

DETAILED TABLE OF CONTENTS

PREFACE

INTRODUCTION

Chapter	I	FORCES INFLUENCING U. S. ENERGY CONSUMPTION
	A.	Trends and Patterns in U.S. Energy Consumption: Brief Review of the Facts
	B.	Research Needs and Their Broad Setting
Chapter	II	FUTURE MINERAL FUEL RESERVES
	A.	Introduction
	B.	Natural Resource Endowment: Improved Knowledge and Its Applications
	C.	Improving Exploration and Development
	D.	Estimating Future Mineral Fuel Reserves
Chapter	III	GASEOUS FUELS FROM UNCONVENTIONAL SOURCES
	A.	Production of High-Btu (Pipeline) Gas from Coal
	B.	High-Btu Gas from Oil
Chapter	IV	LIQUID FUELS FROM UNCONVENTIONAL SOURCES
	A.	Oil from Oil Shale
	B.	Oil from Tar Sands
	C.	Oil from Coal
Chapter	V	ELECTRIC ENERGY FROM FOSSIL FUELS
	A.	Sulfur Dioxide Pollution Control
	B.	Production of Clean Low-Btu Gas from Coal
	C.	Gas Turbines
	D.	Combined Gas-Turbine Steam-Turbine Plants
	E.	Magnetohydrodynamics
	F.	Fuel Cells for Central Station Power Generation
	G.	Other Thermodynamic Cycles
	H.	Transmission of Electric Power
Chapter	VI	ELECTRIC ENERGY FROM NUCLEAR FUELS
	A.	Nuclear Power--Thermal Converter Reactors
	B.	Nuclear Power--Breeder Reactors
	C.	Control of Radioactive Emissions from Reactors and Reprocessing Plants
	D.	Transportation and Management of Radioactive Fuel and Radioactive Wastes
	E.	Prevention and Containment of Accidents in Light-Water Reactors
	F.	Fusion Reactors

Chapter VII AUTOMOTIVE POWER PLANTS

Chapter VIII RESIDENTIAL UTILIZATION TECHNOLOGY

- A. Solar Energy Utilization
- B. Residential Space Heating and Cooling
- C. Fuel Cells for Small Installations

Chapter IX ENVIRONMENTAL EFFECTS

- A. Effects on Climate and Weather
- B. Effects of Thermal Pollution
- C. Effects of Oil Pollution of the Ocean
- D. Effects of Surface Coal Mining
- E. Effects on Health

Chapter X PUBLIC POLICIES AFFECTING THE ENERGY INDUSTRIES

- A. Cost-Efficiency of the Energy Industries
- B. Incentives and Disincentives to Private Energy Industries
- C. Energy Supplies in Relation to National Security and International Affairs
- D. Federal Public Lands As A Source of Mineral Fuels
- E. Energy Research and Development
- F. Energy and Environmental Quality

FORCES INFLUENCING U.S. ENERGY CONSUMPTIONTable of Contents

	<u>page</u>
INTRODUCTION-----	I-1
A. TRENDS AND PATTERNS IN U.S. ENERGY CONSUMPTION: BRIEF REVIEW OF THE FACTS	
1.0 Long-Term Trends in Major Aggregates-----	I-4
2.0 The Changing Importance of Different Primary Energy Sources--	I-9
3.0 The Changing Importance of Different Sectors of Consumption--	I-10
4.0 Shifts Among Energy Sources in Different Sectors of Consumption-----	I-13
5.0 A Closer Look at Energy Consumption and Economic Growth-----	I-19
B. RESEARCH NEEDS AND THEIR BROAD SETTING	
1.0 Future Trends in Energy Consumption Growth and Their Social and Economic Underpinnings-----	I-27
1.1 Population Growth and Consumer Behavior-----	I-27
1.2 Trends in the Energy-GNP Relationship: Some Broad Aspects for Study-----	I-28
1.2.1 Energy Consumption Amidst Short-Term Economic Fluctuations-----	I-29
1.2.2 Energy Consumption Trends in the Transportation Sector-----	I-30
1.2.3 Electric Power-----	I-30
1.3 Inter-Industry Analysis of the Energy-GNP Relationship-----	I-33
1.3.1 Background Considerations-----	I-33
1.3.2 The Desirability of Employing the Input-Output Approach-----	I-38
1.4 The Mix of Energy Sources and Forms in Future Consumption-----	I-41
2.0 Alternative Energy Growth Paths: The Role of Selected Factors	I-43
2.1 The Effects of Slowing or Halting Economic Growth--	I-43
2.2 Alternative Quantities of Energy Consumption at Given Economic Growth Rates-----	I-45
2.3 Analysis of Price-----	I-47
2.4 Non-Price Measures to Curtail Energy Use-----	I-57
a. More Efficient Use-----	I-58
b. A Ban or Tax on Electric Appliances-----	I-60
3.0 Improved Energy Consumption Data-----	I-61
4.0 The Need for an Energy Projections Responsibility-----	I-63
4.1 Long-Term Projections-----	I-63
4.2 Short-Term Forecasting-----	I-69

Chapter II

FUTURE MINERAL FUEL RESERVES

Table of Contents

	<u>page</u>
INTRODUCTION-----	II-1
A. NATURAL RESOURCE ENDOWMENT: IMPROVED KNOWLEDGE AND ITS APPLICATIONS	
1.0 The Problem-----	II-5
2.0 Research Needs-----	II-6
2.1 Theory of Natural Resource Formation and Distribution-----	II-6
2.1.1 Process of Formation and Distribution-----	II-6
2.1.2 Analysis of Distribution-----	II-8
2.2 Quantitative Estimation of Mineral Resource Endowment and Inferred Potential Supply-----	II-11
2.2.1 Characteristics of Sedimentary Rocks-----	II-14
2.2.2 Developing a Probability Distribution of Richness of Deposits-----	II-15
2.2.3 Simulating Supply Prospects-----	II-18
B. IMPROVING EXPLORATION AND DEVELOPMENT	
1.0 The Problem-----	II-23
2.0 The Processes of Exploration and Development-----	II-25
2.1 Research Needs-----	II-26
2.1.1 The Economics of Exploration-----	II-26
2.1.2 Extrapolating the Results of Exploration-----	II-30
2.1.3 The Special Case of the Continental Shelves-----	II-31
2.1.4 Exploration and Development Technology and Techniques-----	II-32
C. ESTIMATING FUTURE MINERAL FUEL RESERVES	
<u>Oil and Gas</u>	
1.0 What the Statistics Measure-----	II-46
2.0 Research Needs-----	II-48
2.1 Improvements in Reporting Resource and Reserve Statistics-----	II-48
2.2 Introducing the Cost Dimension-----	II-51
2.3 Investment Required for Hydrocarbon Reservoir Development-----	II-53
2.4 The Special Case of Alaskan North Slope Discoveries-----	II-57
2.5 Secondary Recovery of Crude Oil-----	II-58
2.5.1 State of the Art-----	II-59
2.5.2 Research Needs-----	II-61
2.6 Improvements in Natural Gas Discovery-----	II-63

	<u>Coal</u>	
1.0	What the Statistics Measure-----	II-65
2.0	Research Needs-----	II-66
	2.1 Introducing the Economic Dimension-----	II-66
	<u>Oil Shale</u>	
1.0	What the Statistics Measure-----	II-70
2.0	Research Needs-----	II-71
	<u>Uranium</u>	
1.0	What the Statistics Measure-----	II-72
2.0	Research Needs-----	II-76
	2.1 The Size of Low-Cost Uranium Reserves-----	II-76
	2.2 Cost Reductions in Poorer Grade Resources	
	<u>Thorium -----</u>	II-83
	<u>Comparability Among Mineral Fuels</u>	
1.0	Reserves and Resources-----	II-84
2.0	Costs and Supply Functions-----	II-85

Chapter III

GASEOUS FUELS FROM UNCONVENTIONAL SOURCESTable of Contents

	<u>page</u>
A. PRODUCTION OF HIGH-BTU (PIPELINE) GAS FROM COAL	
1.0 Introduction-----	III-4
1.1 General Reactions and Processes-----	III-4
1.2 Description of Specific Processes-----	III-9
1.2.1 Hygas-Electrothermal (Institute of Gas Technology)-----	III-9
1.2.2 Molten Carbonate (M.W.Kellog Co.)-----	III-12
1.2.3 Bigas (Bituminous Coal Research, Inc.)-----	III-12
1.2.4 Synthane (U.S.Bureau of Mines)-----	III-12
1.2.5 Hygas-Oxygen (Institute of Gas Technology)-----	III-14
1.2.6 Steam-Iron (Institute of Gas Tech- nology/Fuel Gas Associates)-----	III-15
1.2.7 Hydrogasification (U.S.Bureau of Mines)-----	III-16
1.2.8 CO₂-Acceptor Process (Consolidation Coal Company)-----	III-17
2.0 State of the Art-----	III-17
2.1 Current Technology-----	III-17
2.2 Advanced Technology-----	III-19
2.2.1 Hygas-Electrothermal-----	III-19
2.2.2 Molten Carbonate-----	III-20
2.2.3 Bigas-----	III-20
2.2.4 Synthane-----	III-21
2.2.5 Hygas-Oxygen-----	III-22
2.2.6 Steam-Iron-----	III-22
2.2.7 U.S.Bureau of Mines Hydrogasification-----	III-22
2.2.8 CO₂-Acceptor-----	III-23
2.3 Economics-----	III-23
2.3.1 Earlier and Updated Earlier Estimates of Costs-----	III-24
2.3.2 Current Cost Estimates-----	III-29
2.4 Process Comparisons-----	III-29
3.0 Research Needs-----	III-30
3.1 Gasification Fundamentals-----	III-36
3.2 Physical Behavior of Coal and Ash in Gasifiers-----	III-37
3.3 Entrained Flow-----	III-38
3.4 Fluidized Beds-----	III-38
3.5 Gas Purification and Methanation-----	III-39
3.6 Solids Feeding-----	III-42
3.7 Hydrogen Production-----	III-42
References-----	III-44
B. HIGH-BTU GAS FROM OIL	
1.0 Introduction-----	III-47
2.0 State of the Art-----	III-48
3.0 Research Needs-----	III-50
References-----	III-50

Chapter IV

LIQUID FUELS FROM UNCONVENTIONAL SOURCESTable of Contents

	<u>page</u>
A. OIL FROM OIL SHALE	
1.0 Introduction-----	IV-6
2.0 State of the Art-----	IV-6
2.1 Recovery Methods-----	IV-6
2.1.1 In-Situ Recovery-----	IV-6
2.1.2 Mining and Retorting-----	IV-9
2.2 Upgrading-----	IV-11
2.3 Process-Water Pollution-----	IV-14
2.4 Spent Shale Disposal and Runoff-Water Pollution-----	IV-15
2.5 Economics-----	IV-15
2.6 Status of Development-----	IV-20
3.0 Research Needs-----	IV-21
References-----	IV-24
B. OIL FROM TAR SANDS	
1.0 Introduction-----	IV-25
2.0 State of the Art-----	IV-25
2.1 Recovery Methods-----	IV-25
2.1.1 In-Situ Recovery-----	IV-25
2.1.2 Mining Followed by Sand Processing-----	IV-26
2.2 Upgrading-----	IV-27
2.3 Environmental Considerations-----	IV-29
2.4 Economics-----	IV-30
3.0 Research Needs-----	IV-34
References-----	IV-37
C. OIL FROM COAL	
1.0 Introduction-----	IV-38
2.0 State of the Art-----	IV-38
2.1 Fischer-Tropsch Synthesis-----	IV-38
2.2 Pittsburgh and Midway Solvent-Refined Coal Process-----	IV-39
2.2.1 Technology-----	IV-39
2.2.2 Economics-----	IV-41
2.3 Consolidation Coal Company Process (Solvent Refining and Hydrogenation)-----	IV-46
2.3.1 Technology-----	IV-46
2.3.2 Economics-----	IV-48
2.4 Pressure Hydrogenation (H-Coal)	
2.4.1 Technology-----	IV-49
2.4.2 Economics-----	IV-51
2.5 Staged Pyrolysis-----	IV-53
2.5.1 Project Seacoke-----	IV-53
2.5.2 COED Process-----	IV-56

	<u>page</u>
3.0 Research Needs-----	IV-62
3.1 Pittsburgh and Midway Solvent Refining-----	IV-62
3.2 Consol Solvent Refining and Hydrogenation-----	IV-63
3.3 Pressure Hydrogenation (H-Coal) -----	IV-64
3.4 Staged Pyrolysis-----	IV-64
References	IV-65

Chapter V

ELECTRIC ENERGY FROM FOSSIL FUELSTable of Contents

	<u>page</u>
A. SULFUR DIOXIDE POLLUTION CONTROL	
1.0 Introduction	V-4
1.1 Nature of the Sulfur Dioxide Problem-----	V-4
1.2 Projections of Sulfur Dioxide Emissions-----	V-7
2.0 State of the Art-----	V-11
2.1 Use of Fuel Naturally Low in Sulfur-----	V-11
2.2 Fuel Desulfurization-----	V-12
2.3 Sulfur Removal During Combustion-----	V-15
2.4 Stack Gas Cleaning-----	V-17
2.4.1 Limestone Scrubbing-----	V-20
2.4.2 Limestone--Dry Collection-----	V-21
2.4.3 Cat-Ox Process-----	V-22
2.4.4 Chemico Magnesium Oxide Scrubbing-----	V-23
2.5 Stack Gas Dispersion-----	V-24
3.0 Research Needs	V-25
References	V-28
B. PRODUCTION OF CLEAN LOW-BTU GAS FROM COAL	
1.0 Background	V-29
2.0 State of the Art-----	V-31
2.1 First-Generation Processes-----	V-32
2.1.1 Lurgi Gas Producer-----	V-32
2.2 Second-Generation Processes-----	V-38
2.2.1 General Characteristics-----	V-38
2.2.2 Illustrative Second-Generation Process-----	V 40
2.3 Adaptation of Pipeline Gas Processes-----	V 43
3.0 Research Needs-----	V 44
3.1 General-----	V 44
3.2 Fixed-Bed Processes-----	V 44
3.2 Fluidized-Bed Processes-----	V 45
3.4 Entrained-Flow Processes-----	V 46
References	V 49
C. GAS TURBINES	
1.0 Introduction-----	V-50
2.0 State of the Art-----	V-51
2.1 Postwar Developments-----	V-51
2.2 Projection of Turbine System Performance in Base-Load Operation-----	V-54
2.3 Projection of Economics of Gas Turbine System in Base-Load Operation-----	V-56
3.0 Research Needs-----	V-59

page

D. COMBINED GAS-TURBINE STEAM-TURBINE PLANTS	
1.0 Introduction-----	V-63
2.0 State of the Art-----	V-63
3.0 Research Needs-----	V-73
E. MAGNETOHYDRODYNAMICS	
1.0 Introduction	V-74
2.0 State of the Art-----	V-75
3.0 Research Needs-----	V-77
3.1 Coal Combustion-----	V-77
3.2 MHD Generators-----	V-78
3.3 Electrical Conductivity of Coal Combustion Gases--	V-79
3.4 Materials-----	V-80
3.5 Seed Recovery and Gas Cleaning-----	V-81
3.6. Conclusions and Research Procedure-----	V-82
References	V-83
F. FUEL CELLS FOR CENTRAL STATION POWER GENERATION	
1.0 Introduction	V-84
2.0 State of the Art-----	V-84
3.0 Research Needs-----	V-88
References	V-90
G. OTHER THERMODYNAMIC CYCLES-----	V-91
H. TRANSMISSION OF ELECTRIC POWER	
1.0 Introduction-----	V-92
1.1 Background-----	V-92
1.2 The Transmission System-----	V-92
2.0 State of the Art-----	V-93
2.1 UHV (Ultra-High Voltage) Development (Overhead AC Transmission)-----	V-94
2.2 Underground Transmission (AC)-----	V-97
2.3 Advanced Cable Designs for Underground Transmission (AC)-----	V-99
2.4 High Voltage DC Overhead Transmission and AC/DC Conversion-----	V-104
3.0 Research Needs-----	V-106
3.1 Ultra-High Voltage-----	V-106
3.2 Underground Transmission-----	V-107
3.3 Advanced Underground Transmission-----	V-107
3.4 High Voltage Direct Current and AC/DC Conversion--	V-108
References	V-110

Chapter VI

ELECTRICAL ENERGY FROM NUCLEAR FUELSTable of Contentspage

A. NUCLEAR POWER--THERMAL CONVERTER REACTORS (Light-Water Reactors and High Temperature Gas-Cooled Reactors)	
1.0 Introduction	VI-4
1.1 Background-----	VI-4
2.0 State of the Art-----	VI-8
2.1 Introduction-----	VI-8
2.2 Description of Reactor Types-----	VI-9
2.2.1 Pressurized-Water Reactors-----	VI-9
2.2.2 Boiling Water Reactors-----	VI-9
2.2.3 High Temperature Gas-Cooled Reactors	VI-11
2.3 Performance Characteristics-----	VI-12
2.4 Pollutants and Hazards-----	VI-14
2.4.1 Introduction-----	VI-14
2.4.2 Waste Heat-----	VI-14
2.4.3 Radioactive Emissions from Power Plants-----	VI-15
2.4.4 Radioactive Wastes-----	VI-18
2.4.5 Reactor Safety-----	VI-20
2.5 Future of Present Reactor Types-----	VI-22
3.0 Research Needs-----	VI-23
References	VI-25
B. NUCLEAR POWER--BREEDER REACTORS	
1.0 Introduction	VI-26
2.0 State of the Art-----	VI-29
2.1 Background-----	VI-29
2.2 Reactor Types and Expected Performances-----	VI-33
2.2.1 Liquid Metal Fast Breeder Reactor-----	VI-33
2.2.2 Gas-Cooled Fast Breeder Reactor-----	VI-35
2.2.3 Molten Salt Breeder Reactor-----	VI-38
3.0 Research Needs-----	VI-40
3.1 Introduction-----	VI-40
3.2 Choice of Breeder Concept-----	VI-41
3.3 Liquid Metal Fast Breeder-----	VI-42
3.4 Gas-Cooled Fast Breeder-----	VI-48
3.5 Molten Salt Breeder-----	VI-49
References	VI-52
C. CONTROL OF RADIOACTIVE EMISSIONS FROM REACTORS AND REPROCESSING PLANTS	
1.0 Introduction-----	VI-53
1.1 Release of Radioactive Materials at Nuclear Reactors and Chemical Reprocessing Plants-----	VI-53
1.1.1 Reactors-----	VI-54
1.1.2 Reprocessing Plants-----	VI-55
1.2 Legal Restrictions on Releases-----	VI-55

page

2.0 State of the Art-----	VI-56
2.1 Existing Technology-----	VI-56
2.1.1 Reactors-----	VI-56
2.1.2 Reprocessing Plants-----	VI-57
2.2 New Technology-----	VI-58
2.2.1 Reactors-----	VI-59
2.2.2 Reprocessing Plants-----	VI-61
3.0 Research Needs-----	VI-62
References	VI-64

D. TRANSPORTATION AND MANAGEMENT OF RADIOACTIVE FUEL AND RADIOACTIVE WASTES

1.0 Introduction	VI-65
1.1. Scope and Magnitude of the Problem-----	VI-65
1.2 Health and Safety Aspects of Nuclear Fuel Cycle Plants-----	VI-69
2.0 State of the Art-----	VI-70
2.1 Mining, Conversion, and Enrichment of Uranium and Thorium-----	VI-70
2.2 Radioactive Material Shipments to and from Nuclear Power Reactors-----	VI-71
2.3 Preparation and Shipment of Uranium-233 and Plutonium-----	VI-73
2.4 Fuel Recovery (Reprocessing) Plants-----	VI-74
2.5 Disposal of Radioactive Wastes-----	VI-75
3.0 Research Needs-----	VI-78
3.1 Mining, Conversion, and Enrichment of Uranium and Thorium-----	VI-79
3.2 Radioactive Material Shipments to and from Nuclear Power Reactors-----	VI-79
3.3 Preparation and Shipment of Uranium-233 and Plutonium-----	VI-80
3.4 Fuel Recovery (Reprocessing) Plants-----	VI-80
3.5 Disposal of Radioactive Wastes-----	VI-80
References	VI-83

E. PREVENTION AND CONTAINMENT OF ACCIDENTS IN LIGHT-WATER REACTORS

1.0 Introduction	VI-84
1.1 General Background-----	VI-84
1.2 Siting Criteria-----	VI-87
1.3 The Maximum Hypothetical Accident-----	VI-88
1.4 The Design Basis Accident-----	VI-90
2.0 State of the Art-----	VI-92
2.1 Engineered Safety Systems for Mitigation of the Design Basis Accident-----	VI-92
2.2 Unknowns in Reactor Safety-----	VI-93
2.2.1 Unknowns in the Design Basis Accident-----	VI-93
2.2.2 Unknowns Beyond the Design Basis Accident-----	VI-95

page

3.0 Research Needs-----	VI-96
3.1 Further Work Relevant to the Design Basis Accident-----	VI-96
3.2 Further Work Needed in the Region Between the Design Basis Accident and the Maximum Hypothetical Accident-----	VI-97
3.3 Further Work in the Realm of Accident Prevention-----	VI-99
3.4 Reactor Siting-----	VI-100
3.5 Costs and Payoff of Safety Research-----	VI-100
References	VI-103

F. FUSION REACTORS

1.0 Introduction-----	VI-104
1.1 Background-----	VI-104
1.2 Advantages of Fusion Power-----	VI-106
2.0 State of the Art-----	VI-108
2.1 Scientific Feasibility-----	VI-108
2.2 Engineering Feasibility-----	VI-110
2.3 Public Health and Safety-----	VI-111
2.4 Economic Feasibility-----	VI-113
2.5 Laser Ignition Approach to Fusion-----	VI-115
3.0 Research Needs-----	VI-116
3.1 Concerning Scientific Feasibility-----	VI-116
3.2 Concerning Engineering Feasibility-----	VI-117
3.3 Concerning Laser Ignition Systems-----	VI-118
3.4 Concerning Fusion-Power Related Technologies-----	VI-119
4.0 Summary	VI-120
References	VI-121

Chapter VII

AUTOMOTIVE POWER PLANTSTable of Contents

	<u>page</u>
1.0 Introduction-----	VII-1
1.1 Background-----	VII-1
1.2 Air Pollution Considerations-----	VII-7
2.0 State of the Art-----	VII-9
2.1 Possible Solutions to the Pollution Problem of Conventional Internal Combustion Engines-----	VII-9
2.1.1 CO and HC Reduction-----	VII-9
2.1.2 NO _x Reduction-----	VII-15
2.1.3 Fuel Modification-----	VII-16
2.1.4 Fuel Substitution-----	VII-18
2.2 Alternatives to the Conventional Internal Combustion Engine-----	VII-20
2.2.1 Gas Turbines-----	VII-21
2.2.2 Rankine-Cycle (Steam) Engines-----	VII-24
2.2.3 Electric Drive-----	VII-27
(a) Heat Engine/Electric Hybrid-----	VII-27
(b) All-Electric Battery Powered-----	VII-28
2.2.4 Heat Engine/Flywheel Hybrids-----	VII-33
2.2.5 Other Engine Types-----	VII-34
3.0 Research Needs-----	VII-38
References	VII-40

Chapter VIII

RESIDENTIAL UTILIZATION TECHNOLOGYTable of Contentspage**A. SOLAR ENERGY UTILIZATION**

1.0	Introduction-----	VIII-3
2.0	State of the Art-----	VIII-7
2.1	Flat-Plate Collectors-----	VIII-7
2.2	Focusing Collectors-----	VIII-10
2.3	Photovoltaic Cells-----	VIII-11
2.4	Use of Solar Energy to Grow Plants for Fuel-----	VIII-12
2.5	Conversion of Solar Energy Directly to Chemical Fuels-----	VIII-13
2.6	Solar Power from Orbiting Space Stations-----	VIII-14
2.7	Storage of Energy Produced by Solar Energy Systems	VIII-14
2.8	Residential Space Heating-----	VIII-17
2.9	Integrated Solar-Conventional Energy Utilization Systems-----	VIII-20
3.0	Research Needs	
3.1	Flat-Plate Collectors-----	VIII-20
3.2	Focusing Collector Systems-----	VIII-22
3.3	Photovoltaic Systems-----	VIII-23
3.4	Use of Solar Energy to Grow Plants for Fuel-----	VIII-23
3.5	Conversion of Solar to Chemical Energy in Vitro-----	VIII-24
3.6	Solar Power from Orbiting Space Stations-----	VIII-24
3.7	Storage of Energy Produced by Solar Energy Systems	VIII-26
3.8	Residential Space Heating-----	VIII-27
3.9	Integrated Solar-Conventional Energy Utilization Systems-----	VIII-27
4.0	Summary	VIII-29
	References	VIII-31

B. RESIDENTIAL SPACE HEATING AND COOLING

1.0	Introduction-----	VIII-32
2.0	State of the Art-----	VIII-32
2.1	Organization of Heating and Airconditioning Industry-----	VIII-33
2.2	Material and Equipment Development-----	VIII-35
2.3	Systems Studies-----	VIII-35
2.3.1	Home Heating Cost Formulation-----	VIII-36
2.3.2	Examples of Systems Studies-----	VIII-38
3.0	Research Needs-----	VIII-41
	References	VIII-44

page**C. FUEL CELLS FOR SMALL INSTALLATIONS**

1.0 Introduction-----	VIII-45
2.0 State of the Art-----	VIII-46
3.0 Research Needs-----	VIII-51
References	VIII-52

Chapter IX

ENVIRONMENTAL EFFECTS

Table of Contents

	<u>page</u>
A. EFFECTS ON CLIMATE AND WEATHER	
1.0 Scope-----	IX-3
2.0 The Problem-----	IX-4
3.0 Research Needs-----	IX-9
3.1 General Research Areas-----	IX-9
3.1.1 Improved Instrumentation and Data Collection-----	IX-9
3.1.2 Dynamic Modeling and Prediction-----	IX-10
3.2 Specific Discharges-----	IX-11
3.2.1 Carbon Dioxide-----	IX-11
3.2.2 Oxides of Sulfur-----	IX-11
3.2.3 Oxides of Nitrogen-----	IX-12
3.2.4 Other Pollutants-----	IX-12
3.2.5 Water Vapor-----	IX-13
3.2.6 Heat-----	IX-14
3.3 Special Aspects-----	IX-14
3.3.1 Nucleation, Cloud Formation and Precipitation-----	IX-14
3.3.2 Particular Energy Sources-----	IX-15
3.3.3 Economic Impact-----	IX-15
4.0 Selected References	
B. EFFECTS OF THERMAL POLLUTION	
1.0 Origin and Extent-----	IX-18
2.0 Effects of Thermal Pollution-----	IX-22
2.1 Effects of Heat on Aquatic Life-----	IX-22
2.2 Other Effects-----	IX-24
2.3 Recorded Effects-----	IX-25
3.0 Cooling Systems-----	IX-27
3.1 Once-Through Cooling-----	IX-27
3.2 Cooling Ponds and Lakes-----	IX-29
3.3 Wet Cooling Towers-----	IX-30
3.4 Dry Cooling Towers-----	
3.5 Cooling System Costs-----	
4.0 Other Measures to Reduce Thermal Pollution-----	IX-40
4.1 Power Plant Efficiencies-----	IX-40
4.2 Alternative Power Generation Techniques-----	IX-41
5.0 Productive Use of Waste Heat-----	IX-41
6.0 Research Needs-----	IX-44
6.1 Improved Predictive Capacity-----	IX-44
6.2 Cost/Benefit Research-----	IX-45
6.3 Research on Reducing Thermal Pollution-----	IX-46
6.4 Beneficial Use of Waste Heat-----	IX-47
6.5 Investigative Research-----	IX-48

	<u>page</u>
C. EFFECTS OF OIL POLLUTION ON THE OCEAN-----	IX-50
1.0 Source and Amounts of Oil Entering the Sea-----	IX-51
1.1 Conventional Sources-----	IX-51
1.2 Natural and Indirect Sources-----	IX-53
1.3 Source Quantity Estimates-----	IX-55
2.0 Physical Concentration, Distribution and Fate of Oil in the Sea	IX-57
3.0 Effects of Oil Pollution-----	IX-58
3.1 Uncertainty-----	IX-59
3.2 Toxicity-----	IX-59
3.3 Low Level Effects on Marine Life-----	IX-60
3.4 Effects on the Food Chain-----	IX-61
3.5 Interactions of Oil and Other Pollutants-----	IX-61
4.0 Control Measures and Techniques-----	IX-62
4.1 Prevention-----	IX-62
4.2 Chemical Dispersants-----	IX-64
4.3 Physical Sinking-----	IX-64
4.4 Burning	IX-65
4.5 Mechanical Containment and Removal-----	IX-65
4.6 Biological Degradation-----	IX-66
5.0 Institutional Aspects-----	IX-66
6.0 Economic Considerations-----	IX-67
7.0 Conclusions and Major Lines of Research Needs-----	IX-69
 D. EFFECTS OF SURFACE COAL MINING	
1.0 The Problem	IX-72
2.0 Research Needs-----	IX-72
2.1 Evaluation of External Costs-----	IX-73
2.2 Controlling Environmental Damage-----	IX-73
2.3 Surface Mining in the Context of Land-Use Planning	IX-74
2.4 Specific Research Topics-----	IX-74
2.4.1 Development of Mining Techniques-----	IX-75
2.4.2 Soil-Moisture Relationships-----	IX-75
2.4.3 Erosion and Spoil Bank Stability-----	IX-75
2.4.4 Plant Physiology-----	IX-76
2.4.5 Water Treatment-----	IX-76
 E. EFFECTS ON HEALTH	
Health Effects Associated with Fuel Combustion-----	IX-77
1.0 Sources of Energy-Associated Air Pollutants-----	IX-78
2.0 Oxides of Sulfur and Particulates-----	IX-81
2.1 Main Gaps in Knowledge and Resulting Research Directions-----	IX-83
2.1.1 Epidemiologic Studies-----	IX-83
2.1.2 Environmental Assessment-----	IX-84
2.1.3 Mortality Studies-----	IX-86
2.1.4 Morbidity Studies-----	IX-87

	<u>page</u>
2.2 Research Needs-----	IX-89
2.2.1 Community of Epidemiologic Studies-----	IX-89
2.2.2 Animal Studies-----	IX-90
2.2.3 Studies Involving Man-----	IX-92
3.0 Ozones and Hydrocarbons-----	IX-92
3.1 The Problem-----	IX-92
3.2 Research Needs-----	IX-94
4.0 Carbon Monoxide-----	IX-94
4.1 The Problem-----	IX-94
4.2 Research Needs-----	IX-95
Health Effects Associated with Radiation-----	IX-98
5.0 Introduction-----	IX-98
6.0 History	IX-99
7.0 Units of Radiation-----	IX-101
8.0 Extent of Radiation in the Environment-----	IX-102
9.0 Types of Health Effects-----	IX-105
9.1 Introduction-----	IX-105
9.2 Genetic Effects-----	IX-107
9.3 Somatic Effects-----	IX-108
9.3.1 Neoplastic Diseases-----	IX-108
9.3.2 Cataracts-----	IX-109
9.3.3 Growth and Development-----	IX-110
9.3.4 Life Shortening-----	IX-110
10.0 Movement of Radionuclides in the Environment-----	IX-111
11.0 Radiation Standards-----	IX-112
11.1 Organizations and Their Roles-----	IX-113
11.2 The Current Radiation Standards-----	IX-116
11.2.1 Principal Points of Controversy over Standards-----	IX-116
12.0 Research Needs-----	IX-119
12.1 Biological Effects of Radiation-----	IX-119
12.2 Movement of Radionuclides in the Environment-----	IX-122
12.2.1 Transport and Fate of Radionuclides-----	IX-122
12.2.2 Ecosystem Effects of Radiation-----	IX-123
12.2.3 Environmental Systems Analysis-----	IX-124
12.3 Radiation Protection and Standards-----	IX-125
12.4 Estimates of Radiation Doses-----	IX-126

Chapter X

PUBLIC POLICIES AFFECTING THE ENERGY INDUSTRIESTable of Contents

	<u>page</u>
A. COST-EFFICIENCY OF THE ENERGY INDUSTRIES	
1.0 Oil Production-----	X-3
1.1 The Existing System of State Regulation-----	X-4
1.2 Research Needs-----	X-11
1.2.1 Unitization and Its Alternatives-----	X-11
2.0 Coal Production-----	X-18
2.1 Underground Mining-----	X-18
2.1.1 Research Needs	X-20
(a) Productivity of Mine Labor-----	X-20
(b) Health and Safety Legislation: Its Effects	X-22
(c) Sulfur Limitation: Its Effects---	X-24
(d) Mine Systems Analysis-----	X-25
2.2 Strip Mining-----	X-26
2.2.1 Research Needs-----	X-26
3.0 Fossil Fuel Transportation-----	X-27
3.1 Research Needs-----	X-27
3.1.1 Coal	X-28
3.1.2 Oil and Gas Pipelines-----	X-29
3.1.3 Maritime Transport-----	X-30
4.0 Electric Energy-----	X-31
4.1 The Regulatory System-----	X-32
4.2 Research Needs-----	X-36
4.2.1 Regulatory Economics-----	X-36
4.2.2 Directions for the Future: Technology, Policy, and Industrial Structure-----	X-40
5.0 The Structure, Behavior and Performance of the Energy Industries	X-45
B. INCENTIVES AND DISINCENTIVES TO PRIVATE ENERGY INDUSTRIES-----	X-49
1.0 Distinctive Tax Provisions-----	X-51
1.1 The System in Brief-----	X-51
1.2 Research Needs-----	X-52
1.2.1 The Use of Tax Savings-----	X-52
1.2.2 The Economics of Uncertainty-----	X-54
1.2.3 Interaction of Tax Incentives and State Conservation Regulation-----	X-55
1.2.4 Do Tax Provisions Result in Lower Prices?-----	X-56
1.2.5 The Effects of Common-Cost and Joint- Supply Relationships Between Oil and Gas	X-58

	<u>page</u>
2.0 Regulation of Natural Gas-----	X-59
2.1 The Existing System of Field Price Regulation-----	X-59
2.2 Research Needs-----	X-64
2.2.1 Should Field Prices Be Regulated?-----	X-64
2.2.2 The Basis for Setting Prices-----	X-65
2.3 End Use Controls-----	X-67
 C. ENERGY SUPPLIES IN RELATION TO NATIONAL SECURITY AND INTERNATIONAL AFFAIRS-----	 X-69
1.0 Import Controls and Alternative Approaches to Security of Supply	X-71
1.1 The Present System-----	X-71
1.2 Research Needs-----	
1.2.1 The Basic Concept of Heavy Reliance on Domestic Resources-----	X-72
1.2.2 Approaches Not Dependent Upon A Heavy Reliance-----	X-74
(a) Storage to Meet Emergencies-----	X-74
(b) Cost of "Fallow Fields"-----	X-74
(c) Short-Term Rationing and Long- Term End Use Control-----	X-76
(d) Integrating the U.S. and Canadian Economies-----	X-77
(e) Technological Alternatives to Crude Oil-----	X-77
2.0 The Political Economy of International Oil-----	X-78
2.1 The Problem of Supply Interruptions-----	X-80
2.2 Research Needs-----	X-81
2.2.1 Safeguards Against Supply Interruptions-----	X-81
2.3 Relationships Between Host Governments and Foreign-Owned Oil Companies-----	X-83
2.3.1 Evolution of the Present Situation-----	X-83
2.3.2 Research Needs-----	X-86
(a) The Outlook for International Oil Prices-----	X-86
 D. FEDERAL PUBLIC LANDS AS A SOURCE OF MINERAL FUELS	
1.0 The Government as Landowner-----	X-90
2.0 Research Needs-----	X-91
2.1 Maximizing Government Revenues-----	X-91
2.2 Optimizing Mineral Exploitation-----	X-94
2.3 Harmonizing Diverse Objectives-----	X-96
2.4 Leadership in the Unitization of Oil Production---	X-98
2.5 The Special Case of the Naval Petroleum Reserves---	X-99
2.6 The Special Case of Oil Shale-----	X-100
2.7 The Limits of National Sea-Bed Jurisdiction-----	X-105

E. ENERGY RESEARCH AND DEVELOPMENT

1.0 The Problem	X-108
2.0 Research Needs	X-110
2.1 Adequacy of Total National Energy R&D Effort-----	X-110
2.2 Balance Within Total National Energy R&D Effort----	X-111
2.3 Criteria for Government Financing-----	X-112
2.4 Cost-Benefit Methodology in Relation to Government	
R&D Choices-----	X-116
2.4.1 Use of the Social Discount Rate-----	X-116
2.4.2 The Effects of "Redundancy" and	
Interdependency-----	X-117
2.4.3 The Measurement of Benefits-----	X-119
2.4.4 The Measurement of Costs-----	X-120
2.5 Consistency With Other Government Policies-----	X-121
2.6 Analysis of Government Energy R&D Experience-----	X-122
2.7 Efficiency in R&D Management-----	X-123

F. ENERGY AND ENVIRONMENTAL QUALITY

1.0 The Policy Problem Broadly Defined-----	X-124
2.0 Data Specification and Evaluation Research-----	X-126
3.0 Research on Implementation Alternatives-----	X-130
4.0 Research on Institutional Approaches-----	X-133