

Contents

Preface	xxvii
Acknowledgments	xxxi
Author	xxxiii
1 Introduction to Sustainability, Principles, and Its Effect on Design and Manufacturing	1
1.1 Introduction	1
1.1.1 Water Has No Substitute	3
1.1.2 Sustainable Water Management	3
1.1.3 Recycling Technologies	3
1.1.4 Getting Started	4
1.2 Design for Sustainability	6
1.2.1 Sustainable Initiatives	6
1.2.2 Cleaner Production	7
1.2.3 Design for Sustainability	7
1.3 Objectives for Green Design	7
1.4 Rubicon of Engineering Design	8
1.5 Some Green Design Methods and Tools	8
1.5.1 Systems Thinking	8
1.5.2 Environmental Life Cycle Assessment (LCA)	8
1.5.3 Material Flows and Cycles	8
1.5.4 Green Indices	8
1.5.5 Design for Disassembly and Recycling Aids	9
1.5.6 Risk Analysis	9
1.6 Mathematical Representations of Sustainability	9
1.7 Material Selection and Label Advisors	9
1.8 Green Power Generation	10
1.9 Net Energy Analysis	10
1.10 Greenhouse Gas Emission Rates	11
1.11 Carbon Accounting in Corporations	11
1.11.1 Environmental Full Cost Accounting Methodologies	11
References	13
Bibliography	13

Section I Industrial Ecology and Sustainability

2	Industrial Ecology and Sustainability	17
2.1	Introduction	17
2.2	Global Warming Potential	21
2.2.1	Basic Principles.....	21
2.3	Material Balances.....	25
2.4	Bases and Units	25
2.5	Total Mass and Composition	25
2.6	Continuous Processes	26
2.7	Blending	27
2.8	Drying	27
2.9	Energy Balances	27
2.10	Heat Balances	28
2.11	Other Forms of Energy	30
2.12	Flow Chart	31
2.12.1	Method for Preparing Process Flow Chart	31
2.12.2	Guidance for Material and Energy Balance	31
2.12.3	Steps in Mass and Energy Balance Calculation.....	32
2.13	Ecological Economics	35
2.14	Energy Economics	36
2.14.1	Embodied Energy Methodologies	37
2.14.2	Embodied Energy in Common Materials	37
	References.....	38
	Bibliography	39
3	Economics of Sustainable Engineering	41
3.1	Introduction	41
3.2	Total Revenue, Total Costs, and Profit Relations.....	41
3.2.1	Total Cost Function	41
3.2.2	Total Revenue Function	41
3.2.3	Total Profit Analysis	42
3.3	Life Cycle Cost Analysis	43
3.4	Efficiency and Life Cycle Cost Calculation of a Pump.....	44
3.4.1	Beyond Purchase Price.....	44
3.4.1.1	Calculating Total Life Cycle Cost	45
3.4.2	Reduced Energy Costs.....	45
3.4.3	System Changes.....	45
3.4.4	Energy Savings through Pump Control	46
3.4.5	Maximize Pump Efficiency	46
3.4.6	LCC Educated Pump User	47
3.5	Mechanics of Time Value of Money	47
3.5.1	Relationships for Discrete Compounding.....	47
3.5.2	Geometric Gradient: Constant Percentage Increment	48
3.5.3	Nominal and Effective Interest Rate	51
3.6	Economic Project Selection.....	52
3.7	Benefit–Cost Relation for Recycling	54
3.8	Selection of Renewable Energy over a Time Period	56
3.9	Cost-Estimating Technique.....	56
3.10	Estimating Techniques.....	58
3.10.1	Sources of Estimating Data.....	58
3.11	Indexes.....	58
3.12	Parametric Cost Estimating.....	60
3.12.1	Power-Sizing Technique.....	60
3.12.2	Learning Curve Method	61

3.13	Developing a Cost-Estimating Relationship (CER).....	64
3.14	Sustainability Considerations in Cost Accounting	65
3.15	Carbon Dioxide Sequestration and Storage.....	66
3.16	Sustainable Economy Problems.....	68
	References.....	72
	Bibliography	72
4	Analytical Techniques for Sustainability Analysis.....	73
4.1	Nonlinear Optimization.....	73
4.1.1	Introduction to Optimization and Green Optimal Design.....	73
4.1.2	Optimization Problem and Model Formulation.....	74
4.1.2.1	Basic Components of an Optimization Problem	74
4.1.3	Objective Function.....	74
4.1.4	Statement of an Optimization Problem.....	74
4.1.5	Basic Mathematical Model	75
4.1.6	Requirements for Application of Optimization Methods to Optimal Design	75
4.1.7	Basic Design Problem	75
4.1.8	Optimal Design	76
4.1.9	Selection of Optimal Shape.....	77
4.1.9.1	Circular Tray Design	78
4.1.10	Issues to Be Resolved by the Algorithm Developer	79
4.1.10.1	Gradient-Free Algorithms	79
4.1.10.2	Diagnosis of Function Generator Difficulties (Knowledge-Based Optimization)	79
4.1.10.3	Robust, Sturdy Software.....	80
4.1.10.4	Noise-Tolerant Algorithms.....	80
4.1.10.5	Application-Oriented Software Design	80
4.2	Single and Multiobjective Optimization: A Brief Overview.....	80
4.2.1	Model Development.....	82
4.2.2	Model Validation and Evaluation.....	82
4.2.3	Modeling Techniques	82
4.2.3.1	Optimization Methods: Introduction and Basic Concepts.....	82
4.2.4	Variables	82
4.2.5	Constraints.....	82
4.2.6	Constraint Surfaces.....	83
4.2.7	Formulation of Design Problems as Mathematical Programming Problems	83
4.2.8	Problem Formulation	84
4.2.9	Selection of Design Variables	84
4.2.10	Selection of Constraints	84
4.2.11	Objectives	84
4.2.12	Models.....	84
4.2.13	Representation in Standard Form	85
4.2.14	Problem Solution.....	85
4.3	Function of a Single Variable in Optimal Engineering Design.....	86
4.3.1	Monotonic Function.....	86
4.3.1.1	Unimodal Function	86
4.3.1.2	Optimality Criteria.....	87
4.3.1.3	Inflexion Point or Saddle Point.....	87
4.3.2	Concept of Global Optimum.....	89
4.3.2.1	Algorithm.....	89
4.3.3	Region-Elimination Methods.....	89
4.3.4	Global Optimum	89
4.3.5	Interval Refinement Phase.....	91
4.3.6	Methods Requiring Derivatives.....	94
4.3.7	Newton–Raphson Method.....	94
4.3.8	Newton Second-Order Method	95

4.3.9	Constrained Optimization	95
4.3.10	Equality-Constrained Optimization.....	96
4.3.11	Lagrange Multiplier Method.....	96
4.3.12	Kuhn–Tucker Conditions.....	97
4.4	Engineering Design (Optimal Design) Examples	102
4.5	Geometric Programming	116
4.5.1	Geometric Programming Model	116
4.5.1.1	Examples for Geometric Programming Problems	117
4.6	Comparing Classical and Advanced Techniques for Optimization	136
4.6.1	Classical Optimization Techniques.....	136
4.6.2	Advanced Optimization Techniques	136
4.6.3	Optimization Software.....	137
	References.....	137
	Bibliography	138

Section II Green Design and EOL Treatment

5	Principles of Green Design	141
5.1	Design for the Environment	142
5.2	Environmentally Conscious Production.....	144
5.3	Green Design Tools	144
5.3.1	Mass Balance Analysis	144
5.3.2	Green Indices.....	145
5.3.3	Energy Content.....	145
5.3.4	Eco-Indicators	145
5.4	Footprint Indicators	145
5.4.1	Design for Disassembly and Recycling Aids.....	146
5.4.2	Recycling	146
5.5	Factors in Material Selection for Environmentally Conscious Design	147
5.6	Green Designing and Machining.....	147
5.7	Steps in Eco-Material Selection for Mechanical Components	149
5.7.1	Selection of Material by Cost/Unit Volume Consideration.....	149
5.7.2	Merit Index Method.....	154
5.7.3	Performance Index Method.....	155
5.8	Materials Properties Chart.....	156
	References.....	162
	Bibliography	162
6	End-of-Life Treatment and Environmental Impact Scenario	163
6.1	LCA Analysis at EOL	164
6.2	Minimization of Embodied Energy.....	167
6.3	Minimization of Carbon Footprint	169
6.4	Product's GHG Flow	170
6.5	Low-Carbon Design	170
6.6	Estimation of GHG Emission of a Product.....	171
6.6.1	Raw Materials Stage	171
6.6.2	Manufacturing Stage	171
6.6.3	Distribution Stage	172
6.6.4	Use Stage.....	172
6.7	End-of-Life Scenario	172
6.7.1	Estimation of Embedded GHG Emission of a Part.....	172
6.7.2	Concept of Low-Carbon Product System.....	174
6.7.3	Establishment of GHG Emission Target.....	174
6.7.4	Establishment of BOM Structure	175

6.7.5	Formation of g-BOM	175
6.7.6	Estimation of GHG Emissions Using g-BOM of the Product	175
6.7.7	Identification of Problematic Parts with High GHG Emissions.....	175
6.7.8	Selection of Alternative Parts to Replace Problematic Parts.....	175
References.....		176
Bibliography		176

Section III Green Design of Mechanical Components

7	Spring Design for Sustainability	179
7.1	Green Spring Design	179
7.2	Helical Compression Spring Design.....	181
7.3	Principles of Green Spring Design.....	183
7.3.1	Minimize Total Embodied Energy.....	183
7.3.2	Deflection of Spring.....	184
References.....		189
Bibliography		189
8	Environmentally Conscious Design of Gears	191
8.1	Introduction	191
8.2	Gear Types	191
8.2.1	Spur Gears.....	191
8.2.2	Helical Gears.....	191
8.2.3	Bevel Gears.....	193
8.2.4	Hypoid Gears.....	193
8.2.5	Worms and Worm Gears.....	193
8.2.6	Planetary Gears	194
8.2.7	Rack and Pinion	194
8.3	Common Terms in Gear Design: Power, Torque, Horsepower, and Gear Ratio	194
8.4	Gear Defects	194
8.5	Limits of Wear for Discarding.....	194
8.6	Lubrication of Gears.....	195
8.7	Steps in Spur Gear Drive Design.....	195
8.7.1	Guidelines for Adjustments in Successive Iterations.....	198
8.8	Helical Gear Design	198
8.8.1	Kinematics.....	199
8.8.2	Helical Gears, Geometry, and Nomenclature.....	199
8.8.3	Helical Gears: Force Analysis.....	202
8.8.3.1	Helical Gears Force Analysis: Bending Stress	203
8.8.3.2	Helical Gear: Contact Stress.....	206
8.8.4	Helical Gear: Surface Fatigue Strength.....	207
8.8.5	Helical Gear: Allowable Surface Fatigue Stress (AGMA)	207
8.9	Crossed Helical Gear.....	209
8.9.1	Crossed Helical Gear: Design Tips.....	210
8.10	Worm Gear Design.....	210
8.10.1	Materials Used for Worm and Worm Wheel.....	211
8.10.2	Worm Gear Force Analysis.....	213
8.11	Bevel Gear Design.....	217
8.11.1	Nomenclature of Bevel Gears.....	217
8.12	Losses in Gearboxes	220
8.13	End-of-Life Considerations: Reuse, Recycling of Gears, and Sustainability Considerations....	222
8.14	Environmental Benefits of Gear and Steel Recycling.....	222
8.15	Innovative Gearboxes for the Waste and Recycling Industry	222
8.15.1	Flush Procedure for Gear/Rack Replacement.....	223

Reference.....	224
Bibliography	224
9 Shaft Design	227
9.1 Introduction and Applications of Shaft.....	227
9.1.1 Definitions of Some Common Terms	227
9.1.2 Shaft Materials	230
9.1.3 Functions of a Shaft	230
9.1.4 Shaft Bearings	231
9.1.5 Transmitting Torque to and from Shafts.....	232
9.1.6 Keys	232
9.1.7 Key Data	232
9.1.8 Grub Screws and Set Screws.....	234
9.1.9 Splines	234
9.1.10 Shaft Failure Modes	235
9.2 Stress Concentration and Fatigue Cracking.....	236
9.2.1 Mechanism of Fatigue Cracking.....	236
9.2.2 Load Cycles	236
9.2.3 Fatigue Crack Propagation	237
9.3 Stress Concentrations.....	237
9.3.1 Stress Concentration Factors.....	238
9.3.2 Reducing Stress Concentrations	238
9.4 Shaft Stresses and Design	242
References.....	244
Bibliography	244
10 Bearings and Green Engineering	245
10.1 Shaft Bearings.....	245
10.2 Sliding-Contact Bearings	246
10.2.1 Materials for Plain Bearings	246
10.2.2 Lubrication of Plain Bearings.....	247
10.2.3 Characteristics of Plain Bearings.....	247
10.2.3.1 Design of Plain Bearing	248
10.3 Rolling-Contact Bearings.....	252
10.3.1 Characteristics of Rolling-Contact Bearings	253
10.3.2 Tapered Roller Bearing.....	254
10.3.3 Roller Thrust Bearing.....	255
10.3.4 Needle Roller Bearings	255
10.3.5 Ball Bearings	255
10.3.5.1 Ball Bearing Load Ratings and Life Calculations: General Notes about Bearing Life.....	257
10.3.5.2 Basic Life Rating.....	257
10.3.6 Calculation of Bearing Life.....	257
10.3.6.1 Calculation of Maximum Permissible Axial Load in Newtons.....	258
10.3.6.2 Calculation of Minimum Loads	258
10.3.6.3 Calculation of System Bearing Life	258
10.3.7 General Notes about Bearing Load	258
10.3.8 Dynamic Equivalent Radial Load Factor (P_r)	259
10.3.9 Life of a Ball Bearing.....	259
10.3.10 Basic Static Radial Load Rating	260
10.4 Use of Bearing and End-of-Life Considerations	262
10.4.1 Bearing Failure	262
10.4.1.1 Penetrating Fluid or Particles	262
10.4.1.2 High Temperature or Gradient.....	263
10.4.1.3 Incorrect Mounting	263
10.4.1.4 Shock Loads from Handling	263

10.4.1.5	Vibration at Standstill	263
10.4.2	Bearing Alignment.....	264
10.4.3	Bearing Preload	264
10.4.4	Ball Bearings: Guide to Selection, Applications, and Calculations.....	264
10.4.5	Understanding the Bearing Specification Provided by Manufacturers.....	265
10.4.6	Other Bearing Features	265
10.4.6.1	Accuracy.....	265
10.4.7	Relubrication Feature	266
10.4.8	Classification according to Temperature.....	266
10.4.9	Stabilization Feature	266
10.5	Green Bearing Design.....	266
10.5.1	Reducing Environmental Footprint by Reusing and Recycling Bearings.....	266
10.5.2	Lubrication Management.....	267
10.5.2.1	Lubrication of Bearings.....	267
10.5.2.2	Sealing.....	267
10.5.3	Recycling of Lubricants.....	268
10.5.3.1	Viscosity	270
10.5.4	Specific Gravity (Density)	270
10.5.5	Cloud Point and Pour Point.....	270
10.5.6	Water Content.....	270
10.5.7	Flash Point.....	270
10.5.8	Fire Point	270
10.5.9	Methodology for Recovering Used Lubricants.....	270
10.5.10	Recycling of Bearings at End of Life.....	271
10.6	Plastic Bearing Design	271
10.6.1	Bearing Loading.....	272
10.6.2	Running Velocity.....	272
10.6.3	Bearing PV Limits.....	272
10.6.4	Bearing Media.....	272
10.6.5	Plastic Bearing Lubrication	272
10.6.6	Metal Surface Hardness	272
10.6.7	Metal Surface Finish	273
10.6.8	Typical Plastic Bearing Applications [4–6]	273
	References.....	274
	Bibliography	274
11	Fastener Design	275
11.1	Introduction to Fasteners	275
11.2	Riveting.....	278
11.2.1	Press and Shrink Fits	278
11.2.2	Benefits of Cold Heading	278
11.2.3	Common Industry Guidelines for Semitubular Rivets.....	279
11.2.4	Types of Joint	281
11.2.5	Stresses in Joints	281
11.3	Design of Bolts and Screws.....	285
11.3.1	Fastener Load.....	285
11.3.2	Reciprocating Weight	285
11.3.3	Other Stresses	286
11.3.4	Geometric Configuration	286
11.3.5	Stress Riser Elimination.....	286
11.3.6	Engaged Thread	286
11.3.7	Preload in Connecting Rod	287
11.3.8	Screw Thread Design: Screw Thread Fundamentals.....	287
11.3.9	Effect of Thread Angle on Strength	287
11.3.10	Thread Series.....	289
11.3.11	Fine Thread	289

11.3.12	Coarse Thread.....	289
11.3.13	UNR Threads	289
11.3.14	UNJ Threads	289
11.3.15	Thread Strength.....	290
11.3.16	Standardization of Threads (Standard Inch Units).....	291
	11.3.16.1 Unified Coarse.....	291
	11.3.16.2 Unified Fine	291
11.3.17	Class Fit: Thread Fit	291
11.3.18	Specification of Metric Threads	292
11.3.19	Metric Thread Series	292
11.3.20	Metric Thread Fits.....	292
	11.3.20.1 General Purpose Fit.....	292
	11.3.20.2 Close Fit.....	292
11.3.21	Left-Hand Threads	293
11.3.22	Writing Notes for Threaded Holes	293
11.4	Design of Statically Loaded Bolted Joints	293
11.5	Estimation of Stiffness of Bolt and Joint Members.....	294
	11.5.1 Length Ratio.....	294
	11.5.2 Area Ratio.....	294
	11.5.2.1 Sizing and Strength: How Big of a Screw Is Needed?	296
11.5.3	Rough Guide for Selection of Bolt or Screw.....	298
11.5.4	Preloading of Bolted Joints: Behavior of a Bolted Joint under a Varying Axial Load.....	298
11.5.5	Choice of Preload	300
11.5.6	Control of Preload.....	300
11.5.7	Loss of Preload.....	301
11.5.8	Design of Bolt Assembly	302
	11.5.8.1 Torque Coefficient for Lifting.....	302
	11.5.8.2 Torque Coefficient for Thread	302
	11.5.8.3 Torque Coefficient for Collar.....	302
	11.5.8.4 Determining Torque.....	303
	11.5.8.5 Universal Torque Table	304
11.5.9	Torque Tables	305
11.5.10	Fastener Property Classes	305
11.5.11	Margins of Safety	306
11.5.12	Torque Tension Performance Data.....	307
11.5.13	Typical Torque Tension Specification Requirements.....	307
11.5.14	Failure Modes	307
	11.5.14.1 Tensile Load Calculation	308
	11.5.14.2 Metric System	308
	11.5.14.3 US System.....	308
11.5.15	Evaluate Shear Stress in the Bolt.....	308
11.5.16	Shear Stress in Internal Thread.....	308
11.5.17	Preloading Mechanism Compliance.....	312
11.5.18	Thermal Aspects in Bolt Design	312
11.5.19	Nuts and Bolts of Ceramic Fasteners	314
11.5.20	Working with Alumina and Zirconia.....	314
11.6	Screw Fasteners	314
	11.6.1 Screw Fasteners Have the Following Advantages	314
	11.6.1.1 Disadvantages.....	315
11.6.2	Difference between a Screw and a Bolt?.....	315
11.6.3	A Selection of Various Screw Fastener Heads.....	316
	11.6.3.1 Classification by Fastener Type.....	316
	11.6.3.2 Classification by Driver Type; Required for Fasteners.....	316
11.6.4	Driver Type Summary.....	318
	11.6.4.1 Classification by Head Style	318

11.6.4.2	Head Styles	318
11.6.4.3	Screw Fastener Materials	318
11.6.4.4	Plating of Steel Fasteners.....	318
11.6.5	Fastener Head Proportions.....	319
11.6.6	Specifying a Screw Fastener.....	320
11.6.6.1	Thread Types: Most Common Types and When to Use Which	320
11.6.6.2	Coarse or Fine?.....	320
11.6.7	Fine vs. Coarse Threads.....	320
11.6.8	Rolled vs. Cut (Machined) Threads.....	321
11.6.9	Sustainable Fastener Manufacturing	322
11.6.9.1	Thread Production	322
11.6.10	Substantial Material Saving.....	322
11.6.10.1	UNJ or MJ	323
11.6.10.2	Standards.....	323
11.6.10.3	Constant Pitch Series.....	323
11.6.10.4	Hole Detailing	323
11.6.11	Washers.....	323
11.6.12	Nuts	324
11.6.13	Pins.....	325
11.6.14	Spring Pin (or Roll Pin)	325
11.6.15	Split Pin (or Cotter Pin).....	325
11.6.16	Cotter Pin	326
11.6.17	Keys and Keyways.....	326
11.6.18	Circlips.....	327
11.6.19	Installation Checklist	328
11.6.19.1	Fastener Problems.....	328
11.7	End-of-Life Considerations in Fasteners: Reuse of Fasteners and Bolts, DfE of Fasteners	329
11.7.1	Lubricants and Concerns for the Environment.....	330
11.7.2	Lubricant Benefits	330
11.7.3	Finding the Right Lubricant for Fastener Assembly.....	331
11.7.4	Life Cycle Cost and Profitability	332
11.7.5	Removing Rust from Nuts and Bolts.....	333
11.7.5.1	Removing a Rusted Fastener	333
11.7.5.2	Rust Removal Methods	334
	References.....	334
	Bibliography	334

Section IV Design for Environment (DfE)

12	Design for Environment	339
12.1	Introduction to Design for Environment.....	339
12.1.1	Growing Importance of Design for Recycling.....	341
12.1.1.1	Recovery Priorities.....	341
12.1.2	Materials Most Commonly Recycled in the United States through Collection Programs	342
12.1.3	Waste Prevention and Recycling Effects on Global Warming.....	342
12.1.3.1	Reduce Emissions from Energy Consumption	343
12.1.3.2	Reduce Emissions from Incinerators	343
12.1.3.3	Reduce Methane Emissions from Landfills	343
12.1.3.4	Increase Storage of Carbon in Forests	343
12.2	Design for Assembly.....	343
12.2.1	Cost of Assembled Product	343
12.2.1.1	Methods: Time Measurement for Disassembly and Assembly.....	345

12.3	Design for Disassembly.....	352
12.3.1	Design for Disassembly Guidelines.....	353
12.3.1.1	The Design Problem for DfD	354
12.3.2	Origin of the Concept of DfD	355
12.3.3	Some Existing Separation Techniques.....	358
12.3.4	Distinction between Manual and Mechanical Separation	358
12.3.4.1	Fastener Selection.....	359
12.3.5	Screw Disassembly Procedure.....	359
12.3.6	Embodied Energy in Recycling.....	362
12.3.7	Carbon Footprint Estimation.....	363
12.3.7.1	Material Selection	363
12.3.8	Principles of Design for Dismantling.....	363
12.3.8.1	Use and Materials Selection	364
12.3.8.2	Marking Can.....	364
12.3.8.3	Choose Materials with Physical Properties That Can Be Separated	364
12.3.8.4	Use Surface Treatments Wisely.....	364
12.3.9	Parts Design and Structure of Products	364
12.3.10	Selection and Use of Fasteners	365
12.3.11	Synthesis of Rules of Design for Dismantling	367
12.4	Analytical Methods in Studies of Science for DfD.....	370
12.4.1	Learning Curve Method of Assembly and Disassembly.....	370
12.4.2	Evaluation Method of Disassemble-ability	372
12.4.2.1	Spreadsheet-Like Chart.....	372
12.4.2.2	Energy and Entropy for Disassembly.....	373
12.4.2.3	Entropy Calculation	376
12.4.2.4	EOL Value for a Mechanical Component.....	376
12.4.3	Reduction of EOL Impacts through Design for Disassembly	377
12.4.4	Recycling Cost	377
12.4.5	Repair and Maintenance Cost.....	378
12.4.6	Remanufacture Cost	378
12.4.6.1	Cost-Benefit Analysis of Recycling.....	379
12.4.6.2	Ecoproperties Calculation	386
12.5	Design for Sustainability	387
12.5.1	Benchmarking	387
12.5.2	New Product Design	388
12.5.3	Life Cycle Assessment for EOL Analysis	388
12.5.3.1	Life Cycle Design (LCD)	389
12.5.3.2	Embodied Energy Analysis for Reservoir Power Plant.....	391
12.5.3.3	Electrical Energy Output: Example.....	392
12.5.3.4	Preliminary Investigations and River Diversion.....	392
12.5.3.5	Energy Embodied in Preliminary Investigations and River Diversion.....	392
12.5.3.6	Major Civil Works.....	393
12.5.4	Energy Embodied in Construction Materials of Major Civil Works.....	393
12.5.5	Ancillary Construction Works	393
12.5.5.1	Embodied Energy Associated with Ancillary Construction Works.....	393
12.5.6	Plant Operation and Maintenance	394
12.5.6.1	Difficulties Associated with LCA in EOL.....	394
12.5.6.2	Footprint Indicators	394
12.5.6.3	Goals and Purpose of LCA	395
12.5.6.4	Evaluation Methods of Disassemble-ability for Automotive Components.....	396
12.6	EOL Vehicle Dismantling Process	397
	References.....	397

13 Snap-Fit Design	399
13.1 Introduction to Snap-Fit: General Discussion	399
13.1.1 Reasons to Use Snap Fits	400
13.1.2 Things to Be Aware of When Using Snap Fits	400
13.2 Annular Snap Fits	400
13.3 Cantilever Snap Fits	400
13.3.1 Design Aids	404
13.3.2 Explanation	405
13.3.3 Geometric Factors K and Z for Ring Segment	406
13.3.3.1 Cantilever Snap Joints	406
13.3.4 Permissible Undercut	406
13.3.5 Deflection Force	406
13.3.6 Deflection	412
13.3.7 Deflection Force	413
13.3.8 Annular Snap Joints D: Permissible Undercut	413
13.3.9 Deflection Force and Mating Force	414
References	420
14 Finite Element Analysis (FEA) and Computer-Aided Design (CAD)	421
14.1 Introduction to Computer-Aided Design	421
14.1.1 Objectives of CAD Programs	421
14.1.2 Components of CAD	422
14.2 CAD Software: What to Look For	423
14.2.1 Design Tools	423
14.2.2 Interface Features	423
14.2.3 Editing Tools	423
14.2.4 Help and Support	423
14.2.5 Compatibility	423
14.3 NX 9.0 CAD Software Package	423
14.3.1 NX Master Series Applications	424
14.3.2 I-DEAS Master Series Design Tasks	424
14.3.3 Icon Panel of NX	425
14.3.4 Menu Commands	425
14.3.4.1 File Menu	425
14.3.4.2 Option Menu	425
14.3.4.3 View and Display	425
14.4 Finite Element Analysis	425
14.4.1 FEA Software	426
14.4.2 Benefits of FEA	426
14.4.3 Steps in Finite Element Method	427
14.4.3.1 Step 1: Discretize of Real Structure	428
14.4.3.2 Step 2: Identify the Primary Unknown Quantities and Appropriate Interpolation Function	428
14.4.3.3 Step 3	429
14.4.3.4 Step 4: Solve for Unknown Displacements	430
14.4.3.5 Step 5: Interpret the Result	431
References	435
Bibliography	435
15 Computer-Aided Design Examples	437
Solid Modeling, Assembly, Finite Element Analysis, and Cost Estimation	437
15.1 CAD Example 1: Wind Power Generation	437
15.1.1 Introduction	437

15.1.2	Mechanical Components Design.....	439
15.1.2.1	Analysis and Design	439
15.1.2.2	Solid Modeling	445
15.1.3	Materials	449
15.1.3.1	Cost	449
15.1.4	Life Cycle Analysis of Wind Power Generation	450
15.1.4.1	Embodied Energy Analysis of Wind Power Generation.....	450
15.1.5	Turbine Manufacturing and Dismantling	450
15.1.5.1	Steel	450
15.1.5.2	Glass Fiber.....	452
15.1.5.3	Aluminum.....	452
15.1.6	Site Preparation and Construction.....	452
15.1.7	Wind Farm Operation and Maintenance.....	452
15.1.7.1	Steel	452
15.1.7.2	Copper	452
15.1.7.3	Aluminum.....	453
15.1.7.4	Glass Fiber.....	453
15.1.7.5	Permanent Magnet	453
15.1.7.6	Concrete	453
15.1.7.7	Stone.....	453
15.1.8	Wind Farm Decommissioning and Land Reclamation	454
15.1.9	Discussion	454
15.2	CAD Example 2: Drum Brake	455
15.2.1	Introduction	455
15.2.2	Analysis and Design	455
15.2.2.1	Design of Spring.....	455
15.2.2.2	Design of Solenoid	456
15.2.2.3	Design of Drum.....	457
15.2.3	Solid Modeling.....	458
15.2.4	Assembly.....	462
15.2.5	Finite Element Analysis.....	462
15.2.6	Cost Estimation	463
15.3	CAD Example 3: Crankshaft and Flywheel.....	463
15.3.1	Introduction.....	464
15.3.2	Analysis/Design.....	464
15.3.3	Solid Modeling.....	472
15.3.4	Manufacturing Processes.....	472
15.3.5	Cost Estimation	473
15.3.6	Assembly.....	473
15.3.7	Finite Element Analysis.....	473
15.4	CAD Example 4: Design of Cam, Camshaft, and Rocker Arm.....	474
15.4.1	Design a Cam, Camshaft, Rocker Arm, and Assembly for a V-6 200 hp	474
15.4.2	Design	475
15.4.3	Design of Camshaft—AISI 1020 Steel.....	479
15.4.3.1	Dynamic Check.....	480
15.4.3.2	Design of Spring—Stainless Steel	482
15.4.3.3	Design of Pushrod—Material Selected: AISI 1020 Steel	483
15.4.4	Tolerance Analysis	486
15.4.5	Manufacturing.....	486
15.4.6	Cost Analysis	486
15.4.6.1	Materials.....	486
15.4.7	Overhead Costs.....	487
15.4.7.1	Solid Modeling	487
15.4.8	Finite Element Analysis.....	490
15.4.8.1	FEA: Pushrod	491

	15.4.8.2	FEA: Camshaft	491
	15.4.8.3	FEA: Rocker Arm.....	491
15.5		CAD Example 5: Computer-Aided Design of Central Differential of an Automobile	492
	15.5.1	Analysis and Design	492
	15.5.1.1	Bevel Gear Calculations.....	492
	15.5.1.2	Working Depth.....	493
	15.5.1.3	Addendum of Gear	493
	15.5.1.4	Gear Ratio	493
	15.5.2	Outboard Axle Shaft Calculations.....	493
	15.5.2.1	Shaft Material	493
	15.5.2.2	Dimensions of Axle Shaft	493
	15.5.2.3	Maximum Shear Stress, Moment, and Angle of Twist for Axle Shaft	494
	15.5.3	Solid Modeling.....	494
	15.5.4	Manufacturing Process	499
	15.5.5	Cost Estimation.....	499
	15.5.6	Codes and Standards	503
	15.5.7	Assembly.....	503
	15.5.8	FEA.....	503
15.6		CAD Example 6: Design of Universal Joint in a Car.....	505
	15.6.1	Analysis and Design	507
	15.6.2	Design of Driveshaft	508
	15.6.3	Design of Universal Joint	509
	15.6.4	Solid Modeling.....	509
	15.6.5	Tolerance Analysis	510
	15.6.6	Manufacturing Process	511
	15.6.7	Cost Estimation.....	511
	15.6.8	Codes and Standards	511
	15.6.9	Assembly.....	511
	15.6.10	FEA.....	512
15.7		CAD Example 7: Piston and Connecting Rod	513
	15.7.1	Solid Modeling.....	520
	15.7.2	Tolerance Analysis	522
	15.7.3	Manufacturing Process	523
	15.7.4	Cost Estimation.....	524
	15.7.5	Codes and Standards	524
	15.7.6	Assembly.....	524
	15.7.7	FEA.....	524
15.8		CAD Example 8: Universal Testing Machine.....	526
	15.8.1	Solid Modeling.....	527
	15.8.2	Manufacturing Process	531
	15.8.2.1	Gears	531
	15.8.2.2	Screw Threads.....	532
	15.8.2.3	Crosshead and Frame	532
	15.8.2.4	Thrust Bearings	532
	15.8.3	Cost Estimation.....	532
	15.8.4	Cost Calculations	533
	15.8.4.1	Crosshead Cost Calculations.....	533
	15.8.4.2	Frame Cost Calculations.....	533
	15.8.4.3	Screw Thread Cost Calculations	533
	15.8.5	Assembly.....	534
	15.8.5.1	18-Tooth Spur Gear.....	534
	15.8.5.2	54-Tooth Spur Gear	534
	15.8.5.3	Crosshead	534
	15.8.5.4	Frame	535
	15.8.5.5	Screw Threads.....	535

	15.8.5.6	Thrust Bearings	535
15.8.6		FEA	536
	15.8.6.1	Crosshead	536
	15.8.6.2	Gear Tooth	537
15.9		CAD Example 9: Crankshaft, Connecting Rod, and Flywheel	538
	15.9.1	Introduction	538
	15.9.2	Analysis and Design	539
	15.9.3	Solid Modeling	541
	15.9.4	Tolerances and Allowances	543
	15.9.5	Manufacturing Process	543
	15.9.6	Cost Estimation	543
	15.9.7	Codes and Standards	544
	15.9.8	Assembly	544
	15.9.9	FEA	544
		References	549
		Bibliography	549

Section V Environmentally Benign Manufacturing

16		Introduction to Environmentally Benign Manufacturing	553
16.1		Introduction to Green Manufacturing	554
	16.1.1	Manufacturing Job Creation	555
	16.1.2	Efficient Sustainable Manufacturing	555
	16.1.3	Waste Streams in Machining	557
	16.1.4	Life Cycle Analysis of Manufacturing Waste	557
	16.1.5	Waste of Energy in Form of Heat	558
	16.1.6	Cutting Fluid Heat Transfer	559
	16.1.7	Cutting Fluids Waste Stream	559
	16.1.8	Types of Cutting Fluids	559
		16.1.8.1 Straight Oils	559
		16.1.8.2 Soluble Oils	560
		16.1.8.3 Synthetic Fluids	560
		16.1.8.4 Semisynthetic Fluids	560
		16.1.8.5 Environmental Issues of Cutting Fluids	560
		16.1.8.6 Tooling Stream	561
	16.1.9	Critical Areas for Sustainable Manufacturing	561
	16.1.10	Organization for Economic Cooperation and Development	562
		16.1.10.1 Sustainable Manufacturing Toolkit	562
		16.1.10.2 Prepare	562
		16.1.10.3 Measure	563
	16.1.11	British Standard Institution	563
		16.1.11.1 PAS 2050 (Publicly Available Specifications)	563
		16.1.11.2 Production Materials	564
		16.1.11.3 Energy	564
		16.1.11.4 Capital Goods	565
		16.1.11.5 Manufacturing and Service Provision	565
		16.1.11.6 Transport	565
		16.1.11.7 Storage of Products	565
		16.1.11.8 Use Phase	565
		16.1.11.9 Allocation to Coproducts	565
		16.1.11.10 General Allocation Principle	565
		16.1.11.11 Use of Recycled Materials and Recycling	565
		16.1.11.12 Treatment of Emissions Associated with Reuse	566

16.1.12	Greenhouse Gases	566
16.1.13	Calculation of GHG Emissions of Products Presented by PAS.....	567
16.1.14	Global Warming Potential.....	567
16.1.15	Assessment of Emissions Arising from Recycled or Recyclable Material Inputs.....	567
16.1.16	Single Release vs. Delayed Release.....	569
16.1.16.1	Single Release.....	569
16.1.16.2	Delayed Release	569
16.2	Thermodynamics in Manufacturing Sustainability.....	570
16.2.1	Method of Material and Energy Balance.....	572
16.3	Computational Tools for Green Manufacturing.....	572
16.3.1	Life Cycle Assessment.....	573
16.3.2	Environmentally Conscious Production (ECP)	575
16.3.3	Estimation of Energy Consumption in Manufacturing Operations.....	576
16.3.4	Idle or Start-up Energy Estimation	579
16.3.5	Environmental Burden of Cutting Tool (T_e).....	579
16.3.6	Environmental Burden of Metal Chips (CH_e)	579
16.3.7	Burners.....	581
16.3.8	Burner Controls.....	581
16.3.9	Compressed Air.....	581
16.3.10	Heating System Best Practices	581
16.3.11	Lighting Improvements.....	581
16.3.12	Process Controls.....	581
16.3.13	Process Heat Recovery.....	581
16.3.14	Process Motors, Pumps, and Fans.....	581
16.3.15	Coolant Alternatives.....	582
16.3.16	NESHAP: National Emission Standards for Hazardous Air Pollution	582
16.3.17	LCA of Environmental Burden of Machining Operations.....	582
16.3.18	Milling Machine Life Cycle Assessment.....	582
16.3.19	Narita's Algorithm of Environmental Burden Estimation	583
16.3.20	Electric Consumption of Machine Tool (E_e)	584
16.3.21	Environmental Burden of Coolant (C_e).....	585
16.3.22	Environmental Burden of Lubricant Oil (LO_e)	586
16.3.23	Environmental Burden of Cutting Tool (T_e)	586
16.3.24	Environmental Burden of Metal Chips (CH_e)	586
16.3.25	Electrical Energy Estimation for Manufacturing Processes	589
16.3.26	Estimated Energy Footprint for Tooling	593
16.3.27	Cutting Tool Examples.....	593
16.4	Eco-Manufacturing Processes: Material and Process Families and Eco-Data	595
16.4.1	Energy Requirements for Materials Used in Manufacturing Processes.....	595
16.4.2	Life Cycle Analysis and Selection Strategies	596
16.4.3	Strategy for Minimizing Eco-Impact.....	596
16.5	Manufacturing Processes	597
16.5.1	Carbon Dioxide (CO_2) Emission from Energy Generation	597
	References.....	598
	Bibliography	600
17	Turning Operation	601
17.1	Introduction to Single-Point Metal Cutting: Turning	601
17.1.1	Merchant's Circle for Tool Forces	601
17.1.2	Cutting Power.....	607
17.1.3	Life Cycle Analysis (LCA) of Turning Operation	608
17.1.3.1	Material Balance.....	609
17.1.4	Turning of Plastics	613
17.1.5	Typical Standard Times for Capstan and Turret Lathe Operations.....	613
17.2	Lathe Tool Nomenclature and Setting.....	613
17.2.1	Lathe Components.....	613

17.2.2	Typical Lathe Components.....	614
17.2.2.1	Headstock.....	614
17.2.2.2	Tailstock	614
17.2.2.3	Carriage.....	614
17.2.2.4	Apron	614
17.2.2.5	Cross Slide.....	614
17.2.2.6	Compound Rest.....	614
17.2.2.7	Tool Post	614
17.2.2.8	Bed.....	614
17.2.2.9	Ways.....	615
17.2.2.10	Size.....	615
17.2.3	Turret Lathe.....	615
17.2.4	Square and Hex Turrets.....	615
17.2.5	Horizontal Turret Lathes	615
17.2.6	Vertical Turret Lathes.....	615
17.2.7	Computer-Controlled Lathes	616
17.2.8	Tool Features.....	617
17.2.9	Plan Approach Angle.....	618
17.2.10	Other Features	618
17.2.11	Tool Setting.....	618
17.2.11.1	Parting-Off Tool.....	619
17.2.12	Environmental Burden of Cutting Tool (T_c)	619
17.2.13	Waste Streams after Machining.....	621
17.2.14	Toxicity Ratings for Some of the Materials	621
17.2.15	Classes of Supply for Some of the Elements	621
17.2.16	Dry vs. Wet Machining.....	621
17.3	Minimum Quantity Lubrication (MQL) during Turning.....	622
	References.....	622
	Bibliography	623
18	Drilling Operations.....	625
18.1	Introduction to Drilling and Reaming.....	625
18.1.1	Simple Drill Press.....	625
18.1.2	Radial Drilling Machine	625
18.2	Drilling Tools	627
18.3	Drill Helix and Point Angles	628
18.3.1	Cutting Parameter Calculation in Drilling.....	628
18.4	Reamers.....	629
18.4.1	Drilling Parameters	630
18.5	Drill Bit Materials.....	632
18.5.1	Steel.....	632
18.6	Lubricants for Drilling.....	634
	References.....	634
	Bibliography	635
19	Milling.....	637
19.1	Introduction to Milling Operation.....	637
19.1.1	Up Milling.....	637
19.1.2	Down Milling	637
19.1.3	Up vs. Down Milling	639
19.2	Variants of Milling Machines and Operations	641
19.3	Computer Numerical Control	643
19.4	Milling Cutters.....	643
19.4.1	Milling Parameters	644
19.4.2	Table Feed Rates	648

19.5	Environmental Effect of Chips Removed (CH_c) in Milling.....	650
19.5.1	LCA Analysis of Milling Machine.....	651
19.5.2	Energy	653
19.5.3	Assumptions	653
19.5.4	Waste-Stream Creation in Milling.....	654
19.5.4.1	Oblique Machining.....	654
19.6	Environmentally Conscious Machining.....	654
	References.....	655
	Bibliography	656
20	Grinding.....	659
20.1	Introduction to Grinding.....	659
20.1.1	Grinding Machines.....	659
20.1.1.1	Types of Grinding.....	659
20.1.2	Grinding Wheels.....	661
20.2	Grinding Process Calculations (Cylindrical Grinding).....	662
20.3	Specific Energy Requirements in Surface Grinding.....	664
20.4	Detailed Description of Coolants and Coolant Recycling Systems in Grinding.....	665
20.4.1	Features.....	665
20.4.2	Automatic Operation.....	665
	References.....	666
	Bibliography	667
21	Cutting Tools and Sustainability Considerations.....	669
21.1	Introduction to Cutting-Tool Materials.....	669
21.1.1	Carbon Steels	669
21.1.2	High-Speed Steels.....	669
21.1.3	Carbides.....	669
21.1.4	Laminated Carbide	669
21.1.5	Diamonds	669
21.1.6	Carbide and Ceramic Tools.....	669
21.2	General Information on Metal Cutting.....	671
21.2.1	Cutting Speed and Feed Rates.....	671
21.2.2	Surface Finish	671
21.3	Machining Properties of Thermoplastics.....	672
21.4	Calculation of Machining Cost	672
21.5	Sustainable Machining Economics: Selection of Optimum Turning Conditions Based on Minimum Energy Considerations	674
21.5.1	Estimated Energy Footprint for Tooling	677
21.6	Sustainability Considerations in Metal Cutting Tools.....	679
21.6.1	Cemented Carbides.....	679
21.6.2	Coating.....	680
21.6.3	ISO Standard 513.....	680
21.6.4	High-Speed Steel	680
21.6.5	Cast Alloy Steels	682
21.7	Representation of Eco-Indicators of Tool Materials.....	683
21.8	Environmentally Friendly Machining: Model for Environmental Impact of Machining Process.....	684
21.9	Model Configuration.....	685
21.9.1	Coolant Selection	686
21.9.2	Contaminant Removal and Prevention	687
21.9.3	Coolant Monitoring and Control	687
21.9.3.1	pH Control.....	687
21.9.4	Coolant Concentration.....	687
21.9.5	Contaminant Control and Removal.....	688
21.9.6	Cutting Fluid.....	689

21.9.7	Dry Machining	689
21.9.8	Quenching the Workpiece	689
21.10	Environmental Impact of Waste Streams	691
	References	691
	Bibliography	691
22	Foundry Processes	695
22.1	Introduction to Solidification Manufacturing Processes	695
22.1.1	Environmental Issues and Efficiency of Metal Casting	696
22.1.2	Latest Environmental Statistics Provided by the Environmental Protection Agency for Metal Casting Sector	696
22.1.3	Energy Use	697
22.1.4	Air Emission Reported to Toxics Release Inventory	697
22.2	Sand Casting	699
22.2.1	Environmentally Conscious Sand Casting	699
22.2.2	Shell Molding	701
22.3	Investment Casting (Lost Wax Casting)	701
22.4	Die-Casting	702
22.5	Centrifugal Casting	704
22.6	Continuous Casting	704
22.6.1	Heat Transfer in Casting	705
22.7	Solidification Time Estimation for Sand Casting	705
	References	706
	Bibliography	707
23	Metal-Forming Processes	709
23.1	Introduction to Forming Processes	709
23.2	Forging	709
23.2.1	Preheating	710
23.2.2	Heat Treatment	710
23.2.3	Quenching	710
23.2.4	Tempering	710
23.2.5	Machining	710
23.2.6	Surface Treatment	710
23.3	Fasteners	711
23.3.1	Preheating	711
23.3.2	Pressing	711
23.3.3	Thread Rolling	711
23.3.4	Heat Treatment and Quenching	712
23.3.5	Tempering	712
23.3.6	Washing	712
23.4	Hand Forging and Drop Forging	712
23.4.1	Forging Parameters Calculation	713
23.4.1.1	Open-Die Forging	713
23.4.1.2	Impression-Die Forging	715
23.4.1.3	Flashless Forging	715
23.5	Heading	715
23.6	Quality of Forged Parts	715
23.7	Energy Cost in Forging Plants	716
23.8	Trends in the Forging Industry	716
23.9	Major Energy User Systems for Forging Plants	716
23.10	Observations on Energy Use Pattern for the Forging Industry	716
23.11	Health Hazards of Forging Operations	716
23.12	Rolling	717
23.12.1	Rolling Processes	717

23.12.1.1	Hot Rolling.....	717
23.12.1.2	Cold Rolling.....	717
23.13	Rolling.....	718
23.13.1	Rolled Sections.....	719
23.14	Extrusion.....	720
23.14.1	Hot Extrusion.....	721
23.14.2	Extrusion Parameters.....	721
23.14.3	Cold Extrusion.....	724
23.14.4	Impact Extrusion.....	724
23.15	Drawing Processes.....	725
23.15.1	Drawing.....	725
23.15.2	Drawing Force Estimation.....	725
23.16	Health Hazards of Foundries and Forges.....	726
23.16.1	Specific Health Hazards of Foundries and Forges.....	727
23.16.2	Health Hazards due to Heavy Metals.....	727
23.17	Sheet Metal Work.....	728
23.17.1	Sheet Metal.....	728
23.17.2	Punching Characteristics.....	728
23.17.3	Press Work.....	728
23.17.4	Press Tool Theory.....	728
23.17.5	Punching Process.....	730
23.17.6	Shearing Process.....	731
23.17.7	Plastics.....	732
23.17.8	Drawing Process.....	732
23.17.9	Bending Operation in Sheet Metal Industries.....	732
23.17.9.1	Allowance for Right Angle Bend.....	733
23.17.9.2	Allowance for Bend with Outside Angle θ	733
23.17.10	Bending Process.....	733
23.17.11	Design Considerations for Bending Operations.....	734
23.17.12	Cost.....	735
	References.....	735
	Bibliography.....	736

Section VI Regulations for Sustainable Manufacturing

24	International Regulations for Green Design and Manufacturing.....	741
24.1	Introduction to International Regulations for Green Manufacturing.....	741
24.1.1	Green Manufacturing Technologies: Requirements and Response.....	743
24.2	Environmental Regulations Worldwide.....	744
24.2.1	European Union Directive 2002/96/EC.....	744
24.2.2	Environmental Laws Highlights of Various Countries.....	745
24.2.3	End-of-Life Vehicles (ELV) Regulations.....	748
24.2.3.1	Japan.....	749
24.2.3.2	United States.....	749
24.2.3.3	Australia.....	749
24.3	New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044.....	749
24.3.1	Background, Aims, and Scope.....	750
24.3.2	General Outline of the New Standards.....	750
24.3.3	Main Formal Changes of the New Standards.....	751
24.3.4	Main Technical Changes in the New Standards.....	751
24.3.5	Definitions.....	751
24.3.6	Principles of LCA.....	751
24.3.7	Life Cycle Impact Assessment.....	752

24.3.8	Life Cycle Interpretation	752
24.3.9	Critical Review and Reporting.....	753
24.3.10	Innovative Annex on Application of LCA	753
24.3.11	References.....	753
24.4	Environmental Protection Agency (EPA).....	754
24.4.1	Major Environmental Regulations Affecting Manufacturing Sector	754
24.4.2	Clean Air Act (CAA)	754
24.4.3	Clean Water Act (CWA).....	755
24.4.4	Resources Conservation and Recovery Act (RCRA)	755
24.5	British Standard Institution (BSI): PAS 2050 (Publicly Available Specifications)	756
24.5.1	Introduction	757
24.5.2	Background, Benefits, and Context of PAS 2050	757
24.5.3	Emissions and Removals: Scope of GHG Emissions and Removals	758
24.5.4	Product Life Cycle Processes to Be Included	758
24.5.5	Global Warming Potential (GWP)	758
24.5.6	System Boundary	759
24.5.7	Cradle-to-Gate System Boundary	759
24.5.8	Material Contribution and Threshold.....	759
24.5.9	Elements of Production System	759
24.5.10	Production Materials.....	759
24.5.11	Energy	759
24.5.12	Capital Goods	760
24.5.13	Manufacturing and Service Provision	760
24.5.14	Operation of Premises	760
24.5.15	Transport.....	760
24.5.16	Storage of Products	760
24.5.17	Use Phase.....	760
24.5.17.1	General Principle	760
24.5.17.2	Basis of Use Profile.....	760
24.5.17.3	Time Period for Use-Phase GHG Emission	761
24.5.17.4	Recording Basis of Use-Phase Calculations for Products.....	761
24.5.18	Data	761
24.5.19	Allocation of Emissions	761
24.5.19.1	General Requirements.....	761
24.5.19.2	Recording Allocation Assumption.....	761
24.5.19.3	Emissions from Waste	761
24.5.19.4	Treatment of Emissions Associated with Reuse.....	761
24.5.19.5	Emissions from Energy Production Using CHP.....	762
24.5.20	Emissions from Transport	762
24.5.20.1	Calculation of GHG Emissions of Products	762
24.5.21	Annex A (Normative).....	762
24.5.22	Annex B (Normative)	762
24.5.23	Annex C (Normative).....	764
24.5.24	Annex D (Normative).....	764
24.5.24.1	D.1 General	764
24.5.24.2	D.2 Recycled Content Method	764
24.5.24.3	D.3 Closed-Loop Approximation Method.....	765
24.5.24.4	D.4 Recycling Data.....	765
24.5.24.5	D.5 Other Types of Recycling	765
24.5.24.6	D.6 Recording the Basis of Treatment of Recycling	765
24.5.25	Annex E (Normative)	765
24.5.25.1	General Application.....	765
24.5.25.2	Specific Case-Delayed Single Release.....	765
24.5.25.3	General Case: Delayed Release.....	765
24.5.25.4	Recording the Basis of Carbon Storage Assessment.....	766
24.6	Environmental Regulations in India	766

24.7	Environmental Protection Regulations of Japan	769
24.7.1	Chapter 1 General Provisions.....	770
24.7.2	Chapter 2 Basic Policies for Environmental Conservation	770
24.7.3	Chapter 3 Environment Council, and So On.....	771
24.8	Environmental Laws in China.....	771
24.9	Environmental Laws of Canada	773
24.9.1	Purpose of CEAA 2012.....	773
24.9.2	Pollution Control Act	775
24.10	Brazil Environmental Law.....	775
24.10.1	Air Quality Policy Criteria	776
24.10.2	National Water Resource Management System	777
24.10.3	Solid Waste.....	777
24.10.4	Noise Emissions.....	778
24.10.5	Storage of Hazardous Materials	777
	References.....	779