
An Economy Based on Carbon Dioxide and Water

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Sibudjing Kawi
Editors

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Potential of Large Scale Carbon Dioxide
Utilization

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Preface

The Carbon Dioxide Problem

Surface (biomass) and sub-surface (fossil-C such as coal, oil, gas) C-based assets have been, and will be for long time yet, used as source of energy and goods by humans. The use of all such materials causes the formation of CO₂, which is emitted into the atmosphere. The intensity of the emission of CO₂ has continuously grown and parallels the growth of both the population and average standard of life. (Figs. 1 and 2).

This has caused the continuous accumulation of atmospheric CO₂ which has reached 408 ppm these days with respect to 275 ppm of the preindustrial era. The atmospheric level of CO₂ is the “warning light” for the “health” of our planet. A correlation exists between the consumption of energy—the CO₂ emission—the accumulation in the atmosphere and the increase of the planet temperature (Figs. 3 and 4) that may cause non-return catastrophic events. Whether CO₂ is the direct actor or is an “indicator” of the impact caused by human activities on the atmosphere, is in question. As a matter of fact, humans are using C-based resources in a “highly inefficient” way: the efficiency of conversion of chemical energy (fossils or biomass) into other forms of energy (electrical, thermal, mechanical, etc.) ranges around 27–35%. This means that 73–65% of the original chemical energy is released to the atmosphere in the form of heat, often at high temperature, causing its direct heating. As the emission of CO₂ is related to the amount of C-based fuels burned or goods used, it becomes an easy “witness” of the impact humans are causing on Earth (even if not the direct cause). However, there is a general fear that continuing to accumulate CO₂ into the atmosphere (or continuing with an inefficient use of natural resources) may increase the temperature of our planet. Although CO₂ is a greenhouse gas (GHG), its atmospheric concentration is much lower than that of other GHGs, e.g. water vapour. Is the atmospheric CO₂ that causes planet heating or the released heat or both? A question rises: Supposed that we capture all the produced CO₂, but continue to heat the atmosphere with inefficient conversion of chemical energy (C-based energy sources) into other forms of energy, shall we “cool down” our planet? The most effective solution would be to reduce the use of C-based fuels (that will imply the reduction of CO₂ emission) and the release of

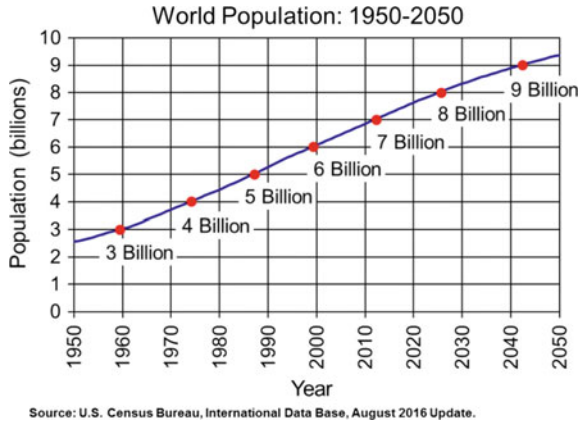


Fig. 1 Growth of world population

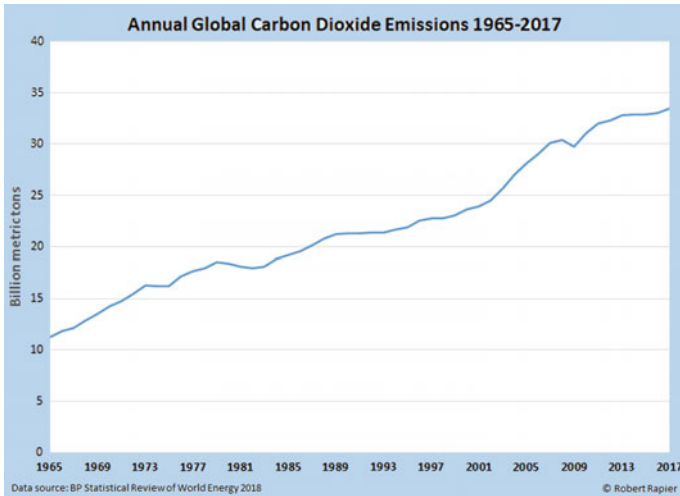


Fig. 2 CO₂ emission

heat to the atmosphere. This will require a great effort in terms of more efficient technologies in the use of primary C-based sources of energy, covering the entire chain of production of electric energy, heating systems, industrial plants and transport sector: our whole life! This will take long time and demand huge economic means. As for now, the policy is to reduce the emission of CO₂ into the atmosphere, will or will not such practice be the solution to the climate change (CC), shifting from fossil-C (that has produced a net increase of the atmospheric CO₂-level) to renewable-C and to perennial C-free energy sources.

How to avoid CO₂, thus?

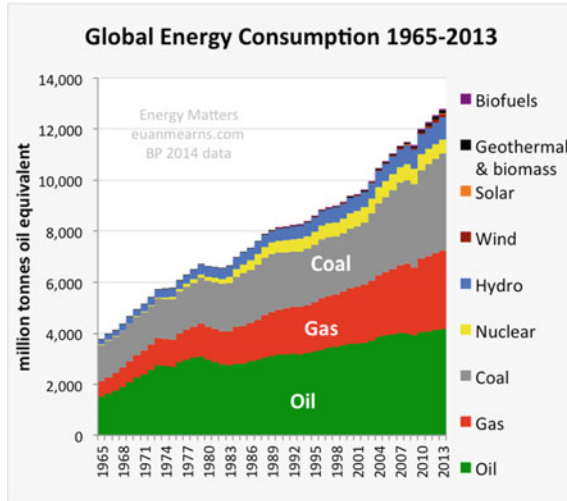


Fig. 3 Energy consumption

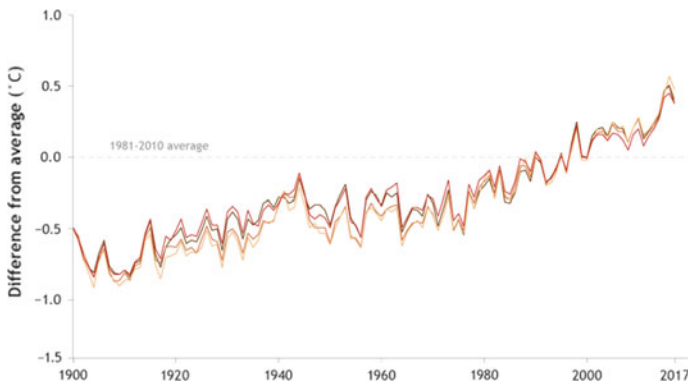


Fig. 4 Increase of average temperature

The agreed target (ONU 2018 and previous International Agreements) is to stay below 2° rise of the average temperature of our planet with respect to 1990. We are already 1.5° above; therefore, we must urgently slow down the use of fossil carbon in order to stay within the target. Defossilization of energy is the necessary action, and the proposal is to advance in such direction in next years. From now to 2050, fossil-C should slowly but steadily be replaced by *quasi-zero-C* emission energy sources. Alternatives are the use of solar, wind, geothermal, hydro-energy sources (SWG, perennial energy sources). The question is whether or not such sources will provide energy with the requested density and intensity for powering industrial sites and other intensive energy users (megapolis). (see P. Moriarty, D. Honnery,

What is the global potential for renewable energy? Renewable and Sustainable Energy Review, 2012, 16, 244–252). On the other hand, the use of biomass will cover a minor part of the energy needs limited by the regeneration rate. The production rate of CO₂ is much higher (around 6–15 g_{CO2} m⁻² s⁻¹ from the combustion of several kinds of wood-see Tran, H.C.; White, R.H. *Fire and Materials*, **1992**, 16, 197–206.) than the fixation of CO₂ by photosynthesis (the best values are observed in microalgae (see Adamczyk, M.; Lasek, J.; Skawinska, A. *Appl Biochem Biotechnol*, **2016**, 179, 1248–1261), better fixing agents than terrestrial plants, that are in the range 0.1–1.7 g_{CO2} l⁻¹ day⁻¹ or 0.00057–0.0098 g_{CO2} m⁻² s⁻¹). Therefore, the combustion rate is from 1000 to 10,000 times faster than the C-fixation by photosynthetic microorganisms and microalgae. Will nuclear come back? This is not excluded, if safe production of electricity will be developed. Our future looks quite problematic and to what extent energy-poor countries in Asia, America and Africa will rise their standard of life is an open question, as it is not easy to state whether Northern America, Europe, Japan will have all to restate their habitudes. Shall we necessarily go towards a global lower energy consumption? When this will occur? In the meanwhile, attention is devoted to reduce the CO₂ emission into the atmosphere.

Measures for the Reduction of the CO₂ Atmospheric Level

The technologies for reducing the use of fossil-C and the emission of CO₂ into the atmosphere can be categorized as reported below.

- *Higher efficiency in the conversion of chemical energy (fossil-C and biomass) into other forms of energy:* thermal, electrical, mechanical, etc. As said above, the average efficiency ranges today around 27–35%; therefore, 73–65% of the original chemical energy is released to the atmosphere in the form of heat, causing its direct heating. Improving the efficiency of the actual energy system is possible using both upstream and downstream technologies, but the economic cost is often quite high. In practice, power stations, industrial processes, transportation means should all be restyled and made adequate to the target of reducing the loss of energy in the form of heat. As a lower profile strategy, new power and industrial plants should all be built according to new efficiency criteria (e.g. all power plants should be built as IGCC), with much higher CAPEX. Heat could be recovered (when and where it makes sense) and used in a range of diverse low-temperature applications (in part this is already done, even if with rare-spot applications). The efficiency of primary energy conversion could be increased by 10–20 points, according to the different sectors. An improvement of the actual system is, thus, possible but it will take long time and demand a lot of economic resources.
- *Efficiency in the utilization of the different forms of energy, avoiding misuses.* This is the easiest route to C-saving and should be implemented by each single person. The implementation of virtuous practices can produce reduction of energy used, and thus produced, with reduction of conversion of fossil-C and CO₂ emission with a possible target of 5–10%.

- *Decarbonization of energy, by using perennial primary sources*, alternative to fossil fuels, such as SWHG. Such change is ongoing, and solar-, wind- and geo-power are being efficiently used, even if still at a moderate global intensity (5–8 % of global consumption) and leopard-spot distribution. It must be emphasized that perennial sources have a different availability on our planet and regional solutions must be implemented. Conversely, fossil-C (coal, oil, gas) is easily transportable and can reach any point on our planet: this is a plus in favour of existing fossil-C-based technologies. The moment being, anyway it is worth to emphasize that virtuous countries exist, which produce large amounts of their energy from SWHG (<https://www.climatecouncil.org.au/11-countries-leading-the-charge-on-renewable-energy/>) as reported in Table 1.

It is worth to emphasize that if the energy sector can be decarbonized, the chemical, polymer, pharmaceutical, cosmetic, materials industry will not. Therefore, C-based goods will continue to exist and most likely the use of fossil-C will be continued for long time yet in the future. As a matter of fact, the international programme 205050 foresees 50% reduction of emissions with respect to 1990 (for USA with respect to 2005) for EU and G20 countries by 2050. Afterwards, the reduction should continue at a rate of 1.5% per year.

- *Use of renewable carbon, such as biomass*. Renewable carbon has a different abundance on Earth and can find a different utilization. Biomass (land and aquatic) already finds application in several fields: from energy to chemicals and materials production. Because of the relative abundance/scarcity, even biomass has an odd usability and its transport is not energetically and economically efficient. Even in this case, fossil-C is a winning option for its higher energy density.

Table 2 says that liquid fuels are the best options for energy storage and transportation. Therefore, the conversion of electricity produced *via* SWGH into liquid fuels by combining CO₂ reduction and water oxidation is a convenient way for storing and transporting energy.

Table 1 Use of energy sources alternative to fossil-C in some virtuous countries

Country	Actual use of SWHG for electricity generation	Perspective use of SWHG
Sweden		100% 2050
Costa Rica	99% (2015)	C-neutral 2021
Nicaragua	54%	90% 2021
Scotland	97% of household electricity	
Germany	36.1+ % average with some >85% spot	
Uruguay	95%	
Denmark	42%	100% (2050)
China	1000 coal mines closed in 2018	
Morocco		50% 2020
Kenya	51% (2015)	70% (2020)

Table 2 Energy density of a variety of energy carriers

Energy carrier	MJ/kg
Diesel	36
Gasoline	34
Coke	30
Brown coal	18
Methanol	17
Bio-oil from algae	13
H ₂ (liquid, 20 MPa)	9
H ₂ (compressed)	2
Battery (lead)	0.33
Battery (lithium)	2.8

Capture of produced CO₂ from point-continuous sources or from the atmosphere. Capture can be applied either to point-continuous-fixed sources (industries or power plants) or even everywhere if the source is the atmosphere. If practised at reasonable economic and energetic costs, capture will make available large amounts of CO₂ that can be either disposed (CCS) or converted into chemicals, materials and fuels (CCU). The separation of CO₂ from flue gases from power stations or industrial processes (Table 3) requires an amount of energy, which depends on the composition of the flue gas and the use one wishes to make of separated CO₂ that drives its purity. The separation is a process that requires energy, and in the actual energy system implies the use of fossil-C. It has been calculated by DoE-USA that recovering CO₂ and disposing it in land reservoirs 40 km away from the power station where it is generated (a particularly rare and favourable case) consumes 25% of the produced electric energy. Such amount increases with the distance of shipping and the nature of disposal site: it may reach 40%+. Consequently, the capture and housing of CO₂ expand the extraction of fossil-C because additional energy is necessary for such end-of-pipe operation. Modern power generation technologies (such as IGCC) proceed to the decarbonization of fossil fuels before combustion. This means that fossil fuels are converted into CO₂ and H₂ and the latter is used for clean energy generation, but not zero-C emission as CO₂ is anyway produced even if in the precombustion phase.

Table 3 CO₂ emission from industrial sectors

Industrial sector	Mt _{CO2} /y produced
Cement	>1000
Oil refineries	850–900
Iron and steel	ca. 900
Fermentation	>200
Ethene and other petrochemical processes	155–300
Ammonia	160
LNG sweetening	25–30
Ethene oxide	10–15

In the short term, it may make sense to recover CO₂ from industrial sources that may provide more pure CO₂ than flue gases from power stations. Table 3 shows that ca. 3 500 Mt/y of quite pure CO₂ is available, which covers ca. 10% of the total emission. The advantage of recovering–converting CO₂ on-site brings to a closed loop. Obviously, this approach is very proficient for sites where several industrial activities are present and an efficient recovery of CO₂ is possible: clustering process is a way to optimize the energy and waste system. And this can be an interesting option for the future of our industry and the energy sector.

Recovery from the atmosphere (medium–long term) has the advantage of not requiring an industrial site or a power station as source. Interestingly, the atmosphere can provide also water vapour: this means that co-processing atmosphere-sourced CO₂ and water vapour will make possible to produce Syngas and thereafter energy-rich products (fuels). Such practice is very suggestive of Nature and can be implemented everywhere on our planet, making possible a local production of necessary fuels and chemicals completely decoupled from the existence in situ of natural fossil resources or emitters, with great benefit for non-industrialized countries which are not even rich of fossil-C.

An Economy Based on CO₂ and Water: it is a *vision* today. Will science and technology be able to make it a reality? Yes, but the correct conditions for the use of perennial energies must be developed and investment in research is necessary at the correct level, with the integrated cooperation of academy, industry and governments.

It is an investment in the future of humankind and our planet.

This book makes the point on where we are and where we have to go for exploiting such option.

After presenting the potential and bottlenecks of large-scale CCU (Chap. 1), the capture (Chap. 2) and the technological applications (Chap. 3), various aspects of utilization are discussed in detail, namely carbonation of basic natural or industrial matrices (Chap. 4), conversion into energy-rich products (Chaps. 5 and 6), electrochemical and photo-electrochemical conversion (Chap. 7) and Plasma technologies (Chap. 8). Bio-based routes are discussed in Chaps. 9–11, highlighting the integration of biotechnologies and catalysis. Chapter 12 makes a techno-economic and energetic analysis of selected CO₂-based processes. At the end, the perspective use of CCU is presented.

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Contents

1	Large Scale Utilization of Carbon Dioxide: From Its Reaction with Energy Rich Chemicals to (Co)-processing with Water to Afford Energy Rich Products. Opportunities and Barriers	1
	Michele Aresta and Francesco Nocito	
1.1	Introduction	2
1.2	CCS Versus CCU: The Amount Issue	2
1.3	CO ₂ Conversion Options: The Energy Issue	2
1.4	CCU and Resources Conservation	6
1.5	CCU and Innovation	9
1.6	CCU and Sustainability of the Chemical and Polymer Industry	11
1.7	Integration of Technologies: Biotechnologies and Catalysis	18
1.8	CCU, Clustering of Processes and the Energy Sector	21
1.9	Miscellanea	26
1.10	Conclusions	27
	References	28
2	Capture of CO₂ from Concentrated Sources and the Atmosphere	35
	Xiaoxing Wang and Chunshan Song	
2.1	Introduction	36
2.2	Development Progress of Supported PEI Sorbents for CO ₂ Capture	38
2.2.1	Effect of Support	38
2.2.2	Effect of PEI-Type	43
2.2.3	Effect of Additives	44
2.3	CO ₂ Sorption Mechanism Over Supported PEI Sorbents	46
2.4	CO ₂ Sorption Kinetics Over Supported PEI Sorbents	51
2.5	Regenerability and Stability of Supported PEI Sorbents	55
2.6	Large-Scale Process Development Using Supported PEI Sorbents	60
2.7	Summary and Prospects	62
	References	64

3	Technical and Industrial Applications of CO₂	73
	Jan Vansant and Peter-Wilhem Koziel	
3.1	On-Site Industrial Large Scale Utilization of Gaseous CO ₂	74
3.2	CO ₂ Liquefaction and Conditioning for On- or Off-site Use	75
3.2.1	CO ₂ Production for the Merchant Market	75
3.2.2	Product Quality	76
3.3	Carbon Dioxide Merchant Market	76
3.3.1	Food Processing	77
3.3.2	Carbonated Beverages	81
3.3.3	Chemical Industry	83
3.3.4	Metal Fabrication	85
3.3.5	Agriculture	85
3.3.6	Rubber and Plastics Processing	87
3.3.7	Other Uses as Solvent	88
3.3.8	Water Treatment	90
3.3.9	Nuclear	91
3.3.10	Well Re-injection	91
3.3.11	Cylinder Filling	93
3.3.12	Other Applications (Not Using Large Quantities of L-CO ₂ Yet)	93
3.4	CO ₂ Used as Dry Ice	93
3.4.1	Production	93
3.4.2	Properties	94
3.4.3	Applications	96
3.5	Volume of the CO ₂ Merchant Market	100
	References	101
4	Mineral Carbonation for Carbon Capture and Utilization	105
	Tze Yuen Yeo and Jie Bu	
4.1	Background and Key Concepts in Mineral Carbonation	106
4.1.1	The Chemistry of Mineral Carbonation	106
4.1.2	The Rates and Mechanisms of Mineral Carbonation	109
4.1.3	The Thermodynamics of Mineral Carbonation	112
4.1.4	Raw Materials for Mineral Carbonation	116
4.2	Overview of Basic Process Designs for Mineral Carbonation	120
4.2.1	Pressure Carbonation	120
4.2.2	Chemically-Assisted Carbonation	123
4.2.3	Other Carbonation Processes	127
4.3	Techno-economic Aspects of Mineral Carbonation	129
4.3.1	The CO ₂ Penalty	130

4.3.2	The Economics of Mineral Carbonation	133
4.3.3	Integrated Mineral Carbonation Processes	136
4.4	Synergy Between Mitigation and Adaptation Actions Against Climate Change, via Mineral Carbonation	140
4.4.1	A Brief Overview of Singapore's Circumstances	140
4.4.2	A Pilot Scale Mineral Carbonation Plant in Singapore	142
4.5	Conclusions and Outlook	145
	References	146
5	Catalytic CO₂ Conversion to Added-Value Energy Rich C₁ Products	155
	Jangam Ashok, Leonardo Falbo, Sonali Das, Nikita Dewangan, Carlo Giorgio Visconti and Sibudjing Kawi	
5.1	Introduction	156
5.2	CO ₂ Hydrogenation to Methane	156
5.2.1	Thermodynamic Consideration	157
5.2.2	Catalysts	158
5.2.3	Reaction Pathway and Kinetics	161
5.2.4	Engineering Challenges	162
5.3	CO ₂ Hydrogenation to CO (Reverse Water Gas Shift Reaction)	164
5.3.1	Thermodynamic Considerations	164
5.3.2	Catalyst Types	165
5.3.3	Mechanistic Considerations	169
5.4	CO ₂ Hydrogenation to Methanol	172
5.4.1	Catalyst Considerations	175
5.4.2	Engineering Challenges	177
5.4.3	Status of Industrial Development	178
5.5	CO ₂ Hydrogenation to Formic Acid	179
5.5.1	Thermodynamic Considerations	179
5.5.2	Catalytic Systems	180
5.5.3	Reaction Mechanism	182
5.5.4	Technological Challenges	184
5.6	CO ₂ -Methane Reforming to Syngas	185
5.6.1	Reaction Thermodynamics	186
5.6.2	Catalysts for DRM	187
5.6.3	Reaction Mechanism	189
5.6.4	Reactor Systems for DRM	190
5.6.5	Minimizing Catalyst Deactivation in DRM	191
5.7	Concluding Remarks	195
	References	198

6	Use of CO₂ as Source of Carbon for Energy-Rich C_n Products	211
	Jiang Xiao, Xinwen Guo and Chunshan Song	
6.1	Introduction	212
6.2	CO ₂ Hydrogenation to Hydrocarbons	214
6.2.1	Co-Based Catalysts	214
6.2.2	Fe-Based Catalysts	217
6.2.3	Fe-Based Bimetallic Catalysts	221
6.2.4	Multifunctional Catalysts	223
6.2.5	Reaction Pathways and Mechanisms of C–C Coupling	227
6.3	CO ₂ Hydrogenation to Higher Alcohols	230
6.3.1	Plausible Reaction Pathways	230
6.3.2	Early Exploration on HAS from CO ₂ Hydrogenation	232
6.3.3	Recent Progress in Fe-, Cu- and Noble Metal-Based Catalysts	232
6.4	Summary and Future Perspective	234
	References	236
7	Electrochemical and Photoelectrochemical Transformations of Aqueous CO₂	239
	Aubrey R. Paris, Jessica J. Frick, Danrui Ni, Michael R. Smith and Andrew B. Bocarsly	
7.1	Introduction	239
7.2	Electrochemical CO ₂ Reduction	243
7.2.1	Heterogeneous Catalytic Systems	243
7.2.2	Homogeneous Catalytic Systems	251
7.2.3	Hybrid Catalytic Systems	257
7.3	Photoelectrochemical CO ₂ Reduction	260
7.3.1	Heterogeneous Catalytic Systems	260
7.3.2	Homogeneous Catalytic Systems	267
7.3.3	Hybrid Catalytic Systems	270
7.4	Miscellaneous CO ₂ Reduction Systems	273
7.4.1	Photoanode-Driven Systems	273
7.4.2	Diamond	274
	References	275
8	Plasma-Based CO₂ Conversion	287
	Annemie Bogaerts and Ramses Snoeckx	
8.1	Plasma, the Fourth State of Matter	288
8.2	Plasma and Its Unique Feature for Energy-Efficient CO ₂ Conversion	289
8.3	Plasma Reactor Types for CO ₂ Conversion	291

8.3.1	Dielectric Barrier Discharge (DBD)	292
8.3.2	Microwave (MW) Plasma	293
8.3.3	Gliding Arc (GA) Discharge	294
8.3.4	Other Plasma Types Used for CO ₂ Conversion	295
8.3.5	Plasma Catalysis	295
8.4	Overview of Plasma-Based CO ₂ Conversion	298
8.4.1	Pure CO ₂ Splitting	300
8.4.2	CO ₂ + CH ₄ : Dry Reforming of Methane	306
8.4.3	CO ₂ + H ₂ O: Artificial Photosynthesis	312
8.4.4	CO ₂ + H ₂ : Hydrogenation of CO ₂	315
8.5	Plasma Technology in a Broader Perspective of Emerging Technologies for CO ₂ Conversion	317
8.6	Conclusion and Future Research Directions	318
	References	320
9	Bioelectrochemical Syntheses	327
	Suman Bajracharya, Nabin Aryal, Heleen De Wever and Deepak Pant	
9.1	Introduction	327
9.2	Bioelectrosynthesis from CO ₂	328
9.2.1	Biocatalysts for CO ₂ Reduction	331
9.2.2	Interaction of Biocatalysts with Electrode for CO ₂ Reduction	338
9.2.3	Electrodes Material Development for CO ₂ Reductions in Bioelectrosynthesis	340
9.3	Progress in Microbial Electrosynthesis	342
9.4	Integrated Concepts for Bioelectrosynthesis Improvement	344
9.4.1	Gas Diffusion Biocathodes	344
9.4.2	Product Concentration and Separation	345
9.4.3	Product Diversification via Chain Elongation	346
9.4.4	Bioanode-Biocathode Integration	347
9.4.5	Metabolic Engineering of Biocatalysts	347
9.4.6	Integration with Anaerobic Digestion	348
9.4.7	Integration with Syngas Fermentation	348
9.5	Techno-Economic Considerations for Upscaling of Bioelectrosynthesis from CO ₂	349
9.6	Future Outlook and Challenges	350
	References	350
10	Enhanced Biological Fixation of CO₂ Using Microorganisms	359
	Fuyu Gong, Huawei Zhu, Jie Zhou, Tongxin Zhao, Lu Xiao, Yanping Zhang and Yin Li	
10.1	Exploring Natural Carbon Fixation Processes	361
10.2	Characterization of Photosynthetic Pathways and Enhancing CO ₂ Fixation in the Calvin Cycle	364

10.3	Applying the Wood–Ljungdahl Pathway for CO ₂ Fixation	368
10.4	Introducing Other Natural Carbon Fixation Pathways into Heterotrophs for CO ₂ Sequestration	368
10.5	Designing and Constructing Novel Synthetic CO ₂ Pathways	369
10.6	Characterizing and Engineering Energy Supply Patterns for Carbon Fixation	370
10.7	Challenges of Biological Carbon Fixation	372
10.8	Perspectives	373
	References	374
11	Enhanced Fixation of CO₂ in Land and Aquatic Biomass	379
	Angela Dibenedetto	
11.1	Introduction	380
11.2	Generalities About the Production and Nature of Aquatic Biomass	383
11.3	Products From Microalgae	384
	11.3.1 Fuel Products	385
	11.3.2 Non-fuel Products	389
11.4	Commercial Production of Microalgae	395
11.5	Economic Evaluation of Microalgae	396
11.6	Conclusions	403
	References	404
12	Technoenergetic and Economic Analysis of CO₂ Conversion	413
	Suraj Vasudevan, Shilpi Aggarwal, Shamsuzzaman Farooq, Iftekhar A. Karimi and Michael C. G. Quah	
12.1	Introduction	413
12.2	Overall Scheme for CCU	415
	12.2.1 Sources of Hydrogen	415
12.3	Potential Fuels/Products from CCU with Zero Emissions	417
	12.3.1 Fuels/Products from Solar Hydrogen	417
	12.3.2 Products from Fossil-Fuel Hydrogen	419
	12.3.3 Break-Even Production Cost	422
12.4	Case Study: Singapore	422
	12.4.1 CO ₂ Emissions Scenario	423
	12.4.2 Scenarios for Solar Hydrogen	423
	12.4.3 Scenarios for Hydrogen from Fossil Fuels	425
12.5	Conclusions	426
	References	427
13	Perspective Look on CCU Large-Scale Exploitation	431
	Michele Aresta	
	Correction to: Technical and Industrial Applications of CO₂	C1
	Jan Vansant and Peter-Wilhem Koziel	