

# Carbon Dioxide Recovery and Utilization

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*Edited by*

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***This book is dedicated to  
my Family***

## **Preface**

This Book is a summary report of the EU Project BRITE-EURAM 1998 BRRT-CT98-5089 “RUCADI-Recovery and utilization of carbon dioxide”. The Book presents an outline of the emissions in the EU (and a reference to the world emission) followed by a series of papers that are a roadmap to carbon dioxide utilization and cover the scientific and technical aspects of: CO<sub>2</sub> separation, CO<sub>2</sub> technological use, utilization of supercritical carbon dioxide, and actual and perspective use of carbon dioxide in chemical and biological processes. An assessment study of carbon dioxide utilization for the synthesis of methanol is also presented.

The Book has been written for consultation not only by scientists, experts and students, but also by the public. Therefore, an effort has been made by the Authors to use an open and plain language, while presenting accurate scientific and technical data and facts. The result is a collection of reports on technologies, scientific facts and data enriched with updated essential lists of references that represent the route to a deeper insight into the Science and Technology of carbon dioxide.

The work done gives a taste of the usefulness of carbon dioxide and may contribute to strengthen the paradigm shift from the concept of carbon dioxide as a waste to that of carbon dioxide as a resource.

Michele Aresta,  
Editor,  
Coordinator of the RUCADI Project.

## Foreword

The recovery and utilization technologies can contribute to the reduction of both the emission of carbon dioxide and its immission into the atmosphere, two issues our Society has to cope with. The evaluation of the contribution that the utilization option can give to the control of the accumulation of carbon dioxide into the atmosphere is not an easy and straight task: in fact one should consider both the direct and indirect influence of the reuse of carbon dioxide. The fixation of CO<sub>2</sub> for the synthesis of commodities and fine chemicals is an example of the direct reduction of the emission of carbon dioxide, that is used as a source of carbon. The development of innovative technologies that use carbon dioxide and/or are simply less carbon-intensive (lower energy input, more direct syntheses, waste solvent reduction, high yield and high-selectivity syntheses with no- or low-waste production) is an indirect diminution of the carbon dioxide emission. Both approaches are quite new and require a detailed analysis for understanding the potential of carbon dioxide utilization as a technology for reducing the CO<sub>2</sub> emission and immission in the atmosphere. In fact, a new synthetic methodology based on carbon dioxide does not contribute to its reduction only with the amount of carbon dioxide incorporated into a chemical, but also through the energy-mass-waste-organic solvents reduction. In some cases the latter can represent a much more important contribution than the former. Only the application of the LCA methodology for comparing the existing and the innovative technology can really consent the evaluation of the avoided carbon dioxide.

The utilization of carbon dioxide is often considered as an impossible task to achieve because of the fact that carbon dioxide lays in a potential energy well. Actually, carbon dioxide can be fixed into organic compounds through many different ways, some of which demand a very low energy input, if any.

In this Book a comprehensive analysis is made of the sources of carbon dioxide, and their purity, of the separation technologies and of the uses of carbon dioxide, as a technological fluid or a reagent, or as a reactive solvent. The fixation of carbon dioxide in biomass that can be used as source of energy or chemicals is also considered.

The Book is organized in Sections that gather Chapters dealing with homogeneous contents.

Section I presents a detailed panorama of the carbon dioxide emission by the EU Industry and a comparison with the world data. The purity of carbon dioxide is discussed as a limiting factor to its use. In fact, for some specific purposes, as in the food-industry, contaminants that are often present in carbon dioxide streams must be absent. The elimination of such species to the required level, would rise the price of carbon dioxide and make not economic its use. Therefore, the knowledge of the purity of CO<sub>2</sub> is a key issue for deciding its most economic use and fate. This Chapter also presents the "merchant uses" of carbon dioxide, i.e. those uses in which there is not a chemical conversion of carbon dioxide.

Section II gives a deep insight into separation technologies, presenting advantages and disadvantages of each of them and their cost. An exhaustive discussion on technical plants is also presented and most innovative technologies detailed.

Section III describes the use of "supercritical carbon dioxide", and the innovative technologies based on it. It is divided in six Chapters dealing each with the: Particle formation in scCO<sub>2</sub>, Supercritical fluid chromatography, Homogeneous catalysis in scCO<sub>2</sub>, Heterogeneous catalysis in scCO<sub>2</sub>, Polymers synthesis in scCO<sub>2</sub>, and Modification of polymers in scCO<sub>2</sub>.

Section IV presents the chemical utilization of carbon dioxide and is organized in four Chapters that address issues such as: Carbon dioxide fixation into organic compounds, with an analysis of the synthesis of compounds that require a low energy input; Linear organic carbonates, essentially focussed on DMC production; Electrochemical conversion of carbon dioxide, that details the opportunities for electrochemical syntheses based on CO<sub>2</sub>; and Carbon dioxide reduction to C1 or Cn molecules, with an analysis of the high-energy options, like fuels synthesis from carbon dioxide and dry-reforming of methane.

Section V introduces the fixation of carbon dioxide into biomass. This topic is divided in two Chapters dealing with the biological utilization of carbon dioxide, as an option for generation of renewable energy. The first Chapter details the use of macro- and micro-algae as source of fuels, the

second highlights the use of terrestrial and residual biomass as source of energy, detailing the existing technologies.

The sixth and last Section of the Book presents an assessment study of the carbon dioxide utilization for the synthesis of methanol and an industrial perspective of the use of carbon dioxide..

All together the Book furnishes a comprehensive prospect of the potential of the utilization option and gives information on the state of the art of a number of uses of carbon dioxide, clarifying if they are, or will be in the short term, exploited at the industrial level. This information, coupled with the presentation of the data relevant to the emission and the detailed report on the recovery technologies, gives a perspective of the usefulness of the Recovery and Utilization options and may inspire new scientific research.

The overall picture is that if the recovery of carbon dioxide will be exploited on a large scale as a technology for limiting the immission of carbon dioxide into the atmosphere, then the utilization option may have a key role as it contributes to reduce both the emission and the immission while generating a profit, that may pay back the recovery costs.

The reader will appreciate the effort made by the Authors to use a plain language, while giving both a sound scientific and technological basis to the presentation.



## **Acknowledgements**

As editor of this Book and co-ordinator of the RUCADI Project I have to thank all RUCADI-Partners, whose names are listed at the beginning of each Chapter: with their enthusiasm and competence they made the Project a success. I am also grateful to those who accepted to be authors of the Chapters for the time they have dedicated to the preparation of the papers. We all are grateful to the EU Commission for having funded the RUCADI Project and made possible the preparation of this Book. I wish to thank the publisher, Vaska Krabbe, at Kluwer Academic/Plenum Publishers for her continuous assistance during the editing of the book. My warmest thanks go to Dr. Angela Dibenedetto for the time and the attention she has dedicated to the preparation of this Book.

# Contents

|   |     |
|---|-----|
| Dedication  | v   |
| Preface   | vii |
| Foreword  | ix  |
| Acknowledgments   | xii |
| <i>Section I: Emission</i>  | 1   |
| <b>Chapter 1: Carbon Dioxide Emission and Merchant Market in the European Union</b> |     |
| by Jan Vansant  | 3   |
| 1 Introduction  | 3   |
| 2 Carbon dioxide emission in the European Union                                     | 3   |
| 2.1 Global carbon dioxide emissions per sector in the EU countries                  | 4   |
| 2.2 Carbon dioxide emission point sources   | 7   |
| 2.2.1 Cement  | 7   |
| 2.2.2 Lime Industry   | 8   |
| 2.2.3 Ammonia   | 9   |
| 2.2.4 Ethylene oxide  | 9   |
| 2.2.5 Power plants  | 11  |
| 2.2.6 Non-ferrous metal industry  | 13  |
| 2.2.7 Glass industry (in Germany)   | 15  |
| 2.2.8 Summary of collected data on CO <sub>2</sub> emission point sources           | 16  |
| 2.3 Projection of carbon dioxide emissions  | 18  |

|   |    |
|---|----|
| 2.4 Large-scale CO <sub>2</sub> storage option                                  | 19 |
| 2.4.1 Storage in depleted oil and gas fields                                    | 22 |
| 2.4.2 Storage in aquifers   | 22 |
| 2.4.3 Storage in unminable coal seams   | 23 |
| 2.4.4 Storage in deep ocean   | 24 |
| 2.4.5 Storage capacities and cost   | 24 |
| 2.5 Conclusions   | 24 |
| 3 Carbon dioxide merchant market in the european union                          | 26 |
| 3.1 CO <sub>2</sub> production and product quality for the merchant market      | 27 |
| 3.1.1 Production  | 27 |
| 3.1.2 Product quality   | 27 |
| 3.2 Merchant market overview  | 28 |
| 3.2.1 Food processing   | 28 |
| 3.2.2 Carbonated beverages  | 32 |
| 3.2.3 Chemical industry   | 33 |
| 3.2.4 Metal fabrication   | 34 |
| 3.2.5 Agriculture   | 35 |
| 3.2.6 Rubber and plastics processing  | 36 |
| 3.2.7 Other uses as solvent   | 37 |
| 3.2.8 Water treatment   | 40 |
| 3.2.9 Use in the nuclear sector   | 41 |
| 3.2.10 Well re-injection  | 42 |
| 3.2.11 Dry ice production   | 42 |
| 3.2.12 Cylinder filling   | 44 |
| 3.2.13 Other applications (not using large quantities of L-CO <sub>2</sub> yet) | 44 |
| 3.3 Volume of the CO <sub>2</sub> merchant market                               | 45 |
| 3.3.1 Carbonated beverage segment   | 45 |
| 3.3.2 European merchant market global data                                      | 47 |
| 3.4 Conclusions   | 48 |
| References  | 49 |

## *Section II: Separation* 51

### **Chapter 2: CO<sub>2</sub> Separation Technologies**

|   |    |
|---|----|
| by Rodney J. Allam, Rune Bredesen and Enrico Drioli | 53 |
| 1. Introduction and objectives                      | 53 |
| 1.1 Introduction                                    | 53 |
| 1.2 Objectives                                      | 54 |
| 1.2.1 Oxy-fuel                                      | 55 |
| 2. CO <sub>2</sub> separation technologies          | 56 |
| 2.1 Absorption                                      | 56 |
| 2.1.1 Introduction                                  | 56 |

|  |     |
|--|-----|
| 2.1.2 The principles of absorption   | 57  |
| 2.1.3 Process equipment for absorption systems                                 | 59  |
| 2.1.4 Limitations of absorption processes                                      | 62  |
| 2.2 Cryogenic distillation   | 63  |
| 2.2.1 Introduction   | 63  |
| 2.2.2 Applications   | 65  |
| 2.3 Adsorption   | 67  |
| 2.3.1 Introduction   | 67  |
| 2.3.2 Microporous adsorbents   | 67  |
| 2.3.3 The principles of adsorption   | 71  |
| 2.3.4 Dynamics of adsorption systems   | 73  |
| 2.3.5 Gas separation by cyclic adsorption system                               | 74  |
| 2.3.6 Industrial CO <sub>2</sub> removal by adsorption                         | 77  |
| 2.4 Membranes  | 86  |
| 2.4.1 Fundamentals and membrane types  | 86  |
| 2.4.2 Membrane modules   | 87  |
| 2.4.3 Gas transport and separation mechanisms                                  | 88  |
| 2.4.4 Commercial polymeric membranes for gas separation                        | 90  |
| 2.4.5 CO <sub>2</sub> separation by polymeric membranes                        | 92  |
| 2.4.6 Emerging technologies and future applications                            | 103 |
| References   | 118 |
| <i>Section III: Supercritical Carbon Dioxide</i>                               | 121 |
| <b>Chapter 3: Particle Formation Using Supercritical Carbon Dioxide</b>        |     |
| by Luc Van Ginneken and Herman Weyten  | 123 |
| 1. Particle forming processes  | 123 |
| 1.1 Conventional methods   | 123 |
| 1.2 Supercritical Crystallisation  | 124 |
| 2 Crystallisation methods using super-critical CO <sub>2</sub>                 | 125 |
| 2.1 Particle Formation by Rapid Expansion of the Supercritical Solution (RESS) | 125 |
| 2.1.1 Concept  | 125 |
| 2.1.2 Experimental set-up  | 125 |
| 2.1.3 First time use   | 126 |
| 2.1.4 Particle size and morphology   | 126 |
| 2.1.5 Industrial perspectives and applications                                 | 127 |
| 2.2 Particle Formation by Supercritical Anti-Solvent Crystallisation           | 128 |
| 2.2.1 Concept  | 128 |
| 2.2.2 Experimental set-up  | 128 |
| 2.2.3 First time use   | 130 |
| 2.2.4 Particle size and morphology   | 130 |

|   |     |
|---|-----|
| 2.2.5 Industrial perspectives and applications    | 131 |
| 2.3 Particles from Gas-Saturated Solutions (PGSS) | 132 |
| 2.3.1 Concept                                     | 132 |
| 2.3.2 Experimental set-up                         | 132 |
| 2.3.3 First time use                              | 133 |
| 2.3.4 Particle size and morphology                | 133 |
| 2.3.5 Industrial perspectives and applications    | 133 |
| 3 Concluding Remarks                              | 134 |
| References  | 135 |

## **Chapter 4: Supercritical Fluid Chromatography (SFC)**

|   |     |
|---|-----|
| by Luc Van Ginneken and Herman Weyten                 | 137 |
| 1. SFC theory and fundamentals                        | 137 |
| 1.1 Chromatography as separation method               | 137 |
| 1.2 Use of supercritical fluids in chromatography     | 138 |
| 1.3 Scale of SFC techniques                           | 139 |
| 2. Analytical-scale SFC                               | 139 |
| 2.1 History   | 139 |
| 2.2 Stationary phases and columns                     | 140 |
| 2.3 Mobile phases                                     | 141 |
| 2.4 Instrumentation                                   | 141 |
| 2.5 Demonstrated applications                         | 142 |
| 3. Preparative-scale SFC                              | 143 |
| 3.1 History   | 143 |
| 3.2 Advantages in comparison to preparative GC and LC | 143 |
| 3.3 Preparative elution SFC                           | 144 |
| 3.4 Preparative simulated moving bed-SFC              | 145 |
| 4. Future perspectives of SFC                         | 147 |
| References  | 147 |

## **Chapter 5: Homogeneous Catalysis in Supercritical Carbon Dioxide**

|   |     |
|---|-----|
| by T. Early , A.B. Holmes, J-K. Lee, E. Quaranta and L.M. Stamp | 149 |
| 1. Homogeneous catalysis  | 149 |
| 2. Hydrogenation reactions                                      | 150 |
| 2.1 Catalytic hydrogenation of supercritical carbon dioxide     | 150 |
| 2.2 Hydrogenation of unsaturated organic substrates             | 151 |
| 3. Oxidation reactions  | 154 |
| 4. Polymerization reactions                                     | 155 |
| 5. Hydroformylation reactions                                   | 157 |
| 6. Carbon-carbon bond forming reactions                         | 160 |
| 6.1 Palladium-catalysed coupling reactions                      | 160 |
| 6.2 Ring closing metathesis                                     | 161 |

|                                 |     |
|---------------------------------|-----|
| 6.3 Diels-Alder reactions       | 162 |
| 6.4 Other cyclisation reactions | 163 |
| References                      | 164 |

## **Chapter 6: Heterogeneous Reactions in Supercritical Carbon Dioxide**

|   |     |
|---|-----|
| by R. Amandi, J. Hyde and Martin Poliakoff        | 169 |
| 1. Introduction                                   | 169 |
| 2. General considerations                         | 170 |
| 3. Hydrogenation                                  | 171 |
| 4. Acid catalyzed reactions                       | 171 |
| 5. Heck coupling and carbon-carbon bond formation | 172 |
| 6. Friedel-Crafts                                 | 173 |
| 7. Hydroformylation                               | 173 |
| 8. Conclusions                                    | 174 |
| References  | 174 |

## **Chapter 7: Polymer Synthesis in Supercritical Carbon Dioxide**

|   |     |
|---|-----|
| by Giuseppe Filardo, Alessandro Galia and Alessandro Giaconia                                   | 181 |
| 1. Introduction   | 181 |
| 2. General considerations   | 182 |
| 3. Synthesis of fluoropolymers  | 183 |
| 3.1 Homogenous synthesis of amorphous high molecular weight fluoropolymers                      | 183 |
| 3.2 Heterogeneous polymerisations of fluorinated monomers in scCO <sub>2</sub>                  | 184 |
| 4. Free radical polymerisations of hydrocarbon monomers in scCO <sub>2</sub> : a brief overview | 186 |
| 5. Other polymerisations in Sc-CO <sub>2</sub>  | 190 |
| 6. Conclusions  | 191 |
| References  | 192 |

## **Chapter 8: Modification of Polymers in Supercritical Carbon Dioxide**

|  |     |
|--|-----|
| by Giuseppe Filardo, Alessandro Galia and Alberto Giaconia | 197 |
| 1. Introduction  | 197 |
| 2. General considerations                                  | 197 |
| 3. Extraction  | 198 |
| 4. Impregnation  | 199 |
| 5. Dyeing  | 200 |
| 6. Grafting  | 200 |
| 7. Reactive blending                                       | 201 |
| 8. Coating   | 201 |
| 9. Extrusion and blending                                  | 202 |

|                             |     |
|-----------------------------|-----|
| 10. Induced crystallisation | 202 |
| 11. Foaming                 | 203 |
| 12. Concluding remarks      | 204 |
| References                  | 204 |

|   |     |
|---|-----|
| <i>Section IV: Chemical Utilization</i> | 209 |
|---|-----|

## **Chapter 9: Carbon Dioxide Fixation into Organic Compounds**

|   |     |
|---|-----|
| by Michele Aresta and Angela Dibenedetto  | 211 |
| 1. Introduction   | 211 |
| 2. Energetics of carbon dioxide utilizing reactions                                   | 214 |
| 3. Low-energy routes to chemicals from carbon dioxide:                                |     |
| a comparison of existing and innovative synthetic methodologies                       | 217 |
| 3.1 Industrial processes that utilize CO <sub>2</sub> as raw material.                |     |
| Existing technologies and perspectives  | 217 |
| 3.1.1 Urea  | 217 |
| 3.1.2 Salicylic Acid  | 218 |
| 3.1.3 4-Hydroxybenzoic acid   | 219 |
| 3.1.4 Organic carbonates  | 220 |
| 3.1.5 Synthesis in-with Supercritical-CO <sub>2</sub> : scCO <sub>2</sub>             |     |
| as reactive-solvent   | 226 |
| 3.1.6 Methanol  | 227 |
| 3.2 Perspective use of carbon dioxide in the synthesis of                             |     |
| carboxylates and carbamates   | 227 |
| 3.2.1 Formic acid, HCOOH  | 227 |
| 3.2.2 Acetic acid, CH <sub>3</sub> COOH   | 230 |
| 3.2.3 Oxalic acid, (COOH) <sub>2</sub>  | 232 |
| 3.2.4 Long chain aliphatic carboxylic acids, R(CH <sub>2</sub> ) <sub>n</sub> COOH    |     |
| and aromatic mono- and di-carboxylic acids,   |     |
| C <sub>6</sub> H <sub>5</sub> COOH, C <sub>6</sub> H <sub>4</sub> (COOH) <sub>2</sub> | 234 |
| 3.2.5 Carbamates and isocyanates  | 237 |
| 3.2.6 Esters and other derivatives (lactones, amides)                                 | 247 |
| 3.2.7 Insertion of CO <sub>2</sub> into C-C Bonds                                     | 247 |
| 3.2.8 Electrochemical syntheses that use CO <sub>2</sub>                              | 248 |
| 3.2.9 Gamma-rays induced syntheses of intermediates                                   |     |
| and fine chemicals  | 251 |
| References  | 252 |

## **Chapter 10: Linear Organic Carbonates**

|  |     |
|--|-----|
| by Danielle Ballivet-Tkachenko and Svetlana Sorokina | 261 |
| 1. Introduction                                      | 261 |
| 2. Properties and Uses                               | 262 |

|   |     |
|---|-----|
| 3. Economic aspects                     | 263 |
| 4. Industrialized Reactions             | 263 |
| 4.1 The phosgene route                  | 264 |
| 4.2 Non-phosgene routes                 | 264 |
| 4.2.1 Dimethyl and diphenyl carbonates  | 265 |
| 4.2.2 Polycarbonates                    | 267 |
| 5. Innovative technologies              | 268 |
| 5.1 Oxidative carbonylation of alcohols | 268 |
| 5.2 Transesterification reaction        | 270 |
| 5.3 Carbonation reactions               | 271 |
| 6. Perspectives                         | 272 |
| References                              | 273 |

## **Chapter 11: Electrochemical Conversion of Carbon Dioxide**

by Jan Augunstynski, C. Jorand Sartoretti and Piotr Kedzierzawski 279

|   |     |
|---|-----|
| 1. Introduction   | 279 |
| 2. Electrolyses of aqueous solutions of CO <sub>2</sub>         | 280 |
| 2.1 Formation of formic acid                                    | 280 |
| 2.2 Electrolyses under high CO <sub>2</sub> pressure            | 284 |
| 2.3 CO <sub>2</sub> reduction using gas-diffusion electrodes    | 285 |
| 3. Electroreduction of CO <sub>2</sub> in non-aqueous solutions | 286 |
| 3.1 Electrochemical carboxylation                               | 288 |
| 4. Conclusions  | 288 |
| References  | 290 |

## **Chapter 12: Carbon Dioxide Reduction to C<sub>1</sub> or C<sub>n</sub> Molecules**

by Michele Aresta 293

|  |     |
|--|-----|
| 1. Introduction  | 293 |
| 1.1 Carbon dioxide dissociation to CO mediated by metal centers              | 294 |
| 1.1.1 Dissociation on metals surfaces  | 295 |
| 1.1.2 CO <sub>2</sub> adsorption on oxides                                   | 297 |
| 2. Methane reforming with CO <sub>2</sub>                                    | 298 |
| 3. Synthesis of methanol   | 303 |
| 4. Conversion of carbon dioxide into C <sub>n</sub> alcohols or hydrocarbons | 305 |
| 5. Conversion of carbon dioxide under plasma conditions                      | 305 |
| 6. Biotechnological process for carbon dioxide conversion to methanol        | 306 |
| References   | 307 |

|  |     |
|--|-----|
| <i>Section V: Biological Utilization</i> | 313 |
|--|-----|

## **Chapter 13: Biological Utilization of Carbon Dioxide: the Marine Biomass Option**

by Angela Dibenedetto and Immacolata Tommasi 315



|   |     |
|---|-----|
| 1. Introduction   | 315 |
| 2. Micro-algae as energy source                                   | 316 |
| 3. Macro-algae for energy production                              | 317 |
| 4. Economics of algae growing                                     | 319 |
| 5. Treatment of the algae and technologies for biofuel extraction | 321 |
| References  | 323 |

## **Chapter 14: Energy from Biomass**

|   |     |
|---|-----|
| by Piergiorgio Zappelli and James J. Leahy                              | 325 |
| 1. Introduction   | 325 |
| 2. The biomass  | 327 |
| 3. Reference scenarios  | 327 |
| 4. Biomass feedstocks   | 328 |
| 4.1 Agro-forestry products  | 330 |
| 4.2 Agricultural crops  | 331 |
| 4.3 Waste   | 334 |
| 4.4 Landfill gases  | 336 |
| 5. Exploitation of the biomass potential in Europe by 2010              | 336 |
| 6. Biomass energetic conversion options                                 | 338 |
| 7. Consolidated power technologies from biomass                         | 339 |
| 7.1 General considerations  | 339 |
| 7.2 Thermal conversion: electricity and heat                            | 341 |
| 7.3 Municipal solid waste combustion                                    | 342 |
| 7.4 Direct combustion   | 343 |
| 7.5 Fluidized bed combustion  | 343 |
| 7.6 Co-combustion   | 344 |
| 7.7 Biomass/MSW cofiring  | 348 |
| 8. Advanced thermal conversion technologies                             | 349 |
| 8.1 Gasification  | 350 |
| 8.2 Integrated gasification   | 351 |
| 8.3 Moving bed gasification   | 352 |
| 8.4 Fluid bed gasification  | 355 |
| 9. Further technological evolution for the biomass to energy conversion | 358 |
| 9.1 Externally fired turbines   | 358 |
| 9.2 Flue gas condensation   | 358 |
| 9.3 Hydrogen by hydrothermal gasification of biomass                    | 359 |
| 10. Comparison of the principal thermal technologies                    | 360 |
| 11. Other thermal technologies  | 361 |
| 11.1 Pyrolysis  | 361 |
| 11.2 Fast pyrolysis   | 361 |
| 11.3 Bio-oil  | 363 |
| 12. Biological conversion   | 365 |
| 12.1 Anaerobic digestion and biogas                                     | 365 |

|  |     |
|--|-----|
| 12.2 The biological treatment of the organic fraction of MSW | 367 |
| 13. Liquid biofuels  | 369 |
| 13.1 Bioethanol  | 370 |
| 13.2 Biodiesel   | 372 |
| 14. Conclusions  | 372 |
| References   | 373 |

## *Section VI: Assessment of CO<sub>2</sub> Utilization and Industrial Perspective* 377

### **Chapter 15: Methanol Production from Natural Gas: Assessment of CO<sub>2</sub> Utilization in Natural Gas Reforming**

by Angeliki A. Lemonidou, Julia Valla and Iacopos A. Vasalos 379

|  |     |
|--|-----|
| 1. Introduction                        | 379 |
| 2. Equilibrium analysis                | 382 |
| 3. Development of process flow diagram | 385 |
| 3.1 Syngas section                     | 385 |
| 3.2 Methanol section                   | 386 |
| 3.3 MEA unit                           | 387 |
| 3.4 Utilities                          | 388 |
| 4. Material and energy balance         | 388 |
| 5. Cost assessment                     | 390 |
| 6. Conclusions                         | 392 |
| References                             | 393 |

### **Chapter 16: Carbon Dioxide as a Building Block for Organic Intermediates: an Industrial Perspective**

by Marco Ricci 395

|   |     |
|---|-----|
| 1. Introduction                         | 395 |
| 2. Methanol                             | 396 |
| 3. Urea                                 | 396 |
| 4. Salicylic and 4-hydroxybenzoic acids | 398 |
| 5. Cyclic organic carbonates            | 399 |
| 6. Overlook and perspectives            | 399 |
| References                              | 401 |

|       |     |
|-------|-----|
| Index | 403 |
|-------|-----|