his company, Elektra Power Corporation was soon to find itself involved in a series of court battles involving the Oregon Department of Fish and Wildlife and the National Marine Fisheries Service. After agreed upon modifications and "the toughest environmental binding contract ever negotiated on a small-hydro project in the United States," a relatively small fish kill led to a temporary

shutdown of Elektra's project.[55] The case eventually involved fourteen separate legal actions. It appeared likely that there would be future legal battles.

By the fall of 1984 a great number of applications, primarily from private developers and utility companies, had been filed to construct low-head hydropower dams in the Northwest. Reisner reported these statistics: Oregon, about 300 applications; California, about 600; Washington, about 400.[56] With such a large number of requests to build new dams, many of which could potentially harm the run of anadromous fish, there was appropriate cause for concern.

In 1983 a number of environmental groups were raising very serious questions about potential damage to entire river systems due to the cumulative effect of many small dams on a single river and its tributaries. The review of hydro projects on a case-by-case basis rather than in the context of the an ecosystem by FERC fails to adequately address concerns like those expressed by Phillip Johnson:

> . . . Even if state-of-the-art fish-passage technology is installed, dams can have more subtle effects that may cumulatively impair the biological health of an entire watershed. Erosion, alteration of sediment flow or gravel distribution, effects on wildlife of new roads and transmission lines, oxygen depletion or nitrogen supersaturation of the water, warming of flowing water impounded behind dams, all may be deemed marginal at any given site yet reach a critical level when rivers are filtered through dams in a series.[57]

Even when only a small portion of the water in a stream is diverted to a pipeline to produce hydropower the developers are subject to environmentists' criticism. Such diversion structures, channeling a relatively small amount of rapidly falling water through a pipeline

known as a penstock, have accounted for the greatest number of applications to FERC.[58] The potential environmental effects are more subtle in many of these settings where the streams fall too rapidly for migratory fish to swim in them. The temporary impounding of the water at several sites on the same stream or river may have the cumulative impact of raising the temperature of the water "beyond the tolerances of cold-water fish" and reducing the nutrients in lower levels of the food chain.[59]

In some places the approach of environmental interests has been to work with environmentalists to designate potential sites which are acceptable for hydropower development. An alliance of several groups in Maine led to the designation of "33 sites, capable of producing 211 megawatts."[60] The dependence of small-scale hydropower producers on the availability of water may tend to make them more sensitive to the needs of other creatures which share their environment.[61]

Availability of Small-Scale Technology

The US has been slow in developing small-scale hydropower technology which is both innovative and economically competitive. The limited level of inventiveness in the use of hydropower was evident in a 1981 US Department of Energy report which indicated a larger number of new patents in the use of biomass, geothermal, wind, ocean, and solar (overwhelmingly larger than the others) than in hydropower.[62] However, the emphasis on appropriate technology for the Third World is

increasingly serving the needs of small-scale applications in the industrialized world as well.

Several innovations in small-scale hydro-technology have been encouraged by the Intermediate Technology Development Group in England. The efforts of this group have been to develop more efficient, mobile, small-scale, and capital competitive technology. One technology which was still being tested in 1981 showed great promise. The Reading team adapted a vertical axis, four-blade windmill designed by Peter Musgrove for use "under water in a free-flowing stream."[63] By testing in the Thames, they found that this water turbine satisfied the requirements of smallness, mobility and efficiency. The three-feet diameter "underwater windmill" produced the power equivalent of a traditional water wheel twenty times as large in diameter. It was expected to satisfy the criterion of being capital competitive, as stated by McRobie, "This water turbine required the highest skills to design it; but it would be inexpensive and easy to make, and can be adapted to water pumping or electricity generation as required.[64]

Similarly, in March, 1982 reports were being circulated in Canada about the development of an aquatic windmill whose blades were turned by moving water in a free-flowing stream.[65] Barry Davis, the inventor, found water turned the propellors with greater ease than wind. Ottawa's National Research Council (NRC) developed a five-foot test watermill which was described as resembling a turnstile. A NRC spokesman indicated the potential of this technology:

> . . . The device has a potential output of 5.6 kilowatts of power anywhere there are five feet of water moving at five feet per second. Deeper and faster water would, of course, produce more energy.[66]

While this specific device would be expected to meet only the needs of a couple classrooms in a school setting, it could be scaled up in size or used in series at larger facilities.

Unfortunately, Canada is a less suitable site than a temperate zone for the development of this kind of technology due to ice-infested waters. However, its enormous potential was indicated by Bruce Pratte of NRC even in frosty climates: "British Columbia's tidal streams and the Mackenzie, Frazier and Slave rivers alone hold 38,000 megawatts of potential electrial power."[67] That compares favorably to the 40,000 megawatts of hydropower which had been developed in Canada in 1982.

Watermills in a free-flowing stream offer distinct advantages. Since a dam is unnecessary, they offer savings on construction costs, unimpeded flow of silt and nutrients, free movement of fish, and no alteration of water tables.[68]

Large-scale technology is frequently inappropriate for small-scale settings. McRobie reported two inventions which promise to provide cost effective use in small-scale hydropower development which do not depend on a stream of high volume or high pressure. Rupert Armstrong-Evans invented an electronic load control device for use where water flow is small. It does not require a high-cost governor to control a large volume of water passing through a turbine to provide a consistent quantity of electricity. To replace the costly governor,

McRobie stated, "Armstrong-Evans has invented a relatively simple and very low-cost electronic device which controls the output of electricity rather than the intake of water . . . ."[69] This permits a reduction as high as two-thirds in the cost of small hydro installations. In 1981 this device was already being used at thirty sites in Britain and in several Third World countries.

Armstrong-Evans also invented turbines capable of operating effectively in lower heads of water than were formerly feasible for hydroelectric power production. McRobie described the turbine as looking "very like a ship's propellor."[70] However, it is less difficult to make and requires that water fall as little as two or three feet to generate power.

The electronic load control device and the low-head turbine greatly expand the potential uses of mini-hydro installations. According to McRobie, the power potential of small applications of these two inventions could meet the needs of ". . . a village of a thousand people to pump their water supplies, run agricultural processing equipment, power a sawmill or workshop, and do some irrigation."[71] The Third World applications McRobie suggested could also be effectively applied in some settings in the US.

McRobie concluded that these inventions "compare favourably with modern thermal power stations in terms of capital cost."[72] Additional savings are achieved due to free fuel and very minimal transmission costs. Furthermore, the small-scale of such devices lends the advantage of local maintenance.

The United States and Canada have purchased Chinese services of design and installation of small hydro turbines and generators. China is the world leader in development of small-scale hydroelectric plants. Indeed, that country alone has built more than 90,000 small-scale hydro systems in the last thirty years.[73] In 1978 the average capacity of small-hydro stations in China was about 50 kilowatts.[74]

A French company made the bulb turbines used at Idaho Falls, Idaho on the Snake River. The bulb turbine permits the generator, since it is enclosed in a metal bulb, to be placed under water. Broad said,

> . . . This eliminates the cost in conventional systems of housing the generator separately. Because of their small size, bulbs are ideal for dams of less than 20 feet—about 34 percent of the existing dams in the United States.[75]

With partial DOE funding, this project was the first to use this type of turbine in the US although the worldwide installation of this system had reached a total of 350 in 1978.

The Hydro-Turbine Division of Allis-Chalmers in Pennsylvania brought a small turbine, called the Tube Turbine, on the market about the same time. These turbines were standardized, rather than being custom designed, to cut costs, with sizes ranging "from 50 kw to 5,000 kw" and capable of handling "up to 50 foot heads."[76]

In 1978 a French company was marketing miniature hydroelectric power plants, called Hydrolec, ranging in size from half a ton to one and one-half tons, standing from four to twelve feet high, and producing from five to forty kilowatts. The plants operate on the siphon principle. Prices began at $7,800 for a system adequate for heating a

small country home. The largest systems was described as "sufficient for heating seven rooms in the average French climate."[77]

The kind of equipment needed to utilize water power depends upon the pressure and volume of the falling water. High-head projects, utilizing water falling from great heights, permit the diversion of a much smaller amount of water to produce more energy. Phillip Johnson stated that "head" is "the term used to describe the distance water falls between two points."[78] According to Herron, the turbines used at high-head projects need to be equipped to

> ". . . utilize the weight of water piled hundreds of feet in a penstock and release through high-pressure jets against a whell of buckets: the impulse turbine or Pelton wheel--abundant energy from relatively little water."[79]

Much of the riparian landscape in the western U.S. requires turbines which respond to a large volume of water flowing through a broad valley floor, served by slow-moving water in irrigation canals. A high volume, little fall, and, therefore, low pressure water supply is best served by low-head, high volume technology designed to generate energy by responding more to volume than pressure. Herron stated:

> . . . Water in volume, conveyed through a fall of 60 feet or less from a dam or reservoir, yields power with little pressure: this setup requires the Francis turbine, a chambered nautilus of gently curving vanes spinning in the base of the powerhouse.[80]

Turbines are also needed which are capable of responding to fluctuating levels of water at dams. The Ossberger turbine has been developed featuring "adjustable vanes that can adapt to changes in water volume."[81] This avoids the wasting of power provided by local floods.

Cost Advantages

Small-scale hydropower can be installed quickly at relatively low cost in appropriate settings when all factors are considered. While hydroelectric plants may cost about two and one half times as much as a coal plant, the lack of fuel costs, minimal operating costs, and short construction make this renewable energy resource financially attractive.[82] When hydropower can be added to an existing dam, the cost is much lower than building a new power plant.

Citing worldwide trends in 1982 away from thermal powered electricity based on oil to coal and uranium, C. L. Boltz saw cost advantages in the use of hydroelectric power. Suitable topography is a major criterion for cheap hydroelectric power. Where this criterion is met, as is the case in Norway, according to Boltz, it is "the cheapest source of electricity."[83] While not so topographically fortunate as Norway, may high-head hydro sites are available in the US.

Although the large-scale hydroelectric plants built during the Depression and the New Deal in the Pacific Northwest are not viewed as appropriate new technology development in the US today for environmental reasons, they do suggest the potential savings achieved by the use of hydropower. Marc Reisner put it this way:

> . . . Because they were built, for the most part, on big constant rivers with Depression labor or Eisenhower interest rates, the dams' most notable by-product, hydroelectricity, was cheap--about the cheapest power in the entire world. In 1974, $196.01 worth of electricity purchased from Consolidated Edison in New York City would have cost $24 from Seattle City Light. . . .[84]

Durability of Equipment

Among the advantages of hydropower systems is their durability. The expected life of most hydro systems is "two to three times the expected life of a conventional thermal power plant" which uses oil, coal or uranium as fuel.[85] An expected life of fifty years or longer for a well-built hydroelectric plant, with very little maintenance, exceeds the life of many school facilities.

Licensing and Other Delays

Most school districts would do well to limit their interest in hydropower to retrofit projects which use existing dam sites or multipurpose projects which to do little to restrict water flow. A number of conflicting interest groups, including utility companies and commissions, boards controlling water quality, those interested in fish, wildlife and water sports, the seafood industry, farmers, historic preservation groups, competing hydropower developers, local, state and federal government agencies and institutions, and real estate developers, among others, vie for control of use of waterways. Consequently, the Federal Energy Regulatory Commission (FERC), an independent federal licensing board, was created to expedite matters related to licensing requirements imposed by federal, state and local government agencies and commissions. Based on experiences of delays of sixteen months to several years, the small-scale hydro division of the Department of Energy tried to streamline regulatory processes involved in application for licenses to develop small-scale hydropower projects.

A goal of from three to six months was set "for plants smaller than 1,500 kw and to less than a year for large units."[86] The need of regulations in Michigan was clearly evident in the comparative income between two conflicting interest groups, with sports fishing generating more than $100 million annually in 1980, compared to a maximum potential of $10 million per year if all dormant hydro sites were renovated.[87] In some instances efforts to reduce regulations have led to more court actions rather than less and, consequently, to additional delays.

School districts or boards of trustees wishing to apply for permits to develop hydropower projects will discover that their state energy office has a person designated to assist in securing the needed information. The Federal Energy Regulatory Commission will process the application and facilitate and coordinate compliance with the federal laws and state and local statutes. For example, Michigan identified at least 17 federal laws and "10 state statutes that might be invoked to directly or indirectly influence hydro development."[88]

The growth of interest in such projects is evident in the number of permits sought, with FERC receiving 18 applications in fiscal year 1977, 1,858 in 1981,[89] and 1,682 in 1982. The 1982 applications included 475 requesting "exemption from full licencing review."[90]

When a hydropower project is expected to produce fewer than five megawatts (5,000 kilowatts), the developer may apply for an exemption from licensing. However, this does not necessarily eliminate the agency entanglements. Matt Herron expressed it this way: "Such exceptions are restricted to projects that are environmentally benign, and state and

federal environmental agencies have absolute authority to impose their requirements on a developer."[91]

In the winter of 1985 the Sierra Club filed suit against FERC seeking to bring an end to federal incentives for new dams. Their basic contention was that, when Congress enacted PURPA in 1978 and the Energy Security Act of 1980, the intention was that federal incentives "apply only to the installation of generators on existing dams."[92] FERC had applied the special incentive to new hydropower projects up to the 80 megawatt limit. The consequence was "a 4,000 percent increase . . . in proposals to build new hydroelectric projects" from 1980 to 1985.[93] If the Sierra Club could not eliminate the incentives, they sought "at least the preparation of an environmental impact statement and revision of FERC regulations."[94]

Expanding Resource Use at Hydropower Sites

While the gravitational energy of falling water has been the traditional source of power at hydropower sites, in 1979 J. L. McNichols and others suggested that a new energy use be added to current hydroelectric reservoirs.[95] They identified the source of energy as "the solar thermal energy stored in hydroelectric reservior thermoclines. . . ."[96] In contrast to the ocean and to solar salt ponds where temperature increases with depth and increasing salt concentrations, the temperature is significantly higher at the surface in fresh water than at greater depths. The heat engines being developed for ocean thermal energy conversion use small differences in temperature

at different depths of the ocean as the source of their power. This technology which is still being developed could be applied to fresh water temperature differences with less abrasive effects due to lower salt concentrations.

Nichols and others offered a number of advantages of use of the thermocline energy source. First, use of this resource would make available more electric power than is available in the existing hydropower reservoir using traditional hydroelectric technology. Second, ". . . power conditioning and transmission equipment are already installed at such sites."[97] Third, the way in which hot and cold water are used in the thermal energy conversion engines is well adapted to providing a water output suitable to downstream usage. Fourth, seasonal variations in water temperature ". . . correspond to the times of peak power demand."[98]

Although the ocean thermal energy technology (OTEC) is still being developed, potential fresh water applications offer a useful addition to the reasons for the development of OTEC heat engines, along with use on oceans and at solar salt ponds. It seems probable that this technology will be numbered among the cost effective renewable energy systems of the next century, providing an abundant new source of energy behind fresh water dams. Furthermore, colleges and universities in proximity to suitable sites would appropriately be numbered among the institutions piloting this technology in the next decade.

Development of Small-Scale Hydropower

When the Army Corps of Engineers completed its evaluation and reported to President Carter, the assessment of small-scale hydro potential was generally favorable. William J. Broad offered this conclusion:

> The Corps . . . in its final report to President Carter concluded that "none of the identifiable constraints to the development of hydroelectric power at existing dams are insurmountable and that the national potential is of such significance to warrant the rapid selection and development of small-scale hydro demonstration projects."[99]

Schools have had limited participation in such projects.

The Department of Energy has assessed regional resources and recommended some sites for development. It has also assisted in the development and evaluation of new hydro technology. In April, 1978 fifty initial grants were awarded for small-scale (up to 15,000 kilowatts) hydro feasibility studies at existing dams.[100]

One of the early DOE awards of major funds for construction was for a four-year period to the city of Idaho Falls, Idaho. The DOE was providing $7.3 million of an anticipated eventual $43.8 million to build the project. The grant was intended to accomplish the two-fold purpose of tripling the electricity output of three small, Snake River dams and to "test the efficiency of bulb turbines at small generating sites."[101]

Another early DOE feasibility study funds recipient provides an irrigation system which does double-duty by generating the electricity needed for the irrigation system. This central California area is primarily powered by high-head hydro with water originating high in the

Sierras. However, some of the untapped, low-head potential of the irrigation system is located in places where the water in the canal drops from six to twenty-six feet. Installation of two hydroelectric systems at a 17-foot drop and a 26-foot drop were expected to generate approximately 4,500 kilowatts of needed electricity.[102]

Public utilities, private entrepreneurs, government agencies, and even a few schools have begun developing small-scale hydropower. Broad indicated that Lawrence Gleeson of Belfast, Maine, was the first of the small investors on record to begin exploiting small-hydro sites.[103] In 1976 Gleenson started with two sites and by 1978 had plans to develop 20 dams through corporations in Maine and Pennsylvania. The first dam site began producing 100 kilowatts of power for the Central Maine Power Company's grid in February of 1978. Another setting which illustrates the financial merit of small-scale hydroelectric renovation was provided in Bartlett, N.H., where sales of electricity to the town recovered the investment capital in about a year.[104]

Utility companies in Syracuse, N.Y., and in Massachusetts were among the first to rehabilitate shall hydroelectric plants. The Syracuse utility company planned to add 205,000 kW to its system over a 14-year period through expansion, rehabilitation and building of facilities at 15 small sites, the smallest being a 2,000 kW unit.[105]

A study by the Polytechnic Institute of New York, funded by New York State's Energy Research and Development Authority, identified more than 1,400 dams in the state. The potential electric power, if developed, might be one million kilowatts of relatively cheaper power

since the fuel bills in the Northeast were the highest in the country in 1978. To encourage the technology and development on various scales, plans were being made to assess renovation possibilities and provide grants for development at several of the more beneficial sites where power output would range from 50 kilowatts to 1,500 kilowatts.[106]

Educational Use of Hydropower

Depending on the location, educational administrators, wishing to develop hydropower resources, will appreciate the distinction between low- (usually large volume, with little fall) and high-head (high fall and high pressure) hydropower (Figure 5, p. 388). Peter Kakela and others offered the basic concept this way, "At hydro facilities, the amount of energy that can be generated depends on two factors: the volume of water (flow) and the vertical distance the water falls (head)."[107] A high-head hydropower site is usually more economical than a low-head site because a smaller volume of water, flowing more rapidly, with greater pressure, can generate more energy using a smaller turbine. Furthermore, low-head sites more seriously impact the surrounding land if increased power is gained by flooding a significant area behind a dam to increase the volume of water available for electricity generation.

Kakela and others described the relative hyrdopower disadvantages of Michigan due to terrain affording few opportunities for high-head projects. They stated the pros and cons of such settings, beginning with this perspective:

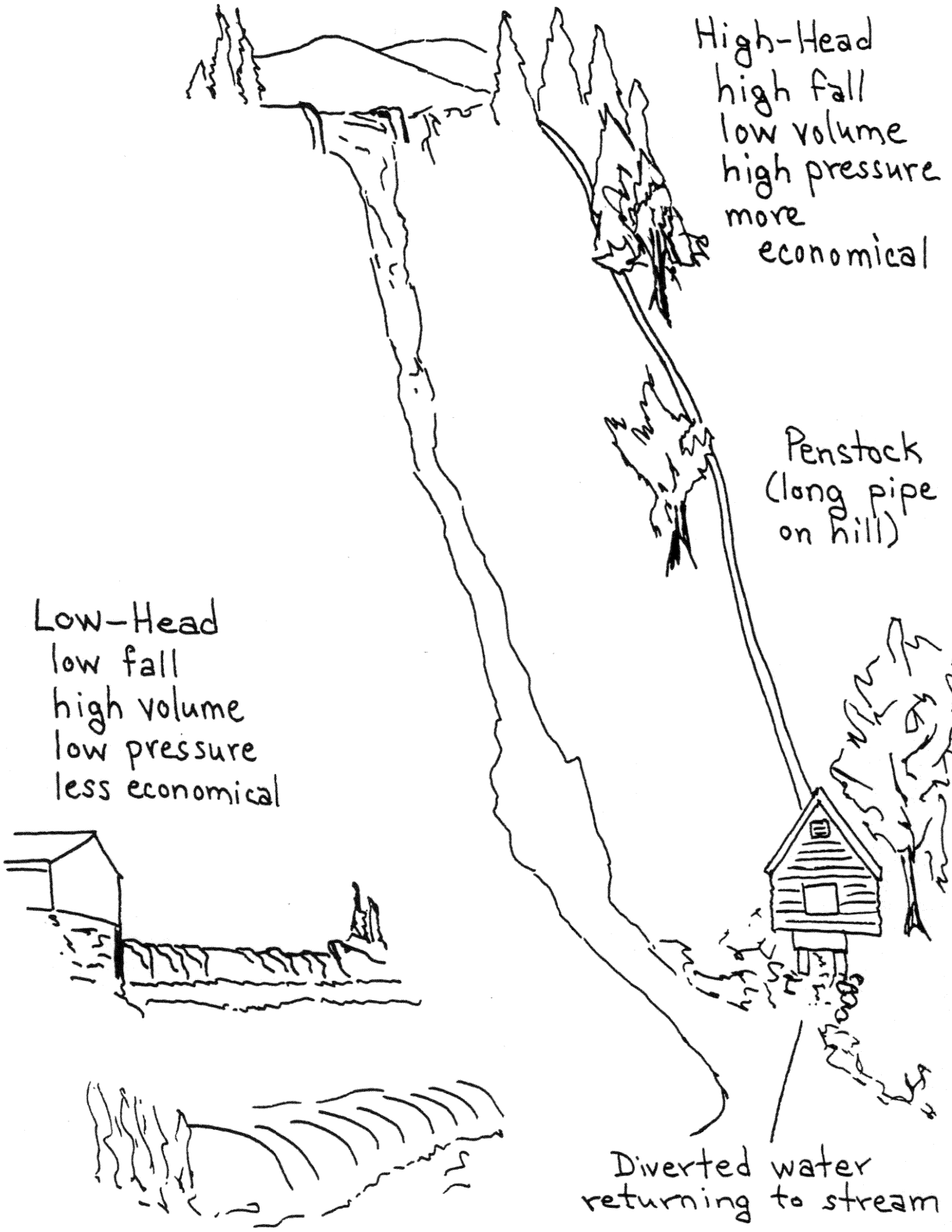


Figure 5

Low- and High-Head Hydropower

> . . . Michigan ranks third in the nation for both the number of retired hydro dams and the amount of unused hydro-generating potential . . . . People living in states with plenty of water, but not much fall, can readily identify with Michigan. Those living in other states with greater topographical relief, or even more water, can expect low-head hydropower to make a larger potential contribution to their state's supply of electricity. Residents of flatter or dryer regions than Michigan must obviously expect a smaller contribution.[108]

In 1985 Kakela and others reported that rehabilitation of the 30 sites which offer the greatest potential would satisfy only 0.7 percent to Michigan's power needs, compared to the current generating capacity of approximately 2.7 percent at 80 existing hydroelectric sites.[109]

Feasible sites for economical development of hydropower are more readily available in some areas of the country than in others. Eastern and central states are likely to have fewer sites available, although some relatively low-head sites are obtainable for development. New England and the Pacific Northwest have more accessible high-head sites. When these sites can be developed without long transmission lines, they are a highly appropriate renewable energy choice for electricity generation.

Self-sufficiency in energy production is usually more feasible in a small town or rural community. Limited availability of hydropower should not be a factor in selecting its use. Other forms of renewable energy may complement this resource, including the use of heat energy in the water behind the dam, by use of heat exchangers, or by application of ocean thermal energy conversion technology to a fresh water setting.

Amory B. Lovins and others recommended a mixing of hydroelectric, windpower and photovoltaics to achieve a high level of

self-sufficiency in renewable energy. He reasoned that these technologies tend to "work better at different times."[110] Furthermore, current hydroelectric capacity and the potential redevelopment of large and small sites could go a long way toward solving the problem of bulk storage of electricity.

An article in American School & University characterized Richard Thomas, vice president of finance at Arkansas College, as a "financial wizard" due to an innovative plan to use hyrdoelectric power production to raise needed funds.[111] In 1977 the college president had instructed Thomas to purchase property for the college's rivers program. The 45-acres site, on the White River, including "an old lock and dam structure built around the turn of the century," offered the potential to profit by the Public Utility Regulatory Policies Act.[112]

In implementing PURPA, private investors who approached Thomas about the potential use of the property led him to discover that "the Federal Energy Regulatory Commission (FERC) gave priority to municipal or government agencies."[113] Actually, according to Matt Herron, "A provision of the 1920 Federal Waterpower Act . . . gives unqualified preference to any qualified municipal body: a city, a flood-control or irrigation district, a state agency."[114] On this basis, the college and the county jointly agreed to apply in 1980 for a license to study the feasibility of developing the site. The resulting study demonstrated that the joint owners would find the construction of a power plant profitable. The expected first year of operation was 1987.

The profits to the college were to come from its share of the power produced and tax incentives. Investment tax credits for hydroelectric projects were boosted to 21 percent by the Energy Security Act of 1980.[115] It was estimated that "By the year 2000, the college's share of the profits could reach the $4 million mark."[116] Tax incentives include ". . . a 10% investment tax credit plus an additional 11% for producing power."[117] Thomas indicated that ". . . the write-off period may be as short as five years."[118]

Many unconventional hydropower technologies have emerged in recent years which call for a broad reassessment of the potential of water power. Some of those were mentioned in this study, such as, pumped storage, application of ocean thermal energy conversion technology to water stored behind dams, use of hydropower in free flowing water, and hydrobarges. These new technologies promise many new applications which call for appropriate demonstration projects, some of which could save public funds in educational settings. However, a review of Energy Research Abstracts from 1981 through 1985 revealed no additional leads to information concerning the development of such projects being studied or funded in educational settings.

CHAPTER 8 ENDNOTES

1. Lester R. Brown, "The Coming Solar Age," Natural History, 91:2:47, February, 1982.

2. Ibid.

3. Peter Kakela, Gary Chilson, and William Patric, "Low-Head Hydropower for Local Use," Environment, 27:1:32, January/February, 1985.

4. Ibid.

5. William J. Broad, "Small Hydro: Sleeping Giant," Science News, 114:3:43, July 15, 1978.

6. Ibid., p. 42.

7. "Hydro and Geo," Scientific American, 242:4:64, April, 1980.

8. Richard C. Dorf, Energy, Resources, & Policy (Reading, Massachusetts: Addison-Wesley Publishing Co., 1978), p. 147.

9. Harry Bacas, "Energy: A Promise Renewed," Nation's Business, 73:7:35R, July, 1985.

10. "Update/Hydropower: Hydropower Potential," Science Digest, 90:3:18, March, 1982.

11. Lester R. Brown, op. cit., p. 47.

12. C. L. Boltz, "Energy: Electricity," Britannica Book of the Year (1983) (Chicago: Encyclopaedia Britannica, Inc., 1983), p. 344.

13. Ibid.

14. Lester R. Brown, op. cit., p. 47.

15. Ibid.

16. Ibid.

17. "Big Energy Supplies From Little Dams," The Futurist, 19:3:50, June, 1985.

18. Ibid., p. 51.

19. "Update/Hydropower," Science Digest, 90:3:19, March, 1982.

20. "Update/Hydropower: Hydropower Potential," Science Digest, 90:3:18, March, 1982.

21. "Hydro and Geo," op. cit., pp. 64 & 66.

22. Harry Bacas, op. cit., p. 35R.

23. "Hydro and Geo," op. cit., p. 66.

24. Lester R. Brown, op. cit., p. 48.

25. Marc Reisner, "Power, Profit, and Preservation: The Invasion of Small-Scale Hydropower," Wilderness, 48:166:32, Fall, 1984.

26. William J. Broad, "Small Hydro: Sleeping Giant," Science News, 114:3:43, July 15, 1978.

27. Phillip Johnson, "Will Small Dams Create Big Problems?," National Wildlife, 21:6:20, October/November, 1983.

28. Ibid.

29. Matt Herron, "The rush is on to find new gold in falling water," Smithsonian, 13:1:87, December, 1982.

30. Peter Kakela and others, op. cit., p. 32.

31. William J. Broad, op. cit., p. 43.

32. Phillip Johnson, "Energy: On Oregon River and Elsewhere, Small-Scale Hydro Is a Mixed Blessing," Audubon, 85:3:141, May, 1983.

33. Ibid.

34. William J. Broad, op. cit., p. 43.

35. Ibid.

36. Matt Herron, op. cit., p. 88.

37. Timothy A. Fausch, "Hydro Growth Peaking In Michigan, Midwest," Alternative Sources of Energy, 80:29, April, 1986.

38. Ibid.

39. William J. Broad, op. cit., p. 46.

40. "Small Hydro Branches Out," Environment, 26:9:21, November, 1984.

41. Ibid.

42. Ibid.

43. Ibid.

44. "Big Energy Supplies From Little Dams," The Futurist, 19:3:50, June, 1985.

45. Matt Herron, op. cit., p. 88.

46. Ibid.

47. "Big Energy Supplies From Little Dams," op. cit., p. 51.

48. Ibid.

49. "Underground Hydropower," Environment, 26:3:22-23, April, 1984.

50. Ibid., pp. 22-23.

51. Ibid.

52. Jay D. Hair, "Small Dams Pose Perils, Too," National Wildlife, 21:6:30, October/November, 1983.

53. Phillip Johnson, "Energy: On Oregon River and Elsewhere . . .," op. cit., p. 142.

54. Marc Reisner, "Power, Profit, and Preservation: The Invasion of Small-Scale Hydropower," Wilderness, 48:166:28, Fall, 1984.

55. Ibid.

56. Ibid., p. 30.

57. Phillip Johnson, "Energy: On Oregon River and Elsewhere . . . ," op. cit., p. 142.

58. Phillip Johnson, "Will Small Dams Create Big Problems?," op. cit., p. 20.

59. Ibid.

60. Ibid., p. 21.

61. Kathleen Courrier and others, Shining Examples: Model Projects Using Renewable Resources (Washington, D.C.: Center for Renewable Resources, 1980), pp. 86-87.

62. Information Resources in the USA on New and Renewable Energy: A Description and Directory (United States Department of Energy: Technical Information Center, June 1, 1981), p. 13.

63. George McRobie, Small Is Possible (New York: Harper & Row, 1981), p. 53.

64. Ibid.

65. "Update/Hydropower: Aquatic Windmills," Science Digest, 90:3:19, March, 1982.

66. Ibid.

67. Ibid.

68. Ibid.

69. George McRobie, op. cit., p. 53.

70. Ibid., p. 54.

71. Ibid.

72. Ibid.

73. Ibid., p. 50.

74. William J. Broad, op. cit., p. 46.

75. William J. Broad, op. cit., p. 46.

76. Ibid.

77. Ibid.

78. Phillip Johnson, "Will Small Dams Create Big Problems?," National Wildlife, 21:6:18, October/November, 1983.

79. Matt Herron, op. cit., p. 89.

80. Ibid.

81. "Update/Hydropower: Community Hydro Plants," Science Digest, 90:3:19, March, 1982.

82. "Big Energy Supplies From Little Dams," op. cit., p. 50.

83. C. L. Boltz, "Energy: Electricity," Britannica Book of the Year (1983), Chicago: Encyclopaedia Britannica, Inc., 1983, p. 344.

84. Marc Reisner, op. cit., p. 27.

85. William J. Broad, op. cit., p. 43.

86. Ibid.

87. Peter Kakela and others, op. cit., p. 37.

88. Ibid., p. 36.

89. Phillip Johnson, "Energy: On Oregon River and Elsewhere . . .," op. cit., p. 141.

90. Phillip Johnson, "Will Small Dams Create Big Problems?," National Wildlife, 21:6:20, October/November, 1983.

91. Matt Herron, op. cit., p. 92.

92. "Suit to Slow Small Hydro," Environment, 27:1:23, January/February, 1985.

93. Ibid.

94. Ibid.

95. J. L. McNichols, W. S. Ginell and J. S. Cory, "Thermoclines: A Solar Thermal Energy Resource for Enhanced Hydroelectric Power Production," Science, 203:4375:167, January 12, 1979.

96. Ibid.

97. Ibid., p. 168.

98. Ibid.

99. William J. Broad, op. cit., p. 43.

100. Ibid., pp. 43 & 46.

101. Ibid., p. 46.

102. Ibid.

103. Ibid., p. 43.

104. Ibid., p. 46.

105. Ibid., p. 43.

106. Ibid., p. 46.

107. Peter Kakela, Gary Chilson, and William Patric, "Low-Head Hydropower for Local Use," Environment, 27:1:31, January/February, 1985.

108. Ibid., p. 32.

109. Ibid., p. 37.

110. Amory B. Lovins and others, Least-Cost Energy: Solving the CO_2 Problem (Andover, Massachusetts: Brick House Publishing Company, 1981), p. 110.

111. "Four Financial Wizards," American School & University, 55:12:19, August, 1983.

112. Ibid.

113. Ibid.

114. Matt Herron, op. cit., p. 92.

115. Phillip Johnson, "Will Small Dams Create Big Problems?," op. cit., p. 20.

116. "Four Financial Wizards," op. cit., p. 19.

117. Ibid.

118. Ibid.

Chapter 9

GEOTHERMAL ALTERNATIVES

Geothermal energy is one of three basic, known energy sources capable of providing energy that cannot be depleted in the foreseeable future. The others are solar energy and controlled nuclear fusion which still faces enormous technological barriers to its large-scale application.[1]

A number of features recommend its use in school settings. Unlike nuclear energy, geothermal energy can be developed in an economical way on a small scale. Like solar energy, geothermal energy is, in principle, renewable, adequate to supply our energy needs, and in most, although not all, cases available in low density.[2] Like direct and indirect forms of solar energy, in appropriate settings this relatively cheap and environmentally safe energy resource does not require long lead times for its development.

However, residents of the Mt. St. Helens area know well the risks associated with living near some of the better geothermal energy sources. Likewise, coastal farmlands have sometimes subsided below sea level during periods of volcanic activity. Geophysicists have made residents of such areas aware of both the potential energy resource and the importance of "laser beams, tiltmeters, riftmeters and seismometers" in measuring the activity of hidden magma chambers to provide advanced warning of earthquakes and volcanoes associated with some areas where geothermal energy is plentiful.[3]

Definition

The source of geothermal energy is the heat inside the earth. The extent of heat energy theoretically available is suggested by the fact that the temperature of the earth's molten core is about 4,500°C, the temperature at the bottom of the earth's crust is about 1,000°C, and the temperature increases from about 20 to 30°C with each kilometer of depth.[4] Richard C. Dorf defined geothermal energy as "the heat energy available in the rocks, hot water, and steam in the earth's subsurface."[5] Contrary to occasional comments in renewable energy literature, it is not a derived form of solar energy, except that soil very close to the earth's surface absorbs solar heat and maintains a relatively stable equilibrium throughout the year. The magma or molten rock in the earth's core, radioactive decay of rocks, friction, especially, the friction of crustal plates, and chemical reactions generate the geothermal heat in the earth's interior. The intense heat is continually radiated to the earth's surface. The cooler outer crust of the earth stores a potential heat source "so vast relative to human needs that it is for all practical purposes a renewable resource," according to Lester R. Brown.[6] Molten rock pouring from an erupting volcano provides a vivid image of the tremendous potential energy in this resource base. Most of the quality sites in the United States for using this source for electrical power are located in the West.

While precise quantification of the available resource base is not likely to be known with any precision for many years, the locations

of greatest potential are readily identified by the presence of frequent volcanic activity and other geological information.[7] Lester R. Brown defined a rich resource base where the crust of the earth is thin, including the US:

> . . . The earth's richest geothermal resources are in the so-called ring of fire that stretches from New Zealand up through New Guinea, the Philippines, Japan, western Siberia, and then down the western United States, Mexico, Central America, and the west coast of South America.[8]

Geothermal energy is already a well developed alternative energy resource with a rapidly changing technology available for its use. It fits broadly within the category of renewable energy resource systems since it is virtually inexhaustible, although there are apparently real limits to its availability. While geothermal energy is widely available for heating purposes, it is available for practical application in electricity generation in relatively few geographical areas of the US.

Potential

The geothermal literature reveals a considerable range of opinions about the potentital resource base available and its most probable uses. In 1974 S. David Freeman reported a wide range of estimates in the scientific community regarding potential geothermal power available. Low estimates indicated a potential of about 100,000 megawatts in the western US. The highest US estimate of available geothermal power was 10,000,000 megawatts, which compared to a 400,000 megawatts total electric power capacity in the US in 1972.[9] It was evident in 1974 that US government estimates of potential geothermal

energy contributions (less than one percent of total national power capacity through 2000) were far below the assessments coming from the scientific and technical community.[10]

The perceived uses of geothermal energy affect the estimates of the geothermal potential. In 1979 the US led the world in electrical application of high temperature geothermal heat resources while the Soviet Union and Hungary used lower temperature geothermal sources for direct heat, greatly exceeding the rest of the world in this respect.[11] Based on limited geothermal exploration and experience, in 1975 Marc Kramer and others stated that

> . . . Most recent estimates indicate that geothermal energy resources from hyperthermal zones are commensurate with the worldwide hydroelectric resource while the resources from low temperature zones are much more extensive. Limited experience to date has shown that geothermal power produced from high temperature steam fields is economically competitive with fossil fuel power.[12]

Their estimates raised a serious third energy contender for the future, as follows: ". . . Total potential resources from the hyperthermal and low temperature geothermal reservoirs are vast and far outweight any present conventional energy source."[13] Kramer and others reported one thousand-fold increases in geothermal resources estimates from 1965 to 1975. In the 1970s estimates moved beyond the hypothermal zones containing ground water to include the more extensive dry hyperthermal zones as alternative technologies were being developed to determine the feasibility of dry fields.[14]

By the early 1980s the US was taking more seriously the low temperature geothermal zones, both those with naturally occurring water

to enable heat extraction and those which would require water injection to extract the heat energy. The US was not prepared by exploration to state emphatically the size of the resource.

By contrast to low, early U.S. government projections, the Soviet Union's extensive geothermal exploration led one Soviet scientist to state that its ". . . geothermal resources exceed all of the other vast energy resources of the Soviet Union," according to Freeman.[15] Marc Kramer and others reported, "From 50-60% of the territory of the USSR is apparently underlain by thermal waters (low temperature geothermal zones) with an enormous total heat content."[16] In equally sharp contrast to US usage of geothermal electricity, which led the world in 1979, was Jay F. Kunze's report that the Soviet Union and Hungary's use of geothermal energy for direct heat was "13 times greater than . . . the rest of the entire world."[17] However, Gordon W. Berg in reference to the US indicated in 1981, "Within the next 20 years geothermal energy should supply 7 to 10 percent of our nation's domestic hot water and space-heating requirements."[18]

In 1982, with great expansion in electricity generation, Lester R. Brown asserted, "Although geothermal heat is used directly in many locations, its greatest long-term potential is in the generation of electricity."[19] Moving from a total US electrical capacity of about 500 megawatts in 1979, Brown expected California, Utah, Nevada, Hawaii, and New Mexico to be producing three percent of their electricity geothermally by 1983, making a total of about 1,800 megawatts. Other projections included these estimates of installed capacity by the end of

the century: California, 25 percent geothermal electricity; Japan, 48,000 megawatts; US, 27,000 megawatts.[20] As early as 1980 the Soviet Union was planning to tap a volcano with a 3.5 km (11,500 feet) well to provide a geothermal resource capable of supplying 5,000 megawatts for 500 years.[21]

In 1985 the Department of Energy expected geothermal generation of electricity to reach from "2,500 to 6,000 megawatts by 2000.[22] In July of 1985 Pacific Gas and Electric Company was producing "1,200 megawatts of power, about 10 percent of the utility's total and 6 percent of Northern California's needs," at the Geysers north of San Francisco.[23] This one site was providing more than the total (516 megawatts) US geothermal electrical power of 1978.[24] Several western states and Hawaii have made significant advances toward reaching a goal of US geothermal electrical power production by the turn of the century significantly higher than DOE projections.

A real drag on the development of geothermal electrical power has been exercised by the promise that many of the most desirable sites are located on federal lands. In 1978 Glenn I. Coury suggested that the important problem is not to quantify the theoretical geothermal energy, but to find economical ways to use part of the million years of supply which is available "in the top ten kilometers."[25] The large number of desirable geothermal sites on federal lands meant a great deal of legal and regulatory framework had to be laid prior to big companies leasing land to identify the more economical sources. When appropriate

geothermal sources have been identified, Coury saw the needed technology as being available and problems solvable at reasonable costs.[26]

While energy investors search for the most favorable, high-temperature sites first for develpment, educational institutions should remember the even larger potential for use of geothermal energy in low-temperature applications for various heating processes rather than for electricity production. The generation of electricity makes indirect use of geothermal heat energy while low temperature applications make direct use of geothermal heat.

The Nevada Alternative Energy Source Book: Business Directory provided a brief description of the use of resources exhibiting a wide range of temperatures in geothermal energy applications. The descriptions were as follows:

> . . . Those resources over 350°F are usually considered primarily for electrical generation while those with temperatures between 250°F and 350°F at this time appear best suited to supplying the needs of industrial processing. Temperatures lower than 250°F are used mainly for space heating, greenhousing, aquaculture (raising fish and prawns), and ethanol production. Residential space heating and DHW applications can make use of water temperatures as low as 60°F with heat pumps and 212°F with current "off-the-shelf" equipment.[27]

Lester R. Brown suggested that the site-specific nature of geothermal energy will tend to cause industial users to gravitate toward those sites. He found precedent for this opinion in the industrial utilization of hydroelectric power and the biomass energy of forests.[28]

Identifying Potential to Meet Needs: Atlantic Coast Geothermal and Gulf Coast Geothermal

In February of 1979 Peter Britton reported efforts being made, primarily with Department of Energy funding, to identify the geothermal potential where it was needed in heavily populated areas of the eastern United States where energy prices were highest. A well was being drilled at Fort Monmouth, N.J., for hot water about thirty miles from Times Square.[29] At about the same time, a test area was being developed near Alvin, Texas, in the Gulf coastal area about 20 miles south of Houston.[30] These two sites were at opposite ends of the Atlantic seaboard and Gulf coastal perimeter, which area was expected by some experts to yield the energy equivalent of 20 percent of the oil imports of 1979.[31]

In 1979 the Atlantic coastal geothermal area of evaluation extended from Fort Monmouth, N.J., to Savannah, Georgia. Plans called for drilling 50 test holes about 1,000 feet deep to find promising areas for deeper drilling. Britton indicated, "Other information will come from gravity data, air surveys of magnetic fields, and other geologic studies."[32] Preliminary estimates indicated, ". . . The prime candidates appear to be the areas along the southern New Jersey coast, the Delmarva Peninsula, and around Norfolk, Va., Wilmington, N.C., Charleston, S.C., and Savannah, Ga."[33]

The anticipated heat source in the East originated about 200 to 400 million years ago. Very large molten granitic intrusions called

plutons pushed up through other layers of rock. While some plutons formed mountain ranges and others cooled, Britton reported,

> . . . But other plutons were rich in radioactive uranium, potassium, and thorium, never completely cooling. In fact, the slow decay of these radioactive minerals assures, according to the theory, a steady reliable source of heat. The heat is conducted to the top of the plutons and normally dissipates. But under the Atlantic coastal plain there is about a mile-thick blanket of shales, clays, and sandstones that acts as insulation, trapping the heat.[34]

The Department of Energy expected to find water lower in temperature than in the West which would be appropriate for low temperature applications rather than for generatation of electricity. The DOE expected to find major aquifer systems in the form of water-holding porous sandstone at the bottom of the materials covering the plutons. The anticipated water temperature was to be as high as 225°F. The water trapped in the area of the pluton would be recovered by drilling wells 4,000 to 7,000 feet deep. The anticipated uses of the heat removed from these aquifers included the following: ". . . residential and commercial space heating, animal-shelter heating, food processing, tobacco and pulp processing, greehouse heating, crop drying, fish farming, for example."[35] Water would be pumped back into the ground.

The hot water in similar geological structures was already being used to heat apartment buildings and greenhouses in Europe. France and Hungary were numbered among the early leaders in use of this relatively low temperature geothermal heat source. In 1979 6,000 Budapest homes were using geothermal hot-water systems which had been installed in the

last four decades. Hungary had established a goal of ". . . space heating . . . an additional 100,000 to 200,000 dwelling units" this way.[36] France's development was about three times as large as that in Hungary, with plans to complete 500,000 earth-heated units by 1985, according to Britton.[37] In some of the apartments in France titanium-plate heat exchangers and heat pumps were the technology being used.

In 1980 J. E. Tillman found, "In the 37 states east of the Rockies, there are no known geothermal resources that can produce electricity in the near term."[38] However, defining moderate temperature hot water as being below 125°C, Tillman found this resource to be both available without the development of new technology under "many areas in the central and eastern United States," and "definable and economically competitive with conventional fuels for use in direct heat applications."[39] The general categories of recommended use of this moderate temperature resource were as follows: "residential space heating, agriculture, district heating, and industrial processing."[40] Tillman distintuished this direct heat application of geothermal energy as requiring temperatures above 45°C, as compared to ground-water heat pumps which can use lower temperature sources. One or two kilometers of depth would be adequate to find this hydrothermal resource by deep drilling in the sedimentary basins of the eastern United States.

The time line for identifiying the technical and economic feasibility of this resource in the U.S. has been delayed. The budget cuts in the Reagan administration have been a primary factor. However, at a slower pace the investigation was expected to continue.

The Gulf Coast geothermal energy resource base is in a geologically different area. It consists of "hot saline water under tremendous pressure."[41] Large quantities of natural gas or methane dissolved in this hot water have made the methane the primary source of interest in that area rather than the renewable geothermal energy. Before the oilmen learned how to tap the occasional pockets of free methane in such sites, they found them to be the dangerous source of occasional blowouts. The hot saline water bearing zones which were formerly cased off and forgotten now promise to be "a potential triple source of energy."[42]

The higher temperature of the Gulf Coastal geothermal resource, up to 300°F, offers a three-step process for extraction of energy which Britton described as "conceptually simple, if operationally difficult."[43] Without explaining all the details, first, methane would be extracted in a high pressure separator (up to 16,000 psi). Second, a pressurized fluid remnant would "go through a hydraulic turbine to produce electricity from the kinetic energy."[44] Finally, the heat would be extracted by a heat exchanger. A number of technical alternatives were described by Britton, including the possibility of piping the hot brine 20 to 30 miles for use.

Britton illustrated the potential of this hot brine resource in a reopened well in southern Louisiana. The geopressured zone produced fluid ". . . at a rate of 10,000 barrels a day, yielding methane at up to 80 cubic feet per barrel."[45] These figures sound impressive and economically competitive. However, Glenn E. Coury, in comparing Btus in

500°F brine to Btus in oil summarily stated, ". . . For the same output of useful energy, 100 to 200 times more brine than oil must be produced."[46]

Britton described some of the reasons why the high-pressure, hot saline water had not been utilized in the past. These include the former low cost of natural gas, the corrosive properties of the extremely salty hot water, utilized under high pressure, potential equipment failure and blowout, and one even more environmentally alarming, namely, potential subsidence. Subsidence means "lowering of the ground level, even up to several feet in a few years."[47] Appropriate studies and equipment were being designed to deal with these problems.

Britton also described a number of environmental and institutional problems which slow the progress of this technology. Environmental factors include brine disposal, both when it is reinjected to the wells and when it is not, noise, and induced earthquakes. His list of institutional barriers included the following:

> . . . resource ownership, jurisdictional responsibilities, tax incentives, loan guarantees, depletion allowances, drilling permits, leasing of federal lands, zoning laws, impacts on local communities, and other arcane dealings.[48]

Writing in 1980, Richard A. Kerr was much less impressed than Britton had been about the potential of geopressured-geothermal energy. Initial Department of Energy findings and the opinions of energy industry experts were suggesting that the concentration of methane in geothermal brines were much lower than originally hoped. Higher

salinity reduces the ability of water to dissolve methane. Furthermore, the reservoirs of geothermal brine may not be of sufficient size to make their energy economically recoverable until natural gas prices go much higher. Due to limited knowledge of size and recoverability of this resource, DOE and industry studies were expected to continue, but at a slower pace.[49]

Geothermal Energy Information

On June 1, 1981 the U.S. Department of Energy published information regarding the availability of scientific and technical data dealing with new and renewable energy resources. Geothermal ranked second after solar in the total data base available. This second ranking was evident in books or contributions to books (765), journal articles (1,784), reports or contributions to reports (2,896), conference papers and proceedings (2,435), and even in patents (147).[50] It ranked third in dissertations, totaling 54 from 1974 through 1981.

State energy offices are very cooperative in providing research assistance. Nevada was able to supply potential residential and other users of geothermal energy with a wide variety of information resources in 1986. The list of agencies and companies included seven governmental offices and fifty-two private businesses which were widely distributed throughout the state.[51]

With the exception of those situations in which the geothermal resource is well known, a feasibility study is in order. The New York State Research and Development Authority and the U.S. Department of

Energy conducted such a study to determine the low-temperature geothermal potential at a site in central New York State. Among the factors assessed were the geological environment, hydrological conditions, reservoir characteristics, and recoverable hydrothermal reserves. The well site selected was based on its proximity to a geological irregularity or anomaly in Cayuga County in which the temperature gradient or increase with depth was known to be quite large, specifically, 30°C per kilometer.[52]

In this case the test well at the Auburn low-temperature reservoir proved to be adequate to provide space heating for the Auburn Middle School and the Cayuga Community College. The investigators reported that a 5,250-feet-deep well was drilled. Expansion of the surrounding hot rock area exposed to water for heat exchange increased the potential energy available. The radial capacity of the well was increased about ten percent by hydraulically fracturing the rock formations by applying 2,450 pounds per square inch of pressure. The average geothermal gradient proved to be 26.7°C per kilometer. The bottom-hole temperature was 126°F, plus or minus one degree. The volume of usable water, with reinjection was quite adequate to supply 117% of the demand of the two schools.[53]

This very lengthy study of the Auburn site was to be followed by other evaluations. These included "the engineering and economics of developing, constructing and operating a geothermal energy surface facility."[54] The investigators recommended all of the subsequent studies which were needed in a four step process, basically, moving from

evaluation of current facilities and needs relative to the resource, through engineering and architectural drawings, to construction, and, finally to operation and maintenance of the geothermal facilities.[55]

Various types of countercurrent heat exchangers can extract the heat from the geothermal water to heat ground water to a temperature suitable for building use. The geothermal water, still at a relatively high temperature, is re-injected to minimize the environmental impact and maintain the geothermal resource.[56]

Heating Applications of Geothermal Energy

The use of geothermal energy for space heating has a long history in the United States and several other countries. The percentage of residential heating supplied by geothermal energy is greater in Iceland than any other country. In 1982 ninety percent of the homes and a number of other facilities in Iceland were heated by "hot water from more than 100 geothermal wells," according to Lane Leonard.[57] Iceland, Hungary, and the Soviet Union are numbered among the countries making extensive use of geothermal heat in greenhouses. Klamath Falls, Oregon, and Boise, Idaho, have a long history of use of geothermal heating and have placed increasing reliance upon this source of energy.

The use of underground steam to heat facilities in Boise, Idaho, began in 1890. A natatorium, providing an Olympic-sized swimming pool and recreational facilities, made use of the first geothermal production

well in Boise. Residences and downtown areas were included in later expansion of the the system.[58]

The Boise Warm Springs Water District, in conjunction with the city, under the name Boise Geothermal, was working on that expansion project in 1980. The city's joining forces in 1975 resulted in a $6 million DOE award "to demonstrate the economic viability of a geothermal district heating system."[59] There were long bureaucratic delays and studies. Energy retrofits to make use of geothermal energy have included state buildings and many city businesses.

Some of the turn-of-the-century mansions in Boise, Idaho, have more than twenty rooms and no insulation, but cost less to heat than many owners of smaller homes pay for one month of heat because they use geothermal heating. One 28-room home built in 1902 was heated for only $40 in the coldest month of 1980.[60] A geothermal expert reported that geothermal hot water heat was costing only about $200 a year in such homes in 1981.[61] That year 82 downtown building owners and more than 300 residences were trying to become connected to the Boise Geothermal Project. The obvious benefits of use of district geothermal heating led a developer to consider developing a 4,000 home community using geothermal heat.[62]

"District heating" refers to the application of a single central heating system to a group of facilites rather than a single facility. Gordon W. Berg identified a number of places where district heating was already being used or planned in 1981. In addition to Boise, Idaho, the following places were listed: Pagosa Springs, Colorado; El Centro,

California; Klamath Falls, Oregon; Reno, Nevada; Susanville, California; Monroe City, Idaho.[63]

One beneficiary of the use of geothermal energy in Boise was the Boise Public Library. Only $17,000 in local funds were required to install the geothermal heating system since the Department of Energy and Bonneville Power Administration granted the balance of the $53,000 cost of converting from a forced hot air system to a hot water system. On June 1, 1984 the projected annual savings to the library was $4,718.[64]

Boise, Idaho, is not alone in having a conveniently available geothermal energy resource. Rick Gore found similar potential in 300 US cities, including Reno, Nevada.[65]

Although direct industrial applications of geothermal heat have developed only in the last few decades, many potential applications are being evaluated and developed. A pulp and paper company in Kawerau, New Zealand, was among the early leaders in the 1950s in using this heat source to run its plant and kiln dry timber.[66] In Reykjahlid, Iceland, a geothermal factory uses a well with an average temperature of 480°F to process an inexpensive, otherwise useless sludge into a high-grade diatomaceous filter for swimming pools and wine distilleries.[67] Plentiful geothermal heat made the drying of wet, diatomaceous earth financially competitive with the mining of dry diatomite.

In evaluating the geothermal energy resources of the Atlantic Coastal Plain, J. E. Tillman found that geothermal heat could be provided at less expense than through use of traditional fuels in favorable industrial settings. Tillman inferred from 1978 cost analysis

conclusions that, ". . . in areas of geothermal resources, no other alternative source can compete economically with geothermal energy."[68]

Ephrata, Washington, offered an interesting example of a small town that stumbled on a desirable geothermal energy resource when the drinking water ran hot. A newly drilled well began pumping water hot enough to be used for heating with a modest boost in temperature. Dan Mintie reported that heat of the geothermal hot water, with a supplemental boost, was "then transferred to a secondary loop that provides space heat for the Grant County courthouse and for a few units of low-income housing."[69] Thus, drinking becomes the secondary purpose of the then cooled water. The town's chief engineer reported that the courthouse could then be heated for about one-tenth of the cost of the former oil furnace.

Low-temperature geothermal zones hold great promise for the future, especially in energy-poor states which house great populations. Their wider distribution and larger reserves suggest that, as ecologically and economically sound development practices emerge, this resource has very great potential relative to the currently preferred hyperthermal zones.[70]

In 1979 Jay F. Kunze suggested a working criterion for economical drilling for geothermal energy. Kunze stated, "Although surveys have assessed resources as deep as six miles, it is seldom economical to drill deeper than one-and-one-half miles."[71] Kunze also suggested a half-mile limit for water less than 200°F and 300°F as being essential to warrant a depth of more than one mile.

Water does not need to be that hot to provide useful heat energy. In fact, a five-year study by Virginia Polytechnic Institute and State University researchers identified potential Virginia and eastern United States resources which usually fall below 200°F. One of the three resources identifed by Dr. J. K. Costain was about 100 hot springs located in northwestern Virginia and in adjacent parts of West Virginia.[72] The range of temperatures available in these hot springs did not reach as high as 200°F. The reported range was "from just above the mean annual air temperature to about 104 degrees Fahrenheit."[73] Water-source heat pumps offer an appropriate technology for tapping this and other low-to-moderate-temperature geothermal heat sources in the commonwealth, including both the normal heat gradient geothermal resources where the heat increases with depth and areas where granite rich in uranium and thorium contributes to relatively higher temperatures.[74]

The Oregon Institute of Technology campus at Klamath Falls, Oregon, made direct use of geothermal hot water for heating. Paul J. Lienau, director of the Geo-Heat Center of that institution, reported that three hot water wells, varying in depth from 400 to 600 meters, were drilled adjacent to the campus.[75] Eight buildings with 530,000 square feet of floor space are adequately served by the 89°C water supplied by one well during the summer months when the primary need is domestic hot water heating. Two wells are required, pumping as much as 750 gallons per minute, when the outside temperature is below -20°C.[76] According to Lienau, "The well water is pumped from the well using deep

hole shaft driven turbine pumps, and is used directly in the heating system in each building."[77] A combination of hot water radiators and forced air systems delivers the heat where it is needed.

The potential for such a system is evident in circumstances where the geothermal heat source is of a substantially lower quality. Lienau noted that the plant engineer indicated that ". . . these heating systems could meet peak heating demands of the campus if 66°C water were used."[78]

The cost effectiveness of the system at Oregon Institute of Technology was remarkable. Annual operating cost and capital recovery cost of the present wells were being provided at one-tenth of the annual estimated heating cost of using conventional fuel oil. Lienau reported, "The savings in fuel oil is 13,000 bbl per year or 182,000 bbl for the life of the system."[79]

The Geo-Heat Center at Oregon Institute of Technology provides several kinds of assistance to those who wish to make direct applications of geothermal energy. A quarterly bulletin, free publications, feasibility studies for various applications, technical assistance, and educational programs are numbered among the services of this institution.[80]

In August of 1979 John W. Lund reported the extent of use of geothermal energy in the vicinity of Klamath Falls, Oregon, for hot water and space heating. Lund stated,

> . . . Approximately 400 shallow-depth wells ranging from 27 to 580 m in depth are used to heat approximately 500 structures. This utilization includes the heating of residences, schools,

> businesses . . ., the heating of swimming pools, and the melting of snow from pavements.[81]

Lund found Klamath Falls to be "the most successful attempt at using geothermal hot water for space heating in the United States."[82] Wells in this geothermal reservoir tapped water temperatures ranging from 21°C to 110°C, but use was limited to well water ranging from 38°C to 110°C.[83] However, water-to-air heat pumps can be used with water as low as 15°C to over 150°C to provide space conditioning, including both heating and cooling.[84] Furthermore, the geothermal resource was vastly larger, affording significantly higher temperatures than those which had been tapped.

Usually closed loop down-hole heat exchangers were used to extract heat from the wells. This basic type of geothermal heat exchanger is illustrated in Figure 6 on page 419. Essentially, water in a coil of pipe of sufficient length to receive the transfer of heat from the geothermal well water is built into the well. As water flows in the pipe, giving up its heat for use where it is needed in the facilities, geothermal heat energy is added in a continuous cycle.[85] Because of the dissolved solids, which cause some scaling and corrosion, in the well water, city water was used in the heat exchangers. In addition to the Oregon Institute of Technology, almost all of the city schools used this energy resource.

Lund offered many details about the drilling and casing process and criteria for adequate wells. Care was exercised to avoid sealing live water flows and to separate cold water flows from hot water flows

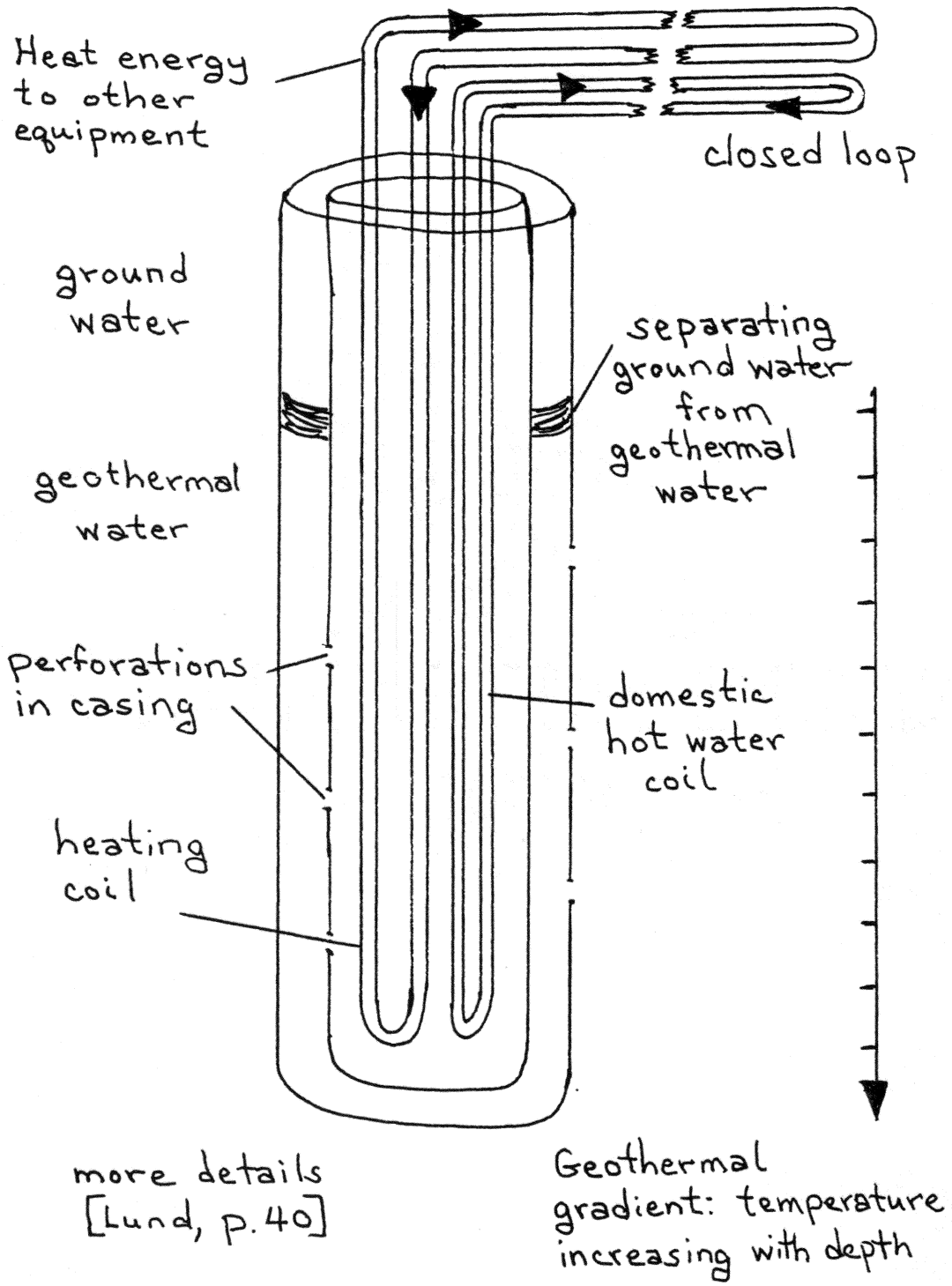


Figure 6

Closed Loop Down-Hole Heat Exchanger

since the drilling of the well itself created a potential channel for previously separated water sources. Occasional perforations in the hot water source area of the casing permit water to flow inside and outside the casing. Both rotary drilling rigs and cable-drilling tools were used. Newer wells were 30 centimeters in diameter and were cased with 20 centimeter casing. The criteria related to the amount of free-flowing water, the adequacy of the source temperature, preferably at or above 88°C, and the length of the coil or heat exchanger required to deliver the needed heat. The casing was set in a solid formation, as required by Oregon law. Burlap packing and grouting were used as needed to separate cold water, near the surface, and hot water flows. Lund stated, "Present casing thickness is 6 mm to 8 mm, and the expected life is well over 50 years."[86] Present casing was much more durable than that which was formerly used, namely, only three millimeters thick and lasting only about 15 years.

Typically, two u-shaped coils or heat exchangers, made of standard black iron pipe, are installed in geothermal wells to get the needed heat. Brass and lead pipe extend the life of the system. Optional use near the top of the well of double strength pipe is made to reduce stress and provide corrosion resistance. Pouring used motor oil or paraffin in the well reduces corrosion. Various corrosion-resistant paints have met with limited success. Lund wrote, "The heating coil is typically 51 mm in diameter and the domestic water coil is 19 mm in diameter."[87] A process known as thermosiphoning uses gravity to circulate the water in hotter wells used in small systems. This means

water which has been cooled as its heat is used in the facility flows down one side of a loop of pipe, since colder fluids are heavier, while the gradually warmed, lighter water rises on the other side of the u-shaped coil of pipe in a closed loop. Alternatively, electrical pumps are needed to circulate water in cooler wells and with larger systems to provide an adequate flow and heat exchange rate which can not be achieved by the natural thermosiphoning process.

Lund listed several advantages of the down-hole heat exchanger system. The system is "economical, minimizes corrosion problems, probably conserves the resource, and eliminates the problem of waste-water discharge."[88]

American School & University reported in December of 1981 that the main school buildings of the Haakon School District in Philip, South Dakota, were being heated by a geothermal, artesian well.[89] The hot water source was a 4,200-feet-deep well. The DOE provided 80 percent of the funds. This rural school district was serving a community of fewer than 1,000 people without spending money on fossil fuel. Participating, nearby merchants in the town were buying surplus heat energy left in the water and expecting to pay for the pipeline in less than three years through savings on fuel oil.

Haakon's cost was doubled by the unforeseen problem of dealing with a high amount of radium found in the water source. Federal standards required the development of a treatment plant to provide safeguards before it was discharged.

Heat exchangers were used to avoid damage to the existing piping in the school buildings by the contaminated geothermal water. Only minor modifications were made in converting the piping from the former steam heating system to use of hot water. The geothermal source temperature was 155°F. The amount of heat given up in heating the facility or domestic hot water by the geothermal water was never greater than seventeen degrees on the Fahrenheit scale, leaving an adequate surplus for other needs in the future.

In the spring of 1981 Gordon W. Berg reviewed the existing and planned uses of geothermal energy as a heat source for preheating of intake air and space and water heating in health facilities.[90] In a preliminary general evaluation of the resource, Berg referred to a 1979 federal survey which reported low-to-moderate temperature resources were available in 37 states, while all 15 western states had hot water resources.[91] Therefore, facilities which use large quantities of relatively low temperature heat may find exemplary facilities useful in considering this widespread alternative energy resource.

Berg identified and described six health facilities which were "already using this low-cost, dependable energy source or . . . in the process of converting to its use."[92] These facilities were as follows: Merle West Medical Center, Klamath Falls, Oregon; St. Mary's Hospital, Pierre, South Dakota; Torbett-Hutchings-Smith Memorial Hospital, Marlin, Texas; Warm Springs State Hospital, Deer Lodge County, Montana; Mavarro College and Hospital, Corsicana, Texas, and Carrie Tingley Hospital, Truth of Consequences, New Mexico.[93]

The anticipated payback and long-term savings made the one hundred percent geothermal heating and domestic hot water system at Merle West Medical Center very economically attractive. The system also provided air conditioning and kept the outside free of snow and ice. Within five years the initial development cost of the geothermal system was expected to be recovered through savings from gas bills. The long-term net savings were conservatively estimated to be "more than $22 million in 40 years as a result of the geothermal system," according to the hospital board estimate reported to Berg.[94]

The various health facilities used a wide variety of well depths and water temperatures. Consequently, they expected widely varied payback periods of the initial capital costs through savings. Well depths varied from 212 feet to 3,855 feet. Water temperatures ranged from 106°F to 191°F. One well, located one-and-one-half miles from a hospital, using uninsulated line at a loss of only four degree in transit, had already provided geothermal energy for therapeutic purposes for forty-one years.[95]

Berg identified several processes included in the cost of conversion to geothermal heating systems, as follows: "exploration fees, drilling cost, pumps, piping, building modifications, and possibly heat exchangers, as well as some retraining of personnel."[96] Berg stated,

> . . . Facilities that are already using geothermal energy, such as the Merle West Medical Center and some schools and businesses, uniformly report that once installed and operational, geothermal systems are practically carefree.[97]

By the spring of 1981 Berg was able to identify 16 states in which direct-heat applications were being made of geothermal energy with almost a third as many projects being planned as where then developed.

Generally speaking, low temperature applications of geothermal energy for space heating are more economical in new than in retrofit usage. This is due to the fact that the hydrothermal resource may require expanded radiators to carry the needed heat. In 1978 it was expected that geothermal energy could be tapped more economically in the residential sector on the Atlantic Coastal Plain than electrical-resistance space heating. In 1978 oil and natural gas prices were sligthly more favorable than use of geothermal heat in the same area.[98]

A state official in the Energy and Minerals Department in New Mexico, based on observations, including one school setting in that state, gave this assessment: " . . . Geothermal systems can be extremely cost-effective when designed, built and maintained properly."[99] That point of view is shared by many others.

Geothermal Generation of Electricity

S. David Freeman reported the use of underground steam to generate electricity as early as 1904 in northern Italy.[100] The plant had a generating capacity of 30 megawatts. After more than 60 years of generating electricity at Larderello, Italy, Marc Kramer and others reported in 1975 that some new wells were being drilled to maintain output due to the fact that more water was being taken out of the reservoir than was flowing in, thus, potentially drying the reservoir if

water were not reinjected to the reservoir.[101] In 1979 Kunze reported Larderello was using 400 megawatts of geothermal power to serve about 2,000,000 people.[102]

Allan Chen noted the preference given by geothermal energy developers to high-temperature sites where the energy available is sufficient to turn turbines to generate electricity. Either steam rises directly from a geothermal well or hot water is extracted to evaporate and give up heat to create pressure to turn a steam turbine to generate electricity. The range of water temperatures suitable for electricity production, according to Chen, was "at least 180°C and preferably hotter than 200°C."[103] That translates to 324°F and 360°F, respectively. Glenn E. Coury recommended a temperature greater than 400°F and a depth less than 10,000 feet as criteria for an economical geothermal source for electric power production.[104] In those relatively rare situations where hot dry steam can be used directly to generate power the situation is even more favorable.

Jay F. Kunze offered an encouraging appraisal of the cost effectiveness of geothermal electricity generation at the Geysers Geothermal Development north of San Francisco. In 1979 Kunze stated, "The cost of the electricity, 1.8¢ per kilowatt-hour, is easily competitive with power generated in coal or nuclear plants."[105]

J. E. Tillman, in describing the same geothermal resource, found it both technically and economically viable, and less likely to be a source of political and environmental conflict than many energy sources. Tillman stated, "For the San Francisco area . . . this energy source is

the most economical method of producing electricity, and plans for its growth far exceed those for other resources in that area."[106]

Strangely, the vast geothermal electricity generation potential available in the Pacific Northwest, which offers the most ideal resources in the country, have only begun to be developed. As late as March 19, 1983 Chen reported little development except at "the Geyser Field, 75 miles north of San Francisco, and at Salton Sea and Brawley plants in southern California."[107]

The heat energy generated by the subducting Farallon Plate, which is being replaced by the North American Plate and the Pacific Plate, makes the Pacific Northwest possibly "the largest geothermal resource area in the world," according to some scientists.[108] Allan Chen reported that a consulting geologist in Salem, Oregon said, "We have a chain of volcanoes from Mt. Meager [British Columbia] to Mt. Pleasant in California 700 miles long. This is one of the largest potential sources of energy in the world."[109]

In March of 1983 only four areas in this 700 miles long geothermal bonanza had been tested. Dry steam had been discovered at 370 meters at 200°C at Mt. Meager. At Newberry Crater in Oregon at 3,100 feet 270°C to 300°C dry steam was found in 1981 by the U.S. Geological Survey.[110] Various estimates indicated that the Newberry Crater alone could produce an output of 740 to 1,843 megawatts for at least 30 years.[111] Chen reported, "Geologists believe that Oregon holds the most promising source areas, followed by California, which possesses

the Medicine Lakes caldera."[112] There are also very promising sites in Washington.

Drilling in the Cascade mountain range is difficult to accomplish without possible undesirable environmental consequences. The possible contamination and drainage of the water table alarms farmers. The Sierra Club has raised many environmental concerns associated with noise, the traffic of construction crews, hydrogen sulfide odors caused by dissolved gases in the geothermal fluids. The cumulative effect of extensive drilling for geothermal energy may disrupt the migration and habitats of wildlife in the area. In park areas where geysers, hot springs and other related geothermal phenomena are focal points of interest, tapping geothermal energy can destroy these natural wonders which have occurred for long periods due to the internal equilibrium of the earth's crust being changed.[113]

In the spring of 1985 the Bureau of Land Management had given California Energy Company approval to drill four of a possible eventual total of twenty-four test wells just outside Crater Lake National Park in Oregon. Each of the wells was to be 4,000 feet deep, seeking potential sources of both heat and electricity. So little is really known about the geothermal resource that regular safeguards of the environment and particularly the park resource have been built in at each step of the development process. The safeguards include tapping the water periodically to see how its chemistry compares to water in Crater Lake to identify leakage between systems.[114]

Given the large, undeveloped, high-temperature geothermal energy resource in the west, school sites must surely exist which have the potential to develop their own geothermal electrical power plants. However, state energy offices have failed to report any existing school or university sites using geothermal energy to produce electricity, although several states, both in western and eastern parts of the US, use geothermal heating. The scale of an electrical plant could be suitable to the school's use or could be larger to generate income for the school or university by selling energy to other users.

Enlarging the Geothermal Energy Service Area

Although the most promising, economical development of geothermal energy has been in volcanic regions of the world, the general availability of geothermal energy should not be overlooked. The temperature gradient inside the earth's crust usually increases with depth, specifically, about 40°F with each mile of depth.[115] Using metric measurements, another author put it this way: "Geothermal . . . energy . . . results from the radioactive decay of rocks, which raises the earth's temperature an average of 25 degrees Celsius with each kilometer of depth."[116] A geologist at Johns Hopkins University Applied Physics Laboratory was more specific, stating,

> . . . The average thermal gradient of the crustal rocks in the eastern United States is between 15° and 25°C per kilometer. This gradient is the product of heat flow from within the earth and the thermal conductivity of the rocks through which the heat flows.[117]

Heat generated by the decay of small quantities of uranium, thorium, potassium, and other radioactive elements helps account for the higher thermal gradients in some areas.

Depending upon the depth of the hole which is feasible to drill, a number of different applications can be made of the heat energy available. While it would not be profitable to drill a hole several miles deep for individual users, district heating and cooling to make more extensive use of the resource base and to avoid the cost of individual furnaces could be feasible. France, the Soviet Union, Iceland, and the US have made use of the economical benefits of district heating, meaning several facilities use the same heating plant. As early as 1980 the Soviet Union planned drilling more than two miles deep. In 1984 Peter John Wyllie reported,

> There was an excellent prospect for extending a planned commercial steam-production well 3.7 km (2.3 mi) deep in the Salton Sea geothermal field in California to 5.5 km (3.4 mi) for scientific study prior to the well's commercial use. Republic Geothermal, Inc., which expected to begin drilling by the end of 1983, responded favorably to the proposal from William A. Elders and Lewis H. Cohen at the University of California at Riverside to drill the deepest geothermal well in the world.[118]

Even in a much less desirable geothermal location than the Salton Sea, drilling to such a depth would be expected to provide a geothermal energy source ranging from about 190°F to 200°F. S. David Freeman reported in 1974 that ". . . wells from 2-6 miles deep" are ". . . within the range of conventional oil drilling rigs."[119] The technology is available if the economics can be demonstrated to be feasible for drilling deep wells to take advantage of the geothermal gradient.

Techniques have been developed for using wells which have internal sources of hot water and steam and, also, wells where only hot rock is available. Injection of water to hot, dry rock areas permits the extraction of heat. Where radioactive granite is relatively near the earth's surface, hot dry rock reservoirs are promising geothermal energy sources. David Scott offered details about experimental wells being drilled under the supervision of the Camborne School of Mines in Camborne, England, in three stages, 1,000 feet, 6,000 feet and 18,000 feet.[120] For dry wells, basically, two wells are drilled, water is pumped into the earth, and the rock is appropriately fractured by just the right quantity of explosives and/or pressure to permit exposure of water to a large surface area of rock and the convective return of heated water or steam to the surface.[121] The fractured rock, in combination with the two wells, work like a giant underground heat exchanger. Relatively shallow wells could serve heating needs. Deep wells with an adequate heat source could be expected to produce about 50 to 100 megawatts of power if used to generate electricity.

Thomas W. Hodler offered a mapping strategy which drew concentric circles around centroids to depict useful sites for use of hydro-geothermal sources in Oregon and California. The site-dependent nature of use of geothermal energy for purposes other than electricity generation is based on the difficulty of transporting the fluid long distances without losing the useful heat energy. Use of "side-looking-airborne-radar (SLAR) and thermal infrared imageries, ground observations, and existing maps" enabled the identification of "four

centers (centroids) of geothermal activity," according to Hodler.[122] Based on measurement of the centroid's water temperature and the ability to transport geothermal waters "in insulated concrete pipe for a distance of eighteen km with only a five degree Celsius temperature drop," circles representing heat loss down to 70°C were drawn.[123] The temperature in a given location helps to identify potential uses.

The practical result of this mapping strategy was the identification of potential geothermal energy uses for an area inhabited by about 11,500 people. The concentric isotherms often represented impractical locations due to a great deal of topographical relief including barriers inhibiting the laying of horizontal pipes. Consequently, many of these potential users would not be served. Three towns were located within the 80°C isotherm or warmer areas. Suggesting 80°C for home heating water, Hodler identified schools among the potential users as follows:

> The most practical applications of hydro-geothermal waters fall in the realm of space heating of homes, schools, greenhouses, and other structures and also for the heating of swimming pools, fish hatcheries, and soil beds.[124]

Hodler listed many other potential uses of this geothermal resource in an area where very limited use was then being made of it for space heating, for a greenhouse, and where former use in heating a pool had been discontinued due to the level of arsenic in the water.

The presence of harmful deposits of salts and minerals in such water often demands the use of heat exchangers to transfer the heat to fresh water in a closed-system to serve the radiators or other heat

transmitting devices. Such a system would permit the heating of a pool by this indirect method, with proper disposal being made of the arsenic laden water which supplied the original heat source.

In 1986 the Solar Energy Research Institute (SERI) reported extensive research and development work being done to more efficiently utilize low-temperature energy differences in heat sources. If work now being done on open and closed Rankine cycle engines can be economically developed, much more extensive use can be made of low-temperature geothermal energy sources, solar ponds, ocean thermal energy, waste heat recovery, and solar thermal systems.[125]

In closed-loop systems, a heat exchanger passes heat from the water source to a working fluid, such as, ammonia, which has a lower boiling point, permitting the working fluid to drive a turbine to produce power. In subsequent steps the working fluid is condensed by flowing through another heat exchanger and recycled through the evaporator. The systems are far more complex than this brief description. However, it demonstrates the potential for using a great deal more of the heat energy of low-temperature sources rather than unnecessarily adding thermal pollution to the environment.

SERI was focusing its research activity on development of the open-cycle OTEC system. These engines showed greater economic promise. In this system the heat exchanger is less expensive. A low pressure chamber permits part of the warm water to flash evaporate into steam to drive a turbine, which in turn drives a generator. SERI reported much

higher second-law efficiency in use of the open-cycle Rankine engines than in closed-cycle engines.[126]

Only future development can demonstrate whether this technology will be widely applied in this century. This system permits the harnessing of potential energy of the thermal difference between the cold water and warm water sources in ocean thermal energy conversion, which typically is about 20°C.[127] Comparable differences of greater magnitude could easily be found in geothermal settings. The wide applicability of the technology to many energy resources demands that its progress be monitored by energy producers and consumers.

Tapping Magma Energy

On February 25, 1984 Science News reported that researchers from Sandia National Laboratories in Albuquerque, New Mexico, were doing studies to determine whether it was feasible to extract geothermal energy from magma (molten rock).[128] In 1981 Sandia had demonstrated the possibility of drilling through magma and keeping the well open for energy extraction. The remaining effort was enormous, considering the fact that drilling equipment would be expected to function in temperatures exceeding 2,000°F. The research team sought to demonstrate the engineering capabilities "to make magma energy commercially appealing to an energy production company," to "study ways to locate and select magma bodies for drilling," to "test materials and systems that can be used in drilling equipment that must function in magma," and to "select a preferred method for extracting heat from magma, using the

heat to produce steam or gas that would power a standard turbo-electric generator on the surface."[129]

The enormous potential of a successful effort seemed to warrant the use of the Department of Energy funds. If the project, which was expected to end in the late 1980s with drilling to extract heat, is successful, the geothermal potential will be enormously enlarged as indicated:

> . . . The United States Geological Survey estimates that magma bodies within six miles of the earth's surface in the continental U.S. could supply 800 to 8,000 times the energy that the nation consumes each year.

New Mexico and California sites were being evaluated with the intention of using a magma source within three miles of the earth's surface.

International Geosphere-Biosphere Program Planned

Environmental consequences of large-scale use of geothermal energy are currently unknown. In 1984 Peter John Wyllie reported plans to study the effects of man-made and natural pollution in "a new program for the 1990s, tentatively called the International Geosphere-Biosphere Program (IGBP)."[130] Here is a partial description of the scope of such a program:

> . . . Its planners were framing scientific programs of a global character in solar-terrestrial relationships, lithosphere dynamics, oceans and atmospheres, and the biosphere. Biogeochemical cycles including the transfer of carbon, nitrogen, and sulfur across land, sea, and air boundaries were central issues and served as examples of the integrating themes envisaged for IGBP. . . . These efforts would involve coordination of global measurements from space platforms, exploit new technologies for observation, and use improved

> computational facilities for data management and mathematical modeling.[131]

The effort would be ". . . to document, understand, and predict 5-50-year global changes that can affect the habitability of Earth."[132]

Many appropriate inferences could be drawn from such global, computer modeling studies. One appears to be that scientists will eventually discover profound effects of large-scale use of geothermal energy on the movement of tectonic plates and the frequency of volcanoes, both of which have realtively large influence on the level of CO_2 in the atmosphere.[133] Through the centuries, use of the earth's internal heat resources may have real limits. Like the use of fossil fuels, the size and nature of forest, and nuclear energy, the use of geothermal energy may have profound effects on the habitability of the planet. Consequently, thoughtful users of geothermal energy will study the findings of the IGBP to identify appropriate concerns in this area.

Conclusions

Geothermal energy is a renewable energy resource the application of which has increased rapidly for generation of electricity and for direct use in space heating and hot water heating. Schools and universities could appropriately use this resource for these and other purposes in a great variety of settings. Although the quality of this resource is undeniably superior in western parts of the United States for electricity generation, the total resource availability for direct

application in heating is much larger and widely available in most of the US at reasonable depths.

While conversion of present heating systems to geothermal energy systems is costly, in a great many settings it offers promise to delivery heating needs at reduced cost while achieving substantial savings in the long term. Geothermal heating with low-temperature and moderate-temperature heat sources has been demonstrated to be cost effective in a great many applications, including many schools.

Assertive management in educational settings can lead to energy savings by use of this resource. This already applies to geothermal energy resources ranging in temperature from that of ground water to very high temperatures, and, perhaps, will eventually include magma. Even when larger fans and heat pumps are required to boost the effectiveness of the delivery system or to provide temperatures high enough to use the existing system, geothermal energy is cost effective in many settings. The point at which a heat pump may be needed to assist is at or below 100°F.[134] New systems tend to be more economical than retrofit applications with low-temperature geothermal sources.

Geothermal energy system technology is readily available at present. No new equipment is needed to utilize the range of temperatures educational institutions would be likely to employ.

CHAPTER 9 ENDNOTES

1. S. David Freeman, "Tapping the Eternal Energy Supplies," Energy: The New Era (New York: Walker and Company, 1974), p. 257.

2. Marc Kramer and others, "Geothermal Energy," Energy and Human Welfare: A Critical Analysis, Vol. II, Alternative Technologies for Power Production, eds. Barry Commoner, Howard Boksenbaum, and Michael Carr (New York: MacMillan Information, 1975), p. 161.

3. Randall Hyman, "An island trembles astride a rift where our planet's crust is forming," Smithsonian, 12:10:58, January, 1982.

4. Glenn E. Coury, "The Meaning and Application of Geothermal Energy," Solar Architecture, eds. Gregory E. Franta & Kenneth R. Olson (Ann Arbor, Michigan: Ann Arbor Science, 1978), p. 251.

5. Richard C. Dorf, Energy, Resources, & Policy (Reading, Massachusetts: Addison-Wesley Publishing Company, 1978), p. 471.

6. Lester R. Brown, "The Coming Solar Age," Natural History, 91:2:50, February, 1982.

7. Lester R. Brown, op. cit., p. 50.

8. Ibid.

9. S. David Freeman, op. cit., p. 260.

10. Ibid., pp. 259-260.

11. Jay F. Kunze, "The Heat from Beneath," USA Today, 108:2410:32, July, 1979.

12. Marc Kramer and others, op. cit., pp. 161-162.

13. Ibid., p. 162.

14. Ibid., pp. 168 and 182-184.

15. S. David Freeman, op. cit., p. 261.

16. Marc Kramer and others, op. cit., p. 171.

17. Jay F. Kunze, op. cit., p. 32.

18. Gordon W. Berg, "Geothermal Energy—a Viable Energy Source for Health Facilities," Public Health Reports, 96:2:99, March/April, 1981.

19. Lester R. Brown. op. cit., p. 51.

20. Ibid.

21. Ibid.

22. Harry Bacas, "Energy: A Promise Renewed," Nation's Business, 73:7:35R, July, 1985.

23. Ibid.

24. Richard C. Dorf, op. cit., p. 147.

25. Glenn E. Coury, op. cit., p. 252.

26. Ibid.

27. Nevada, Governor's Office, Office of Community Services, Nevada Alternative Energy Source Book: Business Directory (4th ed.; Carson City, Nevada: Office of Community Services, 1986), p. 34.

28. Lester R. Brown, op. cit., p. 50.

29. Peter Britton, "Geothermal goes East," Popular Science, 214:2:66, February, 1979.

30. Ibid., p. 67.

31. Ibid.

32. Ibid., p. 68.

33. Ibid.

34. Ibid., p. 67.

35. Ibid., pp. 67-68.

36. Ibid., p. 68.

37. Ibid.

38. J. E. Tillman, op. cit., p. 595.

39. Ibid.

40. Ibid.

41. Peter Britton, op. cit., p. 68.

42. Ibid.

43. Ibid.

44. Ibid.

45. Ibid.

46. Glenn E. Coury, op. cit., p. 250.

47. Peter Britton, op. cit., p. 69.

48. Ibid.

49. Richard A. Kerr, "Geopressured Energy Fighting Uphill Battle," Science, 207:4438:1455, March, 1980.

50. Information Resources in the USA on New and Renewable Energy: A Description and Directory (United States Department of Energy: Technical Information Center, June 1, 1981), p. 13.

51. Nevada, op. cit., pp. 39-48.

52. Robert S. Lynch and Trevor P. Castor, Auburn Low-Temperature Geothermal Well: Final Report, NYSERDA Report 84-18 (Albany, New York: New York State Energy Research and Development Authority, Department of Communications, December, 1983), p. iii.

53. Ibid., pp. S-1-S-5.

54. Ibid., p. S-5.

55. Ibid., p. 4-1.

56. Ibid., pp. B-108-111.

57. Lane Leonard (with photographs by Steven Fuller), "Energy from Earth's Furnace," Science Digest, 90:7:75, July, 1982.

58. Kathleen Courrier and others, Shining Examples: Model Projects Using Renewable Resources (Washington, D.C.: Center for Renewable Resources, 1980), p. 23.

59. Ibid., p. 24.

60. "Warm Welcomes For Hot Water," Nation's Business, 69:5:78, May, 1981.

61. Rick Gore, "Conservation: Can we live better on less?," National Geographic: A special report in the public interest: Energy: Facing up to the problem, getting down to solutions, February, 1981, p. 50.

62. Ibid., pp. 50-51.

63. Gordon W. Berg, op. cit., p. 102.

64. "Energy from geothermal springs will heat Boise Public Library," Library Journal, 109:10:1075, June 1, 1984.

65. Rick Gore, op. cit., p. 51.

66. Lester R. Brown, op. cit., p. 50.

67. Randall Hyman, "An island trembles astride a rift where our planet's crust is forming," Smithsonian, 12:10:56, January, 1982.

68. J. E. Tillman, op. cit., p. 599.

69. Dan Minte, "Energy Underfoot," Progressive, 47:6:18, June, 1983.

70. Marc Kramer and others, op. cit., p. 171.

71. Jay F. Kunze, "The Heat from Beneath," USA Today, 108:2410:31, July, 1979.

72. Carlos Santos, "Geothermal energy called sleeping giant," Richmond [Virginia] Times-Dispatch, August 29, 1982, p. D-1.

73. Ibid.

74. Ibid., p. D-3.

75. Paul J. Lineau, "Geothermal Heating System: Oregon Institute of Technology" (Klamath Falls, Oregon: Oregon Institute of Technology, Geo-Heat Center, 1981), p. 1.

76. Ibid.

77. Ibid.

78. Ibid.

79. Ibid.

80. John W. Lund, "The Use of Geothermal Energy in Klamath Falls, Oregon, USA" (paper presented at The Association for Engineering Education in South East Asia (AEESEA) Conference, Perth, Australia, August 28, 1979, Klamath Falls, Oregon: Geo-Heat Utilization Center, Oregon Institute of Technology), pp. 5-6.

81. Ibid., p. 1.

82. Ibid.

83. Ibid.

84. Ibid., p. 5.

85. Ibid., p. 3.

86. Ibid., p. 2.

87. Ibid., p. 3.

88. Ibid.

89. "School kicks the oil habit," American School & University, 54:4:50, December, 1981.

90. Gordon W. Berg, "Geothermal Energy--a Viable Energy Source for Health Facilities," Public Health Reports, 96:2:99-104, March/April, 1981.

91. Ibid., p. 99.

92. Ibid.

93. Ibid., pp. 100-101.

94. Ibid., p. 101.

95. Ibid., p. 102.

96. Ibid.

97. Ibid., p. 103.

98. J. E. Tillman, op. cit., pp. 598-599.

99. Based on personal correspondence between Charles P. Wood, Resource Development and Management Division, Energy and Minerals Department, State of New Mexico, and Glenn Thomason, June 18, 1986 and July 18, 1986. See Appendix C.

100. S. David Freeman, op. cit., p. 259.

101. Marc Kramer and others, op. cit., p. 165.

102. Jay. F. Kunze, op. cit., p. 32.

103. Allan Chen, "Geothermal Powerhouse," Science News, 123:12:186, March 19, 1983.

104. Glenn E. Coury, op. cit., p. 249.

105. Jay F. Kunze, op. cit., p. 32.

106. J. E. Tillman, "Eastern Geothermal Resources: Should We Pursue Them?," Science, 210:4470:595, November 7, 1980.

107. Allan Chen, op. cit., p. 186.

108. Ibid.

109. Ibid.

110. Ibid.

111. Ibid., p. 187.

112. Ibid.

113. Ibid.

114. "Geothermal Testing Set For Crater Lake Area," National Park, 59:3-4:39, March/April, 1983.

115. Ibid., p. 262.

116. "Geothermal: Tapping the earth's furnace," National Geographic: A special report in the public interest: Energy: Facing up to the problem, getting down to solutions, February, 1981, p. 65.

117. J. E. Tillman, op. cit., p. 597.

118. Peter Joh Wyllie, "Earth Sciences: Geology and Geochemistry," Britannica Book of the Year (1984), Chicago: Encyclopaedia Britannica, Inc., 1984, p. 301.

119. S. David Freeman, op. cit., p. 262.

120. David Scott (drawing by Ray Pioch), "Precision blasting taps geothermal energy from hot rocks," Popular Science, 219:4:76-77, October, 1981.

121. S. David Freeman, op. cit., pp. 262-263.

122. Thomas W. Hodler, "A Mapping Strategy for Hydro-Geothermal Evaluation," Journal of Geological Education, 30:3:168, May, 1982.

123. Ibid., p. 170.

124. Ibid.

125. "SERI Studies Low-Temperature Energy Differences," In Review: A SERI Rearch Update, VIII:2:1-4, February/March, 1986.

126. Ibid., p. 2.

127. Ibid., p. 3.

128. "New steam for magma energy study," Science News, 125:8:125, February 25, 1984.

129. Ibid.

130. Peter John Wyllie, "Earth Sciences: Geology and Geochemistry," Britannica Book of the Year (1984), Chicago: Encyclopaedia Britannica, Inc., 1984, p. 299.

131. Ibid.

132. Ibid.

133. Ibid.

134. Ibid., p. 100.

Chapter 10

RENEWABLE ENERGY RESOURCES IN PERSPECTIVE

A great number of tangential concerns, ranging from ethical to political, local to international, and economical to environmental, are an important part of the context in which energy decisions are made in education. The effort in this chapter has been to identify other issues which impact decisions in the area of energy, rather than to exhaustively examine them, and to provide a brief concluding statement. Future developments in some of these tangential areas may well prove that the current desirability of specific renewable energy applicatons is as transient as the exhaustive use of fossil fuels must become.

Implications of Energy Conservation Era for Education

The growth areas in the field of education may be more directly related to energy-related problems than any other single source for the next two or three decades. The need to maintain the ecological balance will play an increasing role in almost all areas of science and technology. Energy compatible uses of land and space will increasingly influence agriculture and engineering. Methods of food production, preservation, processing, packaging, distribution, and marketing will all be influenced by energy and resource management decisions. World energy shortages will have a major influence on international trade, banking, diplomacy, communication, and languages, and will tend toward the development of globally appropriate ethical values. In countless

ways educators must not only adapt facilties, but also their educational programs, to deal with the emerging energy realities of the next century. The social well-being and safety of this planet may be more closely related to energy decisions and energy education than to such ideas as preservation and transmission of the cultural heritage and traditions.

Current Educational Facilities

Current facilities, transportation systems, institutional expectations, and energy infrastructures, among other factors, place severe limits on the flexibility of educational facilities planners and technology for solving energy problems. Consequently, high quality energy innovation proceeds deliberately from what is given to achieve approximations of informed, emergent ideals which are not static, but changing. Reality demands that educational facilities innovators respond to the imperative of the Latin proverb, namely, "Make haste slowly."

The reality of most school districts is decreasing enrollments, with "those predicting decrease in enrollment numbering two to one over those predicting an increase," according to Deriso. These statistics, coupled with a small percentage of growth in the general population, pose problems relative to future facilities needs. Deriso found that

> . . . On the other hand, over eight out of ten districts reported no predicted change in the square footage of the district. In other words, enrollment was going to decrease, without a corresponding decrease in square footage. This will tend to drive the cost per student up.[1]

School districts appear to have few, if any, good alternatives to this rising cost per pupil when their projections indicate a need of these facilities in the near future.

Many interdependent, often conflicting, factors affect energy decisions and facilities management. One consequence of earlier, energy-related, budget restrictions and benign neglect was an increased percentage of budget devoted to renovation and construction. Deriso said,

> On the average, school administrators are budgeting 22% more renovation and construction money in '83-'84 than was budgeted in '82-'83. On a dollars per square foot basis the percent increase is almost the same, being 21%.[2]

The combination of shortage of funds for needed educational facilities, the high cost of new construction, the potential application of energy saving features to old facilities, and the accumulated problem of deferred maintenance will probably accelerate the trend towards reconstruction. The new baby boomlet, combined with increasing demands for tax dollars to care for the growing numbers of aged individuals, will add restraints to educational dollars for new construction projects which can be deferred. A trend away from facilities models towards "the basics" in education in curriculum areas may tend to discourage new construction as a means to improving the educational product. An energy consequence of these perceived trends is that most school districts will be finding retrofit answers to energy problems in older facilities more frequently than they apply energy ideals in new construction.

Cogeneration, Using Natural Gas

While a description of how to use natural gas more efficiently does not address the topic of renewable energy systems, it is the single most important part of the current energy mix in a great many school systems, especially in urban areas. When schools use fossil fuels without benefit of cogeneration of electricity and heat, they speed the day of reckoning with scarcity in heating systems and transportation. Cogeneration, as opposed to single use practices, using natural gas, can provide electrial energy, space heat and hot water, while conserving energy. "Cogeneration means producing two or more forms of energy from one generating source," according to a definition in American School & University.[3] Usually the energy forms include both electricity and heat.

The same heat energy that warms a dormitory and heats hot water can simultanelously generate electricity. Such a system is in use at San Francisco State University. Although the cogeneration energy plant is not free of the requirement of a fossil fuel, it has proven an excellent opportunity to conserve energy in use in three university residence halls, with excess electricity for use elsewhere on campus. Instead of having separate boilers in each building, one cogeneration plant in the basement of one of the three residence halls satisfied significantly larger energy requirements. In the first year of operation, beginning in the summer of 1984, the system was "expected to net a profit of $350,000 through sale of excess energy to the campus," with profits "expected to grow to $1 million annually" by the year

2000.[4] The cogeneration plant was expected to recover the capital cost by savings over a three year period.[5] The system essentially adds electricity production to the space heating and hot water heating achieved by natural gas before and after the retrofit energy program. Expressing the results another way, the waste heat of electricity generation is captured to heat space and water.[6]

Provision was made for storage and radiation of excess energy production and use of existing boilers to supplement the cogeneration system in times of peak demand. During periods of low demand, two 5,000 gallon tanks will store high temperature hot water. This stored heat energy will be used during periods of high demand. The author reported,

> . . . The storage system has been sized to increase the heat flow to the buildings by 10% for a period of five hours. It is anticipated that this situation will occur two times a day for approximately 240 days of the year.[7]

Cogeneration systems favorably impress utility companies since they effectively deal with the problem of peak demands thus helping utility companies avoid the cost of excess capacity themselves. Furthermore, energy as an income producer for schools and universities, makes cogeneration systems, whether supplied by fossil fuels or renewable energy resources, likely to emerge in many settings as one of the systems of choice.

Since the energy infrastructure of education in facilities can not be changed quickly, many educational administrators will learn to appreciate cogeneration as a temporary income producing answer to increasing energy costs. Shirley Hansen and Christopher Crittenden reported in 1982 a high level of dependence on natural gas, namely, that

". . . 60% of the educational buildings in this country rely on gas as their primary fuel.[8] Regional price distortions were often accompanied by a very high level of dependence on gas as an energy source. Hansen and Crittenden offered some helpful statistics on the variable level of use, sufficient to cause alarm in such places as urban districts in south central states. They noted,

> . . . In education, use ranges from about 15% of the school buildings in the Northeast to 80-90% in the south central states. In elementary and secondary schools, this degree of reliance also varies with the size of the district. The larger the district, the more apt it is to burn gas. Forty percent of the districts of fewer than 600 students use gas while over 70% of the school systems with enrollments over 5,000 rely on it. In higher education, 57% of the nation's 3,000 plus institutions rely on natural gas for their primary fuel.[9]

The limited flexibility of other costs was projected to lead to inevitable effects on personnel. When personnel budgets are so severely impacted by heating, ventilation and air conditioning budgeted costs, alternative strategies must be developed to reduce energy costs, now, totally apart from inevitable long-term shortages in the resource itself.

Transportation

Long-term energy substitutes for fossil fuels must be devised for transportation as well as facilities. Transportation problems yield less readily to renewable energy solutions. The transportation infrastructure of suburbanized, high technology societies requires substantial alteration, beginning with conservation goals in modes of transportation and design of cities, industrial areas, and suburbs to

more readily utilize economical, reliable, mass transit methods. More efficient engines, such as steam engines, are a part of the conservation picture preparing the way for renewable transportation technologies. Some of the renewable energy answers to transportation problems were identified by Paul Abrecht and others in 1978.

> . . . Fermentation of plant materials to yield alcohols which could almost directly replace petrol in engines, or be added to petrol, is known and somewhat promising. The destructive distillation of plant materials could yield hydrocarbon fuels. The idea of the hydrogen economy, whereby hydrogen gas is generated from solar- or wind-powered electrolysis of water for direct use as a fuel, has been studied and preliminary results suggest that the economic point of breakeven is close at hand.[10]

Hydrogen has been recommended by Richard C. Dorf as an important fuel for transportation in the 21st Century.[11] Research is currently in process to devise renewable strategies to make hydrogen available as a plentiful fuel at reasonable costs.

The linear induction engine is another technology which is receiving increasing attention in the area of mass transportation. Such engines reduce much of the rotational motion and friction involved in mass transit systems.

The restraints of the existing habits and infrastructures in the field of transportation in industrialized societies place a brake on rapid change in this area. The attempt to address the mix of needs, wants and demands is difficult in suburban areas which are dependent upon automobiles for transportation and economic stability. Abrecht indicated that

> . . . During the time of transition, attention must be given to increasing the energy efficiency of the car and its use (for example, by imposing speed limits), to providing for public

transportation, walking, and cycling, and to urban planning for lower energy-use cities.[12]

Primary Sources of Electricity

Improvements in the efficiency of appliances and equipment requiring electricity have reduced the relative level of demand for both renewable and non-renewable primary sources of electricity. Consequently, whether the needed electricity is provided by educational institutions or by utility companies, the electricity demand of the next century promises to diminish. A United Kingdom report has suggested that conservation policies and practices in that society "would lead to great reduction in the demand for electricity so that by the year 2025 electricity would provide only 6% of all delivered energy, half the figure in 1976.[13] Such conservation measures tend to delay construction of new energy projects, including both coal and nuclear facilities.[14] Furthermore, renewable energy sources can deal more effectively with reduced demand for electricity brought about by effective conservation policies and practices.

Electrical energy can be provided by a great many primary sources. Primary, in the sense of current original input to the conversion and transfer process, is a word whose most important meaning in the discussion of renewable energy resources suggests the need to look at the limit of the energy base for long-term supply and demand satisfaction. Primary sources have changed and will continue to change with shifting supplies, environmental considerations, economic factors,

regional conflicts, and available technology, to name a few of the factors bearing on primary energy resources.

Heavy reliance in recent years was placed on fossil fuels and nuclear energy in the U.S. as new sources of large-scale hydroelectric power became less feasible for environmental reasons. Environmental pollution and safety concerns are weighty causes for concern in use of all of these traditional sources of energy for electricity. Long-term climatological and environmental damage must be taken as seriously as the limits of fossil fuels in an increasingly populous country, exhibiting an energy- and resource-wasteful life-style.

Proponents of nuclear power argue that nuclear fusion plants may be commercially available by 2000.[15] This dream has yet to be converted to reality. While many would welcome a relatively safer nuclear energy resource, one dependent upon deuterium supplies which are readily available in quantities estimated at more than one billion times the oil reserve, a multitude of high technology problems remain to be solved.[16]

In the fall of 1984 Virginia Power, then called Virginia Electric and Power Company (Vepco), through the company's executive vice president, Jack F. Ferguson, and William W. Berry, company president, informed a congressional subcommittee and Virginia citizens that **six non-conventional technologies** were "the most promising new power sources for the future." According to Don Finefrock, a staff writer for The Richmond New Leader, "The six are photovoltaic cells, wind energy, fuel cells, two new techniques for burning coal and a new fuel made by mixing coal and water."[17] William Berry indicated that most, if not all, of

them would be used to some extent by this public utility. The company executives believed the best prospects for meeting the company's needs were offered by the two coal-burning technologies during the short term for the next 15 years.

The Vepco executives forecasted, "Vepco will need an additional 2,000 megawatts of generating power by the turn of the century.[18] By contrast, two current nuclear reactors at the company's North Anna site "together supply 1,800 megawatts of power."[19] Critics have argued that conservation measures and cogeneration by small-scale, independent power services can provide marked assistance in avoiding new construction of electric power generating facilities by Vepco.[20] On March 27, 1985, it was reported that the utility was then purchasing only "109 megawatts of electricity annually from industrial cogenerators and the owners of small hydroelectric dams."[21]

Large-scale technology is in disfavor at present. Berry indicated that the nuclear power option was no longer considered practical by Vepco. In October of 1984, Berry said, "We don't intend to build any more nuclear plants."[22] Finefrock explained, "And, because of long construction timetables, high costs and uncertain environmental regulation, the company also is wary of committing itself to a large coal-fired plant."[23]

Slower growth in demand for electricity, equaling the pace of the general economy "at an annual rate of 2 to 3 percent," was forecasted by Vepco.[24] This made the addition of capacity in 100 to 200 megawatts bites more attractive since quick construction without major

investment of money was more appealing than a 400-megawatt conventional coal-fired unit which would require three to four years to build.[25]

By contrast to the large-scale technologies favored in a period of more rapid growth in demand, "flexibility is seen as a major advantage of the new technologies."[26] The six new technologies can "be built in shorter periods."[27] Furthermore, the company avoids "the risk of building too much capacity too soon."[28]

Finefrock reported Vepco's perception of some of the relative merits of the six technologies, explaining that "projects are under way or planned" in all six areas to provide further evaluation of the advantages and disadvantages of each. Executives reported plans to start construction of "a 50-kilowatt photovoltaic demonstration project in central Virginia" in expectation of the beginning of operation of the facility in 1986.[29] Finefrock's brief explanation stated, "Photovoltaic cells create electricity by using sunlight to stimulate an exchange of electrons within the cell."[30] Samuel C. Brown, Jr., senior vice president for technical assessment, noted that the cost of photovoltaic cells made this the least favorable alternative in respect to price at present.

> Photovoltaic cells now cost $9,000 to $10,000 to install for each kilowatt of power, and fuel cells cost $4,000 to $5,000 a kilowatt, according to the Electric Power Research Institute in Palo Alto, Calif.[31]

Finefrock's article suggested that no technology was entirely free of problems when measured against the others, thus, adding persuasively to the argument that many small plants, some of which can be provided by schools and universities, may be a more viable approach

in a period of conservation and rapidly emerging improvements in varied energy technologies. The range of comparative considerations was evident in this excerpt dealing with wind energy, coal-fired plants, photovoltaics and fuel cells:

> Brown estimated the cost of a wind-energy system at $2,800 a kilowatt.
>
> By comparison, conventional coal-fired plants cost $1,350 a kilowatt, Brown said.
>
> Each of the three technologies has other potential drawbacks as well. Photovoltaics are better suited to Southern California, with its sunny weather and large, unused tracts of land.
>
> Fuel cells, which create electricity through a clean, electrochemical process, are limited by the availability of natural gas, Berry said.
>
> As for wind power, the best sites for installation--along the coast and in the Blue Ridge--could raise environmental concerns.
>
> Instead, Vepco executives say the two new coal-burning technologies are best suited for the large-scale development needed to meet future demand.
>
> The two are coal gasification-combined cycle, a concept being tested in California, and atmospheric fluidized bed combustion.
>
> A coal gasification-combined cycle system is actually two technologies in one.
>
> The first process--coal gasification--provides a clean gas that is burned in a combustion turbine. Waste heat from the first turbine is used to create steam, which operates a second turbine. The two turbines together form the combined cycle system.
>
> In the fluidized bed technology, limestone particles are mixed with hot air currents and pulverized coal in the bottom of the boiler. The mixing promotes more efficient burning, while the limestome reduces pollution by combining with the sulfur in the coal.
>
> If developed on a commercial scale, both systems could generate electricity at a lower cost than conventional coal units by making more power with less fuel and by reducing the need for expensive pollution control equipment.
>
> Coal gasification-combined cycle systems appear to be the more likely prospect because research into the technology is about five years ahead of that for fluidized bed combustion, Berry said.
>
> A 100-megawatt combined cycle demonstration plant began operation in California's Mojave Desert last spring. Berry said

> Vepco should have a good idea of the potential of this technology within perhaps three years.
>
> Recently, the company announced plans to install two combined cycle systems at its Chesterfield Power Station. Coal gasification could be added to the system later.
>
> According to Brown, the fluidized bed technology looks like a strong contender for the late 1990s.
>
> If these technologies don't mature in time, Berry said the company has another option: a smaller version of a conventional coal-fired unit.
>
> A 400-megawatt plant could be built within three to four years, Brown said.
>
> However, the company is hoping these technologies will arrive in time to help plug the expected power gap in the 1990s.[32]

The combination of small-scale renewable energy technologies and other alternative technologies, together with conservation, offers the prospect that few new large, capital intensive plants will be needed in this century. Educational institutions, by modeling alternatives, will play a vital role in determining which technologies become the long-term leaders in providing new energy for electrical power.

Finefrock's article also offered helpful diagrams of the six alternative technologies being considered and developed in pilot projects by Vepco.[33] There were brief narrative explanations of each in a copyright 1981 article from Electric Power Research Institute, Inc., Palo Alto, Calif.

Hydroelectric power plants provide a renewable source of energy at a relatively low cost. While large-scale hydroelectric projects are still being built, the environmental costs are high. Many sites, some on the campuses of schools and colleges, permit the development of small-scale hydroelectric power to provide renewable energy while avoiding the obvious environmental damage of large-scale projects and

permitting beautiful vistas and recreational opportunities.

Environmental pollution and climatological problems associated with use of the remnant of our coal, oil, gas, and even biomass energy resources raise serious objections to their widespread use. While the limits of coal in the U.S. are much less restrictive than those of gas and oil, many environmental problems have not been solved. Furthermore, as the limits of these resources approach, the price will rise accordingly, thus, maintaining energy instability rather than solving the problem.

This is not an exhaustive list of sources of electricity. Indeed, there are many other renewable and non-renewable sources of electricity, some of which may play highly significant roles in both private and public utility settings. Furthermore, the pace of emerging technology makes all futuristic speculation among the most useful and vulnerable of human endeavors.

Environmental and Social Impact of Energy Decisions

The effectiveness of environmental pollution controls in the next few decades will profoundly affect the quality of life and perhaps the possibility of life for generations. Fowler and Kryger described briefly the near exhaustion of "our environment's ability to absorb our gaseous, liquid and solid trash," a problem which is disproportionately "connected with the production or consumption of energy."[34] A part of the scientific and vocational education process of providing environmental information and skills will be a reduction in the

polarization between environmentalists and producers, with consequent reduction in energy-related social problems.

The social impact of energy decisions would tend to be reduced by decisions for renewable resources at an earlier date. The boom-to-bust energy towns problem would be less catastrophic in areas of oil, coal and nuclear energy production if the phasing in of environmentally appropriate energy systems has a longer lead time. However, large-scale facilities for production of solar energy and water power also tend to require significant one-time disruptions of some existing uses of land and water resources. Certainly the long-term impact on health and environmental consequences of renewable energy resources would be less relative to the CO_2 problem and the risks associated with nuclear wastes and military or terrorist abuses of nuclear potential.

Not the least of the social impact problems is the fact that high technology is capital intensive. Renewable energy on the smaller scale tends to be more labor intensive and more in keeping with the need to provide useful work. The dimensions of the capital requirements in the short term are tremendous, assuming an absence of major shifts in priorities. In 1979 Fowler and Kryger reported government estimates of immediate needs for capital for energy production "between now and 1985 lie in the range of $350 to $450 billion."[35] They said,

> . . . It represents perhaps 25 to 30 percent of nonresidential business investment. But the energy industries in which the money is to be invested are the most capital intensive of all the industries. This means that energy industries use dollars rather than manpower. No group has more right to concern over this than vocational students. A million dollars spent in energy production creates much less employment than the same amount spent in the housing industry, for instance.

> And there are differences within the energy industries. The large, highly centralized industries--electric utilities, oil refineries, coal gasification plants (and solar power satellites in the future)--are much more capital intensive than solar heating and other small-scale, dispersed production alternatives.[36]

The vocational impact of large-scale, capital-intensive technology is an appropriate social concern of educators looking for energy alternatives.

A number of other pressing considerations were mentioned by Fowler and Kryger. Among them was the climatic change which is expected to occur due to the increasing level of CO_2 in the atmosphere with the burning of carbon-containing fuels. Major studies which have been written since their report heighten the sense of urgency that fossil fuels not be used for precisely the reason of the dramatic, dislocating, and major agricultural effects of climatic changes. Worldwide energy inequities will inevitably produce in the next few decades an increasing concentration of CO_2 in addition to the growing problem occasioned by the slow effects of fossil fuels already burned. Major agricultural and population shifts will occur due to delays already made in addressing the problem of providing adequate energy alternatives to fossil fuels.

Polarization of concerns between environmentalists and producers has tended to drive up the price of energy and food in areas where the environmental problems have been least satisfactorily addressed. Although the demonstrations related to nuclear power plants may be the most obvious example of polarization between environmentalists and producers, probably the most important social problems will emerge in the energy-related area of food production and its subsequent processing for use. In January, 1979, Donald R. Price, reported that all aspects

of food production, processing, marketing, home storage, and preparation, when totaled, required about 17 percent of US energy.[37] A quadrupling of energy use occurred in the production aspect of agriculture during two decades (1950's and 1960's). Price said,

> . . . Plant breeding, fertilizers, insecticides, herbicides and mechanization are the major items that helped us to produce more food with less labor, and on less land. With the possible exception of plant breeding, all of these factors are energy intensive.[38]

Price offered cautions regarding the leveling of crop yields in the 1970's, described the importance of natural gas as the source of optimum yields associated with use of nitrogen fertilizers, and emphasized the minimizing of adverse environmental effects of improper application of insecticides and herbicides.[39]

In addition to the important role of agricultural vocational education settings modeling conservation measures, Price identified renewable energy contributions which can also be modeled in these settings. He included some uses of solar, wind, and biomass energy. Alternative energy strategies, modeled in agricultural schools, can make a direct contribution to providing both food and energy, and, thereby, indirectly to reducing international tensions in a world expected to be populated by seven or eight billion people in the year 2000.[40]

Modeling labor-intensive, renewable energy answers in agricultural production in vocational agriculture can also identify future job opportunities and address environmentalists' concerns related to energy usage and the declining fresh water supply. Energy-intensive and capital-intensive agricultural production is taking a heavy toll on

the available fresh water in our underground aquifers. Water takes long periods of time to replenish. Water scarcity and diminished quality forbode even further environmental damage and energy-intensive remedies.

Nuclear Energy in Perspective

A fair treatment of renewable energy demands acknowledgment that many energy experts regard nuclear energy as being the most promising renewable energy answer of the future. If fusion technology can be economically developed, strikingly different conclusions from some of those indicated in this dissertation may be drawn about energy resources in the first or second decade of the next century. The probable course is that research and development of nuclear energy will continue, but at a slower pace than was earlier anticipated.

However, the hazards of nuclear energy risks and uncertainty associated with the nuclear energy alternative as a short-term and long-term solution to our energy problems are well known, so well known that nuclear energy suppliers have mounted expensive advertizing campaigns to reduce the level of public alarm. Harry Clay Blaney, III, made a case for the need to limit the growth of even the peaceful uses of nuclear energy.[41] The nuclear hazard to unborn generations was also evaluated by E. F. Schumacher. The potential ecological damage of radioactive waste products which require "nearly 6000 years for (their) radioactivity to decline to one-half of what it was before" staggers the imagination of a sensitive human being, according to E. F. Schumacher.[42] A knowledgeable public will increasingly demand that such sources of

energy not be used unless safe methods of rendering these waste products relatively harmless can first be identified, especially, if significant, large-scale disasters, like the Chernobyl nuclear accident, occur. This is an increasing probability with nuclear proliferation of peaceful uses of this relatively renewable energy resource. Therefore, this source of energy, which many still hope will provide a growing energy base for the next several decades, seems much less promising than it did ten years ago. This area of energy is likely to become much more expensive with increasing expenditure relative to insuring its use with environmental safety, especially if the industry itself rather than government subsidy bears the costs.

The complexity of nuclear questions is beyond the scope of this dissertation. However, the potential limits and risks involved are a part of the context which makes the arguments important. A brief summary of the kinds of factors which may make nuclear energy a less viable option than government and energy manufacturers supposed in the 1950's through the early 1970's was published in 1978:

> . . . Numerous reports and studies have pinpointed the difficulties and hazards of nuclear power--nuclear weapons proliferation, specific hazards of the fuel cycle itself, the unsolved problem of radioactive wastes, biomedical ignorance and risks, extra dangers of "the plutonium economy", fast-breeder reactor safety, possibilities for terrorism, and uncertainties about nuclear economics.[43]

Any one or several of these factors in combination may make nuclear energy much less desirable than the smaller scale renewable energy systems which pose negligible risks by comparison. This is particularly true if the true cost of nuclear energy, including the long-term wastes

problem, is made to compete on an equal footing with solar and other renewable energy resources. Nuclear economics may be the problem which leads to the demise of that industry, provided that nuclear weapons use does not first dwarf the significance of the whole energy problem scenario and the earth's population as well.

A fair degree of consensus in the energy industry indicates that nuclear fusion "will not be generally available before the year 2000."[44] The practical energy product of nuclear fusion is electricity which may be too expensive to secure in the next couple of decades. Although nuclear fusion relies on the cheaper and much more plentiful supply of deuterium for fuel and it recommends itself for many safety reasons relative to nuclear fission and breeder reactors, this production process not only has yet to be developed, but also has resource limitations and potential risks. The potential modification of the fusion reactor to produce plutonium or U^{233} for weapons is likely to cause concern for decades or even centuries. While the plutonium risk is greater with the current use of nuclear fission and fast breeder reactors, nuclear fusion is by no means free of risks. The water, air, and food supply are numbered among the risks associated with large-scale use of nuclear energy.

The capital intensive nature of the nuclear energy industry is certainly inconsistent with the need to provide meaningful work. It has been reported that "more than 90% of the total generation costs" of both fusion and fission breeder reactor systems "will be directly related to plant capital costs."[45]

Conclusions

Effective school administrators who manage energy aspects of school programs must be broadly knowledgeable of rapidly changing technology in the field of renewable energy systems. Assertive management in this area can save millions of dollars in educational funds for their primary purpose, while appropriately modeling many of the humane values educators affirm. In appropriate settings all of the renewable energy areas dealt with in this dissertation can serve a vital role in educational facilities.

Renewable energy systems are appropriately applied in the context of conservation strategies which can often save 50 percent of the cost of energy required in facilities prior to the energy crisis. Extensive use of insulation, development of energy awareness on the part of users of school facilities, lighting system modifications, utilization of more efficient heating, ventilation and air conditioning equipment, and energy management systems are numbered among the important conservation measures.

An analysis of data provided by state energy offices indicates that solar energy is the most widely applied renewable energy resource in educational facilities. While limited data indicates that active solar heating has been most widely used, passive solar energy and solar hot water heating appear to be the most economical uses of solar energy. Durable solar collectors are widely available. The most expensive design and the highest temperature collector do not necessarily offer advantages equal to the higher cost. Solar salt ponds promise to

provide an economical source of space and water heating, with potential for use in electricity generation as well. Photovoltaic production of electricity is competitive only in remote settings and areas with a very high level of solar insolation, although it is widely used even in Alaska at remote sites.

Wind energy systems have been applied in educational settings for both hot water heating and for electricity generation. Siting in a location which offers at least a ten mph average annual wind velocity, cut-in and cut-out speeds of the equipment selected, safety considerations, storage needs, and noise pollution are numbered among the most important considerations in determination of the feasibility of wind energy. Vertical axis machines of more recent, sturdy design, and moderate size will probably prove to be more economical than the more commonly used horizontal axis machines.

Biomass is the second largest renewable energy resource currently being used in educational facilities if the data supplied by state energy offices is accurate. Wood, wood wastes, crop residues, and municipal wastes have been used increasingly to provide heat in schools and other settings in the last decade. The limits of the biomass resource base demand careful management of sustainable yields of the resources used to avoid long-term environmental damage. Schools in urban areas which have access to a large supply of urban wastes will find increasingly cooperative allies in efforts to convert wastes to energy. Agricultural schools and programs will appropriately model integrated biomass technologies.

Among the renewable energy resources dealt with in this study, hydropower has been least utilized by schools. The very limited use of this resource by educational institutions is difficult to explain. Very promising sites are available for application of hydropower equipment at existing dam sites, the vast majority of which have never been used to generate electricity. High-head sites promise a more economical return on the energy investment. However, recent technological innovations permit the use of hydropower sites having as little as three feet of fall. Recent inventions support the use of hydrobarges and movable hydropower equipment which can be used in free-flowing streams.

Geothermal energy is the third most frequently utilized renewable energy resource dealt with in detail here. While the most promising resource base in the US is in the western part of the country, experts indicate that high temperature sites are quite limited relative to moderate temperature resources. Geothermal energy can be used to provide very competitive electrical energy in several states in the west and northwest part of the country. Although research and development efforts have been delayed on identification of the resource availability in much of the country, heating applications of geothermal energy have been made in schools in both the eastern and western parts of the US.

No states reported use of wave power or ocean thermal energy conversion (OTEC) in educational settings. However, in appropriate settings these energy resources are also promising. The equipment being developed to utilize the temperature differences between water in the ocean offers the promise of broad applicability if it can be developed

to be competitive with the other renewable energy resources. OTEC equipment's applicability is not limited to the ocean where variant temperatures are readily available, but include geothermal and ground water sources, and fresh water behind dams.

A mixing and matching of renewable energy technologies can provide self-sufficiency in some educational settings. Only remote sites are likely to go to that extreme. Wind, hydropower, and solar energy are useful allies in many settings since their relative strengths and weaknesses are unlikely to occur simultaneously. One can back up the other to provide needed heating, cooling, lighting, ventilation, and electricity. Renewable energy resource systems are a necessary alternative to fossil fuels. They can save money for the primary tasks of education while providing useful models to a society whose energy infrastructure must change in the next few decades.

CHAPTER 10 ENDNOTES

1. Jerald L. Deriso, "13th Annual Maintenance & Operations Cost Study," American School & University, 56:7:14, March, 1984.

2. Ibid., p. 16.

3. "Energy Free: Through cogeneration, university moves toward energy independence," American School & University, 55:12:46, August, 1983.

4. Ibid., pp. 46 & 47.

5. Ibid., p. 46.

6. Ibid., p. 47.

7. Ibid., pp. 47-48.

8. Shirley Hansen and Christopher Crittenden, "Warning: Natural gas prices could close your school," American School & University, 55:4:17 & 20-23, December, 1982.

9. Ibid., p. 20.

10. Paul Abrecht, ed., Faith, Science and the Future (Geneva, Switzerland: Church and Society, World Council of Churches, 1978), p. 102.

11. Richard C. Dorf, Energy, Resources, & Policy (Reading, Massachusetts: Addison-Wesley Publishing Company, 1978), p. 339.

12. Paul Abrecht, Faith and Science in an Unjust World: Report of the World Council of Churches' Conference on Faith, Science and the Future, Volume 2: Reports and Recommendations (Geneva, Switzerland: Church and Society, World Council of Churches, 1980), p. 95.

13. C. L. Boltz, "Energy: Electricity," Britannica Book of the Year (1984) (Chicago: Encyclopaedia Britannica, Inc., 1984), p. 345.

14. Ibid.

15. Richard C. Dorf, op. cit., p. 253.

16. Ibid., pp. 254 & 262.

17. Don Finefrock, "Vepco studies six new power sources," Richmond [Virginia] News Leader, p. 1, March 27, 1985.

18. Ibid.

19. Ibid.

20. Ibid., pp. 1 & 6.

21. Ibid., p. 6.

22. Ibid.

23. Ibid.

24. Ibid.

25. Ibid.

26. Ibid.

27. Ibid.

28. Ibid.

29. Ibid., p. 1.

30. Ibid.

31. Ibid., p. 6.

32. Ibid., p. 6, cols. 3-5.

33. Ibid., p. 6.

34. John M. Fowler and King Kryger, "Energizing Vocational Instruction," Vocational Education, 54:1:42, January, 1979.

35. Ibid.

36. Ibid.

37. Donald R. Price, "A New Energy Ethic for Farmers" Vocational Education, 54:1:47-48, January, 1979.

38. Ibid., p. 47.

39. Ibid., pp. 47-48.

40. Ibid., p. 48.

41. Harry Clay Blaney III, "Mass Destruction Risks--Nuclear Weapons Proliferation and Terrorism," Global Challenges: A World at Risk (New York: New Viewpoints, A Division of Franklin Watts, 1979), pp. 176-199.

42. E. F. Schumacher, Small Is Beautiful (New York: Harper and Row, Publishers, 1973), p. 136.

43. Paul Abrecht, ed., Faith, Science and the Future, op. cit., p. 106.

44. Ibid., p. 81.

45. Paul Abrecht, ed., Faith, Science and the Future, op. cit., p. 83.

BIBLIOGRAPHY

Books

Abrecht, Paul, ed. Reports and Recommendations. Vol. 2 of Faith and Science in an Unjust World: Report of the World Council of Churches' Conference on Faith, Science and the Future. Geneva: World Council of Churches, Church and Society, 1980.

_____. Faith, Science and the Future: Preparatory Reading for a World Conference Organized by the World Council of Churches at the Massachusetts Institute of Technology, Cambridge, Mass., USA, July 12-24, 1979. Geneva: Church and Society, World Council of Churches, 1978.

Adams, Jennifer A. The Solar Church. New York: The Pilgrim Press, 1982.

American Petroleum Institute. Two Energy Futures: A National Choice for the 80s. Washington: American Petroleum Institute, 1980.

Anderson, Bruce. Solar Energy: Fundamentals in Building Design. New York: McGraw-Hill, 1977.

Auer, P. L. Renewable Energy Resources. New York: IPC Science and Technology Press, 1978.

Barney, Gerald O. The Summary Report. Vol. I of The Global 2000 Report to the President of the U.S., Entering the 21st Century. New York: Pergamon Press, 1980.

Blaney, Harry Clay, III. Global Challenge: A World at Risk. New York: New Viewpoints, A Division of Franklin Watts, 1979.

Britannica Book of the Year, 1983. Chicago: Encyclopaedia Britannica, Inc., 1983.

Britannica Book of the Year, 1984. Chicago: Encyclopaedia Britannica, Inc., 1984.

Brotti, Ken, and John Perlin, A Golden Thread: 2500 Years of Solar Architecture and Technology. Palo Alto, Calif.: Cheshire Books, 1980.

Brown, Norman L., ed. Renewable Energy Resources and Rural Applications in the Developing World. Boulder, Col.: Westview Press, 1978.

Cassidy, Bruce. The Complete Solar House. New York: Dodd, Mead & Co., 1977.

Commoner, Barry, Howard Boksenbaum, and Michael Carr, eds. Alternative Technologies for Power Production. Vol. II of Energy and Human Welfare: A Critical Analysis. New York: Macmillan Information, 1975.

Constans, Jacques. Marine Sources of Energy. New York: Pergamon Press, 1979.

Courrier, Kathleen, and others. Shining Examples: Model Projects Using Renewable Resources. Washington, D.C.: Center for Renewable Resources, 1980.

Dorf, Richard C. Energy, Resources, & Policy. Reading, Mass.: Addison-Wesley, 1978.

Franta, Gregory E., and Kenneth R. Olson, eds. Solar Architecture. Ann Arbor, Mich.: Ann Arbor Science, 1978.

Freeman, S. David. Energy: The New Era. New York: Walker & Co., 1974.

Goodwin, Joe, and others, eds. Fire of Life: The Smithsonian Book on the Sun. Smithsonian Exhibition Books. New York: W. W. Norton & Co., 1981.

Herman, Stewart W., James S. Cannon, and Alfred J. Malefatto. Energy Futures: Industry and the New Technologies, ed. Leonard H. Orr. Cambridge, Mass.: Ballinger Publishing Co., 1977.

Hooker, C. A., and others. Energy and the Quality of Life: Understanding Energy Policy. Toronto: University of Toronto Press, 1981.

Kahn, Herman, William Brown, and Leon Martel. The Next 200 Years: A Scenario for America and the World. New York: William Marrow, 1976.

Lebens, Ralph M., ed. Passive Solar Architecture in Europe. New York: Halsted Press, 1981.

Lovins, Amory B., and others. Least-Cost Energy: Solving the CO_2 Problem. Andover, Mass.: Brick House Publishing Co., 1981.

McGown, Linda Baine, and John O'M. Bockris. How to Obtain Abundant Clean Energy. New York: Plenum Press, 1980.

McRobie, George. Small Is Possible. New York: Harper & Row, Publishers, 1981.

Manassah, Jamal T., ed. Alternative Energy Sources. Part A. New York: Academic Press, 1981.

Paul, J. K. Solar Heating & Cooling: Recent Advances. Park Ridge, N.J.: Noyes Data Corp., 1977.

Randell, J. E., ed. Ambient Energy and Building Design. New York: Construction Press, 1978.

Schumacher, E. F. Small Is Beautiful: Economics as if People Mattered. New York: Harper & Row, 1973.

Schwaller, Anthony E. Energy Technology: Sources of Power. Worcester, Mass.: Davie Publications, Inc., 1980.

Shinn, Roger L., ed. Plenary Presentations. Vol. I of Faith and Science in an Unjust World: Report of the World Council of Churches' Conference on Faith, Science and the Future. Geneva: Church and Society, World Council of Churches, 1980.

Shurcliff, William A. Solar Heated Buildings of North America: 120 Outstanding Examples. Harrisville, N.H.: Brick House Publishing Co., 1978.

Stunkel, Kenneth R., ed. National Energy Profiles. New York: Praeger Publisher, 1981.

Szokolay, S. V. World Solar Architecture. London: The Architectural Press, 1980.

Tempest, Paul, ed. International Energy Options: An Agenda for the 1980s. Cambridge, Mass.: Oelgeschlager, Gunn & Hain, Publishers, Inc., 1981.

Thring, Meredith, and Roy J. Crookes, ed. Energy and Humanity. Hitchin, Hertford: Peter Peregrinus, 1974.

University of Minnesota. Underground Space Center. Earth Sheltered Housing Design: Guidelines, Examples, and References. New York: Von Nostrand Reinhold Co., 1979.

Government Publications

Both, Deborah, Robert Dubinsky, and Paul Hill. Summary of Findings and Bibliography for the Department of Energy's Innovative Residential

Retrofit Delivery System Demonstration. Santa Monica: The Rand Corporation, 1981.

Both, Deborah R., Robert Dubinsky, and Sue Bodilly. A Description of Integrated Retrofit Delivery Systems and Innovative Conservation Services Programs in Selected Localities. Santa Monica: The Rand Corporation, 1981.

Clarkson College of Technology. Wood-Fired Steam Production at Clarkson College of Technology: Final Report. ERDA report 83-1. [n.p.]: New York State, Energy Research and Development Authority, September, 1982.

Cole, Sandra L. A Solar Collection: Projects Funded by the Appropriate Technology Small Grants Program. Publication No. WAOENG-84-42. Olympia, Wash.: Washington State Energy Office, 1984.

Energy Information Administration. Energy Information Directory. DOE/EIA-0205(86/2). Washington, D.C.: U.S. Department of Energy, National Energy Information Center, Energy Information Administration, August, 1986.

International Energy Agency. Energy Policies and Programmes of the IEA Countries. 1980 Review. Paris: OCDE, OECD, 1981.

Lin, Feng-Bor, Norbert L. Ackermann, and Edward B. Kear, Jr. Potential of Industrial Scale Wood Combustion in St. Lawrence County. Prepared for New York State Energy Research and Development Authority. Potsdam, N.Y.: Clarkson College of Technology, 1979.

Lynch, Robert S., and Trevor P. Castor. Auburn Low-Temperature Geothermal Well: Final Report. NYSERDA Report 84-18. Albany, N.Y.: New York State Energy Research and Development Authority, Department of Communications, 1983.

Michigan. Department of Natural Resources. Michigan Wood Energy Development Plan. Lansing, Mich.: Michigan Department of Commerce, Department of Natural Resources, Forest Management Division, 1986.

Nevada. Governor's Office. Office of Community Services. Nevada Alternative Energy Source Book: Business Directory. 4th ed. Carson City, Nev.: Office of Community Services, 1986.

New York Institute of Technology. Coal Combustion and Cogeneration at New York Institute of Technology, Central Islip Campus: Final Report. NYSERDA report 85-8. [n.p.]: New York State, Energy Research and Development Authority, April, 1984.

Padula, Fred, ed. Aquifer Storage of Winter Chill at Stony Brook State

University. ERDA report 82-20. [n.p.]: New York State, Energy Research and Development Authority, March, 1983.

Pierce, Priscilla J., Jeffrey W. James, and Nancy Kinnear. A Preliminary Survey of Wind Generation in Washington. Olympia, Wash.: Washington State Energy Office, 1984.

Rensselaer Polytechnic Institute. The Rogers' Focusing Heliostat Experimental Program at Rensselaer Polytechnic Institute. ERDA report 80-24. [n.p.]: New York State Energy Research and Development Authority, December, 1980.

South Dakota Energy: Production, Consumption, and Policy. [n.p.]: Bureau of Intergovernmental Relations, Office of Energy Policy, June, 1982.

United Nations. Report of the United Nations Conference on New and Renewable Sources of Energy: Nairobi, 10 to 21 August 1981. New York: United Nations, 1981.

United States. Department of Energy. Information Resources in the USA on New and Renewable Energy: A Description and Directory. Prepared for the 1981 United Nations Conference on New and Renewable Sources of Energy. [n.p.]: Department of Energy, Technical Information Center, 1981.

Washington Department of Natural Resources. Division of Geology and Earth Resources. Geothermal Resources of Washington. Geologic map GM-25. [n.p.]: National Geophysical and Solar-Terrestrial Data Center, National Oceanic and Atmospheric Administration, 1981.

Wheary, Herbert S., ed. Building for Energy Efficiency: Helpful Homework for School Administrators. Richmond, Va.: State Office of Emergency and Energy Services, 1983.

Periodicals

Abelson, Philip H. "Bio-Energy." Science, 204:4398:1161, June 15, 1979.

_____. "Energy from Biomass." Science, 208:4450:1325, June 20, 1980.

Abramson, Paul. "Educational Construction: Seventh Annual Cost Report." American School & University, 53:8:48, 50-56, April, 1981.

_____. "9th Annual Report on Educational Construction." American School & University, 55:8:40-42, 44-45, April, 1983.

_____. "10th Annual Report on Educational Construction." American School & University, 56:8:15-19 & 24, April, 1984.

Adams, M. Ross. "Tax Study Enhances Prospects for Commercial Solar Sales." Solar Age, 6:6:14-15, June, 1981.

"American School & University's Energy Conservation Directory." American School & University, 55:12:49, 51, 53, 54, 57, 58, & 60-71, August, 1983.

Architectural Portfolio. American School & University, 56:3:18-19, 65, 85, 102-103, November, 1983.

"Atlanta Says Yes to Solar Power." American School & University, 52:9:48-50, May, 1980.

Averbuch, Martin. "A Breakthrough in Fuel Savings." American School & University, 56:5:109, January, 1984.

Bacas, Harry. "Energy: A Promise Renewed." Nation's Business, 73:7:34R-35R, July, 1985.

Bacqué, Peter. "Millions of Acres of Energy Cover State, and Price Is Right." Richmond [Virginia] Times-Dispatch, February 3, 1985.

"Bacterial Blubber: Fueling the Future?" Science News, 119:3:40, January 17, 1981.

Barry, Patrick. "Snags in the Biomass Revolution." Environment, 25:1:2-4, January/February, 1983.

Beamon, Todd. "Henrico Board Informally Approves Six Landfill Positions." The Richmond [Virginia] News Leader, March 28, 1985.

Bender, Gerald F., and Jack F. Probasco. "Include Passive Solar in Your Renovations." American School & University, 53:8:38, 40-42, April, 1981.

Benton, Bill. "Solar Screens Give Schools Comfort . . . while They Save Energy!" American School & University, 54:5:42, January, 1982.

Berg, Gordon W. "Geothermal Energy--a Viable Energy Source for Health Facilities." Public Health Reports, 96:2:99-104, March/April, 1981.

Best, Don. "The Advent of Residential Photovoltaics." Solar Age, 6:6:22:25, June, 1981.

_____. "Measured Output of Two Active Systems." Solar Age, 6:7:41-44, July, 1981.

_____. "Solar Portfolio." Solar Age, 6:6:47, June, 1981.

"Best of College Architecture: AS&U's Architectural Competition." American School & University, 53:11:28, 30-33, July, 1981.

"Big Energy Supplies from Little Dams." The Futurist, 19:3:50-51, June, 1985.

"Biomass: Roam on the Range." Science News, 125:12:187, March 24, 1984.

Bleecker, Samuel E. "Energy Management System Uses the Phone to Keep Costs in Line." American School & University, 54:5:76, January, 1982.

Böer, Karl W. "Wind Division's Conference Stressed Dialogue." Solar Age, 6:6:57-60, June, 1981.

Bongartz, Roy. "Power from the Oceans: A New Tidal Wave." Science Digest, 91:9:12-14 & 111, September, 1983.

Britton, Peter. "Geothermal Goes East." Popular Science, 214:2:66-69, February, 1979.

Broad, William J. "Small Hydro: Sleeping Giant." Science News, 114:3:42-43 & 46, July 15, 1978.

Brooks, Albert E. "In Lighting, Less Is More." American School & University, 55:8:20 & 57, April, 1983.

Brown, Lester R. "The Coming Solar Age." Natural History, 91:2:41, 42, 44, 45, 47, 48, 50, 52, 53, 55 & 56, February, 1982.

Bruss, Robert J. "'85 Could Be Energy Credits' Last Year." Richmond [Virginia] Times-Dispatch, March 24, 1985.

Buethe, Chris. "Energy in Your Curriculum." Educational Leadership, 37:2:162-63, November, 1979.

Burr, Donald. "Conserving Energy at School." Vocational Education, 54:1:22, 24, January, 1979.

"Business." Solar Utilization News, 8:7:14, January, 1984.

Bylinsky, Gene. "Biomass: The Self-Replacing Energy Resource." Fortune, 100:6:78-79 & 81, September 24, 1979.

Cage, Bob N. "Thermography." American School & University, 56:12:37-40, August, 1984.

"Can We Reap the Wind?" American School & University, 53:2:56, 58s, October, 1980.

Canipe, Stephen L., Charles Harman and Robert Pittillo. "Energy Retrofit--Step One." American School & University, 55:12:29-30, August, 1983.

Carlson, Carla. "World's Fair Symposium Stresses Biomass." BioScience, 32:6:491-92, June, 1982.

Carroll, Frank. "The Muzzled Wind." USA Today, 108:2416:42-45, January, 1980.

Carrol, Charles W. "The Midas Touch." American School & University, 56:7:52 & 54, March, 1984.

Caruba, Alan. "Indoor Pollution: The Invisible Enemy." American School & University, 56:8:46-47, April, 1984.

Charlier, Roger H. "Ocean-Fired Power Plants." Sea Frontier, 27:1:36-43, January/February, 1981.

_____. "Tides and Turbines." Sea Frontier, 26:6:355-62, November/December, 1980.

Chen, Allan. "Geothermal Powerhouse." Science News, 123:12:186, 187 & 189, March 19, 1983.

Clark, Wilson. "Take Sun and Salt, Add Some Water--The Result Is Energy." Smithsonian, 11:7:143-46, October, 1980.

Clinard, Lillian A. "Conservation--We Have Met the Enemy!" Vocational Education, 54:1:35-37, January, 1979.

"Cogeneration Is Alive and Working Well." American School & University, 55:4:32, December, 1982.

Collet, James. "Urethane Foam: The Energy Alternative." American School & University, 54:5:56, January, 1982.

Collinsworth, Barry G. "School District Goes Diesel--But Not Just for Fuel Economy." American School & University, 54:5:64, January, 1982.

Coy, Peter. "Wood Stove Smoke Is Becoming Major Problem." Richmond [Virginia] Times-Dispatch, February 14, 1982.

Cranston, Alan. "The Cranston Energy Plan." Solar Utilization News, 8:7:7, January, 1984.

Crews, Ed. "Consultants Help Solve Energy-Related Design Problems." The Richmond [Virginia] News Leader, July 5, 1982.

_____. "Developer Sees Tomorrow's Energy in Yesterday's Trash." The Richmond [Virginia] News Leader, March 20, 1982.

Crittenden, Christopher E. "Campus Dollars Go Up in Smoke." American School & University, 56:7:541, March, 1984.

Cross, Aleene A. "Vocational Education for the Occupation of Homemaking." Vocational Education, 55:2:37-39, February, 1980.

"Cut Power Costs with the Wind." Mechanix Illustrated, 76:622:56, March, 1980.

Dankoff, Windy. "Ask Our Experts." Mother Earth News, 97:121, January/February, 1986.

Day, C. William. "The Shape of Schools to Come." American School & University, 56:3:7-8, November, 1983.

Deriso, Jerald L. "13th Annual Maintenance & Operations Cost Study." American School & University, 56:7:14, 16, 18, 20, 24, 26, 28, 32 & 35, March, 1984.

Deriso, Jerald L., and C. Jerome Lane. "Maintenance & Operations Cost Study." American School & University, 55:7:39-40, 42-44, 46, 48, 50, 52 & 54, March, 1983.

DiBona, Charles. "U.S. Faces Clouded Energy Future." The Richmond [Virginia] News Leader, April 25, 1985.

DiMercurio, C. "Ventilation Cooling: An Old Solution to New Problems." American School & University, 53:11:38, 40 & 42-43, July, 1981.

"Directory to Energy Savings." American School & University, 52:4:28,30 & 32, December, 1980.

Doggette, John R., and Mayme R. Crowell. "Technicians: Where Do We Stand?" Vocational Education, 54:1:31-34, January, 1979.

Duggan, Donald D. "Toward Meeting the Nation's Energy Needs." Vocational Education, 54:1:28-30 & 75, January, 1979.

"Energy Audit . . . Here's How." American School & University, 55:12:40, 42, 44 & 45, August, 1983.

"Energy Free: Through Cogeneration, University Moves toward Energy Independence." American School & University, 55:12:46-48, August, 1983.

"Energy from Geothermal Springs Will Heat Boise Public Library." Library Journal, 109:10:1075, June 1, 1984.

"Energy 'on the House.'" American School & University, 55:8:341 & 34n, April, 1983.

"Energy Management Yields Results." American School & University, 52:9:32-35, May, 1980.

"Energy Potential from Biomass High, OTA Says." Chemical and Engineering News, 58:30:11, July 28, 1980.

"Energy Production Set Record in 1984." Richmond [Virginia] Times-Dispatch, May 5, 1985.

"Environmental Aspects of Energy Farms." UN Chronicle, 20:5:42-46, May, 1983.

Esteves, Richard M. "Creative Financing." American School & University, 56:6:48, 50 & 52, February, 1984.

Everett, LeeNora. "Recycling Firm Permit Delayed amid Concerns." Richmond [Virginia] Times-Dispatch, February 14, 1982.

"Exemplary!" American School & University, 56:7:63-65 & 69, March, 1984.

"Facilities Newsfront: Energy Funds Available for School Districts." American School & University, 53:8:30-31, April, 1981.

"Facilities Newsfront: High School Design Cuts Expected Energy Use by 30%." American School & University, 52:7:78-81, March, 1980.

Farnworth, Paul. "Lighting Energy Dramatically Reduced." American School & University, 56:5:42, January, 1984.

Fausch, Timothy A. "Hydro Growth Peaking in Michigan, Midwest." Alternative Sources of Energy, 80:29-30, April, 1986.

Fay, James A. "Harnessing the Tides," Technology Review, 86:5:51, 56 & 58-61, July, 1983.

Feldman, Edwin B., and Susan Sherrell. "14th Annual Maintenance & Operations Cost Study." American School & University, 57:7:9, 10, 12, 14, 19 & 20, March, 1985.

Filegar, Ray. "Trash, Waste Worries Keep Growing." Richmond [Virginia] Times-Dispatch, December 25, 1983.

Fillion, Ruth E. "Pool Blankets Keep Quincy in the Swim." American School & University, 56:5:53, January, 1984.

Fillippini, W. L. "Training for a Place in the Sun." Vocational Education, 54:1:51-53, January, 1979.

Finefrock, Don. "Independents Want Vepco to Buy More." The Richmond [Virginia] News Leader, March 28, 1985.

_____. "Vepco Producing Power from Sun." The Richmond [Virginia] News Leader, February 6, 1986.

_____. "Vepco Studies Six New Power Sources." The Richmond [Virginia] News Leader, March 27, 1985.

_____. "Vepco Talks Conservation, but Commitment Lacking, Critics Say." The Richmond [Virginia] News Leader, March 28, 1985.

Foley, James M. "Roofcraft." American School & University, 56:4:34-36, December, 1983.

"Four Financial Wizards." American School & University, 55:12:19-20, August, 1983.

Fowler, John M., and King Kryger. "Energizing Vocational Instruction." Vocational Education, 54:1:41-43, January, 1979.

Frank, Allan L. "The Solar Clips." Solar Age, 6:7:17-21, July, 1981.

Fuller, Winslow. "What's in the Air for Tightly Built Houses?" Solar Age, 6:6:30-32, June, 1981.

Gannon, Robert. "Push-Pull Windmill." Popular Science, 228:5:85-87 & 118, May, 1986.

"Gasoline Prices around the World." The Richmond [Virginia] News Leader, May 13, 1985.

Gavin, Joseph G., Jr. "Solar Can Thrive in Free-Market Competition." Solar Age, 6:7:49-50, July, 1981.

"Geothermal: Tapping the Earth's Furnace." National Geographic: A Special Report in the Public Interest: Energy: Facing up to the Problem, Getting Down to Solutions, February, 1981, pp. 64-65.

"Geothermal Testing Set for Crater Lake Area." National Park, 59:3-4:39, March/April, 1983.

Godolphin, David. "Simplicity in Adobe." Solar Age, 6:6:27-29, June, 1981.

Gore, Rick. "Conservation: Can We Live Better on Less?" National Geographic: A Special Report in the Public Interest: Energy: Facing Up to the Problem, Getting Down to Solutions, February, 1981, pp. 34-57.

Guebert, Alan. "Cobs, Cords and Stover Fuels New Biomass Grain Dryers." Successful Farming, 81:11:10, October, 1983.

Gustavson, M. R. "Limits to Wind Power Utilization." Science, 204:4388:13-17, April, 1979.

Hair, Jay D. "Small Dams Pose Perils Too." National Wildlife, 21:6:30, October/November, 1983.

"Half of U.S. Population Growth Since '80 Is in 3 States." Richmond [Virginia] Times-Dispatch, April 28, 1985.

Hall, Emory H., and others. "Thermocline Temperature Differences and Realizable Energy." Science, 208:4449:1292-93, June 13, 1980.

Hansen, Shirley J. "This Time, Let's Put Energy Conservation on the Blueprint for New Schools." The American School Board Journal, 172:6:38-39, June, 1985.

Hansen, Shirley, and Christopher Crittenden. "Warning: National Gas Prices Could Close Your School." American School & University, 55:4:17, 20-23, December, 1982.

Hanson, David Jack. "Why Aren't There More Solar Installations?" Solar Utilization News, 8:7:2, January, 1984.

Hartline, Beverly Karplus. "Tapping Sun-Warmed Ocean Water for Power." Science, 209:4458:794-96, August 15, 1980.

Haskins, Paul. "Acid Rain, Growing Problem in Southeast, Despoiling Forests, Crops." The Richmond [Virginia] News Leader, April 4, 1986.

"Heated Bricks." American School & University, 55:12:45, August, 1983.

Helgager, David B. "VocEd Goes Underground in West Virginia." Vocational Education, 54:1:44-46, January, 1979.

Herron, Matt. "The Rush Is on to Find New Gold in Falling Water." Smithsonian, 13:1:87-90, 92 & 94-96, December, 1982.

"High Efficiency Building Recognized for Conservation." American School & University, 52:7:79, March, 1980.

"High Technology Center, Auburn Hills, Michigan." American School & University, 56:7:61, March, 1984.

"Henrico Aims to Convert Landfill Garbage into Fuel." The Richmond [Virginia] News Leader, June 25, 1984.

Hodler, Thomas W. "A Mapping Strategy for Hydro-Geothermal Evaluation." Journal of Geological Education, 30:3:168-71, May, 1982.

Hoke, John. "Guard Building Puts Sun to Work." Richmond [Virginia] Times-Dispatch, March 24, 1985.

Holden, Constance. "Is Bioenergy Stalled?" Science, 227:4690:1018, March 1, 1985.

Holland, Elizabeth. "An Airy Office Complex." Solar Age, 6:7:28-31, July, 1981.

Hopson, Janet L. "They're Harvesting a New Cash Crop in California Hills." Smithsonian, 13:8:122-27, November, 1982.

"Housing Project in Portsmouth to Get Heat from Burning Wood." The Richmond [Virginia] News Leader, June 12, 1986.

"Hydro and Geo." Scientific American, 242:4:64 & 66, April, 1980.

Hyman, Randall. "An Island Trembles Astride a Rift Where Our Planet's Crust Is Forming." Smithsonian, 12:10:52-61, January, 1982.

Ignatius, Paul R., Eugene M. Zuckert, and Lloyd N. Cutler. "Synthetic Fuel: A Possible Alternative." USA Today, 108:2412:20-22, September, 1979.

"Investors Discover Profit in the Wind." Richmond [Virginia] Times-Dispatch, January 1, 1984.

James, Jamie. "Earthscraper." Discover, 5:2:74-77, February, 1984.

Johnson, Phillip. "Energy: On Oregon River and Elsewhere, Small-Scale Hydro Is a Mixed Blessing." Audubon, 85:3:140-43, May, 1983.

_____. "Will Small Dams Create Big Problems?" National Wildlife, 21:6:18-21, October/November, 1983.

Jones, Robert M., and John E. Steinbrink. "Checklists for Administrators: Developing Energy Conservation Programs." NASSP Bulletin (National Association of Secondary School Principals), 64:435:76-82, April, 1980.

Jones, Stewart. "Energy Saving Interest Wavers." The Richmond [Virginia] News Leader, July 27, 1983.

Kahn, Robert D. "Harvesting the Wind." Technology Review, 87:8:56-61, November/December, 1984.

Kakela, Peter, Gary Chilson, and William Patric. "Low-Head Hydropower for Local Use." Environment, 27:1:31-38, January/February, 1985.

Kast, Sheilah. "Conservation Credits Seldom Used." The Richmond [Virginia] News Leader, January 14, 1982.

Kerr, Richard A. "Geopressured Energy Fighting Uphill Battle." Science, 207:4438:1455-56, March, 1980.

Kindley, Mark. "For Eye-in-the-Sky Inventors, Kites Can Be Much More than Toys." Smithsonian, 13:3:56-65, June, 1982.

Kocivar, Ben. "Wave Power Drives Air-Turbine Generators." Popular Science Monthly, 217:4:24, 26 & 30, October, 1980.

Kortus, Diane. "Rubbish!" American School & University, 56:1:56, 58 & 60, September, 1983.

Kramarsky, David. "Lighting the Way to More Efficient Heat." Administrative Management, 37:10:43-44, October, 1976.

Kulm, L. D., and others. "Oregon Subduction Zone: Venting, Fauna, and Carbonates." Science, 231:4738:561-66, February 7, 1986.

Kunze, Jay F. "The Heat from Beneath." USA Today, 108:2410:31-33, July, 1979.

Lamping, Cindy. "Red Rocks Offer Solar Courses." Solar Utilization News, 8:6:3, December, 1983.

Lappen, Alyssa A. "Garbage in, Garbage out?" Forbes, 127:11:50, 52-53, May 25, 1981.

Larson, Ed. "I'll Sum Up Why I'm Converting My School Bus Fleet from Gas to International 6.9 Liter Diesels in Just Two Words." American School & University, 56:6:28-29, February, 1984.

Laurella, Carl L. "Solar Ponds: Wave of Future?" Utah Energy News, 2:4:1, Summer, 1982.

Lawrence, Jerry. "Energy-Conscious Design, Part I." American School & University, 56:12:43, 46, 49 & 50, August, 1984.

_____. "Energy-Conscious Design, Part II." American School & University, 57:2:42 & 44, October, 1984.

Lazarus, Jerry. "Disposal System Is Tested." Richmond [Virginia] Times-Dispatch, March 21, 1982.

_____. "Energy Conservation Paying Off." Richmond [Virginia] Times-Dispatch, March 25, 1982.

_____. "Trash-to-Fuel System Is Ready for Business." Richmond [Virginia] Times-Dispatch, January 20, 1985.

_____. "Warrenton Farmer Is Pioneer in Farm Energy." Richmond [Virginia] Times-Dispatch, November 7, 1982.

"Legislation." Solar Utilization News, 8:7:14, January, 1984.

Lenard, Lane. "Energy from Earth's Furnace." Science Digest, 90:7:70-75, July, 1982.

Lindsley, E. F. "Mid-Size Wind Generator." Popular Science, 221:4:87, October, 1982.

Lippin, Paula. "Offices Go Solar." Administrative Management, 40:9:33-35, September, 1979.

Liuzzo, William F. "Easy on the Eyes." American School & University, 56:12, 34d & 34h, August, 1984.

Lunde, Peter J. "Revised Radiation Data Compound Old Errors." Solar Age, 6:7:47-48, July, 1981.

McAfee, Jerry. "A Decade of Change." USA Today, 108:2412:8-12, September, 1979.

McDermott, Jeanne. "How to Make a Wind-Site Analysis." Popular Science, 217:1:100-02, July, 1980.

McGowan, T. K., and G. E. Feiker. "A New Approach to Controlling Lighting Systems." Administrative Management, 37:10:29-30, October, 1976.

McNichols, J. L., W. S. Ginell, and J. S. Cory. "Thermoclines: A Solar Thermal Energy Resource for Enhanced Hydroelectric Power Production." Science, 203:4375:167-68, January 12, 1979.

"Manage Energy with Computers." American School & University, 55:4:40-41, December, 1982.

Marbach, William D., and Ron LaBrecque. "Steam from the Sunshine." Newsweek, 100:24:92-93, December, 1982.

Marzola, D. L., and D. P. Bartholomew. "Photosynthesic Pathways and Biomass Energy Production." Science, 205:4406:555-59, August 10, 1979.

Maxwell, Jessica. "Wind: The Next Multibillion-Dollar Business." Esquire, 99:4:121-22, April, 1983.

Meredith, T. J., Jerald L. Deriso, and Edwin B. Feldman. "Ninth Annual Maintenance & Operations Cost Study." American School & University, 52:7:50, 56, 58 & 60-62, March, 1980.

Metzenbaum, Howard M. "The Case against Oil Price Decontrol." USA Today, 108:2412:17-19, September, 1979.

Minte, Dan. "Energy Underfoot." Progressive, 47:6:18, June, 1983.

Mitchell, Stephen. "The State of the World 1984." Solar Utilization News, 9:1:15, July 1984.

_____. "University of Minnesota Builds Subterranean Skyscraper." Solar Utilization News, 8:12:8-9, June, 1984.

Mohs, Mayo. "Blowin' in the Wind." Discover, 6:6:68-74, June, 1985.

Morris, Thomas R. "Solar Design Seems to Work." Richmond [Virginia] Times-Dispatch, February 10, 1980.

"New Steam from Magma Energy Study." Science News, 125:8:125, February 25, 1984.

New York State. Energy Research and Development Authority. "Energy Authority and SUNY/Buffalo to Build Solar Pond." New York Energy Review, Summer, 1983, p. 8.

_____. "Long Island Campus Is Site of Wind Machine Test." New York State ERDA Review, Fall, 1981, p. 8.

Newman, J. N. "Power from Ocean Waves." Technology Review, 86:5:50, 52-55, 62, 63 & 69, July, 1983.

"Newsfront: Two Educational Buildings Win Awards." American School & University, 54:12:12, August, 1982.

1983-84 Buyers' Guide and Directory. American School & University, 55:9:5-152, May, 1983.

Odum, Eugene P. "There Is Some Good News about Energy." USA Today, 108:2412:24-26, September, 1979.

Ognibene, Peter. "Energy Farmers: Growing Tomorrow's Fuel." Science Digest, 89:7:98-100, August, 1981.

Olson, Gregory J., Charles M. Harman, and Robert A. Pittillo. "Fix up Those Window Walls." American School & University, 55:4:38-39, December, 1982.

"One Energy Miser's Plan." American School & University, 53:8:64-65, April, 1981.

Ornstein, Allan C. "Baby Boom: Bad News for City Schools." Principal, 62:2:9-13, November, 1982.

Paris, Ellen. "Palm Springs and the Wind People." Forbes, 135:12:170-71, June, 1985.

"Passive Coolness." The Richmond [Virginia] News Leader, March 19, 1985.

"Passive Solar down East." American School & University, 55:4:28-29, December, 1982.

"Passive Solar Energy." Richmond [Virginia] Times-Dispatch, March 14, 1982.

Phillips, Edward J. "Biological Sources of Energy from the Sea." Sea Frontiers, 28:1:36-46, January/February, 1982.

Phillips, Ione. "Editorial: Entering the Age of Energy-Awareness." Vocational Education, 54:1:27, January, 1979.

Pimentel, D., and others. "Environmental and Social Costs of Biomass Energy." BioScience, 34:2:89-94, February, 1984.

"Plants Our Renewable Resource." USA Today, 111:2457:6, June, 1983.

Plotkin, Steven E. "Energy from Biomass: The Environmental Effects." Environment, 22:9:6-13 & 37-40, November, 1980.

Porter, Pamela. "No One's Steamed by this Incinerator." Montgomery [County, Maryland] Journal, June 6, 1986.

Price, Donald R. "A New Energy Ethic for Farmers." Vocational Education, 54:1:47-50, January, 1979.

"Prospects Improve for Ocean Energy." Science News, 120:8:119, August 22, 1981.

Pusey, Robert H. "Why Schools Should Consider Coal." American School & University, 53:11:48-51, July, 1981.

"PV for PV School." ARCO Solar News, 5:2:12-13, Autumn, 1985.

Raftery, Thomas W. "Raftery's Thermo-Fold Draperies Save Energy." American School & University, 54:5:100, January, 1982.

Ramsey, Russ. "Hook Your Wind Machine to the Grid." Mother Earth News, 89:173, September/October, 1984.

Rapley, Frank E. "Bread and Roses." American School & University, 56:7:49-51, March, 1984.

Raven, Helen C., and Diane C. LeFiles. "Fueling an Economy with Industrial Training." Vocational Education, 54:1:56-58, January, 1979.

Reisner, Marc. "Power, Profit, and Preservation: The Invasion of Small-Scale Hydropower." Wilderness, 48:166:26-34, Fall, 1984.

"Replacing Petroleum with Plants." Science Digest, 91:9:36, September, 1983.

"Research: Experimental PV Module Setting Records." Solar Utilization News, 9:2:13, August, 1984.

Rhodes, Bob. "People and Projects, Bronx Cheers for a Solar Lady, [and] Designer Finds His Place in the Sun." Solar Age, 6:6:58-59, June, 1981.

Rippeteau, Jane U. "Making Your Buildings Energy Efficient." Administrative Management, 41:4:52-55 & 58, April, 1980.

Robertson, Gary. "Wood Stove Industry Seeks to Rekindle Market's Embers." Richmond [Virginia] Times-Dispatch, January 3, 1982.

Robison, Rita. "New Directions for Evaporative Cooling Systems." American School & University, 54:2:56-58 & 60-61, October, 1981.

_____. "Solar Energy Now?" American School & University, 52:9:42-43, May, 1980.

Rona, Peter A. "Mineral Deposits from Sea-Floor Hot Springs." Scientific American, 254:1:84-92, January, 1986.

Row, Steve. "Two Energy-Related Firms Change Focus." The Richmond [Virginia] News Leader, November 5, 1984.

Ruberry, William. "Conversion of Trash Is Studied." Richmond [Virginia] Times-Dispatch, August 12, 1984.

Ruegg, Rosalie, and Harold Marshall. "Economics of Building Design." Solar Age, 6:7:22-27, July, 1981.

Russell, Miles C. "An Apprentice's Guide to Photovoltaics." Solar Age, 6:7:32-36, July, 1981.

Sagan, Carl. "The Warming of the World." Richmond [Virginia] Times-Dispatch, (Parade Magazine), February 3, 1985.

Salmon, G. Lee. "Solar News & Views." Solar Age, 6:7:59-61, July, 1981.

Santos, Carlos. "Geothermal Energy Called Sleeping Giant." Richmond [Virginia] Times-Dispatch, August 29, 1982.

Scala, Bea. "Light It Right But Save the Power." Administrative Management, 37:10:27-28, October, 1976.

"School Kicks the Oil Habit." American School & University, 54:4:50-51, December, 1981.

Schwolsky, Rick. "Fixed Glazing." Solar Age, 6:7:45-46, July, 1981.

_____. "Operable Windows: Factors in Solar Construction." Solar Age, 6:6:48-49, June, 1981.

Scott, David. "Precision Blasting Taps Geothermal Energy from Hot Rocks." Popular Science, 219:4:76-77, October, 1981.

_____. "Wave Power Spins a Ram-Air Generator." Popular Science, 224:3:96-98, March, 1984.

_____. "Wave-Tuned Plates." Popular Science Monthly, 214:5:74-75, May, 1979.

Seneker, Harold. "Clean, Plentiful Energy on the Way." Forbes, 126:11:38-40, December 8, 1980.

"SERI Studies Low-Temperature Energy Differences." In Review: A SERI Research Update, 8:2:1-4, February/March, 1986.

"Site Assessment for Alternative Energy." Mother Earth News, 96:58-68, November/December, 1985.

"Small Hydro Branches Out." Environment, 26:9:21, November, 1984.

Smil, Vaclav. "On Energy and Land." American Scientist, 72:1:15-21, January/February, 1984.

Smith, F. G. Walton, and Roger H. Charlier. "Waves of Energy." Sea Frontier, 27:3:139-49, May/June, 1981.

Smith, R. Jeffrey. "Experts Endorse Biomass Energy." Science, 208:4447:1018, May 30, 1980.

"The Solar Age Domestic Hot Water Directory." Solar Age (detachable supplement), 6:6:1-36, June, 1981.

"Solar Business Review." Solar Age, 6:7:49-51, July, 1981.

"Solar Business Review: New PV Prototypes Receive High Marks." Solar Age, 6:6:43-45, June, 1981.

"Solar Cells." Solar Utilization News, 9:5:12, November, 1984.

"Solar Cells: 30 Year Anniversary of Modern Photovoltaics." Solar Utilization News, 9:4:10, October, 1984.

"Solar in the Snow Belt." American School & University, 54:2:54 & 55, October, 1981.

"Solar Water Heaters Popular in Australia." Solar Utilization News, 8:7:1, January, 1984.

"Solar Water Heating Comes Out on Top." Solar Utilization News, 8:6:13, December, 1983.

"SPN Products: Acrylic Sheet Stops Cold, Transmits Light." School Products News, 20:6:38-39, June, 1981.

"Sports Go Underground." American School & University, 52:7:44 & 46, March, 1980.

"State Project to Take the "H" Out of H_2O." Conservationist, 35:5:EQN11, March/April, 1981.

Stewart, Marjorie S., and Willodean D. Moss. "100 Ways to Save Energy." Vocational Education, 54:1:37-39, January, 1979. (Reprinted with permission from the May 1978 issue of the Journal of Home Economics.)

Stone, Cathy. "Knockdown Turbine for Remote Sites." Popular Science, 224:52, June, 1984.

"Stop Those Leaks." American School & University, 55:4:30, December, 1982.

Stump, William P. "'Simplify, Simplify': Here Are the ABCs of Integrated Systems." American School & University, 55:8:26, 28 & 33, April, 1983.

"Suit to Slow Small Hydro." Environment, 27:1:23, January/February, 1985.

"Sun Heats, Cools Columbus Tech." American School & University, 52:9:44 & 46, May, 1980.

"Sunshine in Socorro." American School & University, 55:4:26-27, December, 1982.

Szoke, Stephen S. "Brick." Solar Age, 6:7:37-40, July, 1981.

Tavoulareas, William P. "Talking to Ourselves about the Energy Problem." USA Today, 108:2412:13-14, September, 1979.

Teitelman, Robert. "Tilting at Windmills." Forbes, 132:1:132-34, July 18, 1983.

Temple, Peter. "Thermal Degradation of Wood Associated with Solar Collectors." Solar Age, 6:6:42, June, 1981.

"Thermal." Solar Utilization News, 8:7:13, January, 1984.

"This Pond Is Not for Ducks." American School & University, 53:4:24, December, 1980.

Thurston, Harry. "Fundy's Fecund Barrens." Audubon, 87:5:88-103, September, 1985.

Tillman, J. E. "Eastern, Geothermal Resources: Should We Pursue Them?" Science, 210:4470:595-600, November 7, 1980.

"Tomorrow's Fuel: Green Plants." International Wildlife, 13:3:24-D, May/June, 1983.

"Trading in an Energy Guzzler." American School & University, 55:9:18, March, 1983.

"Underground Hydropower." Environment, 26:3:22-23, April, 1984.

"Underground Research Right at Home." American School & University, 52:9:52-53, May, 1980.

"Unlocking Buried Geothermal Energy." Science News, 118:9:133-34, August 30, 1980.

"Update/Hydropower." Science Digest, 90:3:18-19, March, 1982.

"Use a Consultant." American School & University, 55:4:24-25, December, 1982.

Vories, Rebecca. "Conservation for School District." Solar Utilization News, 8:6:5, December, 1983.

Wallach, Marcia, and Frank Coleman. "Solar Oriented System." Library Journal, 108:21:2205-08, December 1, 1983.

Walton, Susan. "Biomass Could Provide 20% of U.S. Energy by 2000, OTA Says." BioScience, 30:9:631, September, 1980.

_____. "Oddball Crops May Alleviate Energy Shortages, Says OTA." BioScience, 30:12:806, December, 1980.

"Warm Welcomes for Hot Water." Nation's Business, 69:5:78, May, 1981.

"Wave Power." Science Digest, 89:2:27, March, 1981.

Weisz, Paul B., and John F. Marshall. "High-Grade Fuels from Biomass Farming: Potentials and Constraints." Science, 206:4414:24-29, October 5, 1979.

Wellner, Gerald B. "Underground Building Cuts Energy Costs in Half." American School & University, 54:5:52, January, 1982.

Werner, Thomas. "Things Fall Apart." American School & University, 56:6:54, 56, 58 & 63, February, 1984.

"Whirlwind Power Co." Solar Age, 6:6:48, June, 1981.

White, Hank. "Ocean Power Hits Hawaii." Mechanix Illustrated, 76:621:40-41 & 140, February, 1980.

"Whom Do You Believe?" Solar Utilization News, 8:12:1, June, 1984.

"Wind." Solar Utilization News, 8:7:11, January, 1984.

"Wind Energy Industry May Find Growth No Longer a Breeze in '86." Richmond [Virginia] Times-Dispatch, December 29, 1985.

"A Windpower Update from Mother's Eco-Village." Mother Earth News, 86:151, March/April, 1984.

Woodbury, Kenneth B., Jr. "A Practical Guide to Energy Conservation." American School & University, 52:7:68-70, March, 1980.

Wright, Dorothy. "A Preface to Architectural Portfolio." American School & University, 56:3:3, November, 1983.

Yewell, John W. "How You Can Get Funds for Energy Conservation." American School & University, 55:4:44 & 46, December, 1982.

Zausner, Eric R. "Without a Workable Energy Policy--Why?" USA Today, 108:2412:15-16, September, 1979.

Zwarun, Suzanne. "Wind Power in the West." Macleans, 96:42:72, October, 1983.

Unpublished Sources

Lienau, Paul J. "Geothermal Heating System: Oregon Institute of Technology." Klamath Falls, Ore.: Oregon Institute of Technology, Geo-Heat Center, 1981. (Mimeographed.)

Lund, John W. "The Use of Geothermal Energy in Klamath Falls, Oregon, USA." Paper presented at the Association for Engineering Education in South East Asia (AEESEA) Conference, Perth, Australia, August 28, 1979. (Mimeographed.)

APPENDIXES

Three appendixes are provided primarily as a resource to other students wishing to pursue some aspect of this study in greater depth. The student will discover that the level of national and state expenditure devoted to this area of research and development has declined in recent years. However, the data base which is being developed is still expanding quite rapidly. Furthermore, the topic promises to be more important in the future.

Appendix A

Glossary

Absorptance--the ratio of absorption to reflection of radiant energy falling on an object, with greater absorption of heat energy characterizing dark objects than light colored objects.

AlGaAs--aluminum-gallium-arsenide, one of the combinations of materials used to make photovoltaic cells of high efficiency.

Alternating current (ac)--electrical current which rapidly and at regular intervals flows in opposite directions, as is the case with the electricity used in most homes.

Anadromous fish--migrating fish which ascend rapidly falling, fresh water rivers as a part of their life cycle as well as living in the seas and oceans, and, consequently, vulnerable to damage and even extinction by the intrusion of hydropower in their habitat.

Anemometer--an instrument for measuring wind speed at a site of indended use of wind energy.

Anerobic digestion--an oxygen-free conversion process in which bacteria convert biomass into methane (natural gas) in airtight digesters.

Atrium--a enclosed central area which can be opened to adjacent rooms, permitting passive collection and distribution of solar energy through skylights of various configurations.

Berm--see **earth berming.**

Biomass--all living things.

Biomass conversion (bioconversion)--the chemical changing of natural plant and animal materials to fossil fuel substitutes, taking the form of ethanol, charcoal, gasification, methanol, synthetic diesel fuel, synthetic oil, and methane.

Biomass energy--the conversion of living things into other combustible materials and the controlled burning of original and derived biomass by-products to generate heat energy.

Btu--British thermal unit, a measure of heat energy, with one Btu being required to raise the temperature of one pound of water one degree Fahrenheit.

Capital cost--the initial cost of energy equipment, in contrast to operating costs which may be greater than capital cost during the useful life of the equipment.

Clerestory--a window placed near the top of a wall to permit the entry of light, heat gain, and natural ventilation.

Cogeneration--the use of an energy system to simultaneously satisfy multiple requirements, usually including heating and electricity generation.

Cold storage--the retention of cooling capacity in ice, cold water, or other devices for use instead of traditional air conditioning.

Concentric isotherms--a method of mapping geothermal resource availability in terms of the distance from a known geothermal resource, suggesting the distance geothermal water may be pumped through insulated pipe, while feasibly maintaining its value as an energy resource.

Conductivity--the property of a material indicating the amount of heat that will flow through it with changes in temperature when there is direct physical contact.

Conservation--in the context of energy utilization, the process of conserving natural resources through efficient utilization and careful management of their use in such a way as to extend their period of usefulness, including such measures as added insulation, reduced illumination, increased efficiency of operation of equipment, and controls.

Convection--the transfer of heat energy by movement of a gas or liquid as it receives heat from warmed objects changing the temperature or density of the gas or liquid, which may occur in a natural convection loop (passive) or may occur to forced (active) movement of air or water.

Cooling full load hours (CFLH)--a measurement of the annual number of hours during which cooling is needed to maintain comfort.

Crustal plates--the geological faults in the earth's crust, the friction of movement of which generates geothermal heat energy and provides a very large geothermal energy resource.

Cut-in wind speed--the wind speed required to produce useful energy in a given wind machine.

Deforestation--the clear cutting of forest which leads to destruction of habitats and reduced soil fertility and stability.

Degree-day (DD)--the average downward variation for the day of the temperature from the comfort level, a measurement identifying the need for space heating.

DHW (dhw)--domestic hot water, usually includes all heating of water in a facility, except that employed in the heating system, where applicable.

Direct current (dc)--electricity flowing in one direction, as is the case in photovoltaics, lighting, and batteries.

Distribution system--the passive or active system which moves collected heat or cold from collector to storage or to use where it is needed.

District heating--heating several facilities with a heating system housed primarily in one facility, a strategy which helps make solar energy cost effective as well as aesthetically acceptable.

Diurnal--recurring daily or cyclically; used in reference to natural changes in availability of solar and wind energy with the change of time of day.

Double-envelope design--a structural design which provides a relatively unobstructed air space between two structurally sound wall, floor and ceiling areas, through which solar heat can flow in a natural, heat convection loop to storage and to be use as needed.

Down-hole heat exchanger--a geothermal heat transfer device which uses water flowing in a continuous cycle through coils of pipe in a geothermal well to remove the heat of geothermal water for use where it is needed without removing the geothermal water from the well.

Dry hyperthermal zone--very extensive low-temperature geothermal energy resource which does not contain naturally occurring water, and which must, therefore, be injected with water as a heat transfer medium.

Earth berming--a method of using the insulative properties of the earth itself to save heating and cooling expenses, involving sloping of the earth to a significant height on a building's exterior wall; also referred to as earth sheltering, earth integrating, and semi-underground.

Earth-cooling tubes--tubes buried several feet in the ground, but above the water table, to provide cooling of intake air due to the natural properties of the earth which absorbs part of the heat in the air.

Energy audit--a methodical review and quantification of energy uses in specific facilities intended to identify wasteful practices and to set priorities for energy savings.

Energy management system (EMS)--an integrated electrical control system used to improve the monitoring, zoning, and control of use of energy in mechanical and electrical systems.

Ethanol (ethyl alcohol)--a possible biomass energy substitute for gasoline which is a conversion product of sugar-bearing plant materials, such as corn; an additive used to produce gasohol.

FERC--the Federal Energy Regulatory Commission, an independent federal licensing board, the primary agency controlling the development of potential hydropower sites, intended to facilitate the application process for development of sites by simplifying the regulatory maze.

Fossil fuel--coal, crude oil and natural gas, derived from photosynthesis, by way of millions of years of transformation of dead plants and animals, and, consequently, not practially replaceable as they are consumed.

Gasohol--a mixture of gasoline and alcohol, usually containing 10 percent ethanol in the US, and 20 percent ethanol in Brazil.

Generator--a machine which converts mechanical energy to electrical energy.

Geothermal district heating--the use of one geothermal well to serve several facilities, a measure which helps to make the drilling of deep wells more economical since little heat is given up by properly insulated pipes transporting geothermal fluids.

Geothermal energy--the heat in rocks, water, and steam inside the earth which may be tapped to provide both thermal energy and electrical energy.

Geothermal gradient--the increasingly higher temperature with increasing depth in the earth's crust.

Glazing--a translucent or transparent material which permits solar radiation to strike an absorber or interior objects and traps heat energy inside a container (collector) or space.

"Greenhouse effect"--an increase of carbon dioxide in the atmosphere, caused in part by the combustion of fossil fuels, which traps solar radiation, builds up the amount of heat in the atmosphere, and increases the global temperature.

Ground-water heat pump--an electrical heating device which transfers the heat energy in ground water to use where it is needed more efficiently than electrical generation of new heat energy.

Head--the distance water falls at a hydropower site between two points.

Heat exchanger--an electrical device for transferring heat from air, water, or another fluid for use where it is needed.

Heat transfer--the flow of heat energy which occurs through conduction, convection, and radiation.

Heat reclamation system--a system of recovery of exhaust heating or cooling energy by transferring the energy to incoming fresh air, capable of up to 80% recovery.

Heliostat--an axis-mounted, computer-controlled, motorized mirror system which consistently focuses a sunbeam on the same point to concentrate sunlight and generate high levels of heat energy.

High-head hydropower--hydroelectric sites characterized by a high fall, enabling a smaller volume of water to produce more power more economically than a low-head site.

High-temperature geothermal energy resource--a geothermal energy resource which has a high enough temperature to drive traditional turbines to generate electricity, characteristically available in areas of high volcanic and crustal plate activity such as much of the western part of the US.

HVAC (hvac)--used here to describe electricity usage in fans, pumps, associated monitors, and controls related to air and fluid handling, rather than its other common usage to describe heating, ventilation, and air conditioning system as a whole, including the heating and cooling of a mass of fluid or air.

Hybrid solar energy systems--energy systems which use both passive and active methods of solar energy collection, storage, and distribution, and, therefore, require some use of electricity.

Hydrobarge--a portable hydropower station which can be used at flood-control dams.

Hydrocarbons--chemicals composed of hydrogen and carbon which provide food, fiber, fodder, and fuel.

Hydropower--the mechanical and electrical power generated by falling or rapidly flowing water.

Hydrothermal resource--the available supply of heat energy which can be produced by the removal of heat from geothermal water.

Hyperthermal zones--relatively low temperature geothermal energy reservoirs which contain naturally occurring hot water, the heat energy of which is adequate for many heating needs, but the temperature of which is too low for traditional turbines to generate electricity.

Infrastructure--the relatively permanent facilities and equipment involved in energy system operation which require a relatively long time to change.

Intermediate technology--technology characterized by small size, simplicity of operation, low capital cost, and non-violence towards nature.

Latent heat--heat which can be recovered in a phase change by condensing a gas to a liquid or by freezing a liquid without a change in temperature.

Lead time--the time required to move from initial decision to the implementation of significant changes.

Life cycle operating cost--the cumulative cost of energy systems over the useful life of the system, including initial capital cost, maintenance cost, fuel and other operating costs, the cost of borrowing money, building modifications, etc.

Low-grade heat--variously defined, usually from 70°C and lower to 140°C and below--suitable for space and water heating in facilities.

Low-head hydropower--hydroelectric sites characterized by little fall and lower pressure on the turbine, requiring a large volume of water to produce electricity less economically than at a high-head site.

Lumens--a unit of measurement of light available.

Magma--molten rock inside the earth which occasionally rises to the surface in volcanic activity.

Megawatt (mW)--one millions watts of electricity, supplying adequate electrical energy for about 250 homes.

Methane--a natural gas combination of carbon and hydrogen produced by bacterial digestion of biomass materials, usually waste matter, in an airtight environment, and which may be used as fuel.

Methanol--a highly toxic alcohol derived from wood and other fibrous plant materials which may be used as fuel, but damages rubber and plastic parts of fuel systems.

Metric conversions--commonly used energy and related measurements which may need clarification in an English audience, as follows:

centigrade--0°C = freezing, 100°C = boiling

Fahrenheit--32°F = freezing, 212°F = boiling

hectare = 2.47 acres

centimeter = 0.38 inch

millimeter = 0.04 inch

kilometer = 0.62 mile

Modernization--improving an old building by reconstruction to make it satisfy more contemporary facilities needs.

Modular design--the design of building areas into functionally independent portions to permit energizing only portions requiring energy at the time of use.

Non-renewable resources--resources which can not practically be replenished as they are used, including crude oil, natural gas, coal, and uranium.

Ocean thermal energy conversion (OTEC)--the use of the difference in the temperature of water at different ocean depths to power thermal energy conversion engines.

OPEC--Organization of Petroleum Exporting Countries, an international energy cartel which greatly influenced the price and availability of fossil fuels in 1973, and subsequently, especially in 1979.

Operating cost--distinguished from capital costs, and including fuel costs, replacement parts, maintenance, user interaction time, labor, and down time for repair.

Parabolic trough collector--a solar collector which uses mirrors to focus sunlight on a central tank to generate high levels of heat energy.

Passive solar energy--solar energy collected by working with nature by such measures as use of greenhouses, south-facing windows, and natural convection currents, and requiring no pumps, fans or other energy using equipment for energy distribution.

Payback period--the time required to recover the initial capital investment in a new energy system by savings, especially, by the lack of fuel costs in renewable energy systems.

Peak load--the highest energy demand of a facility, which indicates collectively for all users the total required installed electrical capacity of a utility company, and, consequently, a basis for differential charges to those users making larger contributions to this requirement.

Penstock--a pipe or conduit used to conduct falling water to a turbine.

Periscope--an optical instrument housed in a tubular structure which transmits images by way of mirrors and lenses to permit observation of an obstructed or remote view.

Photosynthesis--the energy collection process which uses sunlight falling on chlorphyll, water from the ground, and carbon dioxide from the air to produce living matter or biomass; also the source of fossil fuels.

Photovoltaics (PV)--the direct conversion of sunlight into electricity without moving equipment parts.

Plutons--very large molten granitic intrusions of rock containing radioactive elements which account for their greater temperature relative to the surrounding rock, and, thus, provide a widely available geothermal resource which is located relatively near the earth's surface.

Pumped storage--water artificially pumped behind a dam so that the stored energy available in falling water in the form of hydropower may be available for use as needed.

PURPA--The Public Utility Regulatory Policies Act of 1978 which enabled private and public users to reverse the flow of excessive production of electricity produced by the relatively small-scale user/producer to the utility company, among other provisions.

Pyrolitic incineration--a combustion process in which external heat changes the chemical composition of biomass materials, permitting increased combustion efficiency.

Radial capacity--the extent to which water can reach from the core of a geothermal well to the perimeter to tap the heat stored in the thermal gradient of the earth's rock interior, a measurement which can be substantially increased by hydraulically fracturing the surrounding rock or by using explosives.

Radiation--the transfer of heat energy between bodies separated by space which can occur even in a vacuum, with the flow being from hotter to colder objects.

Rehabilitation--bringing a deteriorated building up to par.

Renewable energy resources--the practically inexaustible energy resources, many of which are derived directly or indirectly from the sun, including direct solar energy, indirect biomass, hydroelectric power, wind, waves, tidal power, and ocean thermal gradients; also, including geothermal energy, and thermonuclear fusion.

Retrofitting--installing new equipment and building modifications in existing facilities.

R-value--a measure of the thermal resistance or the insulative capacity of materials to restrict the flow of heat.

Salt-gradient solar pond--a layered body of water which contains different concentrations of salt in the layers, and, consequently, differentially absorbs solar heat energy while providing a large storage area of solar heat.

Seasonal storage--the capacity of a large, properly insulated body of water or some other device to store solar heat energy for use as needed in cloudy and very cold weather.

Second Law of Thermodynamics--the tendency of energy systems in nature to move toward equilibrium, in which case available energy provides diminishing returns.

Solar collector--a device (including glass to permit the penetration of light, a dark absorber plate, a fluid or gas to transfer heat to where it is needed, and an insulated container) which traps solar radiation and converts it to heat energy for use as needed.

Solar energy--energy derived from the sun, including both primary (direct) solar energy in the form of light and heat, and the derived (indirect) solar energy of the wind, biomass (photosynthesis), hydropower, waves, tides, and ocean thermal gradients.

Solar orientation--the angle of exposure of facilities to solar influx which varies seasonally with the changing relative positions of the earth and the sun.

Storage--the materials or fluids which absorb and contain solar heat for later use.

Subsidence--a relatively quick lowering of the ground level caused by the removal of mass, including water, heat energy, pressure, coal, oil, and other materials, from below.

Superinsulation--the use of very large quantities of insulation to retain heat energy rather than generate new heat energy, a design measure requiring compensatory ventilation with fresh air to avoid interior pollution.

Thermography--a combination of photography and infrared sensing used to identify heat losses and potential remedial strategies.

Thermocline--the variation in fresh water temperature stored behind dams which is significantly higher near the surface than at great depths due the differential absorption of solar energy, and a potential source of energy, with the application of ocean thermal energy technology.

Thermosiphoning--using gravity and the tendency of a fluid or gas to fall with the removal of heat and to rise with the addition of heat to naturally remove geothermal heat energy from a well; also used in some passive solar water heating processes.

Trombe wall--a thick, dark-colored masonry wall which passively absorbs, stores, and distributes solar heat behind glazing.

Turbine--the driving device used in wind, water and other engines which transforms mechanical energy into useful work, such as, the propeller which uses wind energy.

Waste heat--heat generated by energy systems, body heat, and unwanted solar gain, usually described in the context of its potential retrieval for desirable use at reduced cost relative to generating new energy.

Water column (tube)--a water-filled fiberglass tube which requires less space than a Trombe wall and permits penetration of light while providing passive heat collection, storage, and distribution.

Zoning lighting--providing lighting as needed for specific tasks rather than lighting whole area evenly.

Appendix B

State Energy Offices

Kathy B. Erickson, Program Manager of the Division of Energy of the Commonwealth of Virginia Department of Mines, Minerals and Energy, made available the August 1986 listing of state energy offices. She also provided an earlier list which offered significant leads to several recent government reports and permitted correspondence with twenty-seven states which responded to a brief survey of the incidence of usage of renewable energy in educational facilities. The list is updated annually by the Energy Information Administration.[1]

ALABAMA
Fred Braswell, Chief
Department of Economics
and Community Affairs
Energy Division
3465 Norman Bridge Road
P.O. Box 2939
Montgomery, Alabama 36105-0939
(205) 284-8952

AMERICAN SAMOA
Drury Samia, Director
Territorial Energy Office
Office of the Governor
Pago Pago, American Samoa 96799
(684) 699-1101

ARIZONA
Mark Ginsberg, Director
Arizona Energy Office of the
Department of Commerce
1700 West Washington, 5th Floor
Phoenix Arizona 85007
(602) 255-3632

ARKANSAS
Morris Jenkins, Intergovernmental
Coordinator
Arkansas Energy Office
No. 1 State Capitol Mall
Little Rock, Arkansas 72201
(501) 371-1370

---

[1]Energy Information Administration, Energy Information Directory, DOE/EIA-0205(86/2) ([Washington, D.C.: U.S. Department of Energy, National Energy Information Center, Energy Information Administration, August, 1986]), pp. 43-46.

CALIFORNIA
Charles R. Imbrecht, Chairman
Stephen M. Rhoads, Executive Director
California Energy Commission
1516 Ninth Street
Sacramento, California 95814
(916) 324-3326

COLORADO
Hugh Humphreys, Director
Colorado Office of Energy Conservation
112 East 14th Avenue
Denver, Colorado 80203
(303) 866-2507

CONNECTICUT
Bradford S. Chase
Under Secretary for Energy
Office of Policy and Management
Energy Division
80 Washington Street
Hartford, Connecticut 06106
(203) 566-2800

DELAWARE
Robert P. Bartley
Assistant Director
Division of Facilities Management
Energy Office
P.O. Box 1401, O'Neill Building
Dover, Deleware 19903
(800) 282-8616 (Delaware only)
(302) 736-5644

DISTRICT OF COLUMBIA
Charles J. Clinton, Director
DC Energy Office
420 Seventh Street, N.W.
Room 500
Washington, DC 20004
(202) 727-1800

FLORIDA
Katie Tucker, Director
Governor's Energy Office
301 Bryant Building
Tallahassee, Florida 32301-8047
(904) 488-6764

GEORGIA
Paul Burks, Director
Office of Energy Resources
270 Washington Street, S.W.
Room 615
Atlanta, Georgia 30334
(404) 656-5176

GUAM
Dr. Douglas R. Smith, Director
Guam Energy Office
P.O. Box 2950
Agana, Guam 96910
(671) 472-8711 (direct dial)
(671) 734-4452/4530
(overseas operator)

HAWAII
Dr. Takeshi Yoshihara
Energy Program Administrator
Energy Division
Department of Planning and Economic Development
335 Merchant Street, Room 110
Honolulu, Hawaii 96813
(808) 548-4150

IDAHO
Wayne Haas, Administrator
Resources Analysis Division
Department of Water Resources
State House Mail
450 West State Street
Boise, Idaho 83720
(208) 334-4437
FTS 554-4437

ILLINOIS
Dr. Don Etchison, Director
Department of Energy and
Natural Resources
325 West Adams, Room 300
Springfield, Illinois 62704
(217) 785-2800

INDIANA
Charles M. Larason, Director
Division of Energy Policy
(317) 232-8940
Shaukat Naeem, Research Analyst
Energy Resource Development
(317) 232-8985
Indiana Department of Commerce
Indiana Commerce Center
One North Capitol, Suite 700
Indianapolis, Indiana 46204-
2288

IOWA
Dennis Guffey, Acting Director
Iowa Energy Policy Council
Lucas State Office Building
Capitol Complex
Des Moines, Iowa 50319
(515) 281-4420

KANSAS
Gary Haden, Director
Research and Energy Analysis
Kansas Corporation Commission
State Office Building
4th Floor
Topeka, Kansas 66612-1571
(913) 296-5460

KENTUCKY
Geoerge E. Evans, Jr.
Secretary
Kentucky Energy Cabinet
P.O. Box 11888
Lexington, Kentucky 40578-1916
(606) 252-5535

LOUISIANA
Steve Zerangue, Director
Energy Division
Department of Natural Resources
P.O. Box 94396
Baton Rouge, Louisiana 70804
(504) 342-4593

MAINE
Anthony A. Armstrong
Acting Director
Timothy Zorach
Deputy Director of Planning
Maine Office of Energy Resources
State House, Station No. 53
Augusta, Maine 04333
(207) 289-3811

MARYLAND
Dr. Donald E. Milsten, Director
Maryland Energy Office
301 West Preston Street
Suite 903
Baltimore, Maryland 21201-2381
(800) 492-5903 (Maryland only)
(301) 225-1810

MASSACHUSETTS
Sharon M. Pollard, Secretary
Executive Office of
Energy Resources
100 Cambridge Street, Room 1500
Boston, Massachusetts 02202
(617) 727-4732

MICHIGAN
Terry R. Black, Director
Energy Administration
Michigan Department of Commerce
611 West Ottawa Street
North Ottawa Tower
P.O. Box 30228
Lansing, Michigan 48909
(517) 373-9090

MINNESOTA
Mark Dayton, Commissioner
Department of Energy and
Economic Development
900 American Center Building
150 East Kellogg Boulevard
St. Paul, Minnesota 55101
(612) 296-6424

MISSISSIPPI
John W. Green, Jr., Director
Mississippi Department of
Energy and Transportation
Dickson Building
510 George Street, Suite 300
Jackson, Mississippi 39202
(601) 961-4733

MISSOURI
Bob Jackson, Director
Division of Energy
Department of Natural Resources
P.O. Box 176
Jefferson City, Missouri 65102
(314) 751-4000

MONTANA
Van Jamison, Administrator
Energy Division
Department of Natural
Resources and Conservation
1520 East 6th Avenue
Helena, Montana 59620
(406) 444-6697

NEBRASKA
Martha Beaman, Director
Nebraska State Energy Office
P.O. Box 95085, 9th Floor
State Capitol Building
Lincoln, Nebraska 68509-5085
(402) 471-2867

NEVADA
James P. Hawke
Chief of Energy and Community
Development
Governor's Office of Community
Service
1100 East Williams, Suite 117
Carson City, Nevada 89710
(702) 885-4420

NEW HAMPSHIRE
Dennis A. Hebert, Director
Governor's Energy Office
2 1/1 Beacon Street, 2nd Floor
Concord, New Hampshire 03301
(603) 271-2711

NEW JERSEY
Borden R. Putnam, Commissioner
New Jersey Department of
Commerce and Energy
101 Commerce Street
Newark, New Jersey 07102
(201) 648-2744

NEW MEXICO
Paul Biderman, Secretary
New Mexico Energy and Minerals
Department
525 Camino de los Marquez
Santa Fe, New Mexico 87501
(505) 827-5950

NEW YORK
William D. Cotter, Commissioner
New York State Energy Office
2 Rockefeller Plaza, 10th Floor
Albany, New York 12223
(800) 342-3722 (New York only)
(518) 473-4376

NORTH CAROLINA
Carson D. Culbreth, Director
North Carolina Department of
Commerce
Energy Division
P.O. Box 25249
Raleigh, North Carolina 27611
(919) 733-2230

NORTH DAKOTA
Shirley R. Dykshoorn, Director
Office of Intergovernmental Assistance
State Capitol, 14th Floor
Bismark, North Dakota 58505
(701) 224-2676

NORTHERN MARIANA ISLANDS
Elizabeth S. Udui, Acting
Energy Administrator
Office of Energy and Environment
P.O. Box 340
Saipan, Mariana Islands 96950
(885) 099-7174/7284
Routing 1-60-PLUS 671

OHIO
William Whitney
Assistant Deputy Director
Department of Development
Community Development Division
Office of Energy Conservation
30 East Broad Street
24th Floor
Columbus, Ohio 43266-0413
(614) 466-6797

OKLAHOMA
Laurie Haynes, Director
Energy Conservation Services Division
Oklahoma Corporation Commission
Jim Thorpe Building
2101 N. Lincoln Boulevard
Oklahoma Citym, Oklahoma 73105
(800) 522-8573 (Oklahoma only)
(405) 521-3941

OREGON
Lynn Frank, Director
Department of Energy
625 Marion Street, N.E.
Salem, Oregon 97310
(503) 378-4040

PENNSYLVANIA
Robert A. Shinn
Executive Director
Governor's Energy Council
P.O. Box 8010
Harrisburg, Pennsylvania 17105
(717) 783-9982

PUERTO RICO
Lewis L. Smith, Director
Puerto Rico Office of Energy
Office of the Governor
P.O. Box 41089-Minillas Station
Santurce, Puerto Rico 00940-1089
(809) 723-3636

RHODE ISLAND
Clement A. Griscom, Ph.D.
Governor's Office of Energy Assistance
275 Westminster Mall
Providence, Rhode Island 02903
(401) 277-3370/6920

SOUTH CAROLINA
Patricia Jerman, Director
Governor's Office
Division of Energy and Environment
1205 Pendleton Street, 4th Floor
Columbia, South Carolina 29201
(803) 734-0445

SOUTH DAKOTA
Merwyn Larson, Director
Energy Office
217 1/2 West Missouri
Pierre, South Dakota 57501-4516
(605) 773-3603

TENNESSEE
Cynthia Oliphant, Director
Department of Economic and Community Development
Energy Division
320 6th Avenue North, 6th Floor
Nashville, Tennessee 37219-5308
(615) 741-6671

TEXAS
Carol Tombari, Director
Energy Efficiency Division
Public Utility Commission
7800 Shoal Creek Boulevard
Shite 400 North
Austin, Texas 78757
(512) 458-0301

TRUST TERRITORY OF THE PACIFIC ISLANDS
Charles D. Jordan, Director
Office of Planning and Statistics
Office of the High Commissioner
Pacific Islands
Saipan, Mariana Islands 96950
(885) 099-9333

UTAH
Richard M. Anderson, Director
Utah Energy Office
355 West North Temple
3 Triad Center, Suite 450
Salt Lake City, Utah
84180-1204
(800) 662-3633 (Utah only)
(801) 538-5428

VERMONT
Gerald Tarrant, Commissioner
Conservation and Renewable Energy Unit
Public Service Department
State Office Building
Montpelier, Vermont 05602
(800) 642-3281 (Vermont only)
(802) 828-2393

VIRGIN ISLANDS
John Abramson, Director
Virgin Islands Energy Office
P.O. Box 2996
St. Thomas, Virgin Islands
00801
(809) 774-6726

VIRGINIA
Sam O. Bird, Director
Division of Energy
Department of Mines, Minerals and Energy
2201 West Broad Street
Richmond, Virginia 23220
(800) 552-3831 (Virginia only)
(804) 257-6851

WASHINGTON
Richard Watson, Director
Washington State Energy Office
400 East Union
First Floor, ER-11
Olympia, Washington 98504
(206) 586-5000

WEST VIRGINIA
Judith Dyer
Chief Program Manager
West Virginia Fuel and Energy Division
Governor's Office of Community and Industrial Development
1426 Kanawaha Boulevard East
Charleston, West Virginia 25301
(304) 348-8860

WISCONSIN
Roy Christianson, Administrator
Division of State Energy and Coastal Management
Department of Administration
101 South Webster, 6th Floor
P.O. Box 7868
Madison, Wisconsin 53707
(608) 266-8234

WYOMING
Nick Gill, Director
Wyoming Energy Conservation Office
Barrett Building
2301 Central Avenue
Cheyenne, Wyoming 82002
(307) 777-7131

Appendix C

Correspondence

Letters and other documents provided significant new data in the final stages of preparation of this document. The primary source of the information was the state energy office directors and others members of their staffs to whom the responsibility was designated. Included here are the original survey letter and copies of two responses which are quoted in this document. Other materials are on file at the residence indicated in the vita at the end of this document. Summary data has not been presented in this document in tabular form since those who provided the data acknowledged the incompleteness of the data. Consequently, such data would most certainly underestimate the incidence of usage of renewable energy resources in educational facilities. Current regional efforts to collect such data will certainly be helpful to educational institutions looking for models of renewable energy systems which are demonstrably cost effective.

1612 Confederate Avenue
Richmond, Virginia 23227
June 18, 1986

Mr. Paul Burks, Director
Office of Energy Resources
270 Washington Street, S.W., Room 615
Atlanta, Georgia 30334

Dear Mr. Burks:

I have been working for almost five years on a dissertation dealing with the feasibility of using renewable energy resource systems in school facilities. That project is rapidly drawing to a close.

In an effort to be as current in my data and illustrations as possible I am requesting that someone in your office assist me by contributing information in a form which can be documented appropriately in a dissertation. Specifically, I would be very grateful for

1. Summary data regarding the estimated number of schools, colleges and universities using the following renewable energy resources in your state:

   a. passive solar energy _____
   b. active solar heating _____
   c. photovoltaics _____
   d. solar salt ponds _____
   e. other solar energy concentration systems _____
   f. wind turbines _____
   g. small scale hydro _____
   h. biomass conversion _____
   i. wood or other biomass fuel _____
   j. geothermal energy _____
      1) for heat _____
      2) for electricity _____
   k. ocean thermal energy conversion _____

   Person Providing Data _____
   Title _____ Date _____

2. Copy of document(s) regarding exemplary facility(ies) in your state, with author, volume, number, title, source, publisher, date, pagination indicated.

3. Written comments from you or a member of your staff, with title and permission to quote, regarding the current or pending feasibility of the above or other renewable energy resources in educational facilities.

4. Referral to other appropriate sources of recent data regarding usage of renewable energy in educational facilities.

I intend to write for publication in this area. Therefore, assistance offered may serve a wider audience.

Grateful for your assistance,

Glenn C. Thomason
804-359-2694 (home)
804-780-8288 (office)

OFFICE OF ENERGY RESOURCES
270 Washington Street, S.W.
Suite 615
Atlanta, Georgia 30334
(404) 656-5176

Joe Frank Harris
Governor

Paul Burks
Director

June 26, 1986

Mr. Glenn C. Thomason
1612 Confederate Avenue
Richmond, Virginia 23227

Dear Mr. Thomason:

In response to your recent inquiry concerning the use of renewable energy systems in school facilities, the answers to question 1 are noted below:

a.	passive solar energy		4
b.	active solar heating		0
c.	photovoltaics		0
d.	solar salt ponds		0
e.	other solar energy concentration systems		2
f.	wind turbines		0
g.	small scale hydro		0
h.	biomass conversion		2
i.	wood or other biomass fuel		4
j.	geothermal energy		2
	1. for heat	2	
	2. for electricity	0	
k.	ocean thermal energy conversion		0

The use of renewable resources in school facilities, particularly solar and wood, is encouraged under the Institutional Conservation Program (ICP) and through workshops and information dissemination to local school systems. Georgia is an extremely energy dependent State and this Office is committed to energy conservation and the use of renewable resources in all sectors of the population.

For more information concerning the use of wood in Georgia's educational institutions, you may wish to contact Mr. Tommy Loggins, Georgia Forestry Commission, Post Office Box 819, Macon, Georgia 31298-4599.

If this Office may be of further assistance to you, please let me know. I wish you success in the publication of your dissertation.

Sincerely

Paul Burks

PB:rdp

STATE OF NEW MEXICO
ENERGY AND MINERALS DEPARTMENT
525 Camino de los Marquez
Santa Fe, New Mexico
87501

TONEY ANAYA
GOVERNOR

July 18, 1986

Mr. Glenn C. Thomason
1612 Confederate Avenue
Richmond, Virginia 23227

Dear Mr. Thomason:

Presented below is the summary data you requested for schools, colleges and universities using the following renewable energy resources in New Mexico.

Technology		Number	
a.	Passive solar energy	10	
b.	Active solar heating	10	
c.	Photovoltaics	1	
d.	Solar salt ponds	0	
e.	Other solar concentration systems	0	
f.	Wind turbines	3	
g.	Small scale hydro	0	
h.	Biomass conversion	0	
i.	Wood or other biomass fuel	0	
j.	Geothermal energy	1	(for heat)
k.	Ocean thermal energy conversion	0	

It has been the State of New Mexico's experience that passive solar and geothermal systems can be extremely cost-effective when designed, built and maintained properly. Maintenance problems with active solar heating and wind turbine systems at State buildings tend to make many of these systems only marginally cost-effective at best. Photovoltaic systems, though requiring relatively little maintenance, are not cost-effective for most State applications at this time.

Your interest in contacting our office is appreciated. Please contact me at (505) 827-5959 if you have any questions.

Sincerely,

CHARLES P. WOOD
Resource Development and Management Division

The vita has been removed from the scanned document