

Index

a

- acetic acid 251, 255, 256, 341
- acetoacetate decarboxylase (AAD) 202
- acetone 202
- acetyl CoA 202, 203
- acid catalysts
 - *see also individual acid catalysts*
 - aromatic chemicals 193, 205
 - extractives transformation 330, 334, 343
 - furfural from carbohydrates 97, 100–102, 103–107, 109, 112
 - non-thermochemical biorefineries 252
 - turpentine derivatives 339, 341
- acid removal, ethanol dehydration 163
- acyclic carbonates 368, 369–371
- acyclic pathways 107, 108
- adiabatic reactions 161, 162
- Advanced Research Projects Agency-Energy program (ARPA-E) 39
- agricultural crops
 - *see also sugar-based biomass*
 - carbohydrate source 84, 85
 - corn 153, 154, 204, 205, 357
 - sitosterol hydrogenation 321–325
- Alcell pulping process 10, 253
- alcohols
 - alcoholysis of urea 372
 - aldehyde/ketone functions conversion to 190
 - butanols 4, 11, 12
 - carbamates production 365, 377
 - carboxylation 368, 369–371
 - characteristics 170
 - coniferyl alcohol 225, 226
 - fatty alcohols 177–180
 - oxidative carbonylation 368
 - perillyl alcohol 318, 320, 334
 - propargyl alcohols 376
- aldehydes 190, 200, 205, 318, 332, 333, 340, 342
- aldol condensations 342, 343
- algal biomass
 - algaenan 386
 - alginate 385
 - carbohydrate source 84, 85, 92–94
 - carbon dioxide fixation 382–386
 - product selection criterion 47
 - types 180
- alkali earth elements 283
- alkanes 197, 272–274
- alkenes 272, 273, 376
- N*-alkylpyrrolidones 21
- alumina catalysts 159, 160
- aluminium oxide catalysts 330, 331
- aluminium-containing MCM-41 106
- Amazon rain forest 152, 153
- amides 170, 376
- amines 170, 374–377
- p*-aminobenzoic acid 221, 222
- ammonia fiber expansion (AFEX) 252
- Amyris 4, 13, 54–78, 180
- anaerobic digestion 249, 252, 253
- Anderson–Schultz–Flory (ASF) distributions 273
- Anellotech process 195, 198
- aniline 220–222
- anionic polymerization 62, 63
- anthranilic acid 220–222
- aphid alarm pheromones 59
- application strategies 263, 264
- aquatic carbohydrates 92–94
- aqueous halides 101, 102
- aqueous phase reforming (APR) 192, 193
- aqueous sugar streams 192
- arabinogalactans 87, 91
- arabinoglucuronoxylans 88, 91

- arabinose 98, 100, 255
- arabinoxylans 88, 91, 92
- Archer Daniels Midland (ADM) Company 39, 44
- AroE enzyme 212
- aromatic chemicals
 - aromatic acid pathway 209
 - bio-oil derived 197
 - biological routes 199–226
 - BTX biorefinery 186–199
 - Diels–Alder β -farnesene adducts 73–75
 - diisocyanates 378
 - extraction, oils/fuels 96
 - lignin 226–228
 - production from bio-based feedstocks 185–230
 - yields 229
- aromatics from biobased feedstocks, yields 229
- artemisinin 54
- Arthrospira* 383
- artificial photosynthesis 364, 367, 374, 380
- ASPEN simulation model 357–359
- availability of raw materials 41–43
- Avantium Chemicals 17, 22, 207
- azetidines 378
- aziridines 376, 378

- b**
- base oils 77
- batch reactors 128, 129
- benzene–toluene–xylene (BTX) process 185–199
- Billion-Ton study (US DOE/DOA) 185
- bio-based plastics, *see* plastics
- bio-isobutanol 12, 13, 199–201
- bio-oils
 - *see also* fats/oils
 - aromatic chemicals production 188, 189
 - Fischer–Tropsch process 289
 - product selection criterion 47, 48
 - production process 16, 17
 - pyrolysis 195–198
- Biofene 13
- biofuels
 - *see also* diesel biofuels; *individual fuels*
 - from carbon dioxide 379–381
 - life cycle analyses 33, 34
 - renewable
 - – current situation 9–18
 - – existing biorefinery infrastructures 44
 - – outcomes comparison in product selection 40
 - target selection 33
- Biofuels Digest polls 2
- Biological and Chemical Catalysts Technologies Program (US DOE) 32
- biological routes
 - aromatic chemicals 199–226
 - – purified terephthalic acid from *p*-xylene 199
 - biorefineries using 249
 - common aromatic pathway 209–221
 - enzymic reaction types 49
 - fats/oils as raw material 173, 174
 - isobutylene production 201–203
 - organosolv biorefining 245–267
 - polycarbonate production 374
 - valine pathway to isobutylene 200, 201
- biomass feedstocks
 - *see also* sugar-based biomass
 - aromatic chemicals production 185–230
 - – chemistry 187–192
 - energy aspects 352, 353, 359
 - fats/oils as raw material 174, 175
 - 5-hydroxymethyl furfural synthesis 111
 - lignocellulosic
 - – biomass gasification 14, 15
 - – current situation 10, 11
 - – gasification 14, 15
 - – organosolv biorefining 245–267
 - – oxygen removal 14, 16
 - pretreatment/gasification for FT process 288–299
 - pyrolysis 195–198
 - residues available 18
 - statistical design of experiments 135–137
 - usage by companies 4, 5
 - biomass-to-liquids (BTL)
 - Fischer–Tropsch process 271–312
 - – basics 271–278
 - – biomass pretreatment/gasification 288–299
 - – cobalt catalysis 278–285
 - – concept 277, 278, 299–308
 - – energy/carbon efficiencies 310–312
 - – pilot/demo plants 308–310
 - – process concepts 299–308
 - – reactors 285–288
- biopolymers
 - *see also individual polymers and plastics*
 - cyclic carbonates synthesis 373, 374
 - definition 151
 - polyethylene from ethanol 151–164
 - polymerization reactions 164, 257
 - polyurethanes synthesis 377–379
 - precursor rational selection 28
 - storage carbohydrates 84, 86, 87

- structural carbohydrates 86–97
 - terpenes 60–68
 - biorefineries
 - *see also* companies
 - anaerobic digestion catalysts 252, 253
 - benzene–toluene–xylene process 186–199
 - existing infrastructures 43, 44
 - organosolv process 245–267
 - thermochemical treatments 248, 249
 - types 247–251
 - biotechnology 47, 246
 - biphasic reactors 99
 - Blue Tower concept 296, 298, 300
 - boiling point/NIR spectra correlation 144
 - borneol 336, 340
 - bottles for beverages 156, 157, 194, 195, 356–359
 - Bouveault–Blanc reduction 178
 - Braskem
 - ethanol to polyethylene process 151–164
 - – commercial plants 154–157
 - – development reasons 151, 152
 - – legislation/certification 157, 158
 - – polymerization 164
 - – process description 158–163
 - – Triunfo plant 155, 156, 164
 - brassicasterol 322
 - brown macroalgae 93
 - building blocks 19, 35, 36, 58–60, 83–113
 - bulk chemicals 352, 380
 - butanols 4, 11, 12
 - byproduct use product selection criterion 46
- C**
- calcium oxide 381, 382
 - campesterol 322
 - camphene
 - esterification/etherification 339, 341
 - monoterpenes isomerization 325–327
 - α -pinene isomerization 331
 - terpenes isomerization 318
 - campholenic aldehyde 318, 332, 333, 340, 342
 - camphor 327, 340
 - candidate bio-based product selection 27–50
 - carbamates synthesis 374–376, 377–379
 - carbide mechanism 274
 - carbohydrates
 - *see also* sugar-based biomass
 - aquatic 92–94
 - building blocks 19
 - dehydration to fuels 16–18
 - dehydration to furans 94–112
 - DOE 2010 Report on products from 37, 38
 - furan-based building blocks from 83–113, 205
 - potential products 39
 - sources 84–94
 - storage carbohydrates 84, 86, 87
 - – cellulose 84, 86, 87, 89, 253, 254
 - – lignocellulosic biomass 10, 11, 14, 15, 245–267
 - – starch 43, 44
 - structural 86–92
 - top chemical opportunities list 35
 - carbon
 - capture and storage (CCS) 363, 367
 - efficiency 230, 303, 310–312
 - flux 209, 210, 212, 213
 - natural cycle 363
 - sources, carbon dioxide 363–387
 - carbon dioxide
 - carbamates 374–379
 - carbon source 363–387
 - conversion possibilities 367–379
 - cyclic carbonates/polymers synthesis 373, 374
 - cyclic reduction 380
 - energy products from 379–381
 - Fischer–Tropsch process 301, 302, 305, 306
 - fixation into aquatic biomass 382–386
 - industrial use 364–367
 - inorganic carbonates production 381, 382
 - removal, Braskem’s ethanol dehydration 163
 - transesterification/alcoholysis of urea 372
 - carbon monoxide 15, 161, 163, 248, 299
 - *see also* Fischer–Tropsch process
 - carbonates
 - carbon dioxide conversion 367–374
 - inorganic 381, 382
 - organic linear 369, 370
 - urea transesterification/alcoholysis 372
 - carbon–carbon bond cleavage 49
 - carbon–oxygen cleavage 49
 - carboxylation of epoxides 373, 374
 - carboxylic acids 170
 - trans*-carveol 320
 - carvone 320
 - catalysts
 - anaerobic digestion biorefineries 252, 253
 - biomass-derived sugars 193
 - biorefining processes 251–253

- Braskem's ethanol dehydration 159, 160
- catalytic hydrogenolysis 191
- catalytic reforming 191
- coking 147, 162, 195
- deactivation 327–330
- energy savings 351–354
- fats/oils
 - as raw material 173–177
 - transformation requirement 170–173
- fatty alcohols case study 178, 179
- furfural from carbohydrates 101–107, 112
- kinetics/pseudo-kinetics 131, 132
- loadings design 135, 136
- long term performance/deactivation 145–148
- novel, environmental assessment 349–360
- α -pinene isomerization 327
- principal component analysis 139–142
- process conceptual development 173–177
- process energy profiles 351
- product selection criteria 48, 49
- terpenes 53–78
 - polymerization 61–64
- testing equipment for conceptual process design 128–131
- catechol-O-methyl transferase (COMT) 211, 217
- cationic polymerization 63
- cellulose 84, 87, 89, 99, 253, 254
 - see also lignocellulosic biomass feedstocks
- certification 157, 158
- chalcones 222–226
- char 289, 291
- chemical structure preservation 256
- Chemrec technology 295, 297, 300
- Chemurgy movement 27, 53
- chitin 385
- chitosan 385
- Chlorella* 382
- chlorophyll pigments 383
- cholesterol-suppressing agents 321–325
- Choren technology 208, 209, 295, 297, 299, 300
- chorismate pathway 209, 215
- chromic acid 325, 335, 339, 341
- chromium catalysts 100
- chromium trioxide 341
- trans*-cinnamic acid decarboxylase (CADDC) 220
- circulating-bed gasifiers 292–294
- clean-up 301, 302
- Clostridium* spp. 202
- coal, bio-coal 249
- Cobalt Biofuels 11, 12
- cobalt catalysts
 - Fischer–Tropsch process 276–285
 - activation/preparation 278–280
 - activity 280–283
 - long-term performance 146, 148
- Coca-Cola beverage bottles 156, 157
- codes of conduct 157, 158
- coking 147, 162, 195
- commercial interest/activities
 - see also companies
 - aromatics from biobased feedstocks 228–230
 - carbon dioxide 364–367
 - cobalt FT catalyst formulations 283, 284
 - ethanol dehydration 154–157
 - furfural production/applications 95, 96
 - organosolv biorefinery products 257–259
 - status quo 1–23
 - terpene building blocks 57, 58
- commodity aromatic chemicals 185–230
- common aromatic pathway 209–221
- companies
 - see also individual companies
 - bio-isobutanol 12, 13
 - Biofuels Digest 2010-2011 top 50 2
 - carbohydrate potential products 38–40
 - cobalt FT catalyst formulations 284
 - collaboration 7, 8
 - ethanol dehydration for polymers 157
 - Fischer–Tropsch process 272, 308–310
 - geographic spread 4, 5
 - Lignol biorefinery process development 265
 - market drivers 44, 45, 262, 263
 - pilot biomass gasification plants for FT process 295, 296
 - platform chemicals production 3
 - polyethylene from ethanol 151
- complex heteroxylans 92
- concentrators of solar power (CSP) 380
- conceptual process design (CPD) 123–145
- conditioning 301, 302
- coniferyl alcohol 225, 226
- continuous reactors 129, 321
- conversion process types 6
- copper catalysts 179
- corn (maize) 153, 154, 204, 205, 357
- costs
 - Alternative Feedstocks Program 32
 - carbon dioxide industrial use 367
 - conceptual process design 123, 124, 126–128

- Fischer–Tropsch process 307, 308
- metal catalysts 177
- crude oil 47–8
- crude tall oil (CTO) compounds 321–325
- cryogenic distillation, ethylene 163
- current situation 1–23
 - production volumes/energy use 349
 - renewable chemicals 18–22
 - renewable fuels 9–18
 - renewables arena 2–9
- cyclic compounds 107, 108, 373, 374, 376–378

d

- deactivation of catalysts
 - cobalt FT catalysts 282, 283
 - function of 327–330
 - long-term performance 145–148
- degree of polymerization 257
- degree of unsaturation 171
- dehydration route
 - carbohydrates to fuels 16, 17
 - carbohydrates to furans 94–112
 - ethanol to polyethylene 154–157
 - product selection criteria 49
- dehydrogenation, isoborneol 342
- 3-dehydroquinic acid (DHQ) 216, 217
- dehydroshikimic acid (DHS) 212, 213
- Delphi analysis 33
- demonstration projects 266, 294–298, 308–310
- 3-deoxy-D-*arabino*-heptulosonic acid
 - 7-phosphate (DAHP) 209, 210, 212, 213
- 1-deoxy-D-xylulose-5-phosphate synthase (DXS) 214
- 1,4-diamionobutane 36
- Diels–Alder reactions
 - β -farnesene homo Diels–Alder products 71–74
 - isoprene adducts 72
 - purified terephthalic acid
 - – muconic acid route from 210, 213
 - – production via 5-hydroxymethyl furfural 206
 - terpenes 60
- diesel biofuels
 - companies using/producing 6–8, 10
 - – Amyris 55, 56
 - β -farnesene 55
 - Fischer–Tropsch process 271, 276
 - partial least squares analysis 143–145
- diethylcarbonate (DEC) 370
- differential scanning calorimetry (DSC) 65, 66, 73, 75, 76

- dihydroxyacid dehydratase (DHAD) 200
- diisocyanates, aromatic/cyclic 377, 378
- dimethyl carbonate (DMC) 369–371, 377
- dimethyl terephthalate 206
- dimethylallyl pyrophosphate (DMAPP) 56
- 2,5-dimethylfuran (DMF) 124–128
- distilled tall oil 317
- drop-in replacements
 - advanced bio-fuels 44
 - benzene–toluene–xylene process 185–189, 195, 196
 - carbohydrate-derived building blocks 19, 20
 - companies currently using 7
 - Green Polyethylene from ethanol 151–164
- dual bed reactors 291, 292
- DuPont 21
- DXP reductoisomerase (DXR) 214

e

- economics, *see* costs
- elastomers 378
- electrical energy storage 380, 381
- elimination reactions 98, 99
- energy
 - balance in Fischer–Tropsch process 302–305
 - carbon dioxide industrial use 365–367
 - case study 356–359
 - current situation 349
 - Lignol biorefinery process efficiency 256
 - profiles for catalytic processes 351
 - steam cracking 351, 352
- energy-rich products, *see* biofuels
- Enerkem technology 295, 298
- Ensyn/Envergent joint venture 16
- enthalpy 273, 366–369
- Entner–Doudoroff glycolysis pathway 201
- entrained-flow gasifiers 291–293, 297, 300–303, 305, 307, 308
- environmental assessments 349–360, 364, 365
 - life cycle assessment 33, 34, 350, 354, 356, 360
- enzymes
 - *see also* biological routes; fermentation; *individual enzymes*
 - common aromatic pathway 209–221
 - polycarbonates production 374
 - reaction types 49
 - valine pathway to isobutylene 200, 201
- epichlorohydrin Solvay facility 39

- epoxidation 326, 337–340
 - epoxides 365, 373, 374, 376
 - 1,2-epoxy- α -terpineol 326
 - 1,2-epoxycarveol 326
 - 1,2-epoxylimonene 326
 - erythrose-4-phosphate (E4P) 209, 210
 - esters/esterification 170, 172, 339, 341, 342, 372
 - ethane carbonate 365
 - ethanol
 - Braskem process 151–164
 - companies using/producing 4–10
 - current situation 10–12
 - existing biorefinery infrastructures 43
 - ethene carbonate 372
 - etherification 339, 341, 342
 - 5-ethoxymethyl furfural (EMF) 140
 - ethylbenzene 193, 195–199, 353
 - ethylene, *see* polyethylene
 - European ethanol production 153, 154
 - evaluation processes
 - extrudate catalysts performance 131–133
 - life cycle assessment 33, 34, 350, 354–356, 360, 365
 - novel catalytic processes 349–360
 - product selection criteria 41–48
 - existing biorefinery infrastructures 43, 44
 - exothermal reactions 273
 - extractives
 - catalytic transformation 317–344
 - – crude tall oil compounds 321–325
 - – overview 317–321
 - – turpentine compounds 325–343
 - components 317
 - Lignol biorefinery process 255
 - extrudate catalysts 131–133
- f**
- farnesenes
 - Amyris 4, 180
 - current situation 12, 13
 - homo Diels–Alder reaction products 71–74
 - structure 59, 63
 - synthesis routes 58–60
 - terpene production 54–78
 - thermal Diels–Alder reaction 73, 75, 76
 - fast pyrolysis 188, 189, 289
 - fats/oils
 - *see also* bio-oils
 - aromatic chemicals from 96, 197, 198
 - catalytic transformation requirement 170–173
 - fatty alcohols case study 177–180
 - lubricants 68–78
 - process development/design 173–177
 - raw materials 169–181
 - vacuum gas oil, catalyst testing 131
 - fatty acid methyl ester (FAME) 6, 7, 10, 180
 - fatty acids 169, 170, 321–5
 - fatty alcohols case study 177–180
 - feedstocks, *see* biomass feedstocks
 - fermentation
 - algal biomass 385
 - Amyris Biofuel 13
 - artemisinin 54
 - building blocks 19
 - concentration 229
 - ferulic acid 224, 225
 - furfural 97
 - Gevo’s process 11, 44
 - 3-hydroxypropionic acid 46
 - isobutanol removal 201
 - LanzaTech process 15
 - Lignol biorefinery process 254–266
 - muconic acid 210, 213
 - novel chemicals 58
 - process design 121
 - productivity 230
 - simultaneous saccharification and fermentation 97, 253
 - succinic acid 39
 - sugars to ethanol 7, 10, 12, 14, 44, 83
 - syngas 43
 - terpenes 54, 60, 78
 - Fischer–Tropsch (FT) process
 - biomass pretreatment/gasification 288–299
 - biomass-to-liquids 271–312
 - biorefinery processes 251, 252
 - catalyst stability 146
 - cobalt catalysis 278–285
 - DOE biomass programs 33
 - energy/carbon efficiencies 310–312
 - pilot/demo plants 308–310
 - process concepts 299–308
 - reactors 285–288
 - fixation of carbon dioxide 382–286
 - fixed-bed reactors 161, 162, 174–176, 179, 180, 291, 292
 - flash pyrolysis 15, 16
 - fluidized-bed gasifiers 291–294, 297, 298, 303, 305
 - fluidized-bed reaction 160
 - Ford Motor Company 27, 53
 - formic acid 99, 100, 109, 251

- fossil fuels 83, 363
- free radical polymerizations 63
- fructose
- dehydration through cyclic/acyclic intermediates 108, 109, 111
 - 2,5-dimethylfuran synthesis 124–128
 - 5-hydroxymethyl furfural synthesis 110
 - – conceptual process design example 124–128
- fuels
- *see also* biofuels
 - fossil fuels 83, 363
 - jet fuels 306, 307, 311
- functional units 355
- functionally equivalent replacements 45
- furan-based building blocks 83–113
- 2,5-furandicarboxylic acid (FDCA) 21, 22, 205, 206, 356, 357
- furanic polyesters production 22
- furans 205
- furfural
- commercial production 95, 96
 - derivatives 96
 - distribution/properties 95
- furfuraldehyde, from xylose 205
- production from carbohydrates 83–113
 - – carbohydrates dehydration 17
 - – heterogeneous catalysts 103–107
 - – homogeneous catalysts 101, 102
 - – systems 101, 102
 - recovery, Lignol biorefinery process 254, 255
- g**
- galactoglucmannans 87, 90, 91
- gallic acid 216, 217
- gas chromatography 69, 70
- Gas Technology Institute (GTI) 296, 298
- gasification of biomass 248, 251, 290–292
- gel permeation chromatography (GPC) 65, 66, 69
- genetic engineering 246, 384
- geographic spread of companies 4, 5
- Gevo Inc. 4, 11, 12
- Gibbs free energy of formation 366–368
- β -(1->3,1->4)-glucans 92
- glucmannans 87, 90
- glucose 108, 110, 253, 254
- glucuronoxylans 88, 90
- glycerol 46
- gold catalysts 330, 331
- graphene oxide 107
- grasses 84, 85
- green algae 84, 85, 92, 94
- green catalysts 101, 103, 104
- Green Polyethylene (GP) 151–164
- greenhouse gas emissions (GHG)
- carbon dioxide industrial use 364–367
 - corn-based ethanol 153
 - diesel biofuels 306
 - Fischer–Tropsch process 310, 311
 - novel catalytic processes 350, 360
- growth potential 2, 3, 9
- h**
- H2Bioil process 249
- Haematococcus* 383, 384
- halides 61, 101, 102
- heat exchangers 287
- hemicelluloses 89, 99
- hereditary factors 321
- heterogeneous catalysts 103–107, 327
- heterogeneous heteropolyacids (HPAs) 103, 104
- hexose 107, 108
- high temperatures 102, 271, 285
- history
- biomass-to-liquids Fischer–Tropsch process 271, 272
 - carbohydrate dehydration to furans 94–96
 - chemical process development 27
 - ethylene production 154
 - feedstocks 53–54
 - Lignol biorefinery process development 264–266
 - organosolv biorefining 245–246
 - target product selection 31–38
- HMF routes to PTA 207, 208
- HMG–CoA synthase 202, 203
- HMG–CoA reductase pathway 56, 57
- homogeneous catalysis 101, 102
- HP-L@ lignin 253, 258
- market drivers 262, 263
 - new product opportunities 260–262
 - physical/chemical characteristics 260
 - properties 259
- hybrid fractionation processes 97
- hydration reactions 102, 109, 336, 340, 341
- hydrodeoxygenation (HDO) 249
- hydrogen gas 322, 323, 380
- *see also* Fischer–Tropsch process
- hydrogenated fatty acid streams 198
- hydrogenation 140, 190, 191, 337, 338
- hydrogenolysis 178, 190, 191
- hydroquinone 216

- 3-hydroxy-isovaleric acid (3HIVA) 202
 - p*-hydroxybenzoic acid (pHBA) 218, 219
 - 5-hydroxymethyl furfural (HMF)
 - acyclic pathways 107, 108
 - aromatics via 204, 208
 - carbohydrates dehydration 17, 95
 - current situation 21
 - cyclic intermediates 107, 108
 - energy use case study 356, 357
 - fructose route 124–128
 - hydration reaction 102, 109
 - production from carbohydrates 83–113
 - purified terephthalic acid production 206–208
 - hydroxystyrene 219–221
- i**
- imidazolium-based ionic liquids 110
 - impact assessment, *see* environmental assessment
 - impregnation 278, 279
 - impurities
 - Braskem's ethanol dehydration 160, 161, 163
 - cobalt FT catalysts activity loss 283
 - ethylene purification 163
 - fats/oils feedstocks 175
 - Fischer–Tropsch process gas clean-up 301, 302
 - statistical experimental design 138
 - indirect carbamates synthesis 377–379
 - indirect land use change (ILUC) 359
 - industrial activities, *see* commercial interest/activities
 - industrial slag 381, 382
 - Ineos New Plant Bioenergy 15
 - inorganic carbonates production 381, 382
 - International Standard Organization (ISO) standards 355, 356
 - inulin 84, 86, 87
 - inventory analysis 355
 - iodine value (IV) 171
 - ionic liquids 110
 - iron-based catalysts 271, 276, 277
 - isoborneol 327, 342
 - isobornyl acetate 327
 - (+)-isobornyl acetate 336
 - isobutanol 12, 13, 199–201
 - isobutylene 199–203
 - isocyanates 40, 375, 377, 378
 - isomerization
 - monoterpenes 325–335
 - α -pinene 330, 331
 - α -pinene oxide 332
 - β -pinene oxide 335
 - terpenes 318
 - isopentyl pyrophosphate (IPP) 56
 - isoprene 61–63, 72
 - isoprenoids 56, 57, 383
 - isothermal reactions 161
 - isothermal zone length 129, 130
 - isovaleraldehyde dehydrogenase (IDH) 200
- j**
- jet fuels 306, 307, 311
- k**
- karahanaenone 339, 340
 - Karlsruhe Institute of Technology (KIT) 295, 297, 300, 309
 - Keggin-type heterogeneous heteropolyacids 103, 104, 341
 - kerosene 276, 306, 311
 - ketal products 21, 22
 - 2-ketoacid decarboxylase (KIVD) 200
 - ketol-acid reductoisomerase (KARI) 200, 201
 - ketone functions 14, 20, 21, 188–190, 193, 322, 339
 - kinetics 131, 132, 274, 275, 324, 366, 367, 369
 - Kraft pulping process 317
- l**
- land use 152, 153, 359
 - Langmuir–Hinschelwood kinetic expression 274
 - LanzaTech Inc. 14, 15
 - lavender oil 334
 - legislation 122, 157, 158, 355, 356
 - levosandal 340, 343
 - levulinates 17, 18
 - levulinic acid
 - current situation 20–22
 - energy use case study 356
 - fructose conversion to HMF/DMF 124
 - 5-hydroxymethyl furfural hydration reaction 109
 - product selection criterion 46
 - Lewis acids 63, 95, 206, 334, 373
 - life cycle assessment (LCA)
 - biofuels 33, 34
 - carbon dioxide industrial use 365
 - environmental sustainability 350, 354–356
 - novel catalytic processes 360
 - lignans 222–226, 255

- lignins
 - *see also* HP-L® lignin
 - chemicals derived from 122
 - common aromatic pathway 226–228
 - companies, product potential 39
 - derivatives 258, 259
 - Lignol biorefinery process 254
 - native 257
 - organosolv biorefineries 253
 - technical 257–258
 - value-added product selection 36, 37, 39, 40, 46
- lignocellulosic biomass feedstocks 10, 11, 14, 15, 245–267
- Lignol biorefinery process 253–266
- limonene 208, 209, 336, 339, 340
- linalool 318, 337
- linear carbonates synthesis 369, 370
- lipogenesis 173
- loading (catalysts) 280, 281
- loading (principal component analysis) 140
- Lobry De Bruijn-Alberda Van Ekenstein transformation 107
- long-term catalyst performance 145–148
- low-temperature Fischer–Tropsch (LTFT) process 271–312
- lubricants 68–78
 - *see also* fats/oils
- m**
- macroalgae 93, 382–386
- magnesium oxide 381, 382
- maize corn 153, 154, 204, 205, 357
- mandelic acid 219, 220
- market drivers 44, 45, 262, 263, 271, 272
- market-ready opportunities 261
 - *see also* drop-in replacements
- Markley's definition 169
- mass balance 302–305, 323
- mass spectrometry 70, 71
- mass transfer limitations 129–131
- Meerwin–Ponndorf–Verley (MPV) reaction 343
- (3-mercaptopropyl)-trimethoxysilane (MPTS) 104
- mesoporous molecular sieve MCM-41 104–106
- metals
 - *see also* cobalt catalysts
 - amides 376
 - chromium 100, 341
 - copper catalysts 179
 - costs 177
 - Fischer–Tropsch process 276, 277
 - iron-based catalysts 271, 276, 277
 - metal-carbamates 375
 - nickel 276, 277
 - niobium 103, 106, 340, 370, 371, 373
 - oxides, Group 2 381, 382
 - palladium 176, 177
 - ruthenium 146, 148, 179, 276, 277
 - sodium metal catalysts 62
 - tin 107
 - vanadium phosphates 106
 - Ziegler catalysts 61
- methane 272–274, 379
- methanol 3, 251, 276, 353, 354, 370–372, 379–381
- mevalonate pathway 56, 57
- mevalonic diphosphate decarboxylase 202
- microalgae 93, 382–386
- microbial strain engineering 54–57
- microporous zeolites 103
- mineral acid catalysts 101, 102
- molecular weights, chain lengths 273
- mono ethylene glycol (MEG) 154, 156, 157
- monoterpenes
 - derivatives 342, 343
 - epoxidation 337–340
 - esterification 341, 342
 - etherification 341, 342
 - hydration 340–341
 - hydrogenation 337, 338
 - isomerization 325–335
 - oxidization 337
- muconic acid route 210, 212–214
- multitubular reactors 161
- myrtanal 318–320, 334, 335
- myrtenol 320, 334
- n**
- N*-methyl-2-pyrrolidinone (NMP) 35, 36
- N*-vinyl-2-pyrrolidinone 35, 36
- naphtha 159, 191, 192, 197, 198, 271, 276, 306
- near-infrared spectra (NIR) 144
- new chemical process design 121–149
- new property advantages/disadvantages 45
- nickel catalysts 160, 175–177, 276, 277
- niobium 103, 106, 340, 370, 371, 373
- non-renewable energy use (NREU) 354, 358, 359
- non-thermochemical biorefineries 252
- Nopol 340, 343
- nuclear magnetic resonance (NMR) spectra 64, 65, 71–74

o

oils, *see* fats/oils
olefins 197, 374, 379
one-pot synthesis 333, 334
optimization statistical design methods
 133, 134–138
organic catalysts 369–371
organic solvents 109, 110, 112, 250, 251
organosolv biorefining 245–267
original equipment manufacturers (OEMs)
 55, 56
outcomes comparison 40, 41
oxazolidin-2-ones 376
oxygen removal 14, 16
oxygenates removal 163

p

paclitaxel 246
palladium catalysts 176–177
palm oil 4, 171, 172, 174, 198
para-hydroxybenzoic acid (pHBA) 218, 219
paraffins 194, 275, 276
parallel reactor equipment 121–149
parameter estimation 323, 324
partial least squares (PLS) regression 139,
 143–145
particle size of catalysts 280
partnerships between companies 7, 8
pentose phosphate pathway 209, 212
pentose sugar feedstock 97–101
perfumes 58, 60
perillyl alcohol 318, 320, 334
petrochemical industry 1, 56, 191
phenol 218, 219
phenylalanine (PAL) 220
pheromones, aphids 59
phloroglucinol 222, 223
phosgene use 365, 368, 375, 377
phosphoric acid 340, 341
photosynthesis, artificial 364, 367, 374, 380
pigments, algal 383
pilot plants 266, 294–298, 308–310
pinane-2-ol 338
pinene oxides
 – isomerization/hydrolysis 332, 335
 – α -pinene oxide 326
 – β -pinene oxide 326
 – terpenes
 – – hydration 336
 – – isomerization 334
pinenes
 – esterification/etherification 339
 – α -pinene 330, 331, 338
 – β -pinene 340
 – terpenes
 – – hydration 336
 – – isomerization 318, 329, 332
 – – oxidation 319, 320
 – turpentine 325
pinocarveol 320
pinocarpone 320
pinoresinol 225, 226
Pinus ponderosa 317
plant sterols hydrogenation 322
plant-based biomass 10, 11, 14, 15,
 245–267
PlantBottle® 156, 157
plasma gasifiers 292, 294, 296, 298
plastics
 – *see also individual plastics*
 – aquatic biomass-derived 385, 386
 – beverage bottles 156, 157, 194, 195,
 356–359
 – global production increase 349, 350
 platform chemicals 1–4, 7, 14, 20, 21, 33,
 46
 podophyllotoxin 225, 226
 polyalanoates 385, 386
 polycarbonates 373, 374
 polyester of ethylene glycol (PEF) 207,
 208
 polyethylene
 – ethanol-derived process 151–164
 – – Brazil 152–154
 – – commercial plants 154–157
 – – development reasons 151, 152
 – – legislation/certification 157, 158
 – – polymerization 164
 – – process description 158–163
 polyethylene furandicarboxylate (PEF)
 356–359
 polyethylene terephthalate (PET) 154, 156,
 157, 185, 199, 356–359
 poly(farnesene) structures 63
 polyhydroxybenzenes 221, 223
 poly(isoprene) 61, 62
 polymerizations 164, 257, 281
 – *see also* biopolymers
 polyols, sugar-derived 44
 polysaccharides 84, 86–92, 385
 – *see also individual polysaccharides*
 – lignocellulosic biomass feedstocks 10, 11,
 14, 15, 245–267
 polyurethanes synthesis 377–379
 polyvinylchloride (PVC) 154–157
 porous solid acids 103–107, 112
 powder catalysts 131, 132
 pretreatment of biomass 288–299

- principal component analysis (PCA)
139–142
- principal component analysis, yields 141, 142
- pro-chiral centers 72
- process development/design
- Braskem's ethanol dehydration 158–163
 - fats/oils as raw material 173–177
 - Lignol biorefinery process 256, 257
 - parallel reactor equipment 121–149
 - target product selection 27–50
- production volumes 6, 7, 349
- products 33, 34, 275, 276, 306, 307
- *see also* target product selection criteria
- propargyl alcohols 376
- propylene 352
- proteins, aquatic biomass 384
- purified terephthalic acid (PTA) 356
- from *p*-xylene 199
 - limonene to 208, 209
 - production via 5-hydroxymethyl furfural 206–208
 - *p*-xylene conversion 186
- pyrogallol 216, 217, 221–223
- pyrolysis
- biomass fast pyrolysis products 188, 189
 - biomass-derived sugars 192–195
 - biorefineries using 248, 249
 - biorefinery catalysts 251
 - Fischer–Tropsch process 289
 - raw biomass/bio-oil 195–198
- pyrolysis oils, *see* bio-oils
- q**
- Quaker Oats Company 96, 204
- quinic acid 216
- r**
- Range Fuels 2, 15, 290, 292
- rapeseed oil 175
- rapid thermal processing (RPT) 16
- rational selection of target products 27–50
- raw materials
- *see also* biomass feedstocks
 - aromatic chemicals production 187, 188
 - availability, product selection criteria 41–43
 - fats/oils 169–181
 - lignocellulosic biomass feedstocks 10, 11, 14, 15, 245–267
- reaction types/mechanisms
- acyclic carbonates from alcohols
carboxylation 369–371
 - biomass gasification for FT process 290
 - Braskem's ethanol dehydration 158, 159
 - carbamates synthesis 374–379
 - carbon dioxide reactions 366
 - carbonates synthesis 371
 - cyclic carbonates synthesis 373, 374
 - energy products from carbon dioxide 379–381
 - Fischer–Tropsch process 272–275
 - furan formation from sugars 95, 100
 - – elimination reactions 98, 99
 - hydrogenation/hydrogenolysis 190, 191
 - phosgene use 368
 - polyurethanes synthesis 377–379
 - product selection criteria 48, 49
- reactors
- batch reactors 128, 129
 - biphasic 99
 - continuous reactors 129, 321
 - dual bed reactors 291, 292
 - Fischer–Tropsch process configurations 285–288, 290, 291
 - fixed-bed reactors 161, 162, 174–176, 179, 180, 291, 292
 - fluidized-bed gasifiers 291–294, 297, 298, 303, 305
 - heat exchangers 287
 - Lignol organosolv refineries 256, 257
 - multitubular reactors 161
 - parallel reactors 121–149
 - plasma gasifiers 292, 294, 296, 298
 - types 128, 129
 - – Braskem's ethanol dehydration 161, 162
 - – fats/oils as raw materials 174–176, 179, 180
 - – Fischer–Tropsch process 285–288
- redox balance 230
- reduction reactions 279, 280, 290
- relative activity 327
- research and development (R&D) 9, 45, 46, 121–149
- resin acids, crude tall oil 321–325
- response surface model design 136, 137, 139
- rubber 27, 61
- ruthenium catalysts 146, 148, 179, 276, 277
- s**
- Saccharomyces cerevisiae* 201
- Salgema Indústrias Químicas Ltda. 154, 155
- scale effects 132, 133
- scaling up 111, 228–230, 279, 312
- screening processes 27–50, 133, 134
- Segetis Inc. 21

- selection criteria
 - *see also* target product selection criteria
 - hydrogenation catalysts 172, 173
 - reactors for Fischer–Tropsch process 285
 - separable deactivation model 327
 - sesquiterpenes 58–60
 - Shell International 17, 283, 284
 - shikimic acid 209–213, 218, 219
 - side product selectivity 137–139
 - side reactions 160, 161
 - silicate materials 381
 - silicoaluminophosphates (SAPO) 103
 - simultaneous saccharification and fermentation (SSF) 97
 - sitostanol 321, 322
 - sitosterol 321–325
 - slag 381, 382
 - slurry operations
 - catalysts 283
 - fats/oils as raw material 174–177
 - fatty alcohols case study 179, 180
 - FT slurry bubble column 285–288
 - Sobrerol 336, 341
 - sodium metal-catalyzed polymerization 62
 - solid acid catalysts 103–107, 112, 341
 - Solvay 39
 - solvents 109–112, 250, 251
 - organosolv biorefining 245–267
 - Sorona® 44
 - soybeans 53, 152, 153, 172
 - space-time yields 137–139
 - special chemicals 321–325
 - spinning disc reactors 333
 - Spirulina* 383
 - standards 55, 355, 356
 - star diagrams 35, 36, 96
 - starch 43, 44, 84, 86, 87
 - statistical design 132–138
 - Statoil technology 302–305, 307
 - steam cracking 197, 198, 351, 352
 - steam reforming 191, 298
 - stereoregularity 61
 - sterols 322
 - stigmasterol 322
 - stilbenes 222–226
 - storage carbohydrate sources 84, 86, 87
 - storage of electrical energy 380, 381
 - strain engineering 54–57
 - strong Lewis acids 63
 - structural carbohydrates 86–92
 - structure preservation 256
 - styrenes 219–221
 - succinic acid 19, 20, 39
 - sugar-based biomass
 - aromatics from pyrolysis 192–195
 - benzene–toluene–xylene bio-refinery concept 184, 185
 - chemicals derived from 122
 - Lignol biorefinery process 255, 256
 - – pyrolysis 192–195
 - plantations, labor conditions 158
 - polyester of ethylene glycol route 208
 - polyols, ADM 44
 - sucrose sources 84, 87
 - sugar cane, Brazilian ethanol production 152, 153
 - sugar-beet, ethanol production 153
 - sulfated tin oxide catalyst 107
 - sulfated zirconia (SZ) 105, 106
 - sulfite liquor 225
 - sulfonated graphene oxide 107
 - sulfonic acid-functionalized materials 104, 105
 - sulfur 175, 176
 - sunflower oil 172
 - supports for cobalt FT catalysts 282
 - sustainability case studies 356–359
 - syngas 191, 248, 299, 300, 302
 - *see also* Fischer–Tropsch process
 - system boundaries 355
- t**
- Taiwan Chlorella Manufacturing & Co. 382
 - tall oil 321–325
 - tall oil rosin (TOR) 317
 - target product selection criteria 27–50
 - byproduct uses 46
 - carbohydrate-derived products 37, 38
 - catalysis aspects 48, 49
 - chemicals, outcomes comparison 40, 41
 - evaluation processes 41–48
 - existing biorefinery infrastructures 43, 44
 - market drivers 44, 45
 - outcomes comparison 40, 41
 - previous activities 31–38
 - research drivers 45, 46
 - structures/technologies 30, 31
 - terpenes 54
 - validation 38–40
 - value-added processing 46
 - technical lignins 257, 258
 - technology development scenarios 30, 31, 33
 - temperature 102, 271–312, 322, 323
 - tensile strength 67, 68
 - terephthalic acid 21, 206, 213–216

- terpenes
 - building blocks of commercial interest 57, 58
 - catalytic processes development 53–78
 - epoxidation 326
 - esterification 339
 - etherification 339
 - hydration 336
 - isomerization 318
 - lubricants 68–78
 - microbial strain engineering 54–57
 - oxidation 319, 320, 337
 - polymers 60–68
 - sesquiterpenes as building blocks 58–60
 - α -terpineol 336
 - terpinolene oxide 340
 - tetrahydroxybenzene 221–223
 - thermal gravimetric analysis (TGA) 66, 67
 - thermal processes 6, 7, 248, 249, 338
 - thermodynamics 366–369
 - tin oxide catalyst 107
 - toluene, *see* benzene–toluene–xylene (BTX) process
 - Top Ten Value Added Chemicals from Biomass* (US DOE) 57, 58
 - 2004 Report 33, 35–39, 41, 42, 45, 46, 122
 - 2007 Report 122
 - 2010 Report 37, 38, 42
 - top-50 commodity chemicals (US) 352
 - torrefaction 249, 288, 289
 - total acid numbers (TAN) 17
 - Total Petrochemicals 197, 198
 - transesterification 372
 - transportation fuels 18
 - tri-block copolymers 386
 - triglycerides 169, 170
 - Triunfo Braskem plant 155, 156, 164
 - tubular fixed-bed reactors 285, 286
 - turpentine 319, 325–343
 - tyrosine ammonia lyases (TAL) 220
- u**
- Uhde technology 295, 297
 - United States (US)
 - 1993 Report 31
 - Billion-Ton study 185
 - Biological and Chemical Catalysts Technologies Program 32
 - *Biomass as Feedstock for a Bioenergy and Bioproducts Industry* 228
 - ethanol production 153
 - *Top Ten Value Added Chemicals from Biomass* 57, 58, 205
 - 2004 Top Ten Report 33, 35–39, 41, 42, 45, 46, 122
 - 2007 Top Ten Report 122
 - 2010 Top Ten Report 37, 38, 42
 - top-50 commodity chemicals 352
 - transportation fuels 18
 - upgrading of FT hydrocarbons 306, 307
 - urea 369, 371, 372
- v**
- vacuum gas oil (VGO) 131
 - valeric acid-based fuels 16–18
 - validation, target products 38–40
 - valine pathway 200, 201
 - value chain selection criteria 27–50
 - value-added processing
 - Lignol biorefinery process 253–266
 - organosolv biorefining 245–267
 - product selection criterion 46
 - Top listed chemicals 2004/2007 33, 35–39, 41, 42, 45, 46, 122
 - Van Krevelen diagrams 173, 174, 178, 180
 - vanadium phosphates 106
 - vanillic acid 217, 218
 - vanillin 217, 218, 222–225
 - vegetative biomass 10, 11, 14, 15, 245–267
 - Vennestrøm report 45
 - verbenol 319
 - verbenone 319, 335
 - vinyl carbamates 376
 - Virent Energy Systems 192–194, 198, 199
 - viscosity 74, 77
- w**
- waste streams 10, 11
 - water
 - *see also* aqueous...
 - electrolysis 381
 - removal, Braskem's ethanol dehydration 163
 - water gas reaction 379
 - water traps 369, 371
 - water-gas-shift reaction 291, 379
 - water-splitting 379
 - water-tolerant heterogeneous catalysts 103, 112
 - water-soluble bio-oil (WSBO) 196, 197
 - waxes 276
 - wood extractives 255, 317–344
 - wood processing 84, 85
 - woody biomass 10, 11, 14, 15, 245–267
 - workflow for process design 121–149

x

- XTL energy efficiency 310–312
- p*-xylene (PX)
 - *see also* benzene–toluene–xylene (BTX) process
 - biological oxidation to purified terephthalic acid 203, 204
 - from isobutanol/isobutylene 199, 200
 - purified terephthalic acid from 186, 199
 - xylene isomerization 185, 186

- xyloglucans 87, 90
- xylose 98–102, 205
 - D-xylose dehydration 104, 105

y

- yields 138, 175–177, 179, 186, 190, 192, 193, 195, 196, 199, 200, 202, 203, 210, 212

z

- zeolite catalysts 160, 192, 196, 197
- Ziegler catalysts 61