

INDEX

- Absolute pressure, 30
- Absolute temperature, 31, 381, 133, 180
- Absorption, photovoltaic effect, 132
- Ac, *see* Alternate current (Ac)
- ACCEL Instruments GmbH, 288
- Access, for turbine site, 95
- Accumulation reservoirs, hydroelectric plants, 58
- Acetates, 206
- Acetogenic bacteria, 206
- Acidogenic bacteria, 206
- Acid rain, 56
- Active power, induction generators, 246, 248, 306–310, 319, 324
- Active solar heating, 56
- Active stall control, wind turbines, 105
- Actuators, 250
- Adiabatic process:
 - defined, 35
 - reversible compression, 38
 - reversible expansion, 38
- Aerodynamics, 109
- AFC, *see* Alkaline fuel cells (AFCs)
- Agricultural feedstocks, 200
- Agricultural residues, 17, 198–199, 205, 395
- Air, generally:
 - conditioners, 28, 36, 48
 - conditioning systems, 30, 52, 122, 176
 - density ratio, 400
 - heat/heating, 176, 180
 - pollution, 202, 296
 - thermodynamic properties of, 33
- Aircraft, solar powered, 168
- Airflow rate, measurement of, 31, 51–52
- Airgap, induction generators, 243–244
- Alabama Electric Co-operative, 293–294
- Alarm systems, 156
- Alcohol/alcohol fuels, 215, 233, 301
- Aliphatic compounds, 203
- Alkaline fuel cells (AFCs), 163, 165, 169
- Alternate current (AC):
 - ac-ac conversion system, 9, 26, 303, 306, 318
 - ac-ac power converters, 255
 - ac-dc conversion, 318
 - ac-to-dc power converters, 359
 - converting technology, 302
 - generators, 107
 - integrating multiple renewable energy sources, 316–317
 - power, 3, 9
- Alternative energy sources (AESs),
 - integration of, 354–378
- Aluminum, 33, 121
- Ambient variables, 216
- American Society for Testing and Materials (ASTM), 130
- American Superconductor, 289
- Ammonia sulfate, 207
- Amorphous silicon (a-Si), 130–132
- Animal manure:
 - biodigesters in, 210
 - dry matter in, 208
 - gas production from, 207
 - water in, 208

- Animal urine, 207
- Animal waste, 396
- Anthracite coal, 34
- Antifreeze solutions, 122
- Asymmetric EDLC, 279
- Asynchronous generators, 234, 248–249
- Atmospheric pressure, 30, 32–33
- Atomic energy, 5, 8
- Australia, alternative energy technologies, 5, 22, 123–124
- Austria, 5, 17
- Automobile industry, 163–164, 168, 181, 195, 269
- Available state, 55
- Avista, 160

- Backfeeding, 315
- Backup generators, 263
- Bacon, Francis T., 159
- Bacteria, *see specific types of bacteria*
 - biogas formation process, 206
 - development of, 207
- Balanced systems, 23
- Ballard:
 - Generation Systems, 160
 - Mark V fuel cell, 186
- Balloon technique, 93
- Base load generation, 9
- Battelle Pacific Northwest Laboratory, 85
- Battery/batteries, *see specific types of batteries*
 - bank, HOMER modeling, 402–406
 - energy storage in, 316
 - fuel cells and, 172
 - induction generators and, 234
 - micropower system modeling with HOMER, 380–381
 - in photovoltaic systems, 148–150, 153–154
 - as renewable energy source, 3, 23
 - wind turbines, 108–109
- Bellman-Zadeh algorithm, 351
- Benzol, 167
- Bernoulli, generally:
 - equation, 85
 - expression, 62
 - theorem, 58
- Binary cycle power generation, 433
- Biodegradation waste, 17

- Biodiesel, 202
- Biodigesters:
 - characteristics of, 206, 209–210
 - construction of, 210–211
 - sizing, 211
- Biodigestion, 207–209
- Bioenergy potential, 198, 201
- Biofertilizer, 209
- Biofuels:
 - intensity and frequency characteristics of, 7
 - as renewable energy source, 15
 - research on, 213
- Biogas:
 - biological formation of, 206–207
 - biomass for, 205–206
 - caloric power of, 205
 - characteristics of, 204–205
 - distributed generation, 336
 - for domestic purposes, 213
 - electricity generated from, 211–214
 - heat production, 212
 - induction generators and, 233
 - motors, average consumption of, 212
 - as renewable energy source, 6, 14, 17
- Biogasification plants, 21
- Biogasifier, 5
- Biomass:
 - characteristics of, 198–202
 - combustion plants, 446
 - energy, U.S. consumption of, 24
 - energy conversion, 199, 201
 - feedstocks, 199, 203–204
 - fuel cell power plants, 181
 - fuel from, 202–204
 - gasification techniques, 200–203
 - HOMER modeling, 380, 395–397
 - power, 18, 202
 - pyrolysis, 200
 - as renewable energy source, 2, 4–5, 8–10, 19–20, 23
 - solid, 14
 - storage systems and, 296
- Biomass-powered microplants:
 - biodigesters, 209–210
 - biodigestion, factors affecting, 207–209
 - biogas, 204–207, 211–214
 - biomass, overview of, 198–202

- fuel from biomass, 202–204
- U.S. potential in, 199
- Biorefinery, 204
- Bituminous coal, 34
- Black-start services, 330
- Blackouts, 12
- Boats, fuel cell-powered, 163
- Boiler(s):
 - feedwater, 218
 - functions of, 28, 398
 - HOMER modeling, 407
 - simple power plant, 38
 - steam power plants, 41–43
- Boltzmann constant, 133, 423
- Braking systems, lifting turbines, 102
- Brayton, George, 44
- Brayton cycle:
 - for power plants, 38, 44–46
 - microturbine systems, 217, 220
- Brayton-cycle generators, 123
- Brazil, alternative energy technologies, 1, 57, 119, 131, 181, 198
- Brick, thermodynamic properties of, 33
- British thermal unit (Btu), 29–30, 32–34, 46–47
- Buderus Heiztechnik, 160
- Butane, 34, 204
- Butterfly valves, 68
- By-product(s):
 - of fuel cells, 162, 174–175
 - of microturbines, 216
 - polluting, 23
 - of pulp and paper industry, 203
 - of sludge digestion, 214
- C, thermal constant, 118
- Cadmium telluride (CdTe), 130
- California/California Emerging Renewables Program, 120, 151–152
- Caloric energy, 423
- Calorific value, 34
- Canada, alternative energy technologies, 1, 5
- Capacity, energy storage system, 265–267, 271
- Capital costs:
 - energy storage system, 265–267
 - generators, 402
 - geothermal power plants, 435
 - HOMER modeling, 414–415
 - induction generators, 258–259
 - microturbines, 230
 - thermosolar power plants, 126–127
- Capital recovery factor (CRF), 415
- Capstone single-shaft microturbines, 222–223, 231
- Carbon, 34, 126, 207–209, 397–398
- Carbon-carbon ultracapacitors, 279
- Carbon dioxide (CO₂):
 - emissions, 4–5, 8, 16, 18, 22, 119–120
 - implications of, 56, 198, 200, 203, 205–206
 - recycling, 170, 174
 - separation, 170
- Carbonic gas, 205
- Carbon monoxide, 165, 181, 200, 203, 218, 220
- Carnot, Sadi, 36
- Carnot, generally:
 - cycle, 439
 - cycle plant, 38, 40–42
 - principle, 36
- Cast iron, thermodynamic properties of, 33
- Catalytic burners, 174
- Cell phones, 281
- Cell-powered vehicles, 125
- Celsius degrees, 30
- Central America, 119
- Central-station:
 - generators, 375
 - power, 335–336
- Ceramics, 174, 287
- Charcoal, 198
- Charge-discharge history, 411
- Charge double layer, fuel cells, 185, 189–190
- Chemical, generally:
 - delay, 425
 - energy (CE), 46–48
 - feedstock, 123
 - fertilizers, 207
- Chimney effect, in wind turbines, 104
- China, alternative energy technologies, 2, 6, 198, 292
- Churchill Falls power plant (Canada), 1
- Cinergy and Metallic Power and Electric Fuel Co., 168
- Circuit breakers, tripping, 372
- Civil works, hydroelectric plants, 58, 67

- Clarke transformation, 310
- Classical Danish concept, 98. *See also*
 Danish concept
- Clausius, Rudolph, 36
- Clausius statement, 36
- Clean air, 16
- Clean Development Mechanism (CDM),
 6, 8
- Clean energy sources, 4
- Clean technologies, 119
- Closed feedwater heaters, 43
- Closed systems, 28–29, 55–56
- Coal, 9, 18–19, 24, 55, 203–204, 296.
See also specific types of coal
- Coal-fired power station, 5
- Cogeneration systems, 170, 174–175
- Combined cooling or heat and power
 (CCHP) systems, 215
- Combined cycle engines, distributed
 generation and, 335
- Combined cycles, 200
- Combined heat and power (CHP) systems,
 11, 14, 174, 204, 334–335
- Combined/hybrid power generation, 433
- Combustible gases, composition of, 205
- Combustion:
 from biomass, 199
 energy, 194
 microturbine systems, 225–228
 turbines, distributed generation and, 335
- Commercial energy needs, 28–29, 295
- Commercial fuel cell stacks, 172–173
- Commercial solar cells, 131
- Communications, in microturbines, 215
- Commutating machines, 248–249
- Compound generators, 107, 109
- Compressed air energy storage (CAES), 265,
 292–295, 340
- Compressed air storage in vessels (CAS),
 294
- Compressor(s) 49, 221
- Computer software program applications,
 193
- Concrete, thermodynamic properties of, 33
- Condenser:
 Carnot cycle and, 40
 functions of, 49, 52
 simple power plant, 38–39
 steam power plant, 41–42
- Confined vortexes, wind turbines,
 103–104
- Constant temperature, 41
- Consumer protection, 15
- Control equipment, 26, 320–330
- Conventional energy generation, 13, 17, 23
- Conventional power, 23
- Conversion enthalpy, 176
- Converters, *see specific types of converters*
 functions of, 398
 HOMER modeling, 407–408
- Cooling circulation fluid, 175
- Cooling systems/technologies, 15–16,
 20–21
- Copper indium-selenide (CIS), 130
- Copper losses, induction generators,
 238–239
- Copper oxide ceramics, 287
- Cost-resource curves, 13
- Critical temperature, 41, 287
- Croatia, alternative energy technologies, 5
- Cross-coupling, induction generators, 249
- Crude oil, 34, 296
- Cryogenic systems, 288–289
- Cryogenic temperature, 287
- CSIRO, 123
- Current, *see specific types of currents*
 interruption test, 189–192
 pump, in ultracapacitors, 280
 source (CS), 305
 source-controlled converter (CSCC), 177
 source inverters (CSIs), 305
- Cycle charging:
 battery banks, 405–406
 characteristics of, 381
 HOMER modeling, 413
- Cycloconverters, 318
- Daimler-Benz, 160
- Dams, hydroelectric, 292
- Danish concept, 98, 254–255
- Darcy-Weisbach formula, 62
- Darrieus Giromill turbines, 99, 101
- Darrieus-Troposkien turbines, 99, 101–102
- Data acquisition systems, 190
- Dc, *see* Direct current (dc)
- Dedicated storage, 340
- Deep-cycle battery model, 404–405
- Deep-cycle lead-acid batteries, 270

- Deferrable load, HOMER simulation, 394
- Deflectors, 103
- Deforestation, 55
- Demagnetization, 234
- Demand-side management (DSM), 10, 15–19, 337
- Denmark, alternative energy technologies, 5, 17, 84
- Department of Energy, *see* United States, Department of Energy (DOE)
- Deregulation in power industry, impact of, 333
- Deriaz turbine (DT), 70, 80
- Desalination, thermosolar energy, 122
- Desertification, 55
- Deserts, thermosolar power plants, 119
- Developing countries, technology in, 23, 296, 392
- Diesel, Rudolf, 419
- Diesel/diesel fuel, generally:
 - based systems, 301
 - characteristics of, 9, 163
 - cycle, 38
 - generators, 26, 303, 388
 - induction generators and, 233, 246
 - in microturbines, 215
- Diesel engine:
 - characteristics of, generally, 420–421
 - classification of, 426–427
 - combustion process, 424
 - components of:
 - auxiliary systems, 422
 - fixed parts, 421
 - moving parts, 421–422
 - cycle, 425–427
 - electrical conditions of generator driven by, 427–429
 - fuel injection pumps, 427
 - four-stroke, 424–425
 - historical perspectives, 419
 - losses, 425–426
 - terminology of, 422–423
- Diesel power plants:
 - characteristics of, 418–420
 - diesel engine, *see* Diesel engine
- Diffusers, 103
- Digester gas, microturbines, 215
- Diodes, 359
- Dirección General de Telecomunicaciones, 151
- Direct current (dc):
 - dc-ac conversion system, 9, 26, 302, 317–318, 359
 - dc-ac inverter, 172, 186, 317
 - dc-dc converters, 172, 255, 305, 311, 317
 - dc-to-ac power converters, 359
 - dc-to-dc conversion, 306
 - generators, 107, 109, 248–249
 - integrating multiple renewable energy sources, 315–316
 - link, in microturbine systems, 226–227
 - photovoltaic systems, 139–140, 155
 - power, generally, 3, 9, 269
- Direct methanol fuel cells (DMFCs), 163, 166–167
- Direct solar energy, 112
- Direct solar radiation, 130–131
- Direct-steam power generation, 433
- Discharge-charge cycles, batteries, 402–403
- Disconnect devices, 365
- Dispatchable power source, 410
- Dispatchable system components, HOMER modeling, 410–412
- Dispersed generation, 335
- Distributed generation (DG):
 - characteristics of, generally, 10–12, 262–263, 265, 296, 333–335
 - demand-side management, 339–340
 - integrated alternative energy sources, 327, 329–330
 - loads, 335, 341–346
 - multicriterial analysis algorithm, 350–352
 - optimal locations of, 340–350
 - purpose of, 335–338
 - siting, 338–339
 - sizing, 274, 338–339
- Distributed power resources, 24
- Distributed resource (DR), 326
- Distributed service station (DSS), 126
- Distribution network:
 - fuel cells, 185–186
 - induction generators, 246
 - wind power turbines, 107

- Distribution systems, 11. *See also*
 - Distribution generation
- Distribution transformers, 371
- dm/dt , 86
- DMFC, *see* Direct methanol fuel cells (DMFCs)
- DOE, *see* United States, Department of Energy (DOE)
- Domestic water, heating process, 118–119
- Dornier, 160
- Double-layer ultracapacitors, 277–278
- Doubly fed induction generator (DFIG), 250–251
- Drag turbines (Savonius), 100–101
- Drop scheme, 323, 327
- Droughts, global warming and, 24
- D-SMES, 289–290
- Dulux lighting systems, 149
- Earth:
 - as closed system, 54–58
 - fields, 287
 - rotation of, 88
- Ebara Corporation, 160
- ECN, 160
- ECOND, 279
- Economic considerations:
 - demand-side management options, 15–16
 - distribution systems, 11–12
 - electricity generation costs, calculation of:
 - capital recovery factor, 13–14
 - existing plants, 12–13
 - investment costs, 13–14
 - new plants, 13
 - electric power, 157
 - induction generators, 258–259
 - supply-side management options, 16–19
 - wind power plants, 110
- Electrical efficiency, energy storage system, 266–267
- Electrical energy (EE), 46–49, 53, 212
- Electrical network infrastructures, 16
- Electric double layer (EDL), 278–279
- Electric fence, 150
- Electric generator, 357
- Electricity infrastructures, 11–12
- Electric motors, 250
- Electric power:
 - generation with:
 - fuel cells, 161–169
 - induction generators, 248
 - photovoltaic effect, 132–135
 - thermosolar energy, 122
 - supply, 155–156
 - systems (EPSs), 24, 354
- Electric utilities, 366
- Electric vehicles, 162, 284, 337
- Electrochemical:
 - capacitors, 277
 - effects, 9
- Electroelectronic controls, induction generators, 250
- Electrolysis, 154–155, 159, 180
- Electrolyzer(s):
 - fuel cell power plants, 162
 - HOMER modeling, 408
- Electromagnetics, 4
- Electromechanical system, microturbines, 226
- Electronic circuitry, induction generators, 255–256
- Elevation, hydroelectric power plants:
 - implications of, 60–61
 - measurement of, 60–62
- ELIT, 279
- Emergency power systems, National Electrical Code, 361
- E-meters, 272
- Emission(s):
 - coefficients, 407
 - distributed generation and, 336
 - reductions, Kyoto Protocol, 5, 16
- Enercon, 105
- Energy (E):
 - consumption, fluctuations in, 299
 - conversion factors, 47
 - conversion systems, 28
 - crops, 198–199, 396
 - defined, 46
 - density:
 - defined, 282
 - energy storage system, 265–267, 271
 - superconducting magnetic storage system, 286–287

- efficiency, 16, 21, 335
- recovery time, 21–23
- saving technologies, investment in, 6, 8
- shortfalls, 384
- storage schemes, 168, 181. *See* Storage systems
- supply needs, 28–29
- in thermodynamics, 46–47
- transformations, 3–4
- England, alternative energy technologies, 163
- Enthalpy, 31, 33, 176, 229, 290
- Enthalpy-entropy (h-s) diagram, 35
- Entropy, 31–32, 45, 54–56, 218
- Environmental impact, 3
- EPCOS, 279
- Equity investment, 126
- Equivalent fuel-air cycle, diesel engines, 425
- Equivalent model, induction generators, 236–237, 252
- ESMA, 279
- Ethane, 204
- Ethanol fuel, 2, 167, 202
- Eucalyptus, 198
- Europe, high-power turbine production, 105
- European Union (EU):
 - alternative energy technologies, 4
 - demand-side management, 15–16
 - Fifth Environmental Action Programme, 23
 - Kyoto pledged emission reductions, 5
 - supply-side management, 16–19
 - targets for renewables, 14–15
- Evaporator, 49
- Evapotranspiration cycle, 2
- Exajoule, 24
- Exhaust gases, microturbine systems, 218, 230
- Exhaust heat, microturbine systems, 221
- Extensive properties, in thermodynamic system, 29
- ExternE, 18–19
- Fahrenheit scale, 30, 37
- Faraday effect, 9
- Farming applications, thermosolar energy, 115
- Feedback loop, microturbine systems, 224–225
- Feed heaters, steam power plants, 41
- Feed pump, steam power plants, 41
- Feedstock, biomass, 396–397
- Feedwater heaters, 43
- Fermentation:
 - bacteria, 206
 - biodigestion process, 207–209
 - methanogenic, 207
- Fermentative bacteria, 206
- Ferromagnetic materials, 286
- Feynman, Richard P., 36
- Finland, alternate energy technologies, 18
- First law of thermodynamics, 36, 47
- Fischer-Tropsch process, 203
- 5-kW reformer, 171
- Fixed costs, 13–14, 402, 411
- Flash-stream power generation, 433
- Float, measurements using, 63
- Flooded lead-acid batteries, 269–270
- Floods, global warming and, 24
- Flow splitter, 72–73
- Flue gas, thermodynamic properties of, 33
- Fluidized-bed gasifier, 204
- Fluid pressure, 29
- Fluorescent lighting systems, 149, 318
- Flywheels:
 - advanced performance of, 282–283
 - applications, 283–284
 - characteristics of, generally, 282, 340
 - design strategies, 283–285
 - four-stroke diesel engine, 429
 - life cycle of, 285
 - shape factor, 283
 - voltage restoration, 286
- Food conservation, 153–154
- Foot-pound-force (ft-lbf), 29
- Forced-air cooling system, 49
- Forestry, generally:
 - deforestation, 55
 - policies, 18
 - products, 17
 - residues, 17, 198–199, 203
- Form factor, 283
- Fossil energy, 21
- Fossil fuel(s):
 - biomass fuels compared with, 201
 - distributed generation, 336

- Fossil fuel(s): (*continued*)
 fuel cell power plants, 160, 195
 implications of, 1, 11, 15, 17, 19–20, 115, 119
 thermodynamics, 55–56
 thermosolar power plants and, 115, 119
- Fossil fuel-based systems:
 characteristics of, 157, 220, 301–302
 economic considerations, 13–14
- Foucault current, 238
- Four-stroke diesel engine, 424–425, 427–428
- France, alternative energy technologies, 84
- Francis turbines (FTs), 70–71, 74–77
- Fraud, 15
- Free energy state, 55
- Free riding, 15
- Friction, implications of:
 flywheels, 285
 induction generators, 238
 microturbine systems, 228, 230
 pumped hydroelectric energy storage, 291
- Fuel cell(s):
 advantages of, 181–182
 air management, 175–176
 automotive applications, 163–164, 168, 181, 195
 characteristics of, 9–10, 18, 21, 26, 159–162
 commercial technologies, 162–171
 diagram of, 161
 disadvantages of, 181–182
 distributed generation (DG), 335
 electrolyzer systems, 181
 equivalent circuit, 182–188
 equivalent model parameters, determination of, 188–194
 future directions for, 195–196
 heat management, 175–176
 heat storage, 295
 high-temperature, 169–170
 HOMER modeling, 380
 historical perspectives, 159
 hydrogen as fuel, 194–195
 induction generators and, 249
 load curve peak shaving, 176–180
 low-temperature, 169–170
 maintenance, 160, 182
 manufacturing issues, 170–172
 National Electrical Code, 361
 proton exchange membrane, constructional features of, 171–174
 reformers, 181
 reliability of, 182
 safety precautions, 181, 194
 solid oxide, constructional features of, 174
 stacking, 169–174, 176–177, 180–181, 195
 types of, generally, 161
 water management, 175–176
- Fuel cell- powered cars, 162
- Fuel cell-powered systems:
 characteristics of, generally, 234
 for remote applications (FCPS-RA), 171
- Fuel Cell Technologies, 160
- Fuel costs, 12
- Fuel oil, 34
- Fuel processor, 162
- Full-load:
 hours, 13–14
 switching, 368
- Gallium arsenide (GaAs), 130
- Garbage, biogas produced from, 206
- Gas/gasoline, generally:
 EU-25 electricity production mix, 18
 -fired engines, 18, 200
 -fired power stations, 5, 22
 fuel cells, 163, 194
 induction generators and, 233
 microturbines, 26, 161, 205, 215, 303
 sulfidric, 205
 turbines:
 Brayton cycle-based, 44–45
 energy sources, 302
 life span of, 225
 as primary source, 256
 systems, 9–10, 20, 200, 204, 219
- Gasification cofiring, 201
- Gasification technology, 200–203
- Gasifier systems, 20, 200–201
- Gasometer, in biodigesters, 209–210
- Gauge pressure, 30
- Gay-Lussac gas law, 440
- Gel Cell lead-acid batteries, 270–271
- General Motors, 160

- Generating unit, hydroelectric power plant:
 - butterfly valves, 68
 - regulation systems, 67–68
- Generation system, lifting turbines, 102
- Generators, *see specific types of generators*
- HOMER modeling, 401–402
- turbines, 211
- wind turbines, 104–109
- Geothermal, generally:
 - deposits, 296
 - electricity, 6, 17
 - energy, *see Geothermal energy*
 - heat, 4
 - power plants, feasibility study, 434
 - system, DG technologies and, 335
- Geothermal energy:
 - benefits of, 431
 - characteristics of, 7, 10, 15, 19, 21, 23–24, 432–434
 - economics, 434–435
 - electricity, 435–436
 - fuel cell power plants, 181
 - /ground source heat pumps, 436
 - historical perspectives, 431
 - hot springs, 432
 - integrated alternative energy sources, 301
- GE Power Systems, 160
- Germanium diodes, 136–137
- Germany, alternative energy technologies, 17, 84, 156, 163, 293
- GEWind Energy, 105
- Geysers, 432, 435
- Gibbs energy, 183
- Gibbs free energy released, 183
- Gigajoules, 171
- Glass, thermodynamic properties of, 33
- Global electric energy market, 22
- Global energy solutions, 4
- Global positioning systems (GPSs), 60–61
- Global solar radiation, 131
- Global Thermoelectric, 160
- Global warming, 24
- Governors, 250
- Grain driers:
 - heating system, 124
 - water heating system, 115
- Grandfathering, European regulations, 15
- Grants, as financial resource, 126
- Grapevine leaves, 206
- Graphite tubes, 125
- Gravity, acceleration of, 29
- Great Britain, alternative energy technologies, 84
- Greece, alternative energy technologies, 5, 84
- Greenhouse effect, 22, 120
- Greenhouse gas, generally:
 - analysis, 397
 - costs (GCCs), 126
 - emissions, 4, 21, 195, 198, 202
 - heating system, 124
- GreenVolt Power Corp., 168
- Grid, generally:
 - capacity, 12
 - connection, voltage level, 6
 - HOMER modeling, 406–407
 - operators, 20
 - power interruption, 283
 - power price, 406
 - supplies, 19–20
 - voltage, 308
- Grid-based networks, 304–306
- Grid-connected:
 - alternative energy sources, 320–321, 324
 - microgrid, 330
 - network, energy storage systems, 297–299
 - system, 397–398
 - thermosolar power plants, 127
- Grid-fault disconnectors, 20
- Grid-supplied electricity, 9–10, 23
- Gross domestic product (GDP), 21
- Grounding system, 365
- Guri power plant (Venezuela), 1
- Hardwoods, 34
- Heat:
 - balance, 36
 - capacity, 32
 - content, 33
 - engine, 38–39
 - exchangers, 174, 215, 218, 221
 - pump, 48, 52–53
 - recovery, 170, 175, 401
 - recuperators, 215, 218, 220
 - recycling, 175
 - thermodynamics, 46–50

- Heat: (*continued*)
 transfer:
 analysis, 53
 calculation, 115–116
 thermodynamics of, 32, 53
 Heating systems, 15–16, 20–21, 30
 Heating towers, wind turbines, 102–103
 Heliostats, 295
 Helium, 287–288, 439
 Herbicides, chlorinated, 205
 High-energy ultracapacitors, 278–279
 High-frequency ac link (HFAC), 303, 312
 High-grade energy, 55
 High-speed wind, 106, 108, 115
 High-temperature superconductors, 287
 High-velocity flywheels, 285
 High-voltage dc transmission systems, 9
 Higher heating value (HHV), 34, 46
 Hill climbing control, 330
 Home computers, energy transformations, 3–4
 HOMER Micropower Optimization System
 modeling:
 economic modeling, 414–416
 optimization, 380, 385–388
 life-cycle costs, 381, 383, 388
 overview of, 379–382
 physical modeling:
 components, generally, 397–408
 loads, 393–395
 resources, 395–397
 system dispatch, 408–413
 sensitivity analysis:
 characteristics of, 380, 388–389
 hourly data sets, 391–393
 uncertainty, 389–391
 simulation, 380–385
 terminology, 416–418
 Home waste, 198
 Horizontal-shaft turbines, 98
 Hot springs, 432–433
 Hot water, 175–176. *See also* Water heating
 H-Power, 160
 Hungary, alternative energy technologies, 5
 Hurricanes, global warming and, 24
 Hybrid cars, 446
 HYBRID2, 381
 Hydraulic gradient, hydroelectric power plant, 63
 Hydraulic power station, 5
 Hydro-diesel-battery system, 411
 Hydrocarbonates, 175
 Hydrocarbons, 55, 200, 203–204, 218, 301
 Hydroelectric energy, U.S. consumption of, 24
 Hydroelectric power plants:
 accumulation reservoirs, 58
 expedient topographic and hydrological measurements:
 civil works, 58, 67
 elevation, 60–62
 pipe losses, specification of, 62–63
 stream water flow, 63–67
 generating unit:
 butterfly valves, 68
 regulation systems, 67–68
 historical perspectives, 4, 57–58
 implications of, 6, 181, 233
 investment in, 6
 turbine(s):
 Deriaz (DT), 70, 80
 Francis (FTs), 70–71, 74–77
 hydro, specification of, 81–82
 Kaplan (KT), 70–71, 79–80
 Michel-Banki (MBT), 70–71, 74, 77–78
 Pelton (PT), 70–74
 propeller hydraulic, 70, 79–80
 types of, 70–71
 water pumps working as, 80–81
 useful power, determination of, 58–60
 waterwheels, 57, 67–70
 Hydrogen:
 -based systems, 301
 characteristics of, generally, 2, 24, 205–206, 337, 439
 emission-free, 154
 fuel cells, 168, 170, 177–178
 generation of, 154–155, 168, 213
 higher heating value for, 34
 production of, 119, 125–126
 purification of, 162
 safety precautions, 181, 194
 storage, 380, 398
 tank, HOMER modeling, 408
 Hydrogen-carbon monoxide gas mixture, 203

- Hydrogenerator, 125
- Hydrogen sulfide, 125
- Hydrometer, functions of, 273
- Hydropower/hydropower plants:
 - development of, 1–2, 10, 17–20, 23, 302
 - induction generators and, 259
 - intensity and frequency characteristics of, 7
 - investment costs, 13
 - power injection, 302
 - solar energy and, 112
- Hydro turbines:
 - HOMER modeling, 395–397, 400–401
 - induction generators, 246, 250
 - interconnection technologies, 357
 - specification of, 81–82

- Ice, thermodynamic properties of, 33
- Iceland, alternative energy technologies, 5
- Ida Tech/North West Power Systems, 160
- IEEE, *see* Institute of Electrical and Electronic Engineers (IEEE)
- Illumination, photovoltaic solar energy, 140, 149–150
- Impedance-source (Z-source) power converter, 306
- Imported fuels, 17
- Indirect electrical heat, 48
- Indirect solar energy, 112
- Induction generators:
 - calculation routine, 240
 - characteristics of, 233–234
 - Danish concept, 254–255
 - doubly fed, 20
 - economic aspects, 258–259
 - frequency disturbance and, 368
 - grid connection, variable-speed, 255
 - inspections, 258
 - interconnected operations, 246–248, 317, 358
 - load(s):
 - implications of, 242–244, 248
 - source control *vs.*, 250–254, 256–258
 - losses generated, 237–239, 246
 - maintenance, 258
 - operation principles, 234–236
 - power generated, 237–239
 - power injection, 302
 - self-excited, 240–246
 - speed control, 248–250
 - stand-alone operations, 246–248
 - steady-state operation, 236–237, 248
 - voltage control, 247–250
 - wind turbines, 107
- Industrial applications:
 - distribution generation (DG) systems, 334
 - heat storage, 295
 - policies, 18
 - process energy, 202
 - process heating, thermosolar energy, 122
 - thermodynamics, 29
- Industrialized countries, alternative energy technologies, 23
- Industrial liquid flows, 31
- Industrial residues, 201, 206
- Industrial revolution, 1, 55
- Industrial waste, 198–199
- Information technology, 302
- Infrastructure, adaptation of, 15
- Innovation, 15
- Institute of Electrical and Electronics Engineers (IEEE):
 - IEEE 1547, 24, 360, 366, 373
 - Standards Coordinating Committee (SCC), 360
- Integrated energy, planning and development process:
 - distributed generation (DG), 10–11
 - grid-supplied electricity, 9–10
 - load, 10
 - overview of, 8–9
- Integrated gasification combined cycle (IGCC), 201
- Integration of alternative energy sources:
 - challenges of, 302
 - distributed generation (DG) control, power injection and, 301–302, 325–331
 - fossil fuel-based systems compared with, 301–302
 - islanding and interconnection control, 320–325
 - loads, generally, 313–314, 327–328
 - multiple renewable energy sources:
 - AC-link integration, 313–317
 - DC-link integration, 311–316

- Integration of alternative (*continued*)
 - HFAC link integration, 312–314, 316–320
 - overview of, 312–315
 - power control, instantaneous active and reactive, 309–312
 - power injection principles:
 - converting technologies, 302–304
 - power converters for power injection into grid, 304–306
 - power flow, 306–309
 - storage systems, 303
- Integrated renewable energy sources:
 - energy recovery time, 21–23
 - implications of, 19–20
 - sustainability, 23–25
 - in the United States, 20–21
- Intensive properties, in thermodynamic systems, 29, 35
- Interconnected alternative energy sources:
 - dc injection, 370–371
 - disconnection for faults, 368–369
 - examples of, 373–378
 - feeder reclosing coordination, 369–370
 - frequency disturbance, response to, 367–368
 - harmonics, 371–373
 - interconnection technologies, 357–359
 - integration with area EPS grounding, 365
 - islanding protection, unintentional, 373
 - isolation, 365–366
 - loss of synchronism, 369
 - overview of, 354–356
 - standards and codes for, 359–364
 - synchronization, 365
 - voltage:
 - disturbance, response to, 366–367
 - flicker, 371
 - regulation, 364
- Interconnected electrical power production systems, National Electrical Code, 361
- Interconnection control, 320–325
- Intermittent generation, 10
- Internal combustion engine (ICE), 28, 170, 216, 256, 335
- Internal energy, 32
- International Climate Convention (Kyoto), 4
- International Energy Agency, 12
- International Standards Organization (ISO), 29
- Interruptible loads, 10, 340
- Interrupting device, 369
- Inverters:
 - grid-linked, 20
 - induction generators, 240, 249
 - interconnection, 359
 - lead-acid batteries, 269
 - microturbine systems, 215, 223–224, 228
 - technological advances, 356
- Investment capital, 126
- Investor confidence, 14
- Ireland, alternative energy technologies, 5, 57
- Isentropic process:
 - compression, 40, 42
 - defined, 31, 35
 - expansion, 40, 42
- Islanding, integrated alternative energy sources, 320–326
- Isobaric process:
 - defined, 35
 - heat rejection, 42
 - heat supply, 42
- Isochoric process, 35
- Isolated gate bipolar transistors (IGBTs), 257
- Isolated systems, 28, 55
- Isothermal process:
 - implications of, 35, 39
 - reversible compression, 38
 - reversible expansion, 38
- Israel, alternative energy technologies, 295
- Itaipu Binational power plant (Brazil), 1
- Italy, alternative energy technologies, 84
- Japan, alternative energy technologies, 5–6
- Joint ventures, 124
- Joule (J), 28, 119, 266
- Kaplan turbine (KT), 70–71, 79–80
- Kelvin-Planck statement of the second law, 36
- Kerosene, microturbines, 215

- Kilovolts, 129
- Kilowatthour (kWh), 10, 46–47, 103, 171, 258, 266, 272, 387, 431
- Kilowatts, 12, 59, 157, 212, 230, 250, 274
- Kinetic battery model, 403
- Kinetic energy, 3, 29, 70–71, 85–86
- Kuhn, Thomas, 36
- Kyoto Protocol, 4–6, 8, 16

- Landfill(s):
 - biomass-powered microplants, 198
 - gas, 6, 14, 17, 230
- Lanthanum manganite, strontium-doped, 174
- Latent heat:
 - of fusion, 32
 - of vaporization, 33
- Law of conservation of energy, 36
- Lead-acid batteries:
 - charge-discharge cycles, 269–271
 - constructional parameters, 268–269
 - deep-cycle, 148
 - features of, 268
 - loads, 274–275
 - maintenance of, 273
 - maintenance-free, 269
 - operating limits/parameters, 271–273
 - parameters, 267
 - power factor, 275
 - safety precautions, 273
 - sizing, for DG applications, 273–276
 - storage applications, 265
 - storage cost projections, 268
 - storage parameters, 267
- Lead sulfate, 270
- Lifetime, energy storage system, 265–267
- Lifting turbines:
 - characteristics of, 101–102
 - Darrieus-Tropskien turbine, 101–102
- Light technologies, 16, 20, 149–150
- Lignin, 203
- Lignite, 34
- Linear loads, 372
- Linen stem, 206
- Liquefied petroleum gases (LPGs), 34
- Liquid fuels, 203, 219–220, 396
- Liquids, velocity of, 31

- Lithium ion batteries, 267–268
- Litz wire, 223
- Load(s):
 - characteristics of, generally, 10
 - curve flatness, 176–178
 - distributed generation, 341
 - energy storage systems, 297–298
 - HOMER modeling, 393–395, 413
 - induction generators, 242–244, 248, 250–254, 256–258
 - interconnected alternative energy sources (AESs), 356
 - lead-acid batteries, 272
 - management, 337
 - microturbine systems, 221, 225
 - peak period, 177
 - photovoltaic solar energy, 133–134, 155
 - rejection, 73–74
 - shifting, 337
 - thermosolar energy, 117, 121
 - tracking, 221
- Long-distance transmission, 315
- Losses:
 - diesel engine case illustration, 425–426
 - distributed generation and, 342–347
 - integrated alternative energy sources, 334
- Lossless transformers, induction generators and, 238
- Low-energy gasifiers, 200
- Lower heating value (LHV), 34
- Low-grade energy, 55
- Low-temperature, generally:
 - heat energy, 295
 - superconductors, 287
- Luxembourg, alternative energy technologies, 5

- Macroscopic forms of energy, 32
- Magnetism, induction generators, 241–244, 259
- Magnetomotive force, 286
- Mahgreb-Europe gas pipeline, 151
- Manure, biogas formation, 206
- Marginal costs, of energy, 402, 411
- Marine algae, 206
- MatLab/SIMULINK, 193
- Matrix converter, 318

- Maximum power point tracker (MPPT), 399
- Maxwell Technologies, 279
- MCFC, *see* Molten carbonate fuel cells (MCFCs)
- M-C Power, 160
- Medicine conservation, 153–154
- Megawatts, 11, 157
- Membrane electrode assembly (MEA), 164
- Mercaptans, 125
- Mesofilics, 207
- Metallurgical reducing gas, 123
- Meteorological mapping, 87–89
- Methane, 162, 200, 204–205, 206, 212, 215
- Methanogenic bacteria, 206–207, 209
- Methanol, 123, 125, 181
- Methene, 204
- Methyl tertiary butyl ether (MTBE), 202
- Michel-Banki-Ossberger turbine, 78
- Michel-Banki turbine (MBT), 70–71, 74, 77–78
- Micro-irrigation systems, 151–152
- Microgrids, 26, 302–303, 312, 318–321, 325–326, 329–330, 339
- Micropower plants, 211
- Micropower system, qualifications of, 379–380
- Microscopic forms of energy, 32
- Microturbines:
 - applications, generally, 216–217, 230
 - characteristics of, 18, 215–217
 - control-side structure, 224–228
 - development of, 215
 - distributed generation, 335
 - efficiency of, 228–231
 - electrical-side control structure, 222–224
 - electricity generation, 213–214
 - fuel, 219–220
 - HOMER modeling, 380
 - integrated alternative energy sources, 335
 - inverter-based technology, 303
 - loads, 216
 - maintenance of, 216, 230
 - mechanical-side control structure, 220–222
 - modeling, 226
 - operation principles, 217–219
 - power of, 227–230
 - repairs to, 216
 - site assessment for installation, 230–231
 - sizing, 230
 - speed of, 227–228
 - stacking, 216
 - system control structures, 220–228
- Middle East, alternative energy technologies, 181
- Mirrors, thermosolar power plants, 124
- Mitsubishi Electric Corporation, 160
- Mobile computing, 281
- Mobile equipment, 195
- Mobile telephone networks, 150, 340
- Modularity, distributed generation and, 335–336
- Molten carbonate fuel cells (MCFCs), 163, 165, 170, 174
- Monocrystalline silicon, (Si), 130–131
- Moon, tidal energy and, 21
- Morocco, alternative energy technologies, 151
- Mosonyi condition, 73
- MTU, 160
- Multilayer reservoir, thermosolar energy, 115
- Multiple-blade turbines, 99
- Multiple generator systems, 327–328
- Multiple regression analysis, 348
- Municipal waste, 198–199
- Nafion membrane, 184
- Naphtha, microturbines, 215
- National Aeronautics and Space Administration (NASA):
 - Apollo program, 159, 165
 - Gemini spaceship mission, 171
 - Goddard Institute for Space Studies, 24
 - power electronic-based systems and, 317–318
- National building codes, 24
- National Electric Code (NEC), 24
- National Fire Protection Association (NFPA):
 - functions of, 360
 - National Electrical Codes, 361–362, 365

- National Fuel Cell Research Center, 216
- National interconnection standards and tests, 24
- National Renewal Energy Laboratory (NREL), 379
- National safety codes, 24
- Natural gas:
- canalization, 171
 - combined-cycle system, 336
 - combustion of, 221
 - diffusivity, 194
 - distributed generation, 336
 - fuel cells and, 162, 172, 181
 - heating in microturbine, 219
 - higher heating value for, 34
 - induction generators and, 233
 - integrated alternative energy sources, 301
 - microturbine systems, 215, 229
 - nonrenewable, 213
 - solar-thermal dissociation process, 125–126
 - storage systems, 296
 - U.S. consumption of, 24
- NEC, *see* National Electric Code (NEC)
- Negative temperature coefficient (NTC), 136–137
- Neg Micon, 105
- Nernst reversible voltage, 183
- NESS Capacitor Co., 279
- Net metering, 338–339, 378
- Net power in the shaft, 238
- Netherlands, alternative energy technologies, 84
- Newton's second law, 29–30
- New Zealand, alternative energy technologies, 5
- Nickel-cadmium batteries, 267–268, 280
- Nickel-metal hydride batteries, 267–268, 280
- Niobium-titanium wire, 287–288
- Nitrate, 207
- Nitrogen, in biogas formation, 205, 207
- Nitrogen oxides, 120, 159, 200, 218–220
- Nondispatchable power source, 410
- Nonlinear loads, 372
- Nordex, 105
- Norway, alternative energy technologies, 5
- Notable surface action, 170
- NREL, *see* National Renewable Energy Laboratory (NREL)
- Nuclear energy:
- characteristics of, 5–6, 8, 17, 22
 - EU-25 electricity production mix, 18
 - U.S. consumption of, 24
- Nuclear power, *see* Nuclear energy
- grid-supplied electricity, 9
 - plants, 22
 - stations, 5
 - supply and demand, 19
- Nuclear reactors, 5
- Nuvera Fuel Cells, 160
- Ocean-source systems, DG technologies and, 335
- Off-grid services, 19
- Off-peak hours, 178–179, 337
- Off-the-grid systems, 230
- Ohm's law, 185
- Oil:
- canalization of, 171
 - dependence on, 202
 - distributed generation and, 336
 - EU-25 electricity production mix, 18–19
 - formation of, 55
 - imports, 2
- Oily plants, 15
- Okamura, 279
- One-blade turbines, 98
- On-site power generation, 333
- Open-circuit voltage, photovoltaic effect, 137
- Open feedwater heaters, 43
- Open system, 28, 31
- Operating costs, 12, 265–267
- Operating reserve, 394, 409–410
- Optimized systems, 23
- Organic compounds, 2
- Organic garbage, 201
- Organic matter, conversion to liquid fuels, 112
- Organic residues, 206
- Organization of Economic Cooperation and Development, 22
- Otto cycle, 38
- Overfrequency relay (UVR), 322–323, 368
- Overvoltage relay (OVR), 322–323

- Oxygen:
 biomass gasification process, 204
 distributed generation and, 337
 fuel cell manufacture, 170
 generation by electrolysis, 154–155
- PAFC, *see* Phosphoric acid fuel cells (PAFCs)
- Pages, storage systems, 281
- Panasonic, 279
- Parabolic dish technology, 119, 126–127
- Parabolic reflector, 120–121
- Parabolic trough technology, 119–122, 126
- Parallel generators, 107–109
- Passive solar heating, 56
- Payback time (PT), 14
- Peaking generation, 9
- Peak load, 337
- Peak shaving, 264, 340
- Peat, 34
- Peltier coolers, 280
- Pelton turbine (PT), 70–74
- PEM, *see* Proton exchange membrane
- Penalty costs, energy storage systems, 296–297
- Permanent magnet-based generators, 234, 302
- Per-phase equivalent model, 236–237
- Personal digital assistants, 281
- Pesticides, chlorinated, 205
- Petroleum, U.S. consumption of, 24
- pH, biodigestion process, 207–208
- Phosphoric acid fuel cells (PAFCs), 163, 164, 169–170
- Phosphorus, 07
- Photoelectric energy, 19
- Photochemical energy, 19
- Photosynthesis, 2, 19, 112
- Photovoltaic arrays:
 HOMER modeling, 398–399
 lead-acid battery storage, 275
 ultracapacitor storage, 281
- Photovoltaic cells:
 HOMER modeling, 384–385
 induction generators and, 234, 249
 renewable energy sources, 3, 5–6, 10, 20–23, 26
 thermosolar power plants, 112
- Photovoltaic effect, 9, 131–135
- Photovoltaic electricity, 16
- Photovoltaic power plants:
 cell temperature, 135–139
 dark-current electric parameters, 140–141
 distributed generation and, 335, 337
 economic analysis of solar energy, 156–157
 electricity generation by photovoltaic effect, 132–135
 features of, 129–130, 145
 HOMER modeling, 380–381
 photovoltaic panel models and parameters, 139–145
 PV panel with n cells in:
 parallel, 144–145
 series, 142–144
 solar cell output, 137–139, 142–143
 solar modules and panels, 129, 137, 146
- Photovoltaic solar energy, *see* Photovoltaic power plants
 applications, 149–156
 benefits of, 129–130
 economic analysis of, 156–157
 features of, 130–132
 reliability of, 130
- Photovoltaic systems components:
 aluminum structures, 146–148
 battery bank, 148–149
 diesel-battery system, 392
 illumination area, 146
 load controller, 148
 solar modules and panels, 146–148
- Physical delay, 425
- Physical efficiency, energy storage system, 265–266
- Pipes/piping:
 losses, specification of, 62–63
 thermosolar energy, 117, 120
- Pipelines:
 fuel cell power plants, 181
 high-pressure, 291
 microturbine systems, 218–220
- Pitch control, wind turbines, 105
- Plagues, control with photovoltaic solar energy, 153–154
- Plane guides, 103
- Plants, 198

- PLG gases, 212
- Plug Poer, 160
- Point of common coupling (PCC), 325, 356
- Poland, alternative energy technologies, 5
- Poles, induction generators, 251, 254
- Polluter pays principle, 14
- Polycrystalline silicon, (Si), 130, 132
- Portugal, alternative energy technologies, 5
- Positive temperature coefficient (PTC), 136
- Potatoes leaves, 206
- Potential energy, 29
- Poultry houses, heating system, 124
- Pounds per square inch gauge (psig), 30
- Power, generally:
 - conditioning, 26, 356
 - conversion factors, 47
 - converters, 250, 304–306
 - density, 285
 - disturbances, 263
 - generation, 123, 163
 - lines, 20, 340
 - losses, 342–346
 - peak tracking, 139
 - switching, 258
 - in thermodynamics, 46–47
 - transformers, 256
- Power electronic system(s):
 - characteristics of, 26
 - converters, 304–305
 - design of, 309–310
 - integrated alternative energy sources, 302–304, 326
 - in microturbines, 215, 223–224
 - superconducting inductors, 288
 - ultracapacitors and, 280
- Power plant(s):
 - biomass-powered microplants, 198–214
 - with fuel cells, 159–196
 - photovoltaic, 129–157
 - simple, 38–39
 - size of, 1–2
 - small fuel cell, 173
 - thermosolar, 112–127
 - wind, 84–110
- Power-processing technology, 26
- Power stations:
 - electricity generation costs, 12
 - energy recovery time, 21–23
 - fossil-fuel powered, 21–22
 - gas-fired, 22
 - oil-powered, 22
 - size of, 21
- P-q* theory, 319–320
- Pressure:
 - in thermodynamic system, 30
 - volume (P-V) curve vs., 39–40
- Pressure-volume (P-V) diagram, 35, 46
- Primary energy, production of, 21
- Primary load, HOMER simulation, 393–394
- Prime mover/engine, 357
- Prokon, 105
- Propane, 34, 163, 172, 181, 204, 213, 215, 336
- Propeller turbine 79–80
- Properties, in thermodynamics, 29
- Propionic bacteria, 206
- Propylene glycol, 122
- Protection systems, wind power turbines, 107
- Proton exchange membrane (PEM), 160–161, 170–171. *See also* Proton exchange membrane fuel cells (PEMFCs)
- Proton exchange membrane fuel cells (PEMFCs), 163–165, 167–168, 172–173, 184
- Psicrofilics, 207
- Psim, 193
- Pspice, 193
- Pulp and paper industry, 202–203
- Pulse-density modulation (PDM), 250
- Pulse-width modulation (PWM), 250–251, 311
- Pump(s):
 - simple power plant, 38–39
 - steam power plants, 42
 - turbines, 292
- Pumped hydroelectric energy storage:
 - characteristics of, generally, 290–291, 340
 - drawbacks of, 292
 - storage capabilities of, 291–292

- PV-DesignPro, 381
 PV*SOL, 381
 P-V-T surface, 35
 PWM, *see* Pulse width modulation (PWM)
 Pyrolysis, 200
- Quad, 24
 Quenches, superconducting magnetic energy storage (SMES) system, 287–288
- R*, thermal constant, 118
 Radial thrust, 77
 Radiation, solar energy, 56, 113–114, 130–131, 395
 Radio, long-wave, 340
 Rankine, W. J. M., 41
 Rankine cycle for power plants, 38, 41–44
 Rapeseed, 2
 Rare-earth permanent-magnet machines, 285
 Rayleigh distribution, 90, 92
 Reactive power:
 induction generators, 244–248
 integrated alternative energy sources, 306–310, 319, 324, 328
 voltage droop *vs.*, 323
 Real power *vs.* supply frequency, 323
 Receivers, thermosolar power plants, 123–124, 12k6
 Recharge rate, energy storage system, 265–267
 Reciprocating engine generators, 380
 Reclosing, 369–370
 Recovery cycle, 301
 Rectangular spillway, measurement using, 63–64
 Recycling, 170, 174–175
 Reduction-oxidation reactions, 277, 279
 Refineries, 220
 Reflectance coefficient, thermosolar energy, 120
 Reformers, 162
 Refrigerant, 52
 Refrigerators, 28, 48–49, 153
 Refueling, fuel cells, 182
 Regeneration, 167, 443
 Reheater, steam power plants, 41
 Relative humidity, 175
- Relays, 259, 322–323, 368
 Renewable energy:
 alternative energy *vs.*, 4–8
 benefits of, generally, 2, 8, 21
 disadvantages of, 2–3
 economics of, 11–14
 frequency characteristics of, 7
 integration of, 19–26
 intensity of, 7
 European targets for, 14–19
 integrated sources of, 301–302
 need for, 1–2
 planning and development of, 8–11
 power electronics, 26
 sources of, 1–2, 19–25
- REPower, 105
 Residential, generally:
 energy needs, 28
 heat storage applications, 295
 load, 262–263
 thermodynamic examples, 47–48
 water heating process, 118–119
 Resistance, photovoltaic cells, 133–134
 Reversible fuel cells (RFCs), 163, 167–168
 Reynolds number, 62
 Rice straws, 206
 Road infrastructure systems, 150
 Robustness, 222, 227, 234, 269, 314
 Rock beds, 51, 295
 Rolls-Royce, 160
 Root mean cube speed, 91
 Rotating losses, 238
 Rotor:
 accelerating shelters, 103
 flywheel design, 284–285
 induction generators, 241–242, 246, 250–254
 in lifting turbines, 101
 speed:
 induction generators, 234–238, 242–243, 250, 252
 microturbine systems, 221–222
 synchronous generators, 369
 wind turbines, 99, 103, 105
- Round-trip efficiency, in battery bank, 402
 Run-of-river hydro turbine, 396–397
 Run-of-the-river systems, 6, 10, 58, 67, 259

- Rural areas:
- biodigester installation, 210
 - biogas formation, 206
 - energy storage, 296
 - induction generators, 259
 - power lines, 20
- Russia, alternative energy technologies, 1, 5, 279
- Safe work area clearance, 366
- Safety equipment, electrical, 20
- SAFT, 279
- Salt, generally:
- caverns, compressed air storage and, 293–294
 - thermosolar power plants, 124
 - water, heat storage, 295
- Satellites:
- global positioning systems (GPSs), 61
 - propulsion of, 169
- Savonius turbines, 99–101
- Sayano-Shushensk power plant (Russia), 1
- Scale factor, 90
- Schatz Energy Research Center and Energy Partners, 160
- Scherbius variable-speed driver, *see* Doubly fed induction generator (DFIG)
- Schockley's equation, 135–137, 141, 143–144
- Sealed lead-acid (SLA) batteries, 269, 271–272
- Sea levels, global warming and, 24
- Sea tidal energy, 112, 181
- Sea wave energy, 181
- Security, distributed generation and, 337
- Security systems, 156
- SEIG, *see* Self-excited induction generators (SEIGs), 241
- Self-discharge, energy storage system, 265–267
- Self-excited induction generators (SEIGs):
- magnetizing curves, 242–243
 - mathematical description of process, 243–246
 - overview of, 240–242
- Self-renewing resources, 2
- Semiconductors, solar energy conversion, 131
- Sensitivity analysis, HOMER micropower optimization system, 389–392
- Servomechanisms, 250
- Sewage gas, 6, 14, 17
- Sewers, 201
- Shaft design:
- flywheels, 283
 - induction generators, 243–244, 248–249, 258–259
 - microturbine systems, 221–224, 227
- Shaft useful power, 238
- Shallow-cycle lead-acid batteries, 269–270
- Shape factor, 283
- Shockley diode, photovoltaic effect, 132–134, 136
- Shockley's equation, 141
- Short-circuit current:
- diesel power plants, 429
 - induction generators and, 234, 242, 247–248
 - interconnected alternative energy sources, 368
 - photovoltaic effect, 133, 135–136
- SI (Système International d'Units), 29–31, 34
- Siemens-Westinghouse Corporation, 160
- Silicon diodes, 136–137
- Simple-cycle microturbines, 220–221
- Single-shaft microturbines, 222–225
- Sinusoidal pulse-width modulation (SPWM), 227
- Site assessment, for microturbines, 230–231
- Slip factor, induction generators, 236–237, 245, 247, 252–253, 255
- Sludge, anaerobic, 213–214
- Small grid-connected photovoltaic system example, 375, 377–378
- Small hydropower, HOMER modeling, 380
- Small power plants:
- induction generators and, 259
 - renewable energy, 233
- Small-scale distributed power, 215
- SOFC, *see* Solid oxide fuel cells (SOFCs)
- Soft switching, 318
- Softwoods, higher heating value for, 34
- Soil, heat storage, 295
- Solar, generally:
- air system, 51
 - belt, 112, 125
 - cells, 3, 20

- Solar, generally: (*continued*)
- collectors, 51–52, 113–114, 122
 - dish-engine systems, 122–123
 - to-electric conversion, 123, 126–127
 - heating, 56
 - lantern, 149
 - photovoltaic cells, 2, 8, 17
 - plates, 113, 115
 - ponds, 295
 - power tower, 119
 - radiation, 56, 395
 - resource data, 395
 - thermal electricity, 2–3, 6, 8, 15–17, 23
 - thermal power supplies, 337
 - tower power station, 295
 - wind generators, 103–104
- Solar energy:
- benefits of, 130–132
 - economic analysis of, 156–157
 - fuel cell power plants, 181
 - historical perspectives, 111–113
 - HOMER modeling, 395, 397
 - integrated alternative energy sources, 301
 - intensity and frequency characteristics of, 7
 - potential, 8
 - renewable energy source, 4, 6, 20, 23
 - thermodynamic principles, 56
 - U.S. consumption of, 24
 - water heating by, 113–115
- SolarMission Technologies, Inc., 124
- Solar photovoltaic systems, National Electrical Code, 361
- Solar systems, 22
- Solar Systems Pty Ltd., 123
- Solenoids, 250
- Solid oxide fuel cells (SOFCs), 160–161, 163, 166, 169–171, 174–175
- Solid-state power electronics, 9
- South Africa, alternative energy technologies, 6
- South Korea, alternative energy technologies, 6
- Soy straws, 206
- Space heating, thermosolar energy, 121–122
- Spain, alternative energy technologies, 18, 84, 151
- Specific energy, 21, 265–267
- Specific enthalpy, 31
- Specific entropy, 31
- Specific gravity, 266, 273
- Specific heat, 32–33, 114, 228
- Specific internal energy, 31–32
- Specific power, energy storage system, 265–267
- Specific volume, 30
- Specific weight, 29–30, 33
- Speed:
- induction generators, 255
 - lifting turbines, 102
 - microturbines, 227–228
 - rotors, 221–222, 234–238, 242–243, 250, 258
 - wind, 88–94, 101, 104–109, 115, 248, 255, 258
- Spinning reserve, 330, 337, 394
- Split-shaft microturbine system, 221–223
- Stall regulation, wind turbines, 105
- Stand-alone systems:
- fuel-celled power plants, 186
 - induction generators, 240, 242, 246–248
 - integrated alternative energy sources and, 302
 - microturbines, 216, 225
 - synchronous generators, 357–358
- Standby power:
- generation of, 9
 - National Electrical Code, 361
 - storage systems, 269
- Starting system, lifting turbines, 102
- Static power converters, 359
- Stationary fuel cell power plant installation, National Electrical Code, 362
- Stationary power plants, 44
- Statistical analysis, 348
- Steady-state:
- induction generators, 236–237, 248
 - thermal calculations, 115–116
- Steam, generally:
- boilers, 20, 37
 - electric power station, thermodynamics example, 37–39
 - engines, 18, 282
 - generation, thermosolar energy, 122
 - power plants, 44
 - thermodynamic properties of, 33
 - turbines, functions of, 28, 41–42

- Steel, thermodynamic properties of, 33
- Stirling, Robert, 438
- Stirling cycle, 38
- Stirling-cycle generator, 123
- Stirling engine:
- characteristics of, 18, 438–439
 - displacer, 442–443
 - historical perspective, 438
 - Stirling cycle, 439–442
 - two-position, 444–446
- Stoichiometric feeding, 176
- Stone, thermodynamic properties of, 33
- Storage, *see* Storage systems
- components, 22
 - heat, 294–295
 - hydrogen, 195
 - oscilloscope, 190–191
 - power plants, 6
- Storage systems:
- applications, 28, 265, 303
 - classification of, 263
 - compressed air energy, 292–294, 340
 - cost projection, 268
 - as economic resource, 295–299
 - flywheels, 282–286, 303, 340
 - heat, 294–295
 - importance of, 262, 299
 - induction generators and, 259, 303
 - large-scale, 265, 267, 290–291
 - lead-acid batteries, 267–276
 - loads, generally, 264
 - long-term, 263–264, 285
 - parameters, 265–268
 - peak shaving and, 264
 - pumped hydroelectric energy, 290–292, 340
 - self-discharge, 285
 - short-term, 264–265
 - small-scale, 265
 - superconducting magnetic storage system, 286–290
 - time response, 264
 - ultracapacitors, 276–282
 - voltage, 265
- Stream water flow, 63–67
- Street light systems, 149
- Stroboscopic signaling, 150
- Sublimation, 32
- Substation system, 347
- Subtransmission system, power losses of
- equivalent, using experimental design, 348–350, 352
 - estimation of DG influence on, 346–348
- Sugarcane, 15, 181
- Sulfates, 207
- Sulfur:
- biogas formation, 206–207
 - emissions, 159
 - higher heating value for, 34
- Sulfur dioxide (SO₂), 56, 120
- Sulfur oxide, 220
- Sulzer Hexis, 160
- Sun, *see* Solar; Solar energy
- as energy source, 3–4
 - latitude changes, 148
 - mirrored heat, 24
 - renewable energy source, 19–20
 - storage systems and, 296
 - thermodynamic principles, 56
- Sunflower leaves, 206
- Sunshine Energy Pty Ltd., 124
- Supercapacitors, 277
- Superconducting magnetic energy storage (SMES) system:
- characteristics of, generally, 265, 286–287
 - developments in, 288–290
 - economic considerations, 295
 - system capabilities, 287–288
- Supply and demand, 333
- Supply chain, 15
- Supply-side management, 16–19
- Sustainability, 23–25
- Sweden, alternative energy technologies, 18, 84
- Switchable load, 10
- Switched-mode power supply, 372
- Switzerland, alternative energy technologies, 5
- Symmetric EDLC, 279
- Symmetric ultracapacitors, 279
- Symmetric voltage blocking, 318
- Synchronism, 315
- Synchronization, integrated alternative energy sources, 320, 324–325
- Synchronous generators, 236, 247–249, 302–303, 317, 357–358, 375–376

- Syngas, 203
 Synthesis gas, 203
- Taiwan, alternative energy technologies, 6
 Tank walls, 117
 Tariff management, 10, 339
 TARP-WARP system, 102–103
 Telecommunication applications, 151, 162–163, 269
 Teledyne Energy Systems, 160
 Temperature:
 Celsius scale, 30
 Fahrenheit scale, 30, 37
 significance of, 30, 32–33
 thermodynamic, 38
 Temperature-entropy (T-s) diagram, 35
 Therm, defined, 34
 Thermal, generally:
 constants, in thermosolar energy, 118
 efficiency, 39, 42–43
 energy, 19, 176, 178–180
 impedance, 117
 load, 395, 401, 407
 power, HOMER modeling, 398
 systems, DG technologies and, 335
 Thermodynamics:
 commercial applications, 46
 energy balance examples:
 heat pump, 52–53
 heat transfer analysis, 53
 refrigerator, 48–49
 rock bed, 51
 simple residential, 47–48
 solar collector array, 51–52
 water heater, 49–50
 energy calculations, 29–30
 first law of, 36–37, 47
 fundamental laws and principles:
 Brayton cycle for power plants, 38, 44–46
 Carnot cycle plant, 38, 40–42
 energy, 46–47
 example of, 37–40
 overview of, 36–37
 power, 46–47
 Rankine cycle for power plants, 38, 41–44
 planet Earth, as closed system, 54–58
 properties, 29
 residential applications, 46
 second law of, 36–37, 39, 55
 state of system, terminology, 29–35
 temperature, 38
 types of systems, 28
 working fluid, 28, 35, 39, 44, 46
 Thermoelectric power generators, 213
 Thermofilics, 207
 Thermosolar energy, *see* Thermosolar power plants, thermosolar energy
 Thermosolar power plants, thermosolar energy:
 characteristics of, 119–120
 economic analysis of, 126–127
 hydrogen production, 125–126
 parabolic dish, 122–123, 126–127
 parabolic trough, 120–122, 126
 solar power tower, 124
 water heating, 113–119
 Thévenin voltage, 239
 Thin-film solar photovoltaic devices, 23
 Thomson, William, 36
 Three Gorges Dam (China), 2
 Thyristors, 316, 318, 359
 Tidal energy, 4, 6, 19, 21
 Tidal flows, 2
 Tidal power, intensity and frequency characteristics of, 7
 Tidal system, 301
 Time horizon, 326
 Time-series simulation models, 381
 Topography, wind power turbines, 107
 Topping cycle systems, 220
 Toroidal Accelerator Rotor Platform (TARP), 102–103
 Toshiba, 160
 Total net present cost (NPC), 383, 387, 389, 391, 414–416
 Transformers, wind turbines, 107–108
 Transient-state thermal calculations, 116–117
 Transistors, 359
 Transmission systems, 10–11
 Transportation energy need, 29
 Trashcans, biomass source, 201
 Tree(s), *see* Forestry
 deforestation, 55
 deformation, types of, 93
 dry leaves, 206

- Triangular Darrieus turbines, 99, 101
- Triangular spillway, measurement using, 64
- Trip-reclose sequence, 369
- Tubes/tubing, distributed hydrogen process, 125
- Turbine(s), *see specific types of turbines*
 - Carnot cycle and, 40
 - simple power plant, 38–39
- Two-stroke diesel engine, 427–428
- Typhoons, global warming and, 24

- Ukraine, alternative energy technologies, 5
- Ultracapacitors:
 - applications of, 279–282
 - characteristics of, generally, 276–277
 - defined, 277
 - double-layer, 277–278
 - high-energy, 278–279
 - life cycle, 281
- Underfrequency relay (UFR), 322–323, 368
- Undervoltage relay (UVR), 322–323
- Underwriters' Laboratories (UL):
 - functions of, 360
 - independent power systems, inverters, converters, and controllers standards, 362
 - stationary engine generator assembly, safety standards, 363–364
 - transfer switch equipment, 362–363
- Uninterruptible power supplies, 269, 281–282, 284
- Unit conversion factors, 29
- United Kingdom, hydroelectric storage system, 292
- United States:
 - Customary System (USCS), 29–30, 34
 - Department of Energy (DOE):
 - Office of the Biomass Program, 202
 - functions of, 198, 216
 - State Energy Programs, 168
 - economic considerations in, 11
 - electricity system, 334
 - emissions, 4–5
 - energy consumption in, 18, 23–24
 - energy flow, 24–25
 - energy needs, 18
 - integrated renewable energy in, 20–21
 - National Renewable Energy Laboratory (NREL), 379
 - oil dependence, 202
 - photovoltaic system applications, 150
 - wind resources, 85
- Unitized fuel cell, 167
- Unloading, thermosolar energy, 117
- Uranium, 19, 282, 296
- Urban areas, 16, 195, 201, 206
- Urea, 207
- Useful energy output, 53
- UTC Fuel Cells, 160
- Utility/utilities:
 - demand-side management, 339
 - economic considerations, 11–12
 - gas turbine generators, 215
 - grid, 233–234, 236, 249, 255, 324, 329
 - net metering, 375, 378

- Valve-regulated lead-acid (VRLA) batteries, 269
- Vapor(s):
 - Carnot cycle and, 40
 - pyrolysis, 204
 - vaporization process, 32–33
 - water, 33, 176
- Variable costs, 13–14
- Variable-voltage inverters, 305
- Velocity, 31
- Venezuela, alternative energy technologies, 1
- Venturi tubes, 103
- Vestas, 105
- Volatile organic compounds (VOCs), 220
- Voltage, generally:
 - alternate current (AC), 302
 - flywheel systems, 285
 - fuel cells, 185–190
 - induction generators, 234–237, 243, 247–254, 256
 - integrated alternative energy sources, 308, 328
 - lead-acid batteries, 269, 271, 273–274
 - microturbine systems, 226–227
 - power control and, 137
 - regulation of, 339
 - reinforcement, 20
 - source (VS), 305
 - source inverter (VSI), 308–309, 311–312

- Voltage, generally: (*continued*)
 superconducting magnetic energy storage (SMES) system, 287, 289–290
 synchronous generators, 358
 ultracapacitors, 276, 279–280
 wind power turbines, 108–109
- Voltaic cells, 56
- Volume:
 flow rate, 31
 specific, 30–31
- V_{rms} , 91
- Warm-air circulation, in wind turbines, 104
- Waste:
 animal, 207–210, 396
 food oils, 199
 heat, 401
 heat recovery, 397
 incineration, 5
- Wastewater treatment plants, 213
- Water:
 cooling system, 179
 electrolysis, 182
 hammer, 73
 heater, 49–50
 heating process, *see* Water heating
 heat storage, 295
 injection and recirculation of, 170
 pollution, 202, 296
 pumps, in hydroelectric plants, 80–81
 remote meter reading, 156
 salt dilution in, 64–67
 storage, 180
 thermodynamic properties of, 33
- Water heating:
 domestic, 118–119
 distributed generation and, 337
 by solar energy:
 domestic water, 118–119
 process overview, 113–115
 pumping system, 151–153
 thermally isolated reservoirs, heat transfer calculation, 115–118
 thermosolar energy, 121
- Water hyacinth, 205–206
- Water vapor, 33, 176
- Waterwheels, 57, 67–70, 256
- Watt-hour, 266
- Wave energy, 6–7
- Weibull:
 probability distribution, 89–93
 shape factor, 396
- Weight:
 rate of flow, 31
 specific, 30
- Wheat straws, 206
- White pine, thermodynamic properties of, 33
- Wind, *see* Wind energy; Wind power plants
 analysis using visualization, 93
 concentrators, 103
 electricity, 4
 intensity evaluation, 85–87
 patterns, worldwide, 88–89
 speed, 88–94, 101, 104–109
 systems, 22, 301, 335
- Wind Amplified Rotor Platform (WARP), 102
- Wind-diesel-battery system, 384, 387, 391, 413
- Wind-diesel system, 386–387, 389–390, 409
- Wind energy, *see* Wind power plants
 characteristics of, 2, 4, 6, 10, 13, 16–20, 23, 26
 fuel cells and, 181
 induction generators and, 256, 258
 intensity and frequency characteristics of, 7
 intermittent generation with, 10
 markets, 84–85
 storage systems, 296
 U.S. consumption of, 24
- Wind farms, 3, 12
- Wind power plants:
 accessories, 103–104
 access to site, 110
 economic considerations, 110
 generators, 104–109
 induction generators, 233, 248, 255, 259
 meteorological mapping, 87–89
 overview of, 84–85
 purpose of energy generated, 95
 small generating systems, 109–110
 solar energy and, 112
 speed control, 104–109
 System TARP-WARP, 102–103
 topography, 93–95
 turbines, *see* Wind turbines

- wind intensity evaluation, 85–87
- wind power, 95–99
- Weibull probability distribution, 89–93
- Wind-PV-battery system, 392
- Wind-PV-diesel-battery system, 392
- Wind turbines:
 - characteristics of, 3, 5, 20–22
 - Danish concept, 254–255
 - drag turbines (Savonius), 100–101
 - fuel cells and, 169
 - HOMER modeling, 380, 389, 395–397, 399–400
 - integrated alternative energy sources, 357
 - investment in, 6, 13
 - large-scale, 258
 - lifting turbines:
 - characteristics of, 101
 - Darrieus-Tropskien turbine, 101–102
 - multiple-blade, 99
 - one-blade, 98
 - overview of, 97–99
 - rotor turbines, 99
 - system TARP-WARP, 102–103
 - two-blade, 98
 - variable-speed, 20
- WinWind, 105
- Wireless communications, 281
- Wood, generally:
 - fuel, 2
 - higher heating value for, 34–35
 - pellets, 199
 - processing, 199
 - waste, 395
- Working fluid, 28, 35, 39, 44, 46
- Zebra batteries, 267
- Zero-current switching, 318
- Zero-voltage switching, 318
- Zinc-air batteries, 267
- Zinc-air fuel cell, 168
- Zinc oxide, 125
- Z-source converter, 306