Contents

Preface to the Second Updated Edition	XI
Acronyms and Initialisms XIII	
Units and their Abbreviations XV	

1	Introduction 1	
2	History of Coal in the Industrial Revolution and Beyond	11
3	History of Petroleum Oil and Natural Gas 19	
3.1	Oil Extraction and Exploration 23	
3.2	Natural Gas 24	
4	Fossil Fuel Resources and Their Use 29	
4.1	Coal 30	
4.2	Petroleum Oil 35	
4.3	Unconventional Oil Sources 39	
4.3.1	Tar Sands 40	
4.3.2	Oil Shale 41	
4.4	Natural Gas 42	
4.5	Coalbed Methane 49	
4.6	Tight Sands and Shales 50	
4.7	Methane Hydrates 50	
4.8	Outlook 53	
5	Diminishing Oil and Natural Gas Reserves 55	
6	The Continuing Need for Carbon Fuels, Hydrocarbons	
	and their Products 65	
6.1	Fractional Distillation 68	
6.2	Thermal Cracking 69	

VI	Contents	
	7	Fossil Fuels and Climate Change 77
	7.1	Effects of Fossil Fuels on Climate Change 77
	7.2	Mitigation 86
	8	Renewable Energy Sources and Atomic Energy 91
	8.1	Introduction 91
	8.2	Hydropower 93
	8.3	Geothermal Energy 98
	8.4	Wind Energy 102
	8.5	Solar Energy: Photovoltaic and Thermal 105
	8.5.1	Electricity from Photovoltaic Conversion 106
	8.5.2	Solar Thermal Power for Electricity Production 108
	8.5.3	Electric Power from Saline Solar Ponds 110
	8.5.4	Solar Thermal Energy for Heating 110
	8.5.5	Economic Limitations of Solar Energy 111
	8.6	Bioenergy 112
	8.6.1	Electricity from Biomass 112
	8.6.2	Liquid Biofuels 113 Biomethanol 117
	8.6.3	
	8.6.4 8.7	Advantages and Limitation of Biofuels 117 Ocean Energy: Tidal. Wave and Thermal Power 118
	8.7.1	Ocean Energy: Tidal, Wave and Thermal Power 118 Tidal Energy 118
	8.7.2	Wave Power 120
	8.7.3	Ocean Thermal Energy 120
	8.8	Nuclear Energy 121
	8.8.1	Energy from Nuclear Fission Reactions 123
	8.8.2	Breeder Reactors 128
	8.8.3	The Need for Nuclear Power 129
	8.8.4	Economics 130
	8.8.5	Safety 132
	8.8.6	Radiation Hazards 133
	8.8.7	Nuclear By-Products, Waste and Their Management 135
	8.8.8	Emissions 136
	8.8.9	Nuclear Fusion 137
	8.8.10	Nuclear Power: An Energy Source for the Future 140
	8.9	Future Outlook 140
	9	The Hydrogen Economy and its Limitations 143
	9.1	Hydrogen and its Properties 143
	9.2	Development of Hydrogen Energy 145
	9.3	Production and Uses of Hydrogen 148
	9.3.1	Hydrogen from Fossil Fuels 150
	9.3.2	Hydrogen from Biomass 151
	9.3.3	Photobiological Water Cleavage 152
	9.3.4	Water Electrolysis 152

9.3.5	Hydrogen Production Using Nuclear Energy 155
9.4	The Challenge of Hydrogen Storage 156
9.4.1	Liquid Hydrogen 156
9.4.2	Compressed Hydrogen 158
9.4.3	Metal Hydrides and Solid Absorbents 159
9.4.4	Other Means of Hydrogen Storage 160
9.5	Centralized or Decentralized Distribution of Hydrogen? 161
9.6	Hydrogen Safety 163
9.7	Hydrogen as a Transportation Fuel 164
9.8	Fuel Cells 166
9.8.1	History 166
9.8.2	Fuel Cell Efficiency 167
9.8.3	Hydrogen-Based Fuel Cells 169
9.8.4	PEM Fuel Cells for Transportation 173
9.8.5	Regenerative Fuel Cells 175
9.9	Outlook 177
10	The "Methanol Economy": General Aspects 179
17	Methanol and Dimethyl Ether as Fuels and Energy Carriers 185
11.1	Background and Properties 185
11.2	Chemical Uses of Methanol 187
11.3	Methanol as a Transportation Fuel 189
11.3.1	Development of Alcohols as Transportation Fuels 189
11.3.2	Methanol as Fuel in Internal Combustion Engines (ICE) 193
11.3.3	Methanol as Fuel in Compression Ignition (Diesel) Engines 195
11.4	Dimethyl Ether as a Transportation Fuel 197
11.5	DME Fuel for Electricity Generation and as a Household Gas 200
11.6	Biodiesel Fuel 202
11.7	Advanced Methanol-Powered Vehicles 203
11.8	Hydrogen for Fuel Cells Based on Methanol Reforming 203
11.9	Direct Methanol Fuel Cell (DMFC) 207
11.10	Fuel Cells Based on Other Methanol Derived Fuels and Biofuel Cells 212
11 11	
11.11	Regenerative Fuel Cell 213 Methanol and DME as Marine Fuels 213
11.12	
11.13	
11.14	Methanol and DME Storage and Distribution 216 Price of Methanol and DME 219
11.15	
11.16	Safety of Methanol and DME 220 Emissions from Methanol and DME Powered Vehicles 235
11.17	Emissions from Methanol- and DME-Powered Vehicles 225
11.18	Environmental Effects of Methanol and DME 227
11.19	Beneficial Effect of Chemical CO ₂ Recycling to Methanol on Climate Change 230

VIII	Contents
------	----------

12	Production of Methanol: From Fossil Fuels and Bio-Sources to
	Chemical Carbon Dioxide Recycling 233
12.1	Methanol from Fossil Fuels 236
12.1.1	Production via Syn-Gas 236
12.1.2	Syn-Gas from Natural Gas 239
12.1.2.1	Steam Reforming of Methane 239
12.1.2.2	Partial Oxidation of Methane 240
12.1.2.3	Autothermal Reforming and Combination of Steam Reforming
	with Partial Oxidation 240
12.1.2.4	Syn-Gas from CO ₂ Reforming of Methane 241
12.1.3	Syn-Gas from Petroleum Oil and Higher Hydrocarbons 241
12.1.4	Syn-Gas from Coal 242
12.1.5	Economics of Syn-Gas Generation 242
12.2	Methanol through Methyl Formate 243
12.3	Methanol from Methane without Producing Syn-Gas 244
12.3.1	Direct Oxidation of Methane to Methanol 244
12.3.2	Catalytic Gas-Phase Oxidation of Methane 245
12.3.3	Liquid-Phase Oxidation of Methane to Methanol 247
12.3.4	Methane into Methanol Conversion through Monohalogenated
	Methanes 249
12.3.5	Microbial or Photochemical Conversion of Methane into Methanol 251
12.4	Methanol from Biomass, Including Cellulosic Sources 252
12.4.1	Methanol from Biogas 259
12.4.2	Aquaculture 261
12.4.2.1	Water Plants 261
12.4.2.2	Algae 262
12.5	Chemical Recycling of Carbon Dioxide to Methanol 264
12.5.1	Carbon Dioxide into Methanol Conversion with Methane 266
12.5.2	CO ₂ Conversion into Methanol with Bi-reforming of Methane 268
12.5.3	Dimethyl Ether Production from Syn-Gas or Carbon Dioxide 269
12.5.4	Combining Chemical or Electrochemical Reduction and
	Hydrogenation of CO ₂ 271
12.5.5	Separating Carbon Dioxide from Industrial and Natural Sources
	for Chemical Recycling 273
12.5.6	Separation of Carbon Dioxide from the Atmosphere 275
13	Methanol-Based Chemicals, Synthetic Hydrocarbons and Materials 279
13.1	Methanol-Based Chemical Products and Materials 279
13.2	Methyl tert-butyl Ether and DME 281
13.3	Methanol Conversion into Light Olefins and Synthetic
	Hydrocarbons 282
13.4	Methanol to Olefin (MTO) Processes 283
13.5	Methanol to Gasoline (MTG) Processes 285
13.6	Methanol-Based Proteins 287
13.7	Outlook 288

14 Conclusions as	nd Outlook 289
-------------------	----------------

- Where We Stand Now 289 14.1
- The "Methanol Economy", a Solution for the Future 291 14.2

References 297

For Further Reading and Information 317

Index 327