

Index

a

acid–base interactions 279
 adsorption–desorption isotherm
 78–84
 aerobic oxidations 143, 294
 alcohol dehydration 197, 198
 aldol condensation 1, 4, 12, 18, 38, 82,
 90, 91, 157, 212, 290, 292
 alkali earth metals 137
 alkali metal-loaded metal oxides 10, 11
 alkaline earth oxides 5–6
 Claisen–Schmidt reaction 37
 magnesium salt method 35–36
 mesoporous MgO 36–37
 MgO by sol–gel method 36
 MgO catalyst conventional method 35
 alkylation and isomerization reactions
 environmental and economic
 implications 193–195
 petrochemical processes 190–193
 alumina (Al₂O₃) 2, 10, 11, 19, 20, 28, 30,
 52, 57, 89, 100, 130, 142, 156, 157,
 169, 174, 181, 199, 320, 339
 alumina–calcium oxide (Al₂O₃–CaO) 28
 aluminophosphateoxynitrides (ALPON)
 14
 2-aminochromene synthesis 160
 anethole synthesis 19
 attenuated total reflection (ATR) 88
 autohydrolysis 110

b

Baeyer–Villiger oxidation 143, 144
 bamboo charcoal (BC) 63, 64
 Barrett–Joyner–Halenda (BJH) method
 78–83, 286
 base-catalyzed reactions 2, 5, 6, 9, 16, 20,
 34, 52, 53, 81, 89, 131, 170, 279, 305
 basis set superposition error (BSSE) 261
 benzaldehyde and cyclohexanone 31
 bifunctional iminophospharane (BIMP)
 138
 Biginelli multicomponent reaction 155
 Biginelli vs. Hantzsch reaction 162
 bimolecular reaction
 catalyst selection 183–184
 dialkyl carbonate synthesis 183
 industrial scale-up 184–185
 reaction pathway 183–184
 binary oxides 131
 biodiesel production 18–19, 294
 catalysts and mechanisms 175–176
 industrial-scale biodiesel production
 176–177
 transesterification reactions 174–175
 biomass conversion 210
 advanced solid catalysis
 synthesis method 103–105
 types 100–103
 building block chemicals 99
 composition, and properties 105–107

- biomass conversion (*contd.*)
 - high value-added chemicals
 - advantages of 118–119
 - design 116–118
 - electrocatalytic 113
 - solid catalysts 111–112
 - biomass feedstock, chemical composition 107–111
 - biomass utilization 116
 - bisphenol A (BPA) 303
 - Boudouard reaction 319, 320
 - Brønsted acid sites 112, 337
 - Brillouin zone 262
 - Bronsted base 91
 - Brunauer–Emmett–Teller (BET) 3, 78–83, 89, 250, 285
- C**
- calcined hydrotalcite (CHT) 90, 292
 - calcined metal phosphates 14–16
 - calcined water sludge (CWS) 31–32
 - Cannizzaro reaction 1
 - carbon-based catalysts 215, 216
 - carbon capture and sequestration (CCS) 259
 - carbon capture and utilization (CCU) 179, 187
 - carbon nanotubes (CNTs) 215, 339
 - carbon quantum dots (CQDs) 164
 - carbon-to-olefins (CTO) pathway 339
 - catalyst, defined 129
 - catalyst immobilization methods 255
 - catalyst regeneration 1, 31, 198
 - catalytic decomposition of ammonia 212
 - catalytic reactions 63, 136, 169, 195, 199, 208, 210, 216, 280, 298
 - catalytic systems 164, 185, 233, 240, 250, 252, 280, 301, 318, 320, 324–328, 333–338
 - charge-coupled device (CCD) 67
 - charge density
 - CO₂@interface 268–270
 - interfacial medium 268
 - Citrus sinensis peel ash (CSPA) 85, 86
 - Claisen condensation reaction 37
 - Claisen–Schmidt condensation 19, 30, 31, 300
 - Claisen–Schmidt reaction 37, 157, 290, 300
 - Claus reactions 141
 - clay minerals (hydrotalcite) 13–14, 136
 - clean fuel production 202, 203
 - climbing image-nudged elastic band (CI-NEB) method 262
 - CO₂ capturing and sequestration (CCS) 318
 - CO₂ emissions 317, 318, 343
 - CO₂ Fischer–Tropsch synthesis (CO₂-FTS) 341
 - CO₂ hydrogenation to dimethyl ether
 - mechanism 337
 - single-step catalysts 333–337
 - thermodynamics 332–333
 - CO₂ hydrogenation to light olefins
 - mechanism of 341–343
 - reverse water–gas shift (RWGS)
 - methanol mediated pathway 340–341
 - supported metal catalysts 339–340
 - transition metal catalysts 338–339
 - CO₂ hydrogenation to methane
 - catalytic system 324–328
 - methane synthesis catalyst 320
 - methanol synthesis
 - COOH pathway 331
 - HCOO pathway 329–331
 - RWGS+CO hydrogenation pathways 331–332
 - Ni/CeO₂–ZrO₂ catalyst 322
 - Ni/ZrO₂–C catalyst 323
 - reaction pathways 321–323
 - thermodynamics 319–320, 323–324
 - CO₂ methanation reaction 319, 330
 - CO₂ reduction reaction
 - charge transfer and charge density 268–272
 - computational methodology 261–262
 - electronic structure analysis 270–272
 - [EMIm-Z]⁺[SCN]⁻@Au(111) interface 267–268

- HCOOH 272
 heterogeneous catalysts 259–261
 interfacial charge transfer analysis 268–270
 ionic liquids interaction
 gas phase 262–264
 solid–liquid interface 264–265
 cold-plasma/peptide-assembly (CPPA) 327
 COOH pathway 329, 331
 coprecipitation method 4, 38, 39, 203–206, 239, 283, 292–294, 304
 corrosion-resistant 17
 counterpoise (CP) method 261
 COVID-19 pandemic 317
 Cu–ZnO catalyst system 325, 329, 330
 [2+3] cycloaddition reaction 246
 [3+2] cycloaddition reaction 235, 236, 240, 242, 244, 253–254
 cyclohexanone 10, 30, 31, 142, 143
- d**
 dehydration reaction 333–337
 alcohols to olefins 197–198
 of alkanes 199–200
 industrial significance 200
 and process optimization 200
 dehydrogenation reaction 9, 178–182, 216, 326
 deionized water 33, 35, 39, 55, 283
 density functional theory (DFT) 3, 216, 260, 305, 326
 density of states (DOS) 262, 270
 derivative with thermogravimetry (DTG) 74
 dialkyl carbonate 183, 184
 dielectric barrier discharge (DBD) 327
 differential scanning calorimetry (DSC) 288
 differential thermal analysis (DTA) 288
 dihydropyridine (DHP) 156, 160, 163
 dihydropyrimidinones (DHPMs) 155
 1,4-dihydroxyanthraquinone 242
 dimethyl carbonate (DMC) 3, 19, 138, 170, 183, 296, 299
- dimethyl ether (DME) 185, 187, 292, 318, 332–337
 double layered hydroxides (DLHs) 90, 159
 dry impregnation (DI) 104, 203, 204
- e**
 Eley–Rideal mechanism 329
 [EMIm-Z]⁺[DCA]⁻@Au(111) interface 265–267
 [EMIm-Z]⁺[SCN]⁻@Au(111) interface 267–268
 equilibrium composition 321
 ethyl acetoacetate (EAA) 135, 160, 297
 ethylene glycol monomethyl ether monolaurate (EGMEML) 78
- f**
 fatty acid ethyl esters (FAEE) 189, 294
 fatty acid methyl esters (FAMES) 111, 177, 189, 285, 289
 field emission scanning electron microscopes (FE-SEM) 62–66, 88, 244
 Fischer–Tropsch synthesis (FTS) 99, 292, 320, 338, 341
 flavanone synthesis 19
 flue gas 195–196, 210, 217, 259
 fluid catalytic cracking (FCC) 210, 211
 fossil fuel 116, 117, 185, 200, 217, 294, 295, 317, 343
 Fourier transform infrared (FTIR) 3, 56, 59–62, 240, 285, 286
 free fatty acid (FFA) 18, 21, 52
- g**
 γ -valerolactone (GVL) 112
 gas phase, ILs 262–264
 gas–solid reaction 14
 generalized gradient approximation-Perdew–Burke–Ernzerhof (GGA-PBE) 261
 Gewald multicomponent reaction 156
 Gibbs free energy 51, 97, 129
 glycerol carbonate (GLC) 132, 295–297, 301

- Gram-positive bacteria 250
green chemistry 18–20, 27, 113, 132, 182, 185, 195, 197, 199, 201, 213, 234, 256, 279, 290, 299–305
- h**
- HCOO pathway 329–331
HCOOH reaction 272, 274
Henry reaction 1, 157
heterocyclic compounds (HCs) 153, 234, 297
- Biginelli multicomponent reaction 155
Gewald multicomponent reaction 156
Hantzsch multicomponent reaction 156
Mannich multicomponent reaction 156
organic reactions 156–158
Passerini multicomponent reaction 156
solid base catalysts 158–159
Ugi multicomponent reaction 156
- heterogeneous catalysts
CO₂RR applications 259–261
tetrazoles 236–252
- heterogeneous solid-based catalysts 279
- hierarchical porous materials 215–217
- high value-added chemicals
advantages of 118–119
biomass conversion 107–111
electrocatalytic conversion 113–116
solid catalysts 111–112
- homogenous catalyst 51, 97, 233–235
- 4*H*-pyran synthesis 161
- hydrodesulfurization (HDS) 200–202
- hydrogenation and dehydrogenation reactions
catalytic mechanisms 181–182
hydrocarbons 180–181
hydrogenation of oils 179–181
- hydrogenation reaction 178, 212, 321, 325, 328, 329
- hydrotalcites (HTs) 13–14, 90
- base catalyst 143, 144
coprecipitation method 38–39
Michael addition 39
sol-gel method 39
- hydrothermal liquefaction (HTL) 108, 111
- hydrothermal method 207, 284, 298, 304
- 5-hydroxymethylfurfural (HMF) 300
- i**
- IL@Au(111) interface 266, 270–272
- IL@Au(111) liquid-solid interface model
[EMIm-Z]⁺[DCA]⁻@Au(111) interface 265–267
[EMIm-Z]⁺[SCN]⁻@Au(111) interface 267–268
- incipient wetness impregnation (IWI) 203
- infrared (IR) spectroscopy 56–59, 88, 90, 158
- interfacial charge transfer, CO₂@interface 268–270
- ionic liquids interaction
drawback 260
gas phase 262–264
solid-liquid interface 264–265
- iron-based catalysts 339, 341
- isoeugenol synthesis 19
- j**
- Jasmine aldehyde 290
- k**
- K₂O/Al₂O₃-CaO
catalytic activity of 28, 29
preparation of 28
- Knoevenagel condensation 4, 12–14, 17, 28–29, 39, 133, 135, 136, 159, 161, 163, 170, 193, 300, 301
- Knoevenagel reactions 4, 14, 158, 212
- l**
- lanthanum acetylacetonate 283
- layered double hydroxides (LDHs) 55, 281, 285

- Le-Chateliers principle 324
 levulinic acid 98, 111, 115
 Lewis base 4, 55, 162
 lignin 105
 lignin oxidative depolymerization 293
 lignocellulose biomass 109
 linear α -olefins (LAOs) 338
 liquefied petroleum gas (LPG) 186
 liquid chromatography mass spectrometry (LC-MS) 304
- m**
- machine learning algorithms 216
 magnesium carbonate hydrates (MCH) 90
 magnesium-doped ZnO 133
 magnetic core-shell nanoparticles (MNPs) 240
 magnetic nanoparticles (MNPs) 67, 237, 240, 244, 250
 Mannich multicomponent reaction 156
 Meerwein-Ponndorf reaction 157
 MeOH-to-olefins (MTO) reaction 340
 mesoporous materials 13, 80, 98, 101
 mesoporous MgO 36–37
 mesoporous polytriallylamine (MPTA) 141
 mesoporous silica nanostructure (MSN) 83
 metal oxides 131–134
 alkali metal-loaded metal 10–11
 alkaline earth oxides 5–6
 alumina 10
 mixed oxides 10
 rare earth oxides 7–9
 titanium oxides 9
 zinc oxide 9
 zirconium oxides 6–7
 methanation reaction 319, 320, 322, 323, 330
 methanol and dimethyl ether (DME) 185–187
 catalysts and reaction conditions 187
 technological advancements 187–188
 methanol dehydration reaction 338
 methanol-mediated pathway 340–341
 methanol synthesis
 COOH pathway 331
 HCOO pathway 329–331
 reaction 332
 RWGS+CO hydrogenation pathways 331–332
 methyl carbamate (MC) 299
 Mg–Al double layered hydroxide 90
 MgO by sol-gel method 36
 MgO catalyst conventional method 35
 Michael addition 1, 14, 39, 53, 90, 131, 135, 136, 140, 157, 159, 161, 162, 193, 298
 microporous materials 100, 102, 103
 mixed metal oxides (MMOs) 280–281
 catalytic applications
 environmental catalysis 303–304
 green chemistry 299–303
 industrially important reactions 290–297
 organic synthesis 297–299
 challenges and future scope 304–305
 characterization techniques 285–289
 synthesis aspect of 282–284
 mixed oxides, solid base catalysts 10, 282
 molybdenum-based catalyst 142
 monoethanolamine (MEA) 259
 Moseley's law 86
 multicomponent reactions (MCRs)
 Biginelli multicomponent reaction 155
 Gewald multicomponent reaction 156
 Hantzsch multicomponent reaction 156
 Mannich multicomponent reaction 156
 Passerini multicomponent reaction 156
 Ugi multicomponent reaction 156
 multi-walled carbon nanotubes (MWCNTs) 326

n

N-(2-aminoethyl)-3 aminopropyl-trimethoxysilane (AEAPS) 248
 NCS catalyst element composition 86
 Ni-based catalyst 319, 320
 4-nitroaniline (4-NA) 304
 4-nitrophenol (4-NP) 304
 Nitro-Mannich reaction 139
 nonrenewable energy resources 98
 nudged elastic band (NEB) 260, 262

o

olefins, dehydration reactions 197
 orange peel ash (OPA) 84, 86
 organic chemistry 154, 157, 255, 256
 organic reactions 2, 14, 90, 129, 131, 136, 138, 154, 156–159, 298
 organic synthesis
 applications in 297–299
 solid basic catalysts
 clays 136–137
 metal oxides 131–134
 solid-supported basic catalysts 137–144
 zeolites 134–136
 organo-clay 137
 oxidation reactions 141, 143, 193, 282, 294
 oxidative dehydrogenation (ODH) 303
 oxynitride 14

p

palladium-based catalysts 325
 Passerini multicomponent reaction 156
 perovskite-based MMOs (PBMMOs) 296
 peroxymonosulfate (PMS) 304
 petrochemical reactions 209
 photocatalysis 216, 217
 physical vapor deposition (PVD) method 207, 208
 phytosterol esters 20
 polybutylene terephthalate (PBT) 189
 polyethylene terephthalate (PET) 98, 114, 189

pore volume impregnation (PVI) 203
 potassium bromide (KBr) pellet 88
 potassium coated with mixed oxides (K_2O/Al_2O_3-CaO) 27
 power-to-gas (PtG) technologies 319
 projected density of states (PDOS) 262, 270
 pseudoionones 290
 pyrano [2,3&LWx02011;d] pyrimidinone 29–30

r

Raman spectroscopy 91, 286
 rare earth oxides 7–9, 32
 rate-determining step (RDS) 330, 337
 reverse water–gas shift (RWGS) reaction supported metal catalysts 339–340
 methanol-mediated pathway 340–341
 transition metal catalysts 338–339
 RWGS+ CO hydrogenation pathways 329, 331–332

s

Sabatier reaction 319
 scanning electron microscopy (SEM) 3, 58–59, 240, 241, 245, 254, 285, 289
 silica molybdcic acid (SMA) 241
 silica sulfuric acid 238
 silica-supported catalyst 236–256
 silica-supported heterogenous catalysts
 amine, triethyl orthoformate and azide 254–255
 Cu(II) immobilized catalyst 242
 [3+2] cycloaddition 253–254
 $Fe_3O_4@SiO_2@L$ -arginine 237
 $Fe_3O_4@SiO_2@L$ -histidine 244
 $Fe_3O_4@SiO_2/ligand/Cu(II)$ 239
 silica-supported melamine trisulfonic acid (SMTSA) 246
 silico–alumino–phosphate (SAPO) catalysts 340
 single-atom catalysts (SACs) 131, 215
 single metal oxides 131, 280, 294, 296

- sol-gel method 33, 36, 38, 39, 204–206, 283, 284, 293, 299
- solid-acid catalysts (SAC)
- advantages 17–18
 - challenges 20
 - disadvantages 18
 - fundamental constituents 2
 - in green chemistry 18–20
 - history 2–3
 - literary perspective of 3–4
 - scientific community 16–17
 - solid basic sites 4–5
 - types of
 - calcined metal phosphates 14–16
 - clay minerals (hydrotalcite) 13–14
 - mesoporous materials 13
 - metal oxides 5–11
 - oxynitride 14
 - zeolites 11–13
- solid-base catalyst synthesis
- advance characterization techniques
 - Brunauer–Emmett–Teller (BET) surface 78–83
 - field emission scanning electron microscopes (FE-SEM) 62–66
 - Fourier transform infrared spectroscopy (FT-IR) 59–62
 - thermogravimetric analysis (TGA) 73–78
 - transmission electron microscope (TEM) 66–68
 - X-ray diffraction analysis (XRD) 68–72
 - X-ray fluorescence (XRF) 85–87
 - X-ray photoelectron spectroscopy (XPS) 83–85
 - advantages and disadvantages 40–41
 - alkaline earth oxides 34–37
 - alkylation and isomerization reactions
 - environmental and economic implications 193–195
 - petrochemical processes 190–193
 - basic sites characterization 89–91
 - benefits of 129–130, 169
- biodiesel production
- advantages of 174
 - catalysts and mechanisms 175–176
 - industrial-scale 176–177
 - transesterification reactions 174–175
- bimolecular reactions
- catalyst selection 183–184
 - dialkyl carbonate synthesis 183
 - industrial scale-up 184–185
 - reaction pathways 183–184
- calcined water sludge 31–32
- catalyst protocol, XRD 87–88
- characteristics 130–131, 169–170
- comparison with 171
- current challenges
 - emerging technologies and materials 215–216
 - sustainable industrial catalysis 216
- definition 169–170
- dehydration reactions
 - alcohols to olefins 197–198
 - of alkanes 199–200
 - industrial significance 200
 - process optimization 200
- environmental applications 195
- NO_x reduction in catalytic converters 196
 - sulfur removal from flue gas 195
 - waste remediation and pollution control 196
- heterocyclic compounds 159–164
- hydrogenation and dehydrogenation reactions 178–182
- hydrotalcite
 - coprecipitation method 38–39
 - Michael addition 39
 - sol-gel method 39
- industrial catalysis 171–173
- industry applications 53
- K₂O/Al₂O₃-CaO 27–30
- MCRs 159–164
- methanol and DME synthesis 185–188

- nanoscale magnetic 91
 - organic reactions for 157–158
 - processing methods
 - hydrothermal process 206–207
 - impregnation method 203
 - precipitation and coprecipitation method 203–204
 - sol–gel method 204–206
 - vapour phase deposition method 207–208
 - processing procedure 209
 - rare earth oxides 32
 - research and development 217
 - socioeconomic impact 213–214
 - solid base fly ash
 - benzaldehyde and cyclohexanone 31
 - catalyst regeneration 31
 - catalytic activity 30
 - synthesis 30
 - sulfur removal in fuel refining
 - clean fuel production 202
 - hydrodesulfurization catalysis 201
 - sulfur removal mechanisms 202
 - titanium dioxide 33–34
 - traditional characterization techniques
 - scanning electron microscopes 58–59
 - titration method 55–56
 - transesterification of esters
 - catalysts for 190
 - chemical and petrochemical industries 188–190
 - various industries
 - Aldol condensation and Knoevenagel reactions 212
 - biodiesel production 209
 - biomass conversion 210
 - catalytic cracking 210
 - catalytic decomposition of ammonia 212
 - environmental applications 210
 - hydrogenation reactions 212
 - petrochemical industries 209–210
 - water treatment 210–212
 - zinc oxide 34
 - solid base fly ash (SBFA)
 - benzaldehyde and cyclohexanone 31
 - catalytic activity of 30
 - catalyst regeneration 31
 - physiochemical properties 61
 - synthesis 30
 - organic synthesis
 - clays 136–137
 - metal oxides 131–134
 - solid-supported basic catalysts 137–144
 - zeolites 134–136
 - solid basic sites 4–5
 - solid catalysis
 - high value-added chemicals 111–112
 - impregnation method 104
 - nickel sponge/skeletal catalyst 103
 - precipitation method 103–104
 - zeolization 104–105
 - solid–liquid interface 261, 264–268, 270, 273, 274
 - spinel oxides 131
 - Staudinger reaction 139
 - Styrene divinylbenzene sulfonated copolymer 102
 - styrene oxide 292, 293
 - sulfonated polymers 98, 100–102
 - sulfuric acid-modified aluminosilicate (SMA) 241
 - sulfur removal mechanism
 - clean fuel production 202
 - hydrodesulfurization (HDS) catalysis 201–202
 - supported metal catalysts 100, 234, 339–340
 - sustainable technology 300
- t**
- TEM with energy-dispersive X-ray spectroscopy (TEM-EDS) 67

- temperature programmed desorption (TPD) 3, 158, 288
- temperature programmed reduction (TPR) 288
- tetrazoles
- [3+2] cycloaddition reaction 236
 - derivatives 297
 - homogenous and heterogenous catalyst 233
 - nitrogen-rich nature of 235
 - one-pot multicomponent reaction 235
 - silica-supported heterogenous catalysts
 - amine, triethyl orthoformate and azide 253
 - Cu(II) immobilized catalyst 242
 - [3+2] cycloaddition 253–254
 - Fe₃O₄@SiO₂@L-histidine 245
 - Fe₃O₄@SiO₂@L-arginine 237
 - Fe₃O₄@SiO₂/ligand/Cu(II) 239
 - synthetic protocol 234–236
 - synthetic techniques 233
- thermal conductivity detector (TCD) 80
- thermal stability 74–76, 78, 236, 279, 288, 289, 296
- thermodynamic equilibrium 51, 129, 134, 188, 279, 334
- thermodynamics, CO₂ hydrogenation
- to DME 332–333
 - to methane 319–320
- thermogravimetric analysis (TGA) 3, 73–78, 89, 240, 251, 285, 288
- thermogravimetric analyzer 75, 76
- titanium dioxide 9, 33–34, 102
- titanium oxides 9, 33, 34
- titration method 55–56
- transesterification of esters 188–190
- transesterification reaction 4, 19, 20, 59, 74, 75, 89, 91, 137, 138, 140, 174–177, 184, 188–190, 294, 296, 301
- transition metal catalysts 338–339
- transition metal oxides 100, 101, 303, 325
- transmission electron microscopy (TEM) 3, 66, 88, 107, 238, 240, 285, 289
- K/ZrO₂/g-Fe₂O₃ nano-magnetic catalyst 69
- triethyl orthoformate 235, 238–240, 253, 254
- triglycerides 19, 56, 105, 111, 171, 174–176, 189, 190, 209, 211, 285
- 2,4,6 tri-nitrophenol (2,4,6-NP) 304
- U**
- Ugi multicomponent reaction 156
 - UiO-66-NH₂ catalyst 139, 140
- V**
- van der Waals (vdWs) interactions 266
 - vanillin 293, 294, 300
 - vapor phase deposition method 207, 208
 - Vienna Ab-initio Simulation Program (VASP) 261
 - volatile organic compounds (VOCs) 30, 210, 303
- W**
- Wadsworth–Emmons reaction 133
 - water–gas shift (WGS) reaction 280
 - wet impregnation (WI) 104, 203, 204, 246, 284, 295
 - Wittig reaction 1
- X**
- X-ray diffraction (XRD) 3, 68–72, 87, 100, 240, 285, 286, 339
 - X-ray fluorescence (XRF) 85–87, 107
 - X-ray photoelectron spectroscopy (XPS) 3, 83–85, 158, 247, 285, 287
 - X-ray scattering 69, 107
- Y**
- yttria-stabilized zirconia (YSZ) 320

Z

zeolites 3, 4, 11–13, 19, 21, 30, 98, 100,
103, 104, 112, 130, 134–136, 143,
170, 174, 187, 195, 198, 199, 209,
210, 234, 280, 281, 334–337, 339,
340

zinc oxide 9, 34

zirconium oxides 6–7

Zr-based catalyst 140

