

## Contents

About the Editors	<i>xvii</i>
List of Contributors	<i>xix</i>
Preface	<i>xxvii</i>

### Section 1 Modelling and Design of Materials 1

<b>1</b>	<b>The Development of a Molecular Systems Engineering Approach to the Design of Carbon-capture Solvents 3</b>
	<i>Edward Graham, Smitha Gopinath, Esther Forte, George Jackson, Amparo Galindo, and Claire S. Adjiman</i>
1.1	Introduction 3
1.2	Predictive Thermodynamic Models for the Integrated Molecular and Process Design of Physical Absorption Processes 6
1.2.1	An Introduction to SAFT 6
1.2.2	Group Contribution (GC) Versions of SAFT 10
1.2.3	Model Development in SAFT 12
1.2.4	SAFT Models for Physical Absorption Systems 14
1.3	Describing Chemical Equilibria with SAFT 16
1.3.1	Chemical and Physical Models of Reactions 17
1.3.2	Modelling Aqueous Mixtures of Amine Solvents and CO <sub>2</sub> 21
1.4	Integrated Computer-aided Molecular and Process Design using SAFT 24
1.4.1	CAMPD of Physical Absorption Systems 25
1.4.2	CAMPD of Chemical Absorption Systems 28
1.5	Conclusions 29
	List of Abbreviations 30
	Acknowledgments 31
	References 31
<b>2</b>	<b>Methods and Modelling for Post-combustion CO<sub>2</sub> Capture 43</b>
	<i>Philip Fosbøl, Nicolas von Solms, Arne Gladis, Kaj Thomsen, and Georgios M. Kontogeorgis</i>
2.1	Introduction to Post-combustion CO <sub>2</sub> Capture: The Role of Solvents and Some Engineering Challenges 43
2.1.1	The Complex Physical Chemistry of CO <sub>2</sub> and its Mixtures 45

2.1.2	The Corrosive Nature of CO <sub>2</sub>	46
2.1.3	Which is the Best CO <sub>2</sub> Capture Method?	46
2.1.4	Lack of Pilot Plant Data	48
2.1.5	CO <sub>2</sub> Storage	48
2.1.6	The Fragmentation of Science and Technology	49
2.2	Extended UNIQUAC: A Successful Thermodynamic Model for CCS Applications	49
2.2.1	Equilibrium Approach	49
2.2.2	Rate-based Modelling	55
2.2.3	Rate-based Model Validation	58
2.3	CO <sub>2</sub> Capture using Alkanolamines: Thermodynamics and Design	60
2.4	CO <sub>2</sub> Capture using Ammonia: Thermodynamics and Design	61
2.5	New Solvents: Enzymes, Hydrates, Phase Change Solvents	62
2.5.1	Enzymes in CO <sub>2</sub> Capture	62
2.5.2	Gas Hydrates in CO <sub>2</sub> Capture	66
2.5.3	Phase Change Solvents	68
2.6	Pilot Plant Studies: Measurements and Modelling	69
2.7	Conclusions and Future Perspectives	69
	List of Abbreviations	74
	Acknowledgements	74
	References	74
<b>3</b>	<b>Molecular Simulation Methods for CO<sub>2</sub> Capture and Gas Separation with Emphasis on Ionic Liquids</b>	<b>79</b>
	<i>Niki Vergadou, Eleni Androulaki, and Ioannis G. Economou</i>	
3.1	Introduction	79
3.1.1	Importance of CO <sub>2</sub> Capture and Gas Separation	79
3.1.2	Introduction to Ionic Liquids	80
3.1.3	How Do We Design Processes?	80
3.1.4	Brief Introduction to Molecular Simulation	81
3.1.5	Molecular Simulation of Ionic Liquids with Emphasis on CO <sub>2</sub> Capture and Gas Separation	83
3.2	Molecular Simulation Methods for Property Calculations	83
3.3	Force Fields	85
3.3.1	Force Fields for CO <sub>2</sub> and Other Gases	85
3.3.2	Force Fields for Ionic Liquids	86
3.4	Results and Discussion: The Case of the IOLICAP Project	87
3.4.1	Brief Description of the Project	87
3.4.2	The Role of Molecular Simulation and Modeling in IOLICAP	88
3.4.3	Force Field Development and Optimization	89
3.4.4	Property Prediction for Pure ILs	92
3.4.5	Permeability and Selectivity of Ionic Liquids to Gases	98
3.4.6	Other Applications of ILs for CO <sub>2</sub> Capture and Separation Technology	100
3.5	Future Outlook	101
	List of Abbreviations	102
	Acknowledgments	103
	References	103

<b>4</b>	<b>Thermodynamics of Aqueous Methyldiethanolamine/Piperazine for CO<sub>2</sub> Capture</b>	<b>113</b>
	<i>Peter T. Frailie, Jorge M. Plaza, and Gary T. Rochelle</i>	
4.1	Introduction	113
4.2	Model Description	114
4.2.1	Equilibrium Constant Calculations in Aspen Plus*	114
4.2.2	Activity Coefficient Calculation in Aspen Plus*	114
4.3	Sequential Regression Methodology	115
4.4	Model Regression	115
4.4.1	Amine/H <sub>2</sub> O	115
4.4.2	MDEA/H <sub>2</sub> O/CO <sub>2</sub>	118
4.4.3	PZ/H <sub>2</sub> O/CO <sub>2</sub> Regression	120
4.4.4	MDEA/PZ/H <sub>2</sub> O/CO <sub>2</sub> Regression	126
4.4.5	Generic MDEA/PZ Mixture	133
4.5	Conclusions	134
	List of Abbreviations	134
	Acknowledgements	134
	References	135
<b>5</b>	<b>Kinetics of Aqueous Methyldiethanolamine/Piperazine for CO<sub>2</sub> Capture</b>	<b>137</b>
	<i>Peter T. Frailie and Gary T. Rochelle</i>	
5.1	Introduction	137
5.2	Methodology	138
5.2.1	Hydraulic Properties	138
5.2.2	Mass Transfer Correlations	139
5.2.3	Reactions and Reaction Rate Constants	140
5.2.4	Sensitivity Analysis	142
5.3	Results	143
5.3.1	Reaction Constants and Binary Diffusivity	143
5.3.2	Sensitivity Analysis	146
5.3.3	Generic Amines	148
5.3.4	Rate-based Stripper Modeling	149
5.4	Conclusions	150
	List of Abbreviations	151
	Acknowledgements	151
	References	151
<b>6</b>	<b>Uncertainties in Modelling the Environmental Impact of Solvent Loss through Degradation for Amine Screening Purposes in Post-combustion CO<sub>2</sub> Capture</b>	<b>153</b>
	<i>Sara Badr, Stavros Papadokonstantakis, Robert Bennett, Graeme Puxty, and Konrad Hungerbuehler</i>	
6.1	Introduction	153
6.1.1	Solvent Loss in Amine-based PCC	155
6.1.2	Solvent Production	155
6.2	Oxidative Degradation	156

- 6.2.1 Conceptual Uncertainties in Experimental Procedures 156
- 6.2.2 Quantitative Uncertainties in Experimental Procedures 160
- 6.3 Environmental Impacts of Solvent Production 165
- 6.4 Conclusions and Outlook 167
- List of Abbreviations 168
- References 169

## 7 Computer-aided Molecular Design of CO<sub>2</sub> Capture Solvents and Mixtures 173

*Athanasios I. Papadopoulos, Theodoros Zarogiannis, and Panos Seferlis*

- 7.1 Introduction 173
- 7.2 Overview of Associated Literature 176
  - 7.2.1 Systematic Approaches 176
  - 7.2.2 Empirical Approaches 177
- 7.3 Optimization-based Design and Selection Approach 178
  - 7.3.1 Underlying Rationale 178
  - 7.3.2 Design of Pure Solvents 179
  - 7.3.3 Screening of Solvent Mixtures 180
- 7.4 Implementation 183
  - 7.4.1 Design and Selection of Pure Aqueous Amine Solvents 183
  - 7.4.2 Selection of Amine Mixtures 185
- 7.5 Results and Discussion 187
  - 7.5.1 Pure Solvents 187
  - 7.5.2 Solvent Mixtures 192
- 7.6 Conclusions 196
- List of Abbreviations 196
- Acknowledgements 197
- References 197

## 8 Ionic Liquid Design for Biomass-based Tri-generation System with Carbon Capture 203

*Fah Keen Chong, Viknesh Andiappan, Fadwa T. Eljack, Dominic C. Y. Foo, Nishanth G. Chemmangattuvallappil, and Denny K. S. Ng*

- 8.1 Introduction 203
  - 8.1.1 Bio-energy and Carbon Capture and Storage (BECCS) 203
  - 8.1.2 Ionic Liquids 204
- 8.2 Formulations to Design Ionic Liquid for BECCS 205
  - 8.2.1 Input–Output Modelling for Bio-energy Production 206
  - 8.2.2 Disjunctive Programming for Discretization of Continuous Variables 207
  - 8.2.3 Optimal Ionic Liquid Design Formulation 208
- 8.3 An Illustrative Example 212
- 8.4 Conclusions 221
- List of Abbreviations 222
- References 225

## Section 2 From Materials to Process Modelling, Design and Intensification 229

- 9 **Multi-scale Process Systems Engineering for Carbon Capture, Utilization, and Storage: A Review 231**  
*M. M. Faruque Hasan*
  - 9.1 Introduction 231
  - 9.2 Multi-scale Approaches for CCUS Design and Optimization 233
  - 9.3 Hierarchical Approaches 234
    - 9.3.1 Materials Screening 235
    - 9.3.2 Process Simulation and Optimization 236
    - 9.3.3 CCUS Network Optimization 237
  - 9.4 Simultaneous Approaches 237
    - 9.4.1 Materials Screening and Process Optimization 237
    - 9.4.2 Materials Screening, Process Optimization, and Process Technology Selection 240
    - 9.4.3 Multi-scale CCUS Design: Simultaneous Materials Screening, Process Optimization, and Supply Chain Optimization 241
  - 9.5 Enabling Methods, Challenges, and Research Opportunities 242
    - 9.5.1 Developing Reduced Order/Surrogate Models 242
    - 9.5.2 Developing Multi-scale High-fidelity Simulation Tools 242
    - 9.5.3 Addressing Uncertainty 242
  - List of Abbreviations 243
  - References 244
- 10 **Membrane System Design for CO<sub>2</sub> Capture: From Molecular Modeling to Process Simulation 249**  
*Xuezhong He, Daniel R. Nieto, Arne Lindbråthen, and May-Britt Hägg*
  - 10.1 Introduction 249
  - 10.2 Membranes for Gas Separation 250
    - 10.2.1 Membrane Materials 250
    - 10.2.2 Separation Principles 251
    - 10.2.3 Membranes for CO<sub>2</sub> Separation 253
  - 10.3 Molecular Modeling of Gas Separation in Membranes 255
    - 10.3.1 Variables Influencing Transport Properties in Molecular Modeling 255
    - 10.3.2 Computational Models 256
    - 10.3.3 Molecular Modeling Validation 259
    - 10.3.4 Software and Potentials 259
  - 10.4 Process Simulation of Membranes for CO<sub>2</sub> Capture 260
    - 10.4.1 Process Description and Simulation Basis 260
    - 10.4.2 Cost Model 262
    - 10.4.3 Criteria on Energy Consumption 265
    - 10.4.4 Simulation Software 266
    - 10.4.5 Process Design 266
    - 10.4.6 Techno-economic Feasibility Analysis 270

10.4.7	Sensitivity Analysis	272
10.5	Future Perspectives	273
	List of Abbreviations	274
	Acknowledgments	276
	References	276
<b>11</b>	<b>Post-combustion CO<sub>2</sub> Capture by Chemical Gas–Liquid Absorption: Solvent Selection, Process Modelling, Energy Integration and Design Methods</b>	<b>283</b>
	<i>Thibaut Neveux, Yann Le Moullec, and Éric Favre</i>	
11.1	Introduction	283
11.2	Solvent Influence	284
11.3	Process Modelling	286
11.3.1	Thermodynamic Equilibria Modelling	287
11.3.2	Necessity of a Rate-based Approach	287
11.3.3	Model Validation	289
11.4	Process Integration	291
11.4.1	Evaluating the Overall Energy Penalty	293
11.4.2	Integration Between the Capture Process and the Power Plant	294
11.4.3	Integration Within the Capture Process: Flow Scheme Modifications	296
11.4.4	Example of Process Comparison	299
11.5	Design Method	300
11.5.1	Economic Criterion for Design Purpose	301
11.5.2	Sensitivity Analysis	302
11.5.3	Optimization as a Systematic Design Tool	304
11.5.4	Example of Optimization Results for Five Processes	305
11.6	Conclusion	306
	List of Abbreviations	308
	References	308
<b>12</b>	<b>Innovative Computational Tools and Models for the Design, Optimization and Control of Carbon Capture Processes</b>	<b>311</b>
	<i>David C. Miller, Deb Agarwal, Debangsu Bhattacharyya, Joshua Boverhof, Yang Chen, John Eslick, Jim Leek, Jinliang Ma, Priyadarshi Mahapatra, Brenda Ng, Nikolaos V. Sahinidis, Charles Tong, and Stephen E. Zitney</i>	
12.1	Overview	311
12.2	Advanced Computational Frameworks	313
12.2.1	Framework for Optimization, Quantification of Uncertainty, and Surrogates	313
12.2.2	Advanced Process Control Framework	323
12.3	Case Study: Solid Sorbent Carbon Capture System	326
12.3.1	Process Models (BFB)	326
12.3.2	Process Topology via Superstructure and Algebraic Surrogate Models	327
12.3.3	Simulation-based Optimization with Simultaneous Heat Integration	328
12.3.4	Uncertainty Quantification	330

12.3.5	Dynamic Reduced Models from Rigorous Process Models	331
12.3.6	Advanced Process Control	332
12.4	Summary	335
	Acknowledgment	338
	List of Abbreviations	338
	References	339
<b>13</b>	<b>Modelling and Optimization of Pressure Swing Adsorption (PSA) Processes for Post-combustion CO<sub>2</sub> Capture from Flue Gas</b>	<b>343</b>
	<i>George N. Nikolaidis, Eustathios S. Kikkinides, and Michael C. Georgiadis</i>	
13.1	Introduction	343
13.2	Mathematical Model Formulation	346
13.2.1	Problem Statement	346
13.2.2	Mathematical Model	347
13.2.3	Process Performance Indicators	351
13.2.4	Numerical Solution	351
13.3	PSA/VSA Simulation Case Studies	352
13.3.1	Model Validation	352
13.3.2	Parametric Analysis	355
13.4	PSA/VSA Optimization Case Study	359
13.4.1	Formulation of the Optimization Problem	359
13.4.2	Optimization Results	360
13.5	Conclusions	362
	List of Abbreviations	365
	Acknowledgements	366
	References	367
<b>14</b>	<b>Joule Thomson Effect in a Two-dimensional Multi-component Radial Crossflow Hollow Fiber Membrane Applied for CO<sub>2</sub> Capture in Natural Gas Sweetening</b>	<b>371</b>
	<i>Serene Sow Mun Lock, Kok Keong Lau, Azmi Mohd Shariff, and Yin Fong Yeong</i>	
14.1	Introduction	371
14.2	Methodology	373
14.2.1	Mathematical Modeling	373
14.2.2	Simulation Methodology	380
14.2.3	Experimental Methodology	382
14.3	Results and Discussion	384
14.3.1	Validation of Simulation Model	384
14.3.2	Temperature and Membrane Permeance Profile	385
14.3.3	CO <sub>2</sub> Residue Composition and Percentage Hydrocarbon Loss	388
14.3.4	Compressor Power and Stage Cut	390
14.3.5	Gas Processing Cost	392
14.4	Conclusion	393
	List of Abbreviations	394
	Acknowledgments	394
	References	394

<b>15</b>	<b>The Challenge of Reducing the Size of an Absorber Using a Rotating Packed Bed</b>	<b>399</b>
	<i>Ming-Tsz Chen, David Shan Hill Wong, and Chung Sung Tan</i>	
15.1	Motivation for Size Reduction	399
15.2	Rotating Packed Bed Technology	401
15.3	Experimental Work on CO <sub>2</sub> Capture Using a Rotating Packed Bed	405
15.4	Modeling of CO <sub>2</sub> Capture using a Rotating Packed Bed	409
15.5	Design of Rotating Packed Bed Absorbers and Real Work Comparison to Regular Packed Absorbers	410
15.6	Conclusions	417
	List of Abbreviations	417
	References	418

### **Section 3 Process Operation and Control 425**

<b>16</b>	<b>Plantwide Design and Operation of CO<sub>2</sub> Capture Using Chemical Absorption</b>	<b>427</b>
	<i>David Shan Hill Wong and Shi-Shang Jang</i>	
16.1	Introduction	427
16.2	The Basic Process	428
16.3	Solvent Selection	429
16.4	Energy Consumption Targets	429
16.5	Steady-state Process Modeling	431
16.6	Conceptual Process Integration	432
16.7	Column Internals	432
16.8	Dynamic Modeling	433
16.9	Plantwide Control	434
16.10	Flexible Operation	434
16.11	Water and Amine Management	435
16.12	SO <sub>x</sub> Treatment	436
16.13	Monitoring	436
16.14	Conclusions	437
	List of Abbreviations	437
	References	437

<b>17</b>	<b>Multi-period Design of Carbon Capture Systems for Flexible Operation</b>	<b>447</b>
	<i>Nial Mac Dowell and Nilay Shah</i>	
17.1	Introduction	447
17.2	Evaluation of Flexible Operation	451
17.2.1	Load Following	451
17.2.2	Solvent Storage	453
17.2.3	Exhaust Gas Venting	454



17.2.4	Time-varying Solvent Regeneration	454
17.3	Scenario Comparison	457
17.4	Conclusions	459
	List of Abbreviations	460
	Acknowledgements	460
	References	461
<b>18</b>	<b>Improved Design and Operation of Post-combustion CO<sub>2</sub> Capture Processes with Process Modelling</b>	<b>463</b>
	<i>Adekola Lawal, Javier Rodriguez, Alfredo Ramos, Gerardo Sanchis, Mario Calado, Nouri Samsatli, Eni Oko, and Meihong Wang</i>	
18.1	Introduction	463
18.2	The gCCS Whole-chain System Modelling Environment	464
18.2.1	Modelling Reactive Absorption Processes	464
18.2.2	gSAFT Thermodynamics	465
18.3	Typical Process Design Considerations in a Simulation Study	467
18.3.1	Process Steam Requirements	467
18.3.2	Steam Extraction Location	467
18.3.3	Absorber Performance Factors	471
18.3.4	Solvent Selection/Design	471
18.3.5	Part-load Considerations	473
18.3.6	Extreme Weather Conditions	475
18.3.7	Process Design for Flexible Operation	476
18.3.8	Water Balance	476
18.4	Safety Considerations: Anticipating Hazards	477
18.4.1	Configuration Data	477
18.4.2	Unplanned Shut-down at Injection Site	477
18.4.3	Loss of Upstream Compression	478
18.4.4	Additional Hazards for Consideration	479
18.5	Process Operating Considerations	479
18.5.1	CO <sub>2</sub> Capture Plant Control Systems	479
18.5.2	Start-up and Shut-down	483
18.5.3	Load-following Operations	483
18.6	Conclusions	497
	List of Abbreviations	498
	References	498
<b>19</b>	<b>Advanced Control Strategies for IGCC Plants with Membrane Reactors for CO<sub>2</sub> Capture</b>	<b>501</b>
	<i>Fernando V. Lima, Xin He, Rishi Amrit, and Prodromos Daoutidis</i>	
19.1	Introduction	501
19.2	Modelling Approach	503
19.2.1	Simplified IGCC Model	503
19.2.2	Membrane Reactor Model	504
19.2.3	Integrated IGCC-MR Process Model	506

19.3	Design and Simulation Conditions	507
19.3.1	Simulation Setup	507
19.3.2	Control Structure and Scenarios	508
19.4	Model Predictive Control Strategies	508
19.4.1	Linear MPC Approach: DMC	509
19.4.2	Nonlinear MPC Approach	511
19.5	Closed-loop Simulation Results	512
19.6	Conclusions	518
	List of Abbreviations	518
	Acknowledgements	519
	References	519
<b>20</b>	<b>An Integration Framework for CO<sub>2</sub> Capture Processes</b>	<b>523</b>
	<i>M. Hossein Sahraei and Luis A. Ricardez-Sandoval</i>	
20.1	Introduction	523
20.2	Automation Framework and Syntax	525
20.3	CO <sub>2</sub> Capture Plant Model	528
20.4	Case Studies	530
20.4.1	Controllability Analysis	530
20.4.2	Optimal Process Scheduling	533
20.4.3	Simultaneous Design and Control	537
20.5	Conclusions	540
	List of Abbreviations	541
	References	541
<b>21</b>	<b>Operability Analysis in Solvent-based Post-combustion CO<sub>2</sub> Capture Plants</b>	<b>545</b>
	<i>Theodoros Damartzis, Athanasios I. Papadopoulos, and Panos Seferlis</i>	
21.1	Introduction	545
21.2	Framework for the Analysis of Operability	548
21.2.1	Disturbance Rejection Analysis	548
21.2.2	Application to CO <sub>2</sub> Capture Processes	549
21.3	Framework Implementation	552
21.3.1	Employed CO <sub>2</sub> Capture Solvents	552
21.3.2	Employed Flowsheet Configurations	553
21.3.3	Disturbance Scenario and Problem Solution	555
21.4	Results and Discussion	556
21.4.1	Operability Analysis of CF Configuration	556
21.4.2	Operability Analysis of DSS-ICA Configuration	560
21.4.3	Economic Performance	564
21.5	Conclusions	566
	List of Abbreviations	567
	Acknowledgments	567
	References	567

## Section 4 Integrated Technologies 571

- 22 Process Systems Engineering for Optimal Design and Operation of Oxycombustion 573**  
*Alexander Mitsos*
- 22.1 Introduction 573
  - 22.2 Pressurized Oxycombustion of Coal 575
    - 22.2.1 Optimal Design and Operation 575
    - 22.2.2 Ideal Flexibility of Pressurized Oxycombustion 578
  - 22.3 Membrane-based Processes 578
    - 22.3.1 Need for Detailed Modeling 580
    - 22.3.2 Optimal Reactor Design 581
    - 22.3.3 Optimal Process Design 582
    - 22.3.4 Integration with Seawater Desalination 583
    - 22.3.5 Integration with Renewable Energy 584
  - 22.4 Conclusions and Future Work 585
    - List of Abbreviations 585
    - Acknowledgments 585
    - References 586
- 23 Energy Integration of Processes for Solid Looping CO<sub>2</sub> Capture Systems 589**  
*Pilar Lisbona, Yolanda Lara, Ana Martínez, and Luis M. Romeo*
- 23.1 Introduction 589
  - 23.2 Internal Integration for Energy Savings 592
    - 23.2.1 Solids Preheating 592
    - 23.2.2 Carbonator as a Heat Source 594
    - 23.2.3 External Heat Sources 595
    - 23.2.4 Comparative Analysis 597
  - 23.3 External Integration for Energy Use 597
  - 23.4 Process Symbiosis 601
    - 23.4.1 *In situ* Pre-combustion Capture Technologies Integration with Ca-looping 601
    - 23.4.2 *In situ* Integration of the Ca-looping Process with Industrial Cement Production 604
  - 23.5 Final Remarks 605
    - List of Abbreviations 605
    - References 605
- 24 Process Simulation of a Dual-stage Selexol Process for Pre-combustion Carbon Capture at an Integrated Gasification Combined Cycle Power Plant 609**  
*Hyungwoong Ahn*
- 24.1 Introduction 609
  - 24.2 Configuration of an Absorption Process for Pre-combustion Carbon Capture 610
  - 24.3 Solubility Model 616

24.4	Conventional Dual-stage Selexol Process	619
24.5	Unintegrated Solvent Cycle Design	624
24.6	95% Carbon Capture Efficiency	625
24.7	Conclusions	626
	List of Abbreviations	627
	References	627
<b>25</b>	<b>Optimized Lignite-fired Power Plants with Post-combustion CO<sub>2</sub> Capture</b>	<b>629</b>
	<i>Emmanouil K. Kakaras, Antonios K. Koumanakos, and Aggelos F. Doukelis</i>	
25.1	Introduction	629
25.2	Reducing the Energy Efficiency Penalty	630
25.2.1	Steam Thermodynamic Characteristics	630
25.2.2	Lignite Pre-drying	630
25.3	Optimized Plants with Amine Scrubbing: Greenfield Case	631
25.3.1	General Assumptions	631
25.3.2	Reference Power Plant	633
25.3.3	Lignite Power Plant with Post-combustion Capture with Amine Scrubbing	633
25.4	Oxyfuel and Amine Scrubbing Hybrid CO <sub>2</sub> Capture	635
25.4.1	Technology Description	635
25.4.2	Reference Case: Existing Plant	638
25.4.3	Plant with Hybrid CO <sub>2</sub> Capture System	640
25.5	Conclusions	645
	List of Abbreviations	645
	References	645
	<b>Index</b>	<b>649</b>