

Index

Note: Page numbers in *italics* and **bold** refers to figures and tables respectively.

a

- aberration-corrected high-angle
 - annular dark-field scanning transmission electron microscopy (AC-HAADF-STEM) 342
- acidic media, FF oxidation reaction
 - pathways in 324, 325
- adsorbate evolution mechanism (AEM) 344
- adsorption energetics 36
- alcohol-assisted electrolysis 96, 99
 - electrocatalytic performance in 100–105
- alcohol-assisted hydrogen evolution
 - reactions (AAHERs) 83
- alcohol-assisted water electrolysis (AAWE) 25, 26, 48, 82–83
 - adsorbate-driven effects and selectivity drift 33–34
 - assessing stability in hybrid electrolysis 34
 - background and scope 25–27
 - catalytic roles in 29–31
 - challenges 41–44
 - comparative summary of carbides vs. nitrides 40–41, **42**
 - defects, vacancies, and stability–activity trade-offs 34
 - design implications 35
 - electrode-level stability 34
 - engineering strategies to enhance performance 37–40
 - ethanol-assisted hydrogen production 51, 52
 - fundamentals of 49, 50
 - glycerol-assisted hydrogen production 52–53
 - integration of SAECs into 63–66
 - intrinsic properties governing electrocatalytic activity 27–29
 - methanol-assisted hydrogen production 50–51
 - oxidation, corrosion, and conductive-core/active-shell picture 33
 - propanol-assisted hydrogen production 52
 - surface dynamics and stability under operating conditions 31
 - surface reconstruction as activation and degradation 32–33
- alcohol electrooxidation, metal alloys
 - for 83–87, 84, **87–88**
- alcohol oxidation
 - adsorption energetics as selectivity lever 36
 - elementary steps and pathway competition 35–36
 - multicomponent carbides and nitrides in selectivity tuning 37
 - poisoning, carbon balance, and long-term selectivity 36–37
 - reaction pathways and product selectivity in 35

- alcohol oxidation (*Cont.*)
 - selectivity metrics and benchmarking 37
 - surface oxygenated species and reconstructed states 36
- alcohol oxidation reaction (AOR)
 - 99–100, 107, 250
 - borides and selenides as anodic catalysts 112–114
 - ethanol oxidation 107–108, 108
 - glycerol oxidation 109–111, 111
 - methanol oxidation 108–109, 109
 - overall electrolysis performance 116
 - selectivity and product distribution 114–116
- alkaline–alkaline architectures 143
- alkaline hydrogen evolution 26
- alkaline/neutral media, FF oxidation
 - reaction pathways in 324–325
- alkaline water electrolyzer (AWE) 81, 249
- amorphous borides 235
- anion exchange membrane (AEM) 81
- anodic oxidation reaction (AOR) 4, 25, 30–31
- anodic reaction space 9–13
- atomically thin materials (ATMs) 54, 55–56
- atomic layer deposition (ALD) 58–59, 340–341, 341
- b**
- benchmarking
 - device-level benchmarking 143–144
 - during engineering optimization 40
 - selectivity metrics and 37
- bifunctional CoNiP nanosheet-integrated electrode (CoNiP-NIE) 320
- bifunctional electrocatalyst 373
- bifunctional mechanism 85
- bimetallic systems, synergistic effects in 104–105
- biomass 314
- biomass-derived substrates 12, 15
- borides
 - as anodic catalysts 112–114
 - challenges and future perspective 116–117
 - HER activity of borides 101–102
 - bottom-up methods 58–62, 60
 - Brunauer–Emmett–Teller (BET) 180
 - Butler–Volmer (BV) equation 202
- c**
- carbides 31
 - comparative summary of carbides vs. nitrides 40–41, 42
 - surface evolution under hybrid electrolysis conditions 32
- carbon balance 37
- carbon-based oxidation strategies 11
- carbon oxidation 7
- carbon nanotubes (CNTs) 196
- carbon nitride (CN) 55
- catalytic roles in alcohol-assisted electrolysis systems 29–31
- cathode evolution reaction 3, 7–9
- Ce-doped cobalt phosphide (Ce–Co₂P) nanoparticles 321
- chemical bath deposition (CBD) 238
- chemically assisted hydrogen evolution reaction (CAHER) 82
- chemical vapor deposition (CVD) 193, 238, 299
- chronoamperometry 156
- chronopotentiometry 156
- cobalt-based catalysts 158–159, 159, 160
- cobalt–nickel foam (CNF) 377
- cobalt phosphide (CoP) 169
- CoFe-MOF-74@MWCNTs catalyst 376
- commercialization strategies 406–408
- composite engineering 193
- conduction band (CB) 239
- conventional alkaline 25
- conventional OER-based systems 368
- conventional water electrolysis 7
- copper–nickel nitride (Cu₁Ni₂–N) 209
- coprecipitation 62
- cyclic voltammetry (CV) 181, 202
- d**
- deep eutectic solvent (DES) 320, 374
- defect engineering 34, 39, 193
- density functional theory (DFT) 185, 201, 233, 254, 298

density of states (DOS) 193
 device-level benchmarking 143–144
 dihydroxyacetone (DHA) 128
 direct hydrazine fuel cell (DHFC) 192

e

electrification with diverse sources 402
 electrocatalysts 222. *see also* non-oxide
 electrocatalysts; single-atom
 electrocatalysts (SAECs)
 for FOR and opportunities for
 SACs 349–350
 MCNs as 297–298
 metal phosphides 319–321
 metal sulphides 321–323
 electrocatalytic activity, intrinsic properties
 governing 27–29
 electrocatalytic performance
 in alcohol-assisted electrolysis 100–105
 for FF compounds oxidation
 317–323, 318
 electrocatalytic reactions of model
 systems 389
 electrocatalytic systems 401
 electrocatalyzed reactions 395
 electrochemical active surface area
 (ECSA) 181, 203, 278
 electrochemical alcohol oxidation 107
 electrochemical impedance spectroscopy
 (EIS) 181, 201
 electrochemical reactions 97–100
 electrochemical synergy between FOR and
 HER 326
 electrochemical synthesis
 techniques 274–275
 electrodeposition method 59–60, 238
 electrodes
 architecture and transport 40
 conductive scaffolds and self-supported
 electrodes 40
 electrolyzer
 component manufacturing
 404–405, 404
 design 403–404, 403
 lab-to-plant divide in 388–393, 389,
 390–391

electronic metal–support interactions
 (EMSI) 207
 electrooxidation 347
 of furfural 348
 metal alloys for alcohol 83
 reactions and stability issues, SACs
 advantages for 342–343
 energy dispersive X-ray spectroscopy
 (EDS) 277
 energy-saving hybrid water electrolysis 388
 component manufacturing
 404–405, 404
 dynamic operations and advanced
 controls 405–406, 405
 electrification with diverse sources 402
 electrolyzer design 403–404, 403
 future research direction and
 commercialization strategies 406–408
 key performance indicators 393–397
 lab-to-plant divide in electrolyzers
 388–393, 389, **390–391**
 mild operation conditions 401
 oxidation and reduction processes,
 integration of 398–399, 399, **400**, 401
 process consideration 397, 398
 scale-up considerations 402, 402
 simpler and safer operation 401–402
 engineering, procurement, and construction
 (EPC) 249
 engineering strategies
 benchmarking during engineering
 optimization 40
 conductive scaffolds and self-supported
 electrodes 40
 defect and vacancy engineering 39
 electrode architecture and transport 40
 heteroatom doping 39
 heterostructures and interfaces 40
 morphology and surface termination
 control 39
 multicomponent carbides and
 nitrides 39
 nanostructuring and hierarchical
 porosity 38
 performance enhancement in
 alcohol-assisted electrolysis 37, 38

ethanol oxidation, alcohol oxidation
 reaction mechanism of 107–108, 108
 European Chemicals Agency (ECHA) 234
 extended X-ray absorption fine structure
 (EXAFS) 342

f

faradaic efficiency (FE) 6, 47, 155–156
 feedstock realism 18
 flow electrolyzers 392
 furfural (FF) 314, 316
 in acidic media 324, 325
 in alkaline/neutral media 324–325
 electrocatalysts for FOR and
 opportunities for SACs 349–350
 electrocatalytic performance for
 317–323, 318
 electrochemical synergy between FOR
 and HER 326
 oxidation and SACs 347
 oxidation pathways and products
 of 347–349, 348
 oxidation reaction, pathways of 324
 furfural-assisted water electrolysis
 challenges and prospects 327
 electrocatalytic performance for FF
 compounds oxidation and HER
 317–323, 318
 metal phosphides electrocatalysts
 for 319–321
 metal sulfides electrocatalysts for 321–323
 pathways of FF oxidation
 reaction 324–326
 transition-metal-based catalysts,
 importance of 315–317, 316
 furfural oxidation reaction (FOR) 294,
 303–304, 347
 coupling furfural oxidation with
 HER 305–306, 305
 electrocatalysts and opportunities for
 SACs 349–350
 electrochemical synergy between HER
 and 326
 Ni-, Mo- and Co-based carbides/nitrides,
 furfural valorization 304
 selectivity control and product
 distribution 304–305

g

Gibbs free energy of hydrogen adsorption 28
 glucose-oxidation coupled water
 electrolysis
 future perspectives 380
 importance of 367–370, 369
 non-oxide electrocatalysts 370–379, 371,
 373, 375–376, 378–379
 glucose oxidation reaction (GOR) 366
 glyceraldehyde (GLAD) 128
 glyceric acid 128
 glycerol 128
 glycerol oxidation
 alcohol oxidation reaction mechanism
 of 109–111, 111
 alkaline–alkaline and hybrid
 alkali–acid architectures 143
 degradation modes 141–142
 device-level benchmarking 143–144
 durability, poisoning, and hybrid
 electrolyzer architectures 140, 141
 future directions 146–147
 in hybrid electrolysis 129
 key techniques 144–146
 non-oxide electrocatalyst families and
 design strategies for 132–135
 vs. OER and within glycerol
 network 139–140
 operando characterization and future
 directions 144, 145
 from operando data to design rules 146
 performance metrics for glycerol-assisted
 electrolysis 131–132
 reaction network 130, 131
 strategies for durability and poisoning
 resistance 142
 thermodynamic comparison of OER and
 glycerol oxidation 130
 glycerol oxidation-coupled water electrolysis
 active phase and in situ
 reconstruction 136
 activity and selectivity tuning on
 non-oxide surfaces 136
 activity descriptors 136–139, **137–138**
 comparative overview under glycerol
 oxidation conditions 132–135, 133, **134**
 consolidated design rules 140

- design motifs across non-oxide families 135
- families and design strategies for glycerol oxidation 132
- non-oxide electrocatalysts for 127–129, 370–379
- selectivity 139–140
- glycerol oxidation reaction (GEOR) 250
- graphene-based oxide membrane (GOM) 63
- h**
- heteroatom doping strategy 39, 193, 238
- heterostructures engineering 276–278, 277
- hierarchical nanostructures 193
- high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) 279
- high-entropy alloy nanoclusters (HEANCs) 226–227
- high-entropy alloys (HEAs) 86, 222, 226
- high-entropy selenides (HESes) 113
- highest occupied molecular orbital (HOMO) 226
- high-resolution transmission electron microscopy (HRTEM) 179, 277
- hybrid alkali–acid architectures 143
- hybrid electrolysis 387
 - assessing stability in 34
 - glycerol oxidation in 129–132
- hybrid electrolyzer 405
 - catalyst-level considerations and SAC challenges 351–353
 - configuration, integration, and challenges of using SACs 350–353, 350
 - selectivity–current density trade-offs 353
 - system-level considerations 350–351
- hybrid water electrolysis 4, 4, 82, 127
 - advantages beyond voltage 13, 13
 - anodic reaction space and substrate selection 9–13
 - challenges 16–19
 - concept and scope 3–7
 - coproduction 14
 - energy reduction in hybrid electrolysis 6
 - hybrid water electrolysis/value-added electrolysis 293–294
 - interdependence of advantages 16
 - role of system-level metrics 16
 - safety and operational flexibility 14–15
 - sustainability and circularity 15–16
 - thermodynamic and kinetic basis for energy reduction 7–9
- hybrid WE systems 256–261, 257, **259–260**
- hydrazine-assisted HER 154
 - applications 156–159
 - catalytic performance, parameter estimation 154–155
 - cobalt-based catalysts 158–159, 159, 160
 - exchange current density and Tafel slope 155
 - nickel-based catalysts 156–158, 157, 158
 - stability 156
 - turnover frequency (TOF) 155–156
- hydrazine-assisted water electrolysis (Hz-WE) 231–232
 - challenges and future prospects 241–242
 - fundamentals of 170–171, 232–234, 233
 - metal alloy electrocatalysts 221–227
 - metal borides 234–236
 - metal carbides and nitrides electrocatalysts 191–213
 - metal phosphides electrocatalysts 167–185
 - metal selenides 237–240
 - metal sulfide electrocatalysts 153–161
 - single-atom electrocatalysts 249–262
- hydrazine oxidation 154
- hydrazine oxidation reaction (HzOR) 154, 167, 191, 231, 250
- hydrocarbon reforming method 47
- hydrofluoric acid (HF) 196
- hydrogen 95–96, 153–154, 167–168, 313–314
- hydrogen atom transfer (HAT) mechanism 115
- hydrogen evolution reaction (HER) 3–4, 25, 30, 47–48, 88, 97, 127, 153, 168, 191, 221, 232, 249, 271, 317–323, 318
 - activity of borides 101–102
 - activity of selenides 102–104
 - electrochemical synergy between FOR and 326
 - mechanism of 98
 - metal alloys for 88–89

hydrogen evolution reaction (HER) (*Cont.*)
 onset potential in 105–106
 overpotential in 106–107
 schematic of 106
 significance of 100–101
 Tafel slope in 105
 hydrothermal method 274–275
 hydrothermal/solvothermal synthesis 237
 5-hydroxymethylfurfural (HMF) 252

i

inductively coupled plasma (ICP)
 techniques 180
 inverse fast Fourier transform (IFFT) 279
 ion catalysts 257
 ionomers 17
 iron phosphide (FeP) 169
 iron phosphide films (Fe₂P) 374

k

key performance indicators 393
 energy consumption and efficiency
 396–397, 397
 normalized reaction rates 394–396, 395

l

Langmuir–Hinshelwood (LH) 256
 lattice oxygen mechanism (LOM) 344
 layered double hydroxide (LDH) 57, 96
 linear sweep voltammetry (LSV) 155,
 181, 202

m

manganese-doped nickel phosphide catalyst
 (Mn-5Ni₂P) 321
 membrane–electrode assembly (MEA) 351
 membrane electrolyzers 9
 metal alloy
 for alcohol electrooxidation 83–87,
 84, 87–88
 electrocatalysts 221–227
 for hydrogen evolution reaction 88–89
 metal borides
 challenges and future prospects 241–242
 chemistry and structure of 234–236
 compositional control, synthesis
 of 235–236
 electrocatalytic behavior in Hz-WE 236

structural features and stability 234–235
 metal carbides
 hydrazine-assisted water
 electrocatalysis 204–208, 206, 208
 structure and properties of 194–198,
 195, 197
 metal carbides and nitrides (MCNs) 96,
 191–194, 192, 293–294
 carbothermal reduction and nitridation
 methods 299
 challenges and future perspectives 306
 electrocatalysts 297–298
 electrocatalysts for alcohol-assisted water
 electrolysis 25–44
 electrochemical active surface area 203
 electrochemical impedance 203
 for FOR 303–306, 305
 fuel cells 200–201, 200
 hydrogen production 198–200
 measurement criteria for HzOR
 202–203
 metal carbides 204–208, 206, 208
 metal nitrides 209–212
 overpotential 202
 phase control, morphology and scalability
 challenges 301–302
 physicochemical properties 297
 plasma-enhanced and CVD
 techniques 300–301, 301
 sol–gel and hydrothermal
 approaches 300
 stability 203
 stability and corrosion resistance 298
 structure–activity relationship
 principles 298
 structure and properties of 194–198,
 195, 197
 synthesis and strategies 299–302, 299
 Tafel slope 202–203
 template-assisted synthesis 300
 transition metals 297–298
 for UOR 302–303
 urea and furfural-assisted water
 electrolysis 294–297
 metal nitrides
 hydrazine-assisted water
 electrolysis 209–212

- structure and properties of 194–198, 195, 197
 - metal–organic frameworks (MOFs) 175, 282–285, 341
 - metal phosphides 315
 - metal phosphides electrocatalysts 167–169, 168
 - characterization techniques 177–181
 - electrochemical performance evaluation 181–183
 - for FF-assisted water electrolysis 319–321
 - fundamentals of 170–171, 171
 - inductively coupled plasma (ICP) techniques 180
 - post-characterization techniques 183–184
 - study of surface area, porosity and active sites 180–181
 - transition-metal phosphides 171–177
 - transmission electron microscopy (TEM) 178, 179
 - X-ray diffraction (XRD) 178–179, 178
 - X-ray photoelectron spectroscopy (XPS) 178, 179–180
 - metal selenides
 - challenges and future prospects 241–242
 - chemistry and structure 237–240
 - electrocatalytic behavior in Hz-WE 238–240, 240
 - structural features and stability 237
 - synthesis and compositional control 237–238
 - metal sulfide electrocatalysts
 - catalytic performance, parameter estimation 154–155
 - cobalt-based catalysts 158–159, 159, 160
 - design and mechanism 160–161
 - exchange current density and Tafel slope 155
 - for FF-assisted water electrolysis 321–323
 - hydrazine-assisted HER 154–159
 - nickel-based catalysts 156–158, 157, 158
 - stability 156
 - turnover frequency (TOF) 155–156
 - metal sulfides 315
 - metal sulfides and phosphides
 - electrocatalysts 271–272
 - bimetallic integration and controlled doping 280–282, 281, 283
 - compositional modulation and synergistic effects 280–282, 281, 283
 - conductivity phases and controlled morphology 279–280, 280
 - electrochemical synthesis techniques 274–275
 - heterostructures engineering 276–278, 277
 - hybrid architectures and MOF-derived platforms 282–285, 284
 - hydrothermal and solvothermal methods 274–275
 - integrated techniques 274–275
 - morphological and interface engineering 276–280
 - structural and catalytic performances 275–285, 276
 - structure–performance relationship 285, **286–287**
 - synthesis of 274–275
 - UOR mechanism, alkaline media 272–273
 - methanol oxidation, alcohol oxidation
 - reaction mechanism of 108–109, 109
 - methanol oxidation reaction (MOR) 238
 - mitigation strategies 142
 - molybdenum carbide (Mo_2C) 297, 302
 - molybdenum carbide–nitrogen-doped carbon ($\text{MoC}_x\text{-NC}$) 204
 - multicomponent carbides and nitrides 39
 - MXene 195–196, 195, 205–207
- n**
- nanochain-like network (NCN) 226
 - nanomaterial-based SACs (NM-SACs) 55
 - nanoparticle (NP) 48, 251
 - N-doped carbon (NC) 254
 - nickel-based catalysts 156–158, 157, 158
 - nickel/iron-layered double hydroxide (NiFe-LDH) 372
 - nickel–phosphorus (Ni–P) catalyst 320

nickel–phytic acid (Ni–PA) hybrid catalyst 321
 nitrides 31
 comparative summary of carbides vs. nitrides 40–41, **42**
 surface evolution under hybrid electrolysis conditions 32
 nitrogen-containing substrates 12
 non-oxide electrocatalysts 366
 for glycerol oxidation-coupled water electrolysis 128–140, 365–370
 performance evaluation using 370–379, 371, 373, 375–376, 378–379
 non-precious metal catalysts 114–115
 normalized reaction rates 394–396, **395**

O

Occupational Safety and Health Administration (OSHA) 261
 operando and in situ methods 144
 overall hydrazine-splitting (OH₂S) 223, 233
 oxidation processes, integration of 398–399, 399, **400**, 401
 oxygen evolution reaction (OER) 3, 25, 47–48, 97, 127, 153, 167, 191, 221, 231, 249, 271, 337, 365
 glycerol oxidation vs., 139–140
 mechanism of 97–98
 thermodynamic comparison of glycerol oxidation and 130
 oxygen reduction reaction (ORR) 54, 113, 193, 254, 297

P

phosphorized yolk–shell spherical structures of CoNi₂S₄ (P–CoNi₂S₄ YSSs) 279–280, 280
 physical vapor deposition (PVD) 196
 plasma-enhanced chemical vapor deposition (PECVD) 301
 platinum group metals (PGMs) 225
 porous nanosheet arrays (PNAs) 210
 post-characterization techniques 183–184
 projected density of states (PDOS) 223
 proton exchange membrane (PEM) 81

proton-exchange-membrane electrolyzers 25
 proton-exchange-membrane water electrolyzers (PEMWEs) 249
 pulsed laser ablation in liquid (PLAL) 193
 pulsed laser deposition (PLD) 196
 pyrolysis-assisted method 60–61

R

rate-determining step (RDS) 155, 370
 reactive oxygen species (ROS) 48, 82
 reduction processes, integration of 398–399, 399, **400**, 401
 reversible hydrogen electrode (RHE) 168
 ruthenium phosphide (RuP) 181

S

SACs@ATMs 55–58, 56
 scanning electron microscopy (SEM) 277
 selected-area electron diffraction (SAED) 179
 selectivity–current density trade-offs 353
 selenides
 as anodic catalysts 112–114
 challenges and future perspective 116–117
 HER activity of selenides 102–104
 selenium 237
 self-powered hydrogen production system 204–205
 single-atom (SA) 196
 single-atom catalysts (SACs) 48–49, 193, 241, 250, 251–256, 252–254, 338
 advantages for electrooxidation reactions and stability issues 342–343
 definition and features of 338–340, 339
 UOR and 343–347
 WE coupled hydrazine oxidation 261–262
 single-atom electrocatalysts (SAECs) 53, 249–251, 250
 bottom-up methods 58–62
 challenges and perspectives 67–69
 characterization techniques 341–342
 concept and design principles 53–54
 definition and features of SACs 338–340, 339

- fundamentals of 338
 - HzOR 256–261, 257, **259–260**
 - integration of SAECs into AAWE 63–66
 - NM-SACs 54–55
 - SACs 251–256, 252–254
 - SACs@ATMs 55–58, 56
 - synthesis methods 340–341, 341
 - synthesis strategies of 58
 - top-down method 62–63
 - WE coupled hydrazine
 - oxidation 261–262
 - solid oxide electrolyzer cell (SOEC) 81
 - solid-state metathesis (SSM) 235
 - solvothermal techniques 274
 - stability–activity trade-offs 34
 - stability of catalytic activity 156
 - stainless-steel mesh (SSM) 374
 - standard hydrogen electrode (SHE) 272
 - steam methane reforming (SMR) 221
 - strong metal–support interactions (SMSI) 193
 - structure–activity relationships (SARs) 298
 - substrate selection 9–13, **10**
 - sulfur-modulated nickel/carbon composite catalyst (S–Ni@C) 322
- t**
- Tafel slope 105, 155
 - tartronic acid 128
 - thermal atomization method 62
 - top-down method 62–63
 - transition-metal alloys 89
 - transition-metal-based catalysts
 - 315–317, 316
 - transition-metal carbides (TMCs) 294
 - transition-metal dichalcogenides (TMDs) 195
 - transition-metal nitrides (TMNs) 294
 - transition-metal oxides (TMOs) 279
 - transition-metal phosphides (TMPs) 96, 171, 272, 366
 - CO₂ laser-assisted method 175, 176
 - crystal structure and classification 171–172, **172**
 - direct solid-state reaction 175–176, 175
 - electrochemical in situ phosphidation 175, 177
 - electronic structure and conductivity 172–173
 - hydrothermal phosphidation 175, 176
 - metal hydroxide/metal oxide precursors 174–175, 175
 - relevance to electrocatalysis 173–174
 - structure, electronic properties and relevance to electrocatalysis 171–174
 - synthesis strategies 174–177
 - template/MOF-derived methods 175, 176–177
 - transition-metal selenides 237
 - transition-metal sulfides (TMSs) 154, 272
 - transmission electron microscopy (TEM) 178, 179, 279
 - tungsten carbide (WC) 297
 - turnover frequency (TOF) 155–156, 183, 207
 - two-dimensional transitionmetal dichalcogenides (2D-TMDs) 154
- u**
- urea and furfural-assisted water electrolysis
 - comparison with OER 296
 - FOR 295–296, 295
 - sustainable hydrogen generation and chemical coproduction 296, 297
 - thermodynamics and kinetics of UOR 294–295, 295
 - urea-assisted water electrolysis
 - mechanism involving UOR in alkaline media 272–273
 - metal sulfides and phosphides electrocatalysts 271
 - structural and catalytic performances 275–285, **286–287**
 - synthesis of sulfides and phosphides-based electrocatalysts 274–275
 - urea-containing wastewater 15
 - urea oxidation reaction (UOR) 238, 272, 294, 343
 - iron, cobalt and nickel carbides/nitrides 302–303
 - mechanisms, kinetics, and energy advantages compared to OER 343–345, 344

urea oxidation reaction (UOR) (*Cont.*)
 mixed-metal carbides and nitrides
 (MMCs/MMNs) 303
 molybdenum and tungsten carbides/
 nitrides 302
 reaction mechanism insights and
 performance benchmarks 303
 SACs for 345–347
 US Environmental Protection Agency
 (EPA) 234

V

vacancy engineering 34, 39
 vacancy-trapping technique 205, 206
 valence band (VB) 240
 vanadium-doped nickel nitride
 (V-Ni₃N) 209
 van der Waals forces 154
 vapor-phase hydrothermal (VPH) 156
 Volmer–Heyrovsky (VH)
 mechanism 155, 198
 Volmer–Tafel (VT) mechanism 155, 198

W

waste-derived substrates 12
 water electrolysis (WE) 47, 96, 127,
 249, 367
 alcohol-assisted water electrolysis 82–83
 conventional 128
 fundamentals of 81–82
 hybrid 82
 thermodynamic equilibrium potentials
 for 83
 water-splitting-assisted electrocatalysis
 (WSE) 376
 wet-chemical synthesis 61–62
 work function (WF) 240

X

X–M–X formula 154
 X-ray absorption spectroscopy (XAS) 342
 X-ray diffraction (XRD) 178–179, 178
 X-ray photoelectron spectroscopy
 (XPS) 178, 179–180, 277, 342