Contents

Preface	xiii	
Note on	the Text	χv

1	Understanding the Principles of Sustainable Chemistry 1
1.1	Background: Chemistry and the Global Importance of Sustainability 2
1.2	Sustainable Chemistry as the Key to Sustainable Development 5
1.3	What Is 'Sustainable Chemistry'? 5
1.3.1	Preventing Waste and Maximising Atom Efficiency (Principles I and II) 7
1.3.2	Reducing Overall Toxicity and Hazard (Principles III, IV, XI and XII) 11
1.3.3	Using Fewer Reagents, Solvents and Derivatisation (Principles V and VIII) 13
1.3.4	Saving on Energy (Principle VI) 13
1.3.5	Renewable Resources and Biodegradable Products (Principles VII and XI) 14
1.3.5.1	Historical Context: The Century of Change 15
1.3.5.2	Human Impact on the Carbon Cycle 16
1.3.5.3	Human Impact on the Nitrogen Cycle 17
1.3.5.4	The Importance of Biodegradable Products 18
1.3.6	Replacing Stoichiometric Reagents with Catalytic Cycles (Principle IX) 20
1.4	Industrial Examples 25
1.4.1	The BHC Synthesis of Ibuprofen 25
1.4.2	The BP AVADA Ethyl Acetate Process 27
	Exercises 28
	References 31
2	From Sustainable Science to Sustainable Business 35
2.1	Evaluating Sustainable Chemistry Ideas, Projects and Products 36
2.1.1	Understanding the Difference Between Technical Decisions and Judgemental
	Decisions 36
2.1.2	Example: Should You Invest in Sustainable Golf Balls? 37
2.2	The SWOT Analysis 40
2.3	The PEST Analysis 44
2.3.1	Example: New Battery Types 44
2.4	Life-cycle Assessment: Quantifying and Qualifying Sustainability 51
2.5	Converting an Idea into a Business 53
2.5.1	Understanding Business Models 54



Contents	
2.5.2	Dominant Logic: The Driving Force Behind Your Business 57
2.5.3	Archetype and Narrative: What Your Company Is Going to Do 58
2.5.4	The Nitty-Gritty: Business Model Canvas and Activity System 59
2.6	Creating and Capturing Value in a Sustainable Business 61
2.6.1	Independent Energy: A Business Model Example 62
2.6.1.1	Providing Solar Energy for the Oil and Gas Industry 64
2.6.1.2	A Clear and Focused Business Model and Motto 65
2.7	Specific Barriers for Sustainable Chemistry Start-Ups 66
2.8	Co-Founders to Steal Horses with 67
2.9	Intellectual Property (IP) 68
2.9.1	Patent Applications 70
2.9.2	Trade Secrets and Other Alternatives 72
2.9.3	Considering IP as Part of Your Business Model 72
2.10	Raising Investment 73
2.10.1	The Time for Raising Capital 75
2.10.2	FFF Money, Government Grants and Crowdfunding 76
2.10.3	Angel Investors, Strategic Investors and Family Offices 77
2.10.4	Venture Capital (VC) Funds 78
2.11	Further Reading 82
	Exercises 83
	References 87
3	What's in the Water? 93
3.1	Taking Part in Europe's Researcher Mobility Programme 93
3.2	An Invention on the Beach 95
3.3	Water Quality Monitoring: A Real-Life Problem 97
3.3.1	'Grab Sampling' vs. Passive Sampling 99
3.4	First Experiments and Proof-of-Principle 100
3.5	Written Agreements and Patent Application 104
3.6	The Theory and Working Principles of the Sorbisamplers 107
3.6.1	Calculating the Solute Flux and Pore Water Concentration 108
3.6.2	Choosing the Right Tracer Compound 109
3.6.3	Choosing the Right Adsorbent 109
3.7	The Founding of Sorbisense 111
3.8	Sampling Nitrate and Phosphorus in Rivers and Streams 113
3.8.1	A New Invention and Patent 114
3.9	Growing the Company and Entering the Market 116
3.9.1	A Clearer Business Model 117
3.10	Shifting to the Netherlands and a New Market: VOCs 119
3.10.1	The Importance of VOCs 120
3.10.2	Field Tests: The Proof of the Pudding 121
3.11	Growth Pains: The Challenge of Business Scale-Up 124
3.11.1	Venture Capital Investment and a New Growth Strategy 124
3.12	Wastewater Sampling: A New Product and a New Market 126
3.13	Takeover by Eurofins 128
3.14	So What Have We Learned? 129
	References 129

viii



4	Do-It-Yourself Chemical Company 133
4.1	Focus, Hard Work and Organic Growth 134
4.2	Hydrogen and More 138
4.3	Diversifying to Other Catalytic Processes 141
4.4	A Catalyst Development Company 143
4.5	Growing the Company and Moving 148
4.6	Investing Knowledge in Other Companies 151
4.7	Further Growth and a 'Special Sauce' 155
4.8	Expanding into Three Business Areas, All Catalysis Related 156
4.9	Hire Good People and Keep Them Forever 160
4.10	A Solid Company 163
4.10	Exercises 166
	References 169
5	CO ₂ Conversion with Microbes and Electricity 175
5.1	The Players Involved 175
5.2	A Short Overview of the Chemistry and Technology 176
	How It All Started 181
5.3	The C-Level Meeting 183
5.3.1 5.3.2	The Naming of Rheticus 184
	•
5.4	Mimicking a Three-Billion-Year-Old Natural Process 185 Practical Barriers and Challenges 186
5.5	C
5.5.1	A Yellow/Black Tape Siemens 'Embassy' in Marl 187
5.5.2	The Challenge of Starting from TRL Zero 188
5.6	A Working Process and a Scale-Up in Progress 190
5.7	So What Did We Learn? 193
	References 194
6	Biomass Valorisation to Energy and Fuels 197
6.1	A Short Overview of Petroleum Diesel and Biodiesel 197
6.1.1	Comparing Biodiesel and Petrodiesel Performance Parameters 199
6.2	The Rise of Biodiesel in the Beginning of the 21st Century 202
6.2.1	The Different Types of Biodiesel 204
6.3	Esterification of Free Fatty Acids 204
6.3.1	Searching for a Suitable Solid Acid Catalyst 206
6.3.2	Tuning the Catalyst Surface Hydrophobicity 208
6.3.3	Shifting the Equilibrium to the Product Side Using Reactive Distillation 210
6.4	A Much Larger Market: Transesterification of Triglycerides 212
6.4.1	A Modular Biodiesel Process Using Hydrotalcite Base Catalysts 215
6.4.2	A Comprehensive Solution: Combining Esterification and
	Transesterification 216
6.4.3	Changing the Production Paradigm Through a Mobile Process 218
6.5	An Overwhelming Market Interest 220
6.6	The Founding of Yellow Diesel BV 221
6.7	Building a Continuous Biodiesel Microplant 223
6.8	Solarix: Making Biodiesel from the Ground Up 225



x	Contents	
	6.8.1 6.8.2 6.9 6.10 6.11	GTBE – A New Fuel Additive? 227 The Allure and Disappointment of Small-Scale Production 228 More Exotic Variants: Jatropha Oil and Algae Oil 229 Biodiesel: From Boom to Bust 230 So What Did We Learn? 231 References 231
	7	Flight of the Phoenix 235
	7.1	An Exciting Hydrogen Carrier Concept 236
	7.2	Improved Technology at Small Scale 238
	7.3	The Solid Fuel Paradigm Shift 240
	7.3.1	A Complete Ecosystem for Low-Carbon Fuels 241
	7.4	Searching for a Stable Catalyst for Hydrogen Release 244
	7.4.1 7.4.2	A Co/Al ₂ O ₃ Catalyst – The Straightforward Option 245 Catalytic Minireactors Made from Shrimp Shells 246
	7.4.2.1	Moving from Batch to Continuous Operation 248
	7.4.2.1	3D-Printed Catalysts via Laser Welding 248
	7.4.3.1	Catalyst Particles 'Landlocked' within the Walls 251
	7.4.3.2	The Hundred-Year-Old Invention 252
	7.5	Scaling Up the Technology: MOSES and JOSHUA 254
	7.6	For Lack of Hydrogen, the Phoenix Burns 258
		References 259
	8	Waking Up the Sleeping Giant 261
	8.1	Contract Research or Own IP? 262
	8.2	The Secret Meeting and the Furanics 'Bible' 267
	8.3	Scaling Up from Grams to Tons: Too Big to Succeed? 271
	8.4	First Contract with NatureWorks 273
	8.5	Coca-Cola, Danone and the 'Golden Bottle' 274
	8.6	Completing the Route from Sugar to Plastic 277 The Pig Mongy: A Joint Venture with PASE 279
	8.7 8.8	The Big Money: A Joint Venture with BASF 278 Even More Money: Avantium Becomes a Publicly Listed Company 279
	8.9	The End of the Affair: BASF Steps Out of the JV 283
	8.10	A Positive Outlook for PEF, with a Sprinkling of Patience 285
	8.11	So What Have We Learned? 287
		References 290
	9	Once in a Lifetime 293
	9.1	The Rocker Chemist 293
	9.2	Inspiration in Monterey 294
	9.3	The Incredible Accidental Discovery of Sticky Goo 295
	9.3.1	A Reactor Made of 'Space-Age Materials' for €4.95 297
	9.3.2	A Material that Sticks to Everything – Except Hydrophobic Surfaces 298
	9.3.3	A New Polymer That Doesn't Exist? 301
	9.4	Media Attention and Lots of Opportunities 303
	9.4.1	First International Investment for Pressing Chess Pawns 304

 \bigoplus

 \bigoplus



Contents	хi
----------	----

9.4.2	Biodegradable Plant Pots – From National Geographic to IKEA 305
9.5	The Boardroom Table and the Big Oven 306
9.6	The Founding of Plantics BV 308
9.6.1	Moving to the Garage at the Port of Amsterdam 308
9.7	Too Many Applications? 309
9.7.1	Doing the Incubator and Accelerator Circuit 310
9.8	A New CEO and a Business Vision for the Company 311
9.9	R&D Projects Turning into Real Products 313
9.10	Scaling Up Production to Multi-ton Scale 314
9.11	Appointing an Advisory Board 316
9.12	A License Business Model and a Broad Technology Platform 317
9.12.1	First Product Launches: Plant Pots and Sustainable Furniture 317
9.13	More People, New Equipment and a New Building 319
9.13.1	Sustainable Traffic Signs and Filament Winding Poles 321
9.13.2	Construction and Insulation Panels: Particle Boards and the Tiny House 322
9.13.3	Application of the Panels: The No-Waste Kitchen 323
9.14	A New Strategic Partner: Saint-Gobain Invests in Plantics 324
9.15	So What Did We Learn? 324
	References 326

Index 329

