Appendix A

A
Acid rain, 146
Active thermal design, 785
Agriculture, 770
Aircraft, 753
Air pollution, 147

Clean Air Act, 154
Criteria pollutants, 147
HAPs, 151
Source apportionment, 149
Toxics, 151

Alternative fuels, 310
Aluminum industry, 766
Arrhenius equation, 117
Assessment models and scale, 241

Automobiles, 728, 739
Electric, 739
Fuel economy, 741
History, 728
Hybrids, 742
Life cycle assessment, 744
Costs, 746
Energy use, 747
GHG emissions, 748
Lightweighting, 749
Operating costs, 746
New technologies, 749
Availability, 652

B
Batteries, 654, 666
Bellagio principles, 287
Betz ratio, 624
Biofuels, 432
Conversion, 308, 432, 437
Fermentation ethanol, 240, 437
Biogas, 437
Biological CO2 storage, 333, 336
Biomass energy (see Ch. 10), 419
Advantages, 421
Bagasse, 433
Bioengineering, 444
Chemical/physical properties, 429
Co-firing, 426
Conversion processes, 432
Definition, 420
Derived products, 425
Digester (China, India), 439
Disadvantages, 426
Economics, 443
Electricity production, 432
Deregulation impacts, 433
Gasiﬁcation, 434, 437
Environmental impacts, 424, 440
Ethanol, 441
Fuels, 434
Higher heating value, 431
Production, 430
Production rates, 428, 430
Properties, 429, 431
R&D, 444
Renewability indices, 421
Resources, 420, 427
Scaling, 429
Sulfur content, 431
Time constants, 422
Trace elements, 431
Use expansion, 424, 436
Vermont gasiﬁer project, 435
Waste to energy, 426
Wood stoves, 442
Bitumen, 299
Bottoming cycle, 108
Brayton cycle, 106
BTU tax, 339, 718
Buildings (see Ch. 20), 777
Active thermal design, 785
Comfort standards, 786
Commercial, 789
Desiccant systems, 787
Efﬁciency, 785, 789
Embodied energy, 781
Energy use patterns, 779
Heat transfer, 783
History, 778
Indoor air, 783, 791
Life cycle analysis, 780
Life cycle costs, 779
Lights/appliances, 783
Passive thermal design, 785
Recycling, 782
Residential, 784
Smart buildings, 790
Sustainability issues, 792
Ventilation, 783

Commercial buildings, 789
Conduction, thermal, 122
Consumption, excessive, 285, 338
Convection, thermal, 123
Conversion factors, 53, 827
Cost of money, 215

Carbon management, 333
Carbon sequestration (storage), 178, 722
Biological, 179, 336
Capture costs, 179, 722
Capture and storage, 179, 334
Geological, 335
Ocean, 336
Carbon taxes, 722
Carnot engines, 100
Carrying capacity, 261
Cars (see Automobiles)
Cartels, 78, 81
Catalysis, 119
CCGT, 108, 323
Cement industry, 767
Chemical industry, 769
Chemical rate processes, 116
Kinetics, 118
Chernobyl, 377
Clean Air Act, 154
Climate change, 158
Cloud effects, 161
FCCC, 266
Models, 162
vs. weather, 172
CO₂ (see also Carbon)
Emissions, 333
Utilization, 334
CO₂ concentrations (atm.), 158
Coal, 310
Gasification, 312, 324
Liquefaction, 311
Pyrolysis, 310, 311
Transport, 675
Coefficient of performance, 99
Combined (power) cycle, 108
Combustion, 108, 317
Attributes, 317
Droplet model, 321
Fuel, 317
Heat of, 299
Imperfections, 332
Incomplete, 330
Micromixing, 319
Reaction rates, 116
Temperature limitations, 333
Zone, 321
Combustors, 322
Comfort standards, 786

Dams (see Hydropower), 522
Decision analysis, 229, 802
Monte Carlo, 230
Trees, 232
Depletion, oil, 64, 75, 276
Depletion rates (example), 304
Deregulation, 697
Development
History, 260
Sustainable, 2, 354
Diesel engines, 110
Discount rates, 220
Constant vs. current $, 222
Real vs. nominal, 220
Distributed electric generation, 678

Earth system ecology, 192
Ecology, 191
Ecological footprint, 283
Economic analysis (see Ch. 5), 208
Annual fixed charge, 216
Basics, 211
Busbar costs, 216, 224
Cash flow, 213
Compounding interest, 211
Constant dollar analysis, 222
Continuous compounding, 211
Cost of money, 214
Discount rates, 211, 220
Economies of scale, 225
Escalation rate, 214
Externalities, 208
Fossil energy, 341, 346
Future worth, 211
History, 210
Inflation rate, 214
Interest rate, 211
Learning curve, 225
Levelized costs, 213, 245
Oil cost comparisons, 343
Payback time, 225
Pitfalls, 220
Plant capacity factor, 214
Present value (worth), 213
Price spikes, 72, 337
Production costs, 215
Purchasing power parity, 264
Index

Energy
Accounting, 239
Biomass (see Ch. 10), 421
Carrier, 55, 723
Crises, 79
Consumption, per capita, 3, 26
Conversion, 9, 55
Definition, 9
Economics, 341
Efficiency, 18, 57
Equity, 338
Prosperity-envir. dilemma, 41
Forms, 54
Fossil (see Ch. 7), 295
Fusion, 397
GDP correlation, 25, 26
Geothermal (see Ch. 11), 454
Hydropower (see Ch. 12), 520
Infrastructure, 648
Intensity, 267
Internal, 12
International trade, 21, 22
Kinetic, 12
Markets, 715
Nuclear (see Ch. 8), 361
Ocean (see Ch. 14), 589
Potential, 12
R&D, 269
Renewable, US, 29, 31
Renewable, World, 24
Solar (see Ch. 13), 543
Sources, 24
Storage/transport (see Ch. 16), 647
Systems, 9, 191
Taxes, 339
Technology evaluation, 346
Transmission, 670
Coal, 675
Electricity, 676
Gas, 674
Oil, 671
Units, 53, 827
US supply and use, 30
Wind (see Ch. 15), 613
World use by fuel & region, 264
Energy carriers, 55, 723
Energy distribution, 678
Enforcement issues, 184, 200
Entropy, 90
Environment (see Ch. 4), 137
Costs of impacts, 41
Effects of energy use, 138
Energy impacts, 32
Energy-prosperity dilemma, 41
Equity issues, 4, 40
External costs, 34, 232
Impacts, by supply techn., 37

Electric power costs, 706
Economic estimation, 216
Fossil vs. nuclear, 236, 344
Nuclear O&M costs, 216, 345
Sensitivity to fuel price, 344
Uncertainties, 229, 346

Electricity
Distributed generation, 678
Grid, 678
Losses, 141
Transmission, 670
US production and utilization, 30

Electromagnetic radiation, 140

Emissions (see Ch. 4), 137
Air toxics, 151
Carcinogens, 330
CO, 149, 330
CO2, 333
GHG per capita, 333
HAPs, 151
HCs, 149
Length and time scales, 143
Mineral matter, 329
NOx, 149
Particulates, 152
PICs, 329
Soot, 330
SOx, 149
Thermal NO, 149
Trading, SO2, 200
US Standards, 155
VOCs, 150

Electric Power (see Ch. 17), 693
Carbon sequestration, 722
Central generation, 700
Costs of generation, 706
Demand side management, 708
Deregulation, 697, 708
Federal Power Commission, 696
Growth, US usage, 696
History, 694
ISOs, 697
Market imperfections, 712
Planning case study, 710
Pollution, 696, 701
PURPA, 697
Real-time pricing, 698
Sustainability issues, 719
Transmission/distribution, 708

Efficiency, 17
Buildings, 780
Energy devices, 54, 58, 100
Heat engine cycles, 100

Economic terrorism, 338
Economies of scale, 214, 348
Efficiency, 17
Buildings, 780
Energy devices, 54, 58, 100
Heat engine cycles, 100
Electric Power (see Ch. 17), 693
Carbon sequestration, 722
Central generation, 700
Costs of generation, 706
Demand side management, 708
Deregulation, 697, 708
Federal Power Commission, 696
Growth, US usage, 696
History, 694
ISOs, 697
Market imperfections, 712
Planning case study, 710
Pollution, 696, 701
PURPA, 697
Real-time pricing, 698
Sustainability issues, 719
Transmission/distribution, 708

Standard deviation, 229
Subsidies and tax breaks, 221
Economic terrorism, 338
Economies of scale, 214, 348
Efficiency, 17
Buildings, 780
Energy devices, 54, 58, 100
Heat engine cycles, 100
Electric Power (see Ch. 17), 693
Carbon sequestration, 722
Central generation, 700
Costs of generation, 706
Demand side management, 708
Deregulation, 697, 708
Federal Power Commission, 696
Growth, US usage, 696
History, 694
ISOs, 697
Market imperfections, 712
Planning case study, 710
Pollution, 696, 701
PURPA, 697
Real-time pricing, 698
Sustainability issues, 719
Transmission/distribution, 708

Electric power costs, 706
Economic estimation, 216
Fossil vs. nuclear, 236, 344
Nuclear O&M costs, 216, 345
Sensitivity to fuel price, 344
Uncertainties, 229, 346

Electricity
Distributed generation, 678
Grid, 678
Losses, 141
Transmission, 670
US production and utilization, 30

Electromagnetic radiation, 140

Emissions (see Ch. 4), 137
Air toxics, 151
Carcinogens, 330
CO, 149, 330
CO2, 333
GHG per capita, 333
HAPs, 151
HCs, 149
Length and time scales, 143
Mineral matter, 329
NOx, 149
Particulates, 152
PICs, 329
Soot, 330
SOx, 149
Thermal NO, 149
Trading, SO2, 200
US Standards, 155
VOCs, 150

Energy
Accounting, 239
Biomass (see Ch. 10), 421
Carrier, 55, 723
Crises, 79
Consumption, per capita, 3, 26
Conversion, 9, 55
Definition, 9
Economics, 341
Efficiency, 18, 57
Equity, 338
Prosperity-envir. dilemma, 41
Forms, 54
Fossil (see Ch. 7), 295
Fusion, 397
GDP correlation, 25, 26
Geothermal (see Ch. 11), 454
Hydropower (see Ch. 12), 520
Infrastructure, 648
Intensity, 267
Internal, 12
International trade, 21, 22
Kinetic, 12
Markets, 715
Nuclear (see Ch. 8), 361
Ocean (see Ch. 14), 589
Potential, 12
R&D, 269
Renewable, US, 29, 31
Renewable, World, 24
Solar (see Ch. 13), 543
Sources, 24
Storage/transport (see Ch. 16), 647
Systems, 9, 191
Taxes, 339
Technology evaluation, 346
Transmission, 670
Coal, 675
Electricity, 676
Gas, 674
Oil, 671
Units, 53, 827
US supply and use, 30
Wind (see Ch. 15), 613
World use by fuel & region, 264
Energy carriers, 55, 723
Energy distribution, 678
Enforcement issues, 184, 200
Entropy, 90
Environment (see Ch. 4), 137
Costs of impacts, 41
Effects of energy use, 138
Energy impacts, 32
Energy-prosperity dilemma, 41
Equity issues, 4, 40
External costs, 34, 232
Impacts, by supply techn., 37
Lifetime, 472, 487
Recoverable power, 472
R&D, 509
Thermal stress, 473
Well spacing, 470
Resource types, 454
Categories, 455
High grade, 455
Low grade, 455
Natural fluids, 454
Steam, 454
Resource size/distribution, 464
Resource base, 464
Accessible base, 465
Resource, 466
Reserve, 467
Reservoir productivity, 455
Sustainability, 487
CO₂ reduction, 490
Technology, today, 491
Total geo-energy estimates, 468
Ultra low-grade systems, 461
World capacities, 468
Geothermal fluids, chemistry, 465
Global change
Anthropogenic factors, 161
Climate models, 160, 165
Environmental consesq., 167, 260
Global warming potential, 170
Length and time scales, 145
Solar variability, 170
Global circulation models, 160
Clouds, 161
Forcing components, 163
Predictions of future T rise, 175
Scenario analysis, 176
Uncertainties, 177
Global concerns, 260
Greenhouse effect, 160, 167
Greenhouse gases, 171
Emissions per capita, 3, 25, 286, 333

H
Half-life, 118
Health effects, 143
Cancer and mutagenicity, 145
Length and time scales, 143
Heat, waste, 139
Heat engines, 98
Brayton cycle, 106
Carnot cycle, 99
Diesels, 112
Otto cycle, 110
Irreversible, 102
Rankine cycle, 103
Heat islands (urban), 138
Heat of combustion, 299
Heat transfer, 120
Conduction, 122
Convection, 123
Coupled, 128
Radiation, 124
Time scales, 129
Heavy oil, 305
Hubbert curve, 71
Hybrid cars, 650
Hydrogen
Energy carrier, 55, 723
J-T properties, 96
Storage, 55, 655, 665
Hydrogen/carbon ratios, 299
Hydropower (see Ch. 12), 519
Dams, 522
Construction, 527
Development potential, 531
Economics, 535
Energy conversion, 525
Efficiencies, 527
Energy sources, 525
Environmental issues, 522
Fish migration, 534
Growth potential, 537
Health risks, 533
Hydro-engines, 539
Overview, 520
Potential energy, 520
R&D needs, 537
Regulatory issues, 537
Representative mega-projects, 521
Resource assessment, 522
Sedimentation, 534
Sustainability attributes, 531
Three Gorges Dam, 523
Turbines, 529
Fish-friendly, 538
Francis & Kaplan, 529
Hydraulic, 529
Matrix, 539
Pelton, 529
Ultra-low head, 540
Types, 525
Impoundment, 525
Pumped storage, 525
Run-of-river, 525
Water management, 522, 527
World capacity estimates, 524

I
Imports
Natural gas, world, 22
Petroleum, US, 21
Indicators of sustainability, 280
Early warning, 281
Ecological footprint, 197, 282
Flow, 282
HDI, 265, 284
Literate life expectancy, 284
Pressure-state-response, 282
Stock, 282
Indoor air quality, 791
Industrial energy use (see Ch. 19), 761
Agriculture, 770
Cement industry, 767
Chemical industry, 769
CO₂ streams, 769
Depletion, 764
Eco-efficiency, 764
Forest products industry, 770
GHG emissions, by industry, 763
History, 762
Metals industry, 766
Aluminum, 767
Ferrous, 766
Mixed alloys, 767
Recycling, 767
Sustainability issues, 773
Sustainable design, 763
Waste management industry, 772
MSW GHG emissions, 773
Waste minimization, 765
Industrial ecology, 7, 42, 192
Integrated global climate models, 160, 165, 812
Interurban/continental transport, 753
Infrastructure
Fossil fuel, 352
International accords, 338
ISO Std. 9000, 278
ISO Std. 14,000, 279
ITER, 402

J
Joule Thompson expansion, 96

K
Kaya equation, 46, 267
Kerogen, 299
Kinetic energy storage, 654, 661
Kinetics
Chemical (rates), 116
Energy, kinetic, 12
Kyoto Protocol, 183, 195

L
Life cycle assessment, 273
Automobiles, 744
Buildings, 781
Energy technologies, 36, 186
Example (McDonald’s), 274
Industries, 760
Methodology, 273
Wind turbine energy, 635
Limits to growth, 7, 807
LNG, 22, 657, 674, 719
Load curves (electric), 649

M
Metals industry, 766
Methanation, 313
Micromixing, 319
Millenium Summit, 817
Mitigation options, 178
Models
Global circulation, 162
Scales, 241
Monte Carlo methods, 230
Montreal Protocol, 195
Municipal solid waste, 772

N
Natural gas (methane), 298
Global trade, 22, 715
LNG, 22, 657, 674, 719
Peak shaving, 656
Storage/transport, 655, 674
Negotiation, 805
Neutrinos, 363
NO formation, 320, 333
Noise
Emissions, 139
Nuclear (see Ch. 8), 361
Actinide burning, 385
Advanced reactors, 387
 Burning and breeding, 368, 384
BWR technology, 377
CANDU reactor, 380
Chernobyl, 377
Containment, 372, 383
Cooling system, 372
Cost comparisons, 217, 345
“Critical” definition, 366
Defense-in-depth, 372
Economics, 369
First plant, 363
Fission, 362
Fission reactors, 374
Fuel conversion, 368, 391
Fuel cycle, 389
Fuel enrichment, 391
Fuel fabrication, 392
Fuel reprocessing, 393
Fuel rods, 374
Fusion, 397
Future prospects, 404
Gas cooled, 380
Generating units operating, 363
Heavy water cooled, 380
High level wastes, 385, 394
History, 362
Liquid metal reactors, 384
LWR technology, 374
Fuel cycle, 389
Moderators, 365
Pebble bed reactor, 382
Physics, 364
Power O&M costs, 216, 344
Prismatic reactor design, 382
Proliferation, 368
PUREX, 393
PWR technology, 374
Radioactive decay, 385, 392
Radioactive species, 394
Reactor safety, 372
Reactors, 368, 374
Regulation, 369
Reprocessing, 393
RMBK technology, 377
Social acceptance, 405
Steam generator, 374
Spent fuel, 389, 392
Submarines, 363
Technology choice, 374
Three Mile Island, 370
Tokamak, 402
US capacity & projections, 32
Weapons, 363, 368, 393
Safeguards, 395

Waves, 597
“Ducks”, 597
Run-up ramps, 597

Oil, 298
Cartels, 78, 81, 337
Competition with gas, 715
Cost comparisons, 342
Dependence, 77
Economics, 66, 78
Embargo, 1973, 337
Geology, 65
Geopolitics, 79
Gulf War, 337
Heavy, 305
Imports, US, 21
Kerogen, 299
Middle East, 337
OPEC, 21, 339
Price spikes, 72, 337
Prices, 72
Production rates, 70
Refiner’s margin, 309, 352
Refining, 309
Reserves, 60, 75
Shale, 298
Tar sands, 298
Transmission, 671
Otto cycle, 110
Ozone
Hole, 38
Smog role, 38, 153
Tropospheric, 157

Passive thermal design, 781
Peak shaving, 648, 656
Petroleum (see Oil), 298
Photovoltaics (see Solar)
Policy
Cap and trade, 182
Carbon management, 178
Carbon taxes, 181
SO2 experience, 196, 200
Pollution (see also Emissions)
Combustion engines, 141
Developing countries, 354
Source identification, 190
Toxic, 151
Transport and transformation, 151, 157
Population growth, 23, 27, 268
Power, 9
For various activities, 19
Project evaluation, 346
Project siting, 352
PURPA, 505, 697
Pyrolysis, 310
Quality, fuel, 307

R&D, 269
Radiation
  Nuclear, 364
  Biological effects, 364
  Thermal, 124
  Radioactivity, 362
  Rankine cycle, 103
  Rayleigh distribution, 619
  Reaction rates, 118
  Recycling, construction materials, 783
  Reduced consumption, 708
  Refiner's margin, 309, 352
  Refining (oil), 309
    Hydrodesulfurization, 309
    Hydrogen use, 310
  Methanation, 313
  Synthesis gas, 314
  Water gas shift, 312
  Reformers (see Fuel cells)
  Renewability indices, 421
Renewable energy (see Chs. 9–15)
  Barriers, 413
  Environmental impacts, 412
  Funding, 415
  Future, 415
  History, 408
  Overview, 408
  Recovery fraction, 411
  Resources, 412
    Quality, 411
    Siting issues, 412
  Storage, 414
  Technology development, 413
  Time scales, 411
  Types and transfer processes, 409
  US sources, 29
  Variability, 410
Renewable portfolio standard, 506
Reprocessing nuclear wastes, 393
Residential design, 784
Resources (see Ch. 2), 51
  Fossil, 59
  Renewables, 412
Resource depletion, 64
  Fixed stock, 66
  Hubbert curve, 68
  Oil and gas, 59
  Reserve growth, 61
  Types, 75
Revenue scaffolds, 339
Risk
  Acceptability, 277
  Energy systems, 143
  Human health, 278
  Management, 277
  Models, 276
Sleipner Project, 179
Smart buildings, 787
SMES, 669
Smog (ozone production), 39, 157
Solar cells, 572
  Amorphous, 578
  Cadmium telluride, 579
  Copper indium selenium, 579
  Polycrystalline, 578
  Silica-based, 578
  Single crystals, 579
  Triple junction, 582
Solar energy (see Ch. 13), 543
  Active systems, 556
  Buildings, 554
  Capture efficiency, 546
  Collector orientation, 546, 550
  Concentrated solar power, 562
    Costs, 567, 570
    Future, 569
  Cooling applications, 556
  Dish systems, 568
  Flat plate, 558, 575
  Future potential, 584
  History, 544
  Million solar roofs, 584
  Molten salt systems, 566
  Parabolic troughs, 565
  Passive solar, 555
Photovoltaic systems, 572
  Balance of system, 581
  Cell efficiency, 576, 578
  Durability, 576
  Future potential, 580
  Silica-based, 578
  Solid state chemistry, 573
  Thin films, 582
  Power tower, 562
  Reliability, 583
  Resource assessment, 544, 548
  Semiconductors, 573
  Source, 544
  Storage, hot water, 557
  Sustainability, 582
    Land impacts, 583
    Pros and cons, 582
    Tracking, 546
    Trombe walls, 555
    Variability, 547
    Water heating, 557
    Windows, 582
Index

Sound, 139
Source identification, 140, 190
Special relativity, 13
Stakeholders, 800
Storage and transmission (see Ch. 16), 647
Advanced systems, 684
Batteries, 654, 666
Chemical energy, 665
Dispatchability, 648
Economics, 684
Efficiency, 648
Efficiency chains, 651
Infrastructure, 648
Interruptability, 648
Kinetic energy, 654, 661
Load curves, 649
Modes, 654
Natural gas, 655
Peak shaving, 648, 656
Regulation, 648
Storage times, 656
Sustainability issues, 683
Technology characteristics, 655
Thermal energy, 664
Transmission, 670
Coal, 675
Electricity, 676
Gas, 674
Oil, 671

S
Sunk costs, 215, 220
Supercapacitors, 669
Sustainability (see Chs. 6, 21)
Approaches, 41
Definitions, 8
Drivers of change, 284
Fossil fuel, 353
Impact of cheap oil, 78
Limits to growth, 261, 807
Metrics, 45
Politics, 40
Tragedy of the commons, 261
Sustainability indicators, 280
Early warning, 281
Ecological footprint, 282
Flow, 282
HDI, 265, 284
Literate life expectancy, 284
Pressure-state-response, 282
Stock, 282
Sustainable development
Bellagio principles, 287
Definition, 8, 261
Sustainable energy
Criteria, 2
Definitions, 7

T
Tar sands, 298
Technology
Competition, 375
Development, 350
Emerging, 353
Environmental control, 196
Evaluation, 346, 351
Investment levels, 350
Maturity levels, 353
Readiness levels, 351
Scale-up, 348
Time scales, 352
Temperature
Future global ranges, 175
Global surface, 159
Limitations on combustion, 318
Mean surface T anomalies, 164
Thermodynamics (see Ch. 3), 87
Availability, 652
Brayton cycle, 106
Carnot cycle, 99
Closed systems, 10
Coefficient of performance, 99
Combined cycles, 108
Diesels, 112
Efficiency, 99
Enthalpy, 13
Entropy, 90
First and second laws, 10, 90
Heat, 10
Heat engines, 99
J-T expansion, 96
Otto cycle, 110
Perfect gas law, 93
Power, 12
Rankine cycle, 103
Topping and bottoming, 109