### **Contents**

List of Contributors XI
Short CVs of Contributors XIII
Preface XVII
Acknowledgments XIX
Executive Summary XXI
Markus Schmidt
Biofuels XXI
Bioremediation XXII
Biomaterials XXIV
Novel Developments in Synthetic Biology XXV

#### Introduction 1

Markus Schmidt

What Are Synthetic Biology Applications? 1
Which Synthetic Biology Applications Did We Consider? 2
Selecting and Assessing Synthetic Biology Applications 3
The Regulatory Context for Synthetic Biology 4
References 6

#### 1 Biofuels 7

Markus Schmidt, Manuel Porcar, Vincent Schachter, Antoine Danchin, and Ismail Mahmutoglu

- 1.1 Biofuels in General 7
- 1.1.1 Introduction 7
- 1.1.2 Economic Potential 8
- 1.1.3 Environmental Impact 13
- 1.1.3.1 Land Requirements for Projected Biofuel Use 14
- 1.1.3.2 Other Environmental Concerns 16
- 1.1.3.3 Impact of Legislative Decicions 16
- 1.1.4 Foreseeable Social and Ethical Aspects 17
- 1.1.4.1 How Could the New SB Application Impact Society at Large? 18

1	Contents	
	1.2	Ethanol 19
	1.2.1	Introduction 19
	1.2.2	Economic Potential 20
	1.2.3	Environmental Impact 21
	1.2.4	Foreseeable Social and Ethical Aspects 24
	1.2.4.1	Could the Application Change Social Interactions? 26
	1.2.4.2	Producing Countries, Rich Countries? 26
	1.3	Non-ethanol Fuels 27
	1.3.1	Introduction 27
	1.3.2	Economic Potential 31
	1.3.3	Environmental Impact 32
	1.3.4	Foreseeable Social and Ethical Aspects 33
	1.3.4.1	Impact on Social Interaction 34
	1.4	Algae-based Fuels 35
	1.4.1	Introduction 35
	1.4.2	Economic Potential 37
	1.4.3	Environmental Impact 41
	1.4.4	Foreseeable Social and Ethical Aspects 42
	1.4.4.1	Could the Application Change Social Interactions? 42
	1.5	Hydrogen Production 43
	1.5.1	Introduction 43
	1.5.2	Economic Potential 46
	1.5.2.1	
	1.5.3	Environmental Impact 49
	1.5.3.1	
	1.5.4	Foreseeable Social and Ethical Aspects 51
	1.5.4.1	Could the Application Change Social Interactions?  If Yes, in Which Way? 52
	1.6	Microbial Fuel Cells and Bio-photovoltaics 52
	1.6.1	Introduction 52
	1.6.2	Economic Potential 56
	1.6.3	Environmental Impact 56
	1.6.4	Foreseeable Social and Ethical Aspects 59
	1.7	Recommendations for Biofuels 59
		References 61
	2	Bioremediation 67
		Ismail Mahmutoglu, Lei Pei, Manuel Porcar,
		Rachel Armstrong, and Mark Bedau
	2.1	Bioremediation in General 67
	2.1.1	Introduction 67
	2.1.2	Economic Potential 68
	2.1.3	Environmental Impact 69
	2.1.4	Foreseeable Social and Ethical Aspects 70
	2.2	Detection of Environmental Pollutants (Biosensors) 70

2.2.1	Introduction 70	
2.2.2	Economic Potential 73	
2.2.3	Environmental Impact 74	
2.2.4	Foreseeable Social and Ethical Aspects	76
2.3	Water Treatment 77	
2.3.1	Introduction 77	
2.3.2	Economic Potential 78	
2.3.3	Environmental Impact 78	
2.3.4	Foreseeable Social and Ethical Aspects	<i>7</i> 9
2.4	Water Desalination with Biomembranes	<i>7</i> 9
2.4.1	Introduction 79	
2.4.2	Economic Potential 80	
2.4.3	Environmental Impact 81	
2.4.4	Foreseeable Social and Ethical Aspects	81
2.5	Soil and Groundwater Decontamination	82
2.5.1	Introduction 82	
2.5.2	Economic Potential 83	
2.5.3	Environmental Impact 84	
2.5.4	Foreseeable Social and Ethical Aspects	85
2.6	Solid Waste Treatment 85	
2.6.1	Introduction 85	
2.6.2	Economic Potential 87	
2.6.3	Environmental Impact 87	
2.6.4	Foreseeable Social and Ethical Aspects	87
2.7	CO <sub>2</sub> Recapturing 89	
2.7.1	Introduction 89	
2.7.2	Economic Potential 92	
2.7.2.1	How Is Carbon Traded? 93	
2.7.3	Environmental Impact 95	
2.7.4	Foreseeable Social and Ethical Aspects	96
2.8	Recommendations for Bioremediation	98
	References 99	
	Further Reading 101	
3	Biomaterials 103	
3	Lei Pei, Rachel Armstrong, Antoine Danchir	1
	and Manuel Porcar	',
3.1	Biomaterials in General 103	
3.1.1	Introduction 103	
3.1.2	Economic Potential 104	
3.1.3	Environmental Impact 106	
3.1.4		107
3.2	Biopolymers/Plastics 108	107
3.2.1	Introduction 108	
3.2.2	Economic Potential 111	
J. L. L	LCOHOLLIC I OCCILIAL 111	

VIII	Contents	
	3.2.3	Environmental Impact 113
	3.2.4	Foreseeable Social and Ethical Aspects 115
	3.3	Bulk Chemical Production 117
	3.3.1	Introduction 117
	3.3.2	Economic Potential 120
	3.3.3	Environmental Impact 123
	3.3.4	Foreseeable Social and Ethical Aspects 124
	3.4	Fine Chemical Production 126
	3.4.1	Introduction 126
	3.4.1.1	Vitamins and Pharmaceuticals 128
	3.4.2	Economic Potential 129
	3.4.3	Environmental Impact 131
	3.4.4	Foreseeable Social and Ethical Aspects 133
	3.5	Cellulosomes 134
	3.5.1	Introduction 134
	3.5.2	Economic Potential 136
	3.5.3	Environmental Impact 137
	3.5.4	Foreseeable Social and Ethical Aspects 138
	3.6	Recommendations for Riomaterials 139

## 4 Other Developments in Synthetic Biology 145 Rachel Armstrong, Markus Schmidt, and Mark Bedau

- 4.1 Protocells 145
- 4.1.1 Introduction 145
- 4.1.2 Economic Potential 147

References 140 Further Reading 143

- 4.1.3 Environmental Impact 147
- 4.1.4 Foreseeable Social and Ethical Aspects 149
- 4.2 Xenobiology 150
- 4.2.1 Introduction 150
- 4.2.2 Economic Potential 151
- 4.2.3 Environmental Impact 152
- 4.2.4 Foreseeable Social and Ethical Aspect 154
- 4.3 Recommendations for Protocells and Xenobiology 154
   References 155
   Further Reading 156

# 5 Regulatory Frameworks for Synthetic Biology 157 Lei Pei, Shlomiya Bar-Yam, Jennifer Byers-Corbin, Rocco Casagrande, Florentine Eichler, Allen Lin, Martin Österreicher, Pernilla C. Regardh, Ralph D. Turlington, Kenneth A. Oye, Helge Torgersen, Zheng-Jun Guan, Wei Wei, and Markus Schmidt

- 5.1 United States of America 157
- 5.1.1 Introduction 157

5.1.2	United States Federal Regulations and Guidelines 158					
5.1.2.1	National Institutes of Health: Guidelines for Research Involving					
3.1.2.1	Recombinant DNA Molecules 158					
5.1.2.2	Environmental Protection Agency, US Department of Agriculture and					
J.1.2.2	Food and Drug Administration 164					
5.1.2.3	USDA Animal and Plant Heath Inspection Service 167					
5.1.2.4						
5.1.2.5						
5.1.2.6	Department of Commerce Regulations 170 Select Agent Rules 172					
5.1.2.7	Screening Guidance for Providers of Synthetic Double-Stranded					
J.1.Z./	DNA 175					
5.1.3	International Conventions and Agreements 176					
5.1.3.1	The Convention on Biological Diversity 176					
5.1.3.2	The Cartagena Protocol on Biosafety and the Nagoya-Kuala Lumpar					
	Supplementary Protocol on Liability 177					
5.1.3.3	The Biological Weapons Convention 178					
5.1.3.4	The Australia Group Guidelines 179					
5.1.4	Conclusions: Current Coverage and Future Considerations 181					
5.1.4.1	- Control of the Cont					
5.1.4.2	Future Prospects 183					
5.2	Europe 185					
5.2.1	Introduction 185					
5.2.1.1	Synthetic Biology as a Novel Science and Engineering Field 186					
5.2.1.2	Synthetic Biology versus Genetic Engineering 189					
5.2.2	Existing Regulations 190					
5.2.2.1	European Union 190					
5.2.2.2	Examples of National Regulations 195					
5.2.2.3	Austria 196					
5.2.2.4	Germany 198					
5.2.2.5	United Kingdom 201					
5.2.2.6	Switzerland 203					
5.2.3	Options for Adapting and Improving Regulations 205					
5.2.4	Outlook 209					
5.3	China 210					
5.3.1	Introduction 210					
5.3.2	General Provisions 211					
5.3.3	Biosecurity and Dual Use 217					
5.3.4	Options for Adapting and Improving Regulations 218					
5.3.5	Outlook 219					
	References 220					
	Further Reading 226					
	A A 11 . CD1 C 1 C 207					

Annex A List of Biofuel Companies 227 Annex B List of Bioremediation Companies 229 Index 231