

Contents

Introduction	1
1 Fundamentals of C₄-Hydrocarbons	5
1.1 Nomenclature and Chemical Structure of the C ₄ -Hydrocarbons	5
1.2 Definition of the C ₄ -Cut from Steam Crackers and Its Raffinates	6
1.3 Terms for the C ₄ -Hydrocarbon Streams Within the Refinery	6
1.4 Product Specifications	7
2 Production Scheme for C₄-Hydrocarbons	9
2.1 Methods for Establishing the Production Scheme	9
2.2 Production of C ₄ -Hydrocarbons	9
2.2.1 C ₄ -Hydrocarbons from Natural Sources	11
2.2.2 C ₄ -Hydrocarbons from Refinery Gases	16
2.2.3 C ₄ -Cut as Co-product of Ethylene Production	19
2.2.4 C ₄ -Hydrocarbons Through Synthesis	23
2.2.4.1 Petrochemical Syntheses	23
2.2.4.2 Syntheses Based on Coal	26
2.2.4.3 Biotechnological Syntheses	28
2.3 Production of C ₄ -Aldehydes and Alcohols	29
2.3.1 Butanals	30
2.3.2 Butanols	31
2.3.3 Butanediols	33
3 Processes of Separation and Transformation in C₄-Chemistry	35
3.1 Separation of the C ₄ -Cut and C ₄ -Gases from Refineries	35
3.1.1 Separation Processes for Obtaining Butadiene	36
3.1.2 Separation Processes for Obtaining Butenes	38
3.1.2.1 Survey	38
3.1.2.2 Sulfuric Acid Processes	40
3.1.2.3 Molecular Sieve Processes	41
3.1.2.4 Other Processes	42

3.2	Processes of Butane Conversion	46
3.2.1	Isomerisation	46
3.2.2	Dehydrogenation	47
3.2.3	Oxidation	51
3.2.4	Alkylation	54
3.2.5	Chlorination	56
3.2.6	Cyclisation	58
3.2.7	Other Applications	59
3.3	Processes of Butene Conversion	60
3.3.1	Components of Gasoline Fuels	61
3.3.1.1	Polymer Gasoline	61
3.3.1.2	Methyl <i>tert</i> -Butyl Ether (MTBE)	62
3.3.2	Chemical Secondary Products from Raffinate I	67
3.3.2.1	Polybutene	67
3.3.2.2	Di- and Tri- <i>i</i> -butenes	68
3.3.2.3	Propene	68
3.3.2.4	Specialities	69
3.3.3	Chemical Secondary Products from Raffinate II	69
3.3.3.1	Oligomers of <i>n</i> -Butenes	69
3.3.3.2	Butadiene	71
3.3.3.3	Methyl Ethyl Ketone	72
3.3.3.4	Maleic Anhydride	72
3.3.3.5	Acetic Acid	73
3.3.3.6	Specialities	74
3.3.4	Chemical Secondary Products from Pure <i>i</i> -Butene	74
3.3.4.1	Poly- <i>i</i> -butene	75
3.3.4.2	Butyl Rubber	75
3.3.4.3	Methacryl Compounds	76
3.3.4.4	Isoprene	82
3.3.4.5	Specialities	85
3.3.5	Chemical Secondary Products from Pure <i>n</i> -Butenes	85
3.3.5.1	Poly-1-butene	85
3.3.5.2	HDPE-Comonomer and LLDPE	86
3.3.5.3	1,2-Butene Oxide	87
3.4	Processes of Butadiene Conversion	89
3.4.1	Butadiene Polymers and Copolymers	89
3.4.1.1	Polybutadiene	89
3.4.1.2	Polychloroprene	92
3.4.1.3	Styrene-butadiene Rubber	95
3.4.1.4	Nitrile Rubber	96
3.4.1.5	Acrylonitrile-butadiene-styrene Polymers	96
3.4.1.6	Ethylene-propene-diene Polymers	97
3.4.1.7	Rubber and Latex Specialities Containing Butadiene	97
3.4.2	Styrene	99
3.4.3	Polyamides	99
3.4.4	1,4-Butanediol and Derivatives	102
3.4.5	Anthraquinone	103

3.4.6	Sulfolane	104
3.4.7	Other Butadiene Specialities	104
4	Processing Scheme for C₄-Hydrocarbons	107
4.1	Method of Ascertaining the Processing Scheme	107
4.2	Analysis of the Processing Scheme for Butane Secondary Products	112
4.2.1	Butane Derivatives Processing Scheme	112
4.2.2	Production Amounts of Butane Secondary Products	112
4.2.3	Specific Butane Consumption Coefficients for the Secondary Products	113
4.2.4	Processing Scheme for Butanes	113
4.3	Analysis of the Processing Scheme for Butene Secondary Products	113
4.3.1	Butene Derivatives Processing Scheme	113
4.3.2	Production Amounts of Butene Secondary Products	116
4.3.3	Specific Butene Consumption Coefficients for the Secondary Products	119
4.3.4	Processing Scheme for Butenes	119
4.4	Analysis of the Processing Scheme for Butadiene Secondary Products	119
4.4.1	Butadiene Derivatives Processing Scheme	119
4.4.2	Production Amounts of Butadiene Secondary Products	119
4.4.3	Specific Butadiene Consumption Coefficients for the Secondary Products	124
4.4.4	Processing Scheme for Butadiene	125
5	Competition Factors of the C₄-Hydrocarbons	126
5.1	Macroeconomic Competition Factors	126
5.1.1	Competition Criteria of Products in the Application Hierarchy	126
5.1.2	Limiting Factors of Trading	128
5.1.3	Threshold Effects of Market Changes	130
5.2	Microeconomic Factors of Competition	132
5.2.1	Competition Factors Related to Products and Suppliers	132
5.2.2	Criteria of Quality as Factors in Competition	133
5.2.2.1	Classification of Product Properties According to the Application Hierarchy	133
5.2.2.2	Economic and Metaeconomic Criteria for Quality	136
5.2.2.3	Property Standards of Products	136
5.2.3	Prices as Factors of Competition	137
5.2.3.1	Prices After Fulfilment of Standards of Minimum Properties	137
5.2.3.2	Economically Calculable Application Properties of a Product as Price Parameter	137
5.2.3.3	Price Evaluation of the Metaeconomic Benefits of Use	139
5.2.4	Quantity as a Factor in Competition	140
5.3	Costs as a Basis of Price Competitiveness of a Product	141
5.3.1	Cost Reduction via Increased Sales	141
5.3.1.1	Lowering the Procurement Costs	141

5.3.1.2	Lowering the Production Costs	142
5.3.1.3	Lowering Marketing Costs	144
5.3.1.4	Recovery of R and D Costs	144
5.3.2	Lowering Costs by Utilization of Technological Progress	145
5.3.2.1	Cost Reduction by Routine Work and Automatization	145
5.3.2.2	Cost Reduction by Process Changes	145
5.3.2.3	Cost Advantages Through Production Integration	148
5.3.2.4	Cost Increases or Decreases Through Co-products	148
5.3.3	Full Costs as Price Parameters	149
5.3.3.1	Problems of Evaluating Full Costs of Co-products	149
5.3.3.2	Company-Related Interpretations of Full Costs for Co-products	150
5.3.3.3	Intercompany Transfer Prices	151
5.3.4	Methods of Cost Estimation	151
5.3.4.1	Estimation of Production Costs	151
5.3.4.2	Forecasting Costs	155
5.3.4.3	Forecasting the Resource Costs of the Products	155
5.3.4.4	Forecasts of Costs on the Basis of Energy and Crude Oil Equivalents	155
6	Analyses of Competition of C₄-Chemical Products	156
6.1	Prospects for C ₄ -Technologies in the Field of Gasoline Components for Increasing Octane Numbers	156
6.1.1	The Need for High-Octane Components	156
6.1.2	Material Balance in Optimising the Octane Number	159
6.1.3	Technical Alternatives in Production of Gasoline of High Octane Number	162
6.1.3.1	Survey	162
6.1.3.2	Direct Blending of Refinery B-B	163
6.1.3.3	Conversion of Refinery B-B into Liquid Components	165
6.1.4	Comparison of Quantities	166
6.1.5	Comparison of Costs	169
6.1.5.1	Production Costs for Alkylate Gasoline	169
6.1.5.2	Production Costs for Polymer Gasoline	171
6.1.5.3	Production Costs for MTBE	172
6.1.5.4	Production Costs for TBA	173
6.1.5.5	Production Costs for MTBE and TBA from Butanes	175
6.1.5.6	Production Costs for SBA	178
6.1.6	Evaluation of Profit for High-Octane Components	178
6.1.6.1	Comparison of Properties	179
6.1.6.2	Comparison of Profitability	181
6.1.7	Market Development for Oxygenates	185
6.2	Prospects for C ₄ -Technologies in the Plastics Field	188
6.2.1	C ₄ -Products in the Plastics Field	188
6.2.2	Costs of Obtaining Pure C ₄ -Base Chemicals	190
6.2.2.1	Production of Pure <i>i</i> -Butene	190
6.2.2.2	Production of Pure 1-Butene	191

6.2.2.3	Production of Pure Butadiene	191
6.2.3	Butane Secondary Products in the Plastics Field	197
6.2.3.1	Maleic Anhydride and Fumaric Acid	197
6.2.3.2	Other Secondary Products	202
6.2.4	Butene Secondary Products in the Plastics Field	203
6.2.4.1	Methyl Methacrylate	203
6.2.4.2	Poly-i-butene	206
6.2.4.3	Poly-1-butene	207
6.2.4.4	Processing of Other Polyolefines by Use of 1-Butene as Comonomer	214
7	Summary	221
	References	226
	Company Index	235
	Subject Index	237