
Contents

Preface	xxxi
Chapter 1 Historical Roots of Hybrid Automobiles.....	1
Ancient History: Crossroads	1
Steam Cars	1
Electric Cars	2
Gasoline Cars	3
Carriages	4
Crossroads	4
Invention of Hybrid Automobile	4
Key Features of Hybrid Automobile	5
Early Hybrid Vehicles	5
Woods Gas–Electric Car	6
Control Systems for Early Hybrids	6
Modern Period of Hybrid History	7
Hybrid Automobiles: Stirring of Interest in the 1990s.....	8
GM EV-1 Electric Car	8
Renewed Interest in Hybrids	8
Partnership for a New Generation of Vehicles	10
Crossroads 2008: Sneak Preview of the Future	12
References	13
Additional References	14
Chapter 2 Why the Crisis? Hybrid Vehicles as a Mitigation Measure.....	15
Introduction	15
Story	16
Setting the Stage.....	16
Depletion of Petroleum.....	18
Estimating Oil Production.....	19
Oil Reserves and Resources	19
Demand for Petroleum	20
Oil in the United States	21
Hubbert’s Peaking Theory	22
Swimming Pool Model.....	22
Standard Presentation of Hubbert’s Curves	24
New Analytical Representation.....	25
Variation of the Production Rate, $r(t)$	26
Limit of P/Q as Time Approaches Negative Infinity	27
Characteristic Production Time, τ	28
Finding r_0 and Q_T	29
When Do Hubbert’s Curves Apply?.....	30
When Do Hubbert’s Curves Not Apply?.....	30
Near-Term Situation	30
Transportable Fuels Crisis.....	30

Current Fleet of Low Miles per Gallon Vehicles	30
Application of Increased Engine Efficiency	31
Vehicle Power	32
Vehicle Weight.....	32
Vehicle Size	32
Vehicle Powertrain	33
Options and Accessories	33
Posted Speed Limits	33
Energy Conservation	33
Summary	34
References	34
 Chapter 3 Overview of Hybrid Vehicles	 37
Introduction	37
Approaches to Beat the High Cost of Gasoline.....	37
Saving Gasoline.....	37
Hybrid Performance	38
Allure of Plug-In Hybrids.....	38
Conversion or Clean Sheet Design	39
Conversion or Clean Sheet Design: Impact on AWD and 4WD	39
Current View on Hybrids	39
Reasons to Buy a Hybrid	40
“More Playthings than You”	41
Reasons Not to Buy a Hybrid	41
Diesel/Electric Hybrids	41
Role of Design in Buying Decision	41
Concept Hybrids and Electric Vehicles.....	42
Different Types of Concept Hybrids.....	42
Audi Metroproject Quattro.....	42
BMW Connected Drive X5 Hybrid SUV.....	42
BMW X6 ActiveHybrid Sport AWD Coupe	42
Cadillac Provoq FC Hybrid.....	42
Chinese GAC A-HEV Sedan.....	43
Chinese Great Wall Gwkulla Concept Electric Car.....	43
Chinese Plan 863 for Hybrids and Alternate Fuels	43
Chrysler Citadel.....	43
Chrysler Eco Voyager FCV	43
Citroën Aircscape Hybrid	43
Citroën4 Hybrid Sedan.....	43
Citroën C-Cactus Hybrid Sedan.....	43
Daihatsu Hybrid Vehicle Sports: Sports Car.....	43
Dodge ESX3 PNGV Sedan	44
Dodge Powerbox SUV Hybrid	44
Dodge Zeo EV	44
Fisker Hybrid Luxury Sedan	44
Ford Edge with HySeries Drive.....	44
Ford Fiesta Hybrid.....	44
Ford Focus FCV	44
Ford Focus Hydrogen–ICE Conventional Vehicle	44

Ford Reflex or Refl3x.....	45
Ford HySeries Edge: An FC/Battery Plug-In Hybrid.....	45
GM Chevrolet Volt (Cadillac Volt).....	45
GM Graphyte SUV.....	46
GM Precept: Product of PNGV Program.....	46
GM Precept: Diesel Hybrid.....	46
GM Precept: FC Version.....	46
GM Sequel.....	46
GM Ultralite: Another PNGV Supercar.....	47
Honda Clarity FC Hybrid.....	47
Honda CR-V Crossover Hybrid.....	47
Honda CR-Z Hybrid.....	47
Honda FC Hybrid, FCX.....	47
Honda Hybrid Sedan.....	47
Honda Small Hybrid Sports Concept.....	48
Honda Puyo FCV.....	48
Hyundai i-Blue FCV.....	48
Jeep Renegade Diesel–Electric Hybrid.....	48
Kia FCV.....	48
Land Rover LRX SUV.....	48
Land Rover “E” SUV.....	48
Range Rover Hybrid.....	48
Lexus LF-Xh.....	48
Loremo Diesel 2 + 2 Subcompact.....	49
Loremo Diesel GT Subcompact.....	49
Mazda Premacy Hydrogen RE Hybrid.....	49
Mazda <i>Senku</i> HEV Sports Car.....	49
Mercedes Benz C-Class.....	49
Mercedes Benz F-Class HCCI Hybrid.....	49
Mercedes Benz S-Class Bluetec Hybrid.....	49
Mercedes Benz S-Class Direct Hybrid.....	50
Mercedes Benz Vision Grand Sports Tourer Hybrid.....	50
Mercury Meta One Crossover.....	50
Mitsubishi Concept CT MIEV Hybrid.....	50
Mitsubishi Pure EV.....	50
Mitsubishi iMiEV Sport Pure EV.....	50
Nissan Mixim EV.....	51
Nissan Pivo 2.....	51
Nissan Tino Hybrid Sedan.....	51
Opel (GM) Astra Diesel Electric.....	51
Opel Corsa Hybrid.....	51
Opel Flextreme.....	51
Peugeot 307 Hybrid Sedan.....	51
Phoenix Electric Sport Utility Truck.....	51
Porsche Panamera Sports Sedan Hybrid.....	52
Saturn Vue Green Line Plug-In Hybrid.....	52
Subaru B5-TPH Two-Seat GT.....	52
Subaru G4e.....	52
Subaru R1e.....	52
Suzuki Kizashi 2.....	52
Suzuki Twin-Turbo.....	52

Tesla Electric Sports Car	52
Tesla Motors Blue Star Economy EV	53
Tesla Motors White Star Luxury EV	53
Toyota 1/X Plug-In Hybrid	53
Toyota A-BAT Hybrid Pickup	53
Toyota FT-HS Sports Car Hybrid	54
Toyota Hi-CT Plug-In Hybrid	54
Toyota Hybrid X	54
Volkswagen Pure Diesel “Ecoracer”	54
Volkswagen Space Up! Blue FC Hybrids	54
Volkswagen Up! and Space Up! Plug-In Hybrids	54
Volvo 3CC	54
Volvo ReCharge	55
Concept Hybrids on Two (or Three) Wheels	55
Suzuki Crossage FC Motorcycle	55
Twike	55
Vectrix Electric Maxi-Scooter	55
Yamaha Luxair Motorcycle Hybrid	55
Park the Car	55
Intercity Congestion Forces Trend	55
Description of a Few Select Hybrids	56
Chevrolet Tahoe SUV 2008 and GMC Yukon SUV 2008:	
Full Dual-Mode Hybrid	56
Ford Escape SUV	56
GM Chevrolet Malibu Mild Hybrid	58
GM Saturn VUE Green Line Mild Hybrid SUV	58
Honda Civic Hybrid 2006	58
Honda Accord Hybrid 2007	59
Toyota Highlander SUV/Lexus RX 400h	59
Toyota Prius I Hybrid Sedan	60
Toyota Prius II Hybrid Sedan	60
Discussion of Prius Configuration	60
Chevrolet Silverado Mild Hybrid Pickup	62
Toyota 2007 Camry Hybrid Sedan	63
Mass to Power Ratio	63
Hybrid Truck and Bus Technology	64
Economics of Bus and Truck	64
Comparison Lifetimes or Cycles of Operation	64
Attractiveness of Supercapacitor for Trucks and Buses	64
Duty Cycle and Application of Hybrid	65
Emissions	65
Future for Diesel/Electric Heavy-Duty Hybrids	65
Organizations Considering Hybrid Trucks	65
Truck Original Equipment Manufacturers Working on Hybrids	65
Concept and Production Hybrid Trucks	65
FedEx Hybrid Delivery Truck	65
GM/Chrysler Hybrid Light Trucks	66
Daihatsu Hybrid Small Light Delivery Truck	66
Ford Hytrans Light Commercial Vehicle	66
Dodge Sprinter Plug-In Hybrid Van	66
Kalmar Hybrid Terminal Tractors	66
Nissan Condor Medium-Size Hybrid Truck	66

Hydrogen Electric Racing Federation	66
Production Hybrid Buses.....	67
Gillig-GMC Hybrid Bus.....	67
Mercedes Benz Hybrid Bus.....	67
Mitsubishi Aerostar Hybrid Bus.....	67
Orion VII Hybrid Bus (BAE Systems).....	68
Military Applications of Hybrids.....	68
Hybrids and Military Interest.....	68
DARPA Advanced (Military) Vehicle.....	68
Shadow: A Reconnaissance, Surveillance, and Tracking Vehicle	68
Parting Perspective.....	68
Alternate Vehicles	68
Summary	69
Appendix 3.1	70
References	70
 Chapter 4 Hybrid Automobile: What Is It?	 73
Hybrid Definition	73
New Idea for a Hybrid	73
Hybrid Electric Vehicle	73
Inherently More Expensive	75
Hybrids: Mainstream or on the Fringe? Success or Failure?	75
HEV Propulsion Design Options	76
HEV Propulsion Design Options: Series	76
Discussion of Various Operating Modes: Series.....	78
HEV Propulsion Design Options: Parallel.....	78
Discussion of Various Operating Modes: Parallel	80
Comment on Toyota Prius.....	81
Choice of Series, Parallel, or Mixed	81
Technologies for a Successful Hybrid	81
Operation with a “Dead” Battery	81
Summary	82
 Chapter 5 Why Hybrids Get Good Mileage	 83
Introduction	83
Hybrid Specific.....	83
Heavy Hitters Lineup	83
Regenerative Braking	83
Engine Downsizing.....	84
Electrical-Only: Motor Assist.....	86
Electrical-Only: Plug-In Hybrid Fuel Economy	86
Nickel and Dime Improvements	87
Engine Idle-Off: Start–Stop	87
Automobile Auxiliary Components.....	87
Special Focus on Air-Conditioning.....	88
Tripled Savings by Shifting the Auxiliary Load	88
Damping Driveline Oscillations and Shudders	89
Vehicle Launch	89
Common with CVs	89
Also-Ran.....	89

Electrical Power Steering	90
Fast Warm-Up.....	90
Aerodynamics	90
Rolling Resistance of Tires.....	91
Vehicle Weight.....	92
Engine Efficiency.....	92
Powertrain.....	92
Improved Lubricants: Friction and Wear.....	93
Improved Fuels	93
Range and Miles per Gallon: Cruise Mode.....	93
Hybrid: Pure Electric Mode.....	95
Hybrid: All Power through the Battery	96
Hybrid: Bypass the Battery.....	96
Conclusions from the Three Different System Designs	97
Summary	97
References	98

Chapter 6 Multifaceted Complexity of Batteries	99
Introduction	99
Brief Overview of the Three Electrochemical Devices	99
Function of the Battery or Capacitor.....	100
Function of an FC.....	100
Electrical Definitions for Hybrid Vehicles	100
Battery and Electrical Definitions.....	100
Battery Capacity	102
Battery Properties Used to Assess Performance	102
Importance of Energy Density and Specific Energy	103
Energy Density or Energy Density?	103
Battery Electrochemistry	104
Electrochemistry of Cells	104
Electrochemistry of Eels	105
Computational Electrochemistry.....	105
Discharge Characteristics.....	105
Temperature Sensitivity.....	106
Self-Discharge	106
Performance Boundaries in a Hybrid or Electrical Vehicle	106
Battery Peculiarities	107
Battery Peculiarities: NiMH Battery Voltage Depression with Memory Effect.....	107
Battery Peculiarities: Voltage Recovery	107
Polarization.....	108
Number of Different Possible Cells: Different Cell Chemistries	108
Battery Design.....	108
Battery Life	110
What Is Battery Failure?.....	110
State of Charge: Restrictions and Battery Utilization	110
Determining Actual SOC and Battery Aging	111
Determining Actual SOC: Lead Acid Battery	111
Determining Actual SOC: NiMH Battery.....	111
Battery Charging and Discharging	112

Charging Rate.....	112
Discharging Rate	113
Thermal Runaway	113
Battery Data	113
Lead Acid Battery	113
Nickel Metal Hydride Battery	114
Lithium-Ion Battery.....	115
Lithium-Ion Battery for HEV	115
Safety.....	115
Cost.....	115
Calendar Life.....	116
Guide to Long Battery Life	116
Electrochemistry	116
Lithium-Ion Battery.....	116
Liquid/Gel Electrolyte	116
Solid Electrolyte Interphase	117
Temperature Limits	117
Charge/Discharge Cycle.....	117
Lithium-Ion Alkaline Battery	117
Advantages	117
Disadvantages.....	118
Lithium-Ion Polymer Battery	118
Advantages	118
Disadvantages.....	119
Advanced Technology	119
Nanostructure	119
Application of Nanotechnology.....	119
Advanced Anodes (Negative Electrode upon Discharge)	119
Advanced Cathodes (Positive Electrode upon Discharge)	120
Advanced Electrolytes.....	120
Battery Management System.....	120
Application of Lithium-Ion Battery in Hybrids	120
Application of Li-Ion Battery	120
Application of Batteries in Hybrid and Electric Vehicles	122
Batteries in Spacecraft.....	122
Prius I Battery.....	122
Nissan Battery	123
Application of Li-Ion Battery: Two Approaches	123
Application of Li-Ion Battery: Mitsubishi Pure EV	123
Application of Li-Ion Battery: Nissan and NEC	123
Interchangeable Power Packs	123
Comparisons for Different Energy Storage Devices	124
Battery Selection	124
Direct Effect on Miles per Gallon.....	124
Customer Satisfaction.....	124
Safety	124
Hybrid Cost on the Showroom Floor	125
Permissible Operating Environment	125
Avoiding Unanticipated Recalls	125
Recycling Batteries.....	125
Cost of Battery.....	126

Battery Properties.....	126
Battery Safety	126
Battery Efficiency and Internal Impedance of Battery	126
Monitoring Individual Cells	127
Thermal Management	127
Hybrids Using Electrochemical Storage	127
FC/Electrochemical Capacitor Hybrid.....	128
Battery Electrochemical Capacitor Hybrid	128
Tribrid, the Three-Way Hybrid: Fuel Cell, Hydrogen ICE, and Battery Hybrid.....	129
Maps Based on Battery Energy and Power.....	130
Relation of Battery to Overall Hybrid	130
Plug-In EV or EV: Adequate Power, Large Energy	131
HEV: High Peak Power, Small Energy	132
Fuel Cells.....	132
Fuel Cell: Electrochemistry.....	132
Fuel Cell: Types.....	134
Fuel Cell: Characteristics	135
Fuel Cell: Efficiency	135
Fuel Cell: Applications.....	135
Fuel Cell: Hybridness	138
Hydrogen Production.....	138
Reforming: Hydrogen Production	138
Capacitors.....	139
Electrolytic Capacitors (SCs).....	139
Features of SCs.....	140
Charge/Discharge Efficiency.....	140
Characteristic Time Constant.....	141
Energy Stored	141
Comparison Lifetimes or Cycles of Operation.....	142
Attractiveness of SC for Trucks and Buses	142
Some Analogies.....	142
Summary	143
Appendix 6.1: Electrochemistry of a Voltaic Cell and Fuel Cell.....	144
Introduction	144
Components of a Cell.....	144
Voltage Distribution in Cell and External to Cell	146
Electrolysis	147
Electrochemical Potential	148
Electrochemistry of Cell (Battery).....	149
Lead Acid Battery	149
Voltage and Power from a Cell.....	151
Electrochemistry of FC.....	151
Hydrogen/Oxygen FC.....	151
Appendix 6.2: Capacitors	154
References	154

Chapter 7 Obesity: Bad in Humans, Bad in Cars	157
Introduction	157
Vehicle Weight and Fuel Economy	157

First Passing Comment.....	157
Second Passing Comment	158
How to Improve Fuel Economy?.....	158
How to Decrease Vehicle Weight?	158
Interplay: Production Lines and Vehicle Design.....	159
Weight Factors Affecting Fuel Economy	159
Power and Fuel Consumption.....	159
Rolling Resistance due Mainly to Tires	160
Power to Climb Grades	160
Power for Acceleration	160
Correlation between Acceleration and Fuel Economy	161
Correlation between Weight and Fuel Consumption at Cruise	161
Fuel Economy for Cars, Trucks, and Both	162
Weight and Performance	163
Engine Efficiency Improvement to Match Weight Gain	165
Vehicle Weight and Vehicle Safety	165
Weight Reduction and Vehicle Safety	165
Seeming Paradox.....	168
Added Comments on Acceleration.....	168
Acceleration Based on Crumple Zones and Driver Motion	168
Fractional Form for Acceleration Based on Crumple Zones and Driver Motion	170
Velocities Relative to the CG.....	171
Compensation for the Double Acceleration.....	172
Compensation for Realistic Weight Disparity.....	172
NHTSA Action.....	173
Weight Disparity.....	174
Effect of Footprint on Safety	174
CO ₂ Emissions versus Vehicle Weight	175
Summary	176
Appendix 7.1: Mathematics of Fractional Change	176
Appendix 7.2: Derivation of Equation 7.12	177
References	178

Chapter 8 Vital Role of the Control System	181
History of Automobile Control	181
Example of Engine Controls from 1980s	181
Function of Control System.....	182
Analogy with Symphony Orchestra Conductor	182
Fringe Benefits of Control System	182
Simulation and Modeling	182
Design Sequence	183
Algorithm Development.....	183
Conflict: Fuel Economy and Exhaust Emissions	184
Exhaust Emissions: Origin of Pollutants.....	184
Various Operational Modes to Be Controlled.....	184
Elements of Control Theory	186
Overview of Control System: Cartoon Version.....	187
Overview of Control System: ECU Version.....	189
Descriptions of ECUs.....	189

Hybrid ECU.....	189
Engine ECU.....	190
M/G ECU	190
CVT ECU	190
Power Electronics ECU	190
Battery ECU or Battery Management System	190
Air-Conditioning ECU.....	190
Control Area Network.....	190
Control Variables: Variables Connecting the ECUs	191
Engine Management.....	191
Exhaust Gas Recirculation	192
Engine Efficiency Map.....	192
Load Leveling.....	193
Control Complexity and Difficulty	193
Adaptive Control Strategy.....	194
Robustness of Control System.....	194
Four Control Strategies	194
Rules-Based Control Algorithm.....	195
Optimization.....	195
Hardware-Constrained Optimization.....	197
Fuzzy Logic Control: What Is It?.....	197
Fuzzy Logic Control Application to Hybrid Control	197
Neural Network Control: What Is It?	198
NN Control: Application to Hybrid Control	198
Comparison of Fuzzy Logic and NNs for Control.....	199
Combined Fuzzy Logic and NNs for Control	199
Electrical Components: Electrical Motors and Generators.....	200
Summary	200
References	200
Chapter 9 Regenerative Braking	201
Introduction	201
Function of Regenerative Braking.....	201
Integration of Functions and Components	201
Logic Relative to Size of Regenerative Brakes	201
Brake Cooling, Aerodynamic Drag, and Regenerative Braking	201
Brakes and Tires Primer.....	202
Why Discuss Tires?.....	202
Slip, Slide, and Skid.....	202
Relation between Tire Force and Weight on Tire.....	203
Weight on Each Wheel	203
Braking “Dive”: Shift of Weight to Front Tires	204
Tire Patch.....	205
Longitudinal Tire Forces.....	205
Longitudinal Tire Forces: Traction.....	205
Longitudinal Tire Forces: Braking.....	206
Locked Wheels.....	207
Lateral Tire Forces	207
Directional Stability	207
Antilock Brake System.....	208
Regenerative “Coasting”	208

Energy to Be Recovered by Regenerative Braking	208
Bands of SOC for Battery.....	209
Stopping Distance.....	210
Time and Stopping Distance: Friction Brakes	212
Time and Stopping Distance: Regenerative Brakes	212
Efficiency of Regenerative Braking.....	214
Typical Driving Cycle.....	214
Braking Force from Electrical Generator.....	215
Two Design Approaches for Regenerative Braking	216
Regenerative Braking Integrated with Conventional Hydraulic System	216
Driver Input	217
Brake Actuator	217
Three-Port Switch	217
Controller: Inputs	218
Controller: Outputs.....	218
M/G: Generator Mode.....	218
Summary	218
Appendix 9.1: Equations for Regenerative and Friction Brakes	219
Regenerative Brakes	219
Friction Brakes	220
References	221
Chapter 10 Narrow Operating Band for Gasoline Engine.....	223
Introduction	223
Demands of Driving Cycle.....	223
Driving Cycle	223
Roads	223
Intensity of Traffic	224
Terrain	224
Road Quality.....	224
Weather.....	225
Mission of Vehicle: Widespread Usage.....	225
Mission of Vehicle: Specialty	225
Real-World Data	225
Variables for Driving Cycle.....	226
Minimum Fuel Consumption Line.....	226
Engine Map	226
Superimpose Engine Power Contours	226
Basic Operating Line: Minimum Fuel Consumption Line.....	227
Narrow Operating Band for Gasoline Engine.....	228
Matching the Wheels to the Engine	229
Effect of Number of Transmission Speeds on Fuel Economy.....	230
Effect of Number of Transmission Speeds on Control of Engine Speed	230
Role of Electric Motor in a Hybrid.....	231
Summary	231
References	232
Chapter 11 Hybridness: A Basic Design Decision.....	233
Definition of Hybridness	233
Story	233

Hybrid Design Philosophy	234
Hybridness: Parallel Hybrid	234
Hybridness: Series, Mixed, and Range Extender (Plug-In) Hybrids.....	235
Range Extender	236
Optimization and Hybridness	237
Battery Power and Electric Motor Power.....	237
Residual Performance with a “Dead” Battery	238
Effect of Low Charge.....	239
Power-to-Weight Ratio	239
Interpretation of Ramps	239
Various Techniques to Enhance Hybrid Performance	240
Start–Stop	241
Damping Driveline Oscillations.....	241
Vehicle Launch.....	241
Regenerative Braking	241
Motor Assist	241
Electric-Only Propulsion.....	241
Downsize the Engine.....	242
Miles per Gallon Gain.....	242
Mild or Micro Hybrid Features	242
Why Is H About 50% a Good Spot for High Miles per Gallon?.....	242
Plug-In Hybrid.....	242
All-Wheel Drive Hybrid.....	243
Summary	245
Appendix 11.1: Derivation of Range Extension Equations	245
Appendix 11.2: Range of a Plug-In Hybrid	247
Reference	247
 Chapter 12 Mileage Ratings	 249
Introduction	249
Mileage Ratings	249
Introduction	249
Little History	250
Previous EPA Mileage Estimates.....	252
What Changes and What Does Not Change?.....	252
Facts Concerning Mileage Ratings	252
Driving Cycles.....	252
Standardized Test Procedures	253
Vehicles Exempt from EPA Mileage Sticker.....	253
Mileage Shortfall.....	254
Consequences of Mileage Shortfall.....	254
Effective \$/Gal due to Shortfall.....	255
Deficiencies in Old and New EPA Methods.....	255
Revised Tests and Standards	255
Effects of Ambient Temperature	256
Testing Four-Wheel Drive	256
Rolling Friction	256
Aerodynamic Drag	256
Vehicle Load.....	256
Aggressive Driving.....	257
Driving Cycle	257

A/C and Auxiliaries	257
Terrain, Curves, and Altitude	258
Weather.....	258
New EPA Tests to Estimate Mileage.....	258
Five-Cycle Estimate: EPA-Weighted Combination of Tests.....	258
Importance of Weighting Factors	260
Change in Vocabulary: City and Highway	260
Transition Period: 2008–2010	261
Testing Hybrids	261
Hybrids and the New EPA Tests to Estimate Fuel Economy	261
Hybrid Modes of Operation.....	261
Driving Technique.....	261
Regenerative Braking	261
Battery State of Charge	261
Hybrids, Braking, and the Panic Stop	262
Corporate Average Fuel Economy	262
Introduction	262
Marked Inconsistency.....	263
Definitions for Passenger Cars and Trucks	263
Passenger Car Standards	264
Truck Standards: Unreformed System	264
Truck Standards: Reformed System	264
Penalties for Failure to Meet CAFE Standards	265
CAFE Credits	265
Import Fleets	265
Special Rules for Alternate Fuel Vehicles.....	265
CAFE Exempt Vehicles.....	265
National Academies' National Research Council Recommendations	265
CAFE and Hybrid Technology.....	266
General Motors View on 35 mpg CAFE Standard	266
How to Improve Fuel Economy: Tips for Better Miles/Gallon.....	266
Debunking Tips for Better mpg: What Is a Myth?.....	266
Negative Miles/Gallon.....	267
Overview of Analysis	267
Fractional Change in Brake-Specific Fuel Consumption, B	267
Conventional Vehicle.....	268
Hybrid Vehicle.....	268
Driving Techniques	268
Preliminaries	268
Engine Break-In.....	268
Statistical Variations in Vehicles	268
Most Efficient Engine Operating Point	268
Buying Gasoline	269
Buy Gas in the Cool of the Morning	269
Buy When Tank Is One-Fourth Full	270
Do Not Overfill Tank.....	270
Do Not Buy Premium Fuel.....	270
Different Brands of Gasoline	270
Different Brands of Gasoline: Ethanol E85.....	271
Credit Card Rebate	271
How Far to Drive to Save a Penny?.....	271
Test Accuracy	271

How Much Gasoline Is Used for a Test?	272
EPA Tests.....	272
EPA: Appropriate Implied Accuracy	272
Plan Ahead	272
Avoid Unneeded Miles	272
Drive a Quarter Mile Down the Road	272
Just Do Not Drive	272
Alternate Transportation.....	273
Combine Trips	273
Rush-Hour Traffic.....	273
Parking.....	273
Know Where You Are Going	273
Vehicle Maintenance	273
Keep a Mileage Log	273
Check Engine Light.....	273
Tune-Up	274
Engine Oil Viscosity.....	274
Plugged Air Filter	274
Wheel Alignment	275
Wheel Balance.....	275
Tire Inflation.....	275
Change in Tire Pressure with Temperature.....	276
Tire Purchase and Construction	276
Tire Purchase and Construction: Speed Rating	277
Rolling Friction Coefficient: Other Factors: Temperature	277
Rolling Friction Coefficient: Other Factors: Aspect Ratio	278
Rolling Friction Coefficient: Other Factors:	
Vehicle Velocity.....	279
Snow Tires.....	279
Aerodynamic Drag: Wheel Wells, Hubcaps, and Wheels.....	279
Getting Better mpg Cruising along the Interstate	279
Introduction	279
Cruise Control	280
Story: Optimum Speed.....	280
Optimum Cruise Speed	280
Resistance to Vehicle Motion: Crossover Velocity.....	282
Speeding: In Cruise Condition	284
Tailgating: Behind a Truck on Interstate	284
Tailgating: Analysis.....	284
Tailgating: Good and Bad.....	285
Aggressive Driving.....	285
Fuel Economy Meter (Instantaneous mpg)	285
Aggressive Driving: Definition	285
Aggressive Driving versus Gentle Driving	285
Aggressive Driving: Rapid Acceleration	285
Aggressive Driving: Rapid Acceleration:	
Neglecting Aerodynamic Drag.....	287
Another Quote	288
Reconcile Fuel Economy Meter (Instantaneous mpg)	
and Previous Conclusions.....	288
Yet Another Quote.....	288
Aggressive Braking: Braking Hard.....	288

Speeding: In Acceleration	289
Virtual Test Track	291
Driving Tips	292
Overdrive and Higher Gears with Manual Transmission.....	292
Aerodynamic Drag: Pickup Truck Tailgate.....	293
Aerodynamic Drag: Sunroof	293
Aerodynamic Drag: Deformation of Convertible Tops	293
Aerodynamic Drag: Roof Rack	293
Brake Drag	293
Reduce Use of Brakes.....	294
Idling	294
Idling: Engine-Off in Conventional Vehicle	294
Idling: Engine-Off in Hybrid Vehicle	294
Power-Hungry Accessories and Auxiliaries.....	294
Two-Wheel and Four-Wheel Drive.....	294
Extra Weight in Vehicle.....	295
Anticipate Traffic Conditions	295
Anticipate Red Lights.....	296
Towing a Trailer	296
Never “Rev-Up” the Engine	297
Air-Conditioning and Windows Down	297
Air-Conditioning: Background.....	297
Air-Conditioning: Effects of Humidity	298
Air-Conditioning: Control	298
Air-Conditioning: Zone and Recirculation	298
Air-Conditioning: Thermostat Control.....	298
Air-Conditioning: Cold Modulated with Heat	299
Air-Conditioning: Pure Cold	299
Air-Conditioning: Reported Losses	299
Air-Conditioning: Equation for Loss of Fuel Economy due to A/C	299
Air-Conditioning: Sample Calculations for Fuel Economy Loss.....	300
Air-Conditioning: 2005 Cadillac STS.....	301
Open Windows	301
Open Window (Sunroof) Ventilation: Comments.....	301
Open Window Ventilation: Loss of Fuel Economy.....	301
A/C versus Open Windows	302
A/C versus Open Windows: Sample Calculations	302
Analytical Result for V_E	303
Where You Drive.....	303
Headwind and Tailwind.....	303
Warming Up the Engine.....	304
Cold and Hot Weather	304
Curves in Road	304
Ice and Snow.....	306
High Altitude	306
Terrain: Climbing Hills	306
Dirt and Gravel Roads	307
Snow and Water Puddles on Road.....	307
Rough and Undulating Roads	307
Mileage Scams	307
Mileage Scams: Detecting Scams	307
Mileage Scams: Consequences of Using Scam Device.....	308

Mileage Scams: EPA Tests	308
Mileage Scams: A Perspective	308
Mileage Scams: Unsubstantiated Calculations.....	309
Summary	309
Appendix 12.1: Optimum Cruise Speed	309
Appendix 12.2: CAFE Fleet Average Fuel Economy and Vehicle Average	312
Fleet Average Fuel Economy.....	312
Vehicle Average.....	313
Appendix 12.3: Change in Fuel Economy EPA Estimates: Old versus New Test Methods.....	313
References	314
 Chapter 13 Enhancing the Sales Brochure	317
Introduction	317
Function of Sales Brochure: Consumer Viewpoint.....	317
Function of Sales Brochure: Car Manufacturer Viewpoint.....	317
Hybrid Components	317
Battery	318
Electrical Motor/Generator.....	318
Gasoline (Diesel) Engine.....	318
Combined Engine and Motor Torque and Power	318
Transmissions	319
Accessories and Auxiliaries	319
Hybrid System	319
Conversion or Clean Sheet Design	319
Conversion or Clean Sheet Design: Impact on AWD and 4WD	319
Regenerative Braking	319
Hybrid System Layout	320
Hybridness or Hybridization	320
Plug-In Hybrid	320
Starting the Engine.....	320
Hybrid Performance	321
Electric-Only	321
Fuel Economy during Cruise.....	321
Fuel Economy	321
Performance with a “Dead” Battery.....	322
Miscellaneous.....	322
Crossover Velocity.....	322
Optimum Cruise Velocity.....	322
Instrumentation and Displays	323
Summary	323
Reference	323
 Chapter 14 Torque Curves: A Match Made in Heaven.....	325
History of Electrical Alternators, Motors, and Generators in Automobiles	325
Functions of the Motor/Generator.....	325
Origin of Forces and Torques.....	325
Types of Motors and/or Generators.....	327

Permanent Magnets	327
Definitions for Motors and Generators.....	328
Simple DC Motor/Generator	328
Rotating Magnetic Field	328
DC Brushless Motor	329
Alternator	330
Induction Motor and Asynchronous Generator.....	330
Switched Reluctance Motor: Stepping Motor	330
Losses and Motor Efficiency	332
Cooling	332
Selection of M/G	332
Design and Control Aspects.....	333
Desired and Attainable Torque Curve: Match Made in Heaven	333
Switching from Motor to Generator and Vice Versa	335
2006 Honda Civic Torque Curves	336
2006 Honda Civic Hybrid Electric Motor.....	337
Alternate View of Electric Motors: Torque or Speed.....	338
Summary	339
Appendix 14.1: Matching Poles for a Switched Reluctance Motor.....	339
References	340
 Chapter 15 Economics of Hybrid Ownership.....	 341
Introduction	341
Costs to Produce a Hybrid.....	341
Table from the Internet.....	341
Economics of Bus and Truck.....	342
Base Model versus Top-of-the-Line	342
Benefits of Hybrids.....	342
Summary of Benefits.....	342
Pay at the Pump.....	342
Perspective on Cost of Fuel: Pay at the Pump.....	342
Fuel Costs	343
Annual Cost of Gasoline (Diesel) Fuel	343
Fuel Savings	345
Annual Fuel Savings Equation	345
Combined EPA Mileage Ratings.....	346
Real-World Fuel Economy and Market Realities	346
Marginal Savings: One More Mile per Gallon.....	346
Years to Recoup.....	347
Years to Recoup Price Premium	347
Tax Savings	347
Tax Credit and Tax Deduction	347
State Tax Credit and Tax Deduction	347
Gas Guzzler Tax	348
Car Pool Lane Permits: Two-Tier Value.....	348
Costs	348
Costs: Added Costs as a Result of Price Premium.....	348
Costs (Savings): Maintenance and Repair.....	348
Costs: Automobile Insurance.....	348
Costs: Depreciation Takes Effect	349

Costs: The Showroom Syndrome	349
What Is a Major Improvement?	349
Costs: Depreciation and Pace of Technology	350
Costs: Amount of Depreciation for Various Vehicles	352
Threat of Battery Replacement.....	352
Interplay Hybrid Technology and Price Premium	353
Graphical Representation of Profit/Loss and Reward/Penalty	353
Summary	358
Appendix 15.1: Classified Advertisement for Toyota Prius II.....	359
References	360

Chapter 16 New Technologies: Hybrids..... 361

Overview	361
Factors Affecting New Technology.....	362
Factors Affecting New Technology: Overall Items.....	362
Elusive Fuel Cell.....	362
Impact of Emission Requirements: ZEV Program.....	362
Infrastructure: Charging EV and Plug-In HEV	363
Infrastructure: Hydrogen	364
Impact of Emissions Requirements: Internal Combustion Engine H ₂ Powered	364
Relative Importance of ICE and Fuel Cell: Creation of Hydrogen Infrastructure.....	364
Three General Vehicles and Associated Infrastructure	365
Generalized Hybrid	365
Shared Components: Fuel Cell and HEV	365
Biggest Gains	367
Biggest Gains: Saving Gasoline	367
Mining the Obvious: Energy Storage.....	368
Batteries.....	368
Ultracapacitor or Supercapacitor	369
Flywheel	369
Hydraulic/Pneumatic.....	369
Compressed Air Vehicle.....	370
Spiral Springs	370
Rubber Torsion Springs	370
Mining the Obvious: Other Hybrid Technologies.....	370
Integration and Control	370
Power Electronics	370
Wheel Motors and Electrical M/G	371
Energy Conversion	371
Powertrain	371
Savings from New Transmission.....	372
Automated Manual Transmission.....	372
Starting the Engine.....	372
Solar Cells	373
Innovation: Seeking the Novel	373
Modular Hybrid Units	373
Generator in Shock Absorbers.....	373
Generator Driven by Exhaust Turbine.....	373

Fuel-Cell/Gas-Turbine Hybrid	374
Free Piston Engines	374
Transmotor: Rotating Rotor and Rotating Stator	374
Digital versus Analog Control	374
Photosynthesis and Other Bioinspired Chemistry	375
Cold Fusion	375
Motivation for New Technology	375
Uncertain Future	375
Summary	375
Appendix 16.1: Saving Gasoline	376
References	376

Chapter 17 New Technologies: Internal Combustion Engine..... 377

Introduction	377
What and Where Are the Losses?	377
Technology to Increase Efficiency	380
Advanced Combustion: Gas and Diesels	380
Stop and Go: Wear and Tear	380
Recover Thermal Energy Dumped by Exhaust and Radiator	380
Recover Thermal Energy Dumped by Power Electronics	380
Variable Valve Timing and Variable Valve Lift	380
Direct Injection Stratified Charge Engines	381
Dual Injection	381
Comments on Diesels	381
New Technology: Diesels	382
Partnership for a New Generation of Vehicles: Supercar Diesel Engines	383
Clean Diesel for SUV: DOE Program	383
Heavy Truck Diesels	383
Examples of New Designs	383
Closing All Valves	383
Cylinder Deactivation	384
Atkinson Cycle Engine	384
Miller Cycle	388
Stirling Cycle	388
Alvar Engine	388
Offset Crankshaft	388
Free Piston Engines	389
Convergence of Gas and Diesel	389
Advances in mpg in Recent Years	389
Hybrid Engines	390
HCCI Engine	390
Turbocharging and/or Supercharging	391
Six-Stroke Engine	391
Trends in mpg for Gasoline and Diesel Propulsion and HEV	392
Summary	393
Appendix 17.1: Combustion Processes in ICE	393
Gasoline Engines	393
Diesel Engines	395
References	395

Chapter 18	Hybrids: Mainstream or Fringe?	397
	Introduction	397
	Determining Factors	397
	Dominant Factors	397
	Other Factors	397
	Regulation of Greenhouse Gas	398
	Consumer Perception of Gas Prices	398
	Alternate Fuels	398
	Uncertainty Concerning Hybrids	399
	Corporate Average CO ₂ Emissions	399
	Competition: HEV versus Gas/Diesel	399
	Competition to the HEV	399
	Favorable Factors for HEV	399
	Unfavorable Factors for HEV	399
	Future for HEV	400
	Time Lag: Vehicle Populations	400
	Discussion of Future for HEV	401
	Home Generation of Electricity	402
	Competition: HEV versus FCV	402
	Fuel Cell Vehicle Future	403
	Summary	404
	References	404
Chapter 19	Factors Influencing Resale Value	405
	Introduction	405
	Common Factors	405
	Warranties	405
	Reliability and Quality	405
	Desirability	405
	Undesirability	405
	Options and Accessories	406
	Depreciation	406
	New Car Rebates	407
	Mileage and Vehicle Condition	407
	Resale Factors Specific to Hybrids	408
	Battery	408
	Warranties	408
	Aftermarket Modifications	409
	Finger in the Dike: Replacing Individual Cells	409
	Depreciation and Pace of Technology	409
	Summary	409
Chapter 20	Dangers of Aftermarket Add-Ons	411
	Service and Repair	411
	Prevalent Beliefs Concerning Hybrids	411
	Training	411
	Safety	411
	Service and Repair of Hybrids	411
	Repair of Collision Damage	412

Performance Modification.....	412
Avoid Voiding the Warranty.....	412
Training	412
Safety	412
Performance Enhancement.....	412
Just More Computers.....	412
Logic on Complexity of Hybrid Control	413
Adding a Second Gas Tank	413
Adding a Second Battery.....	413
Making a Home for the Battery.....	414
Payload Penalty	414
Performance and Handling Penalties due to Added	
Battery Weight.....	414
Performance Penalty.....	415
Obesity Penalty due to Added Battery Weight.....	415
Two Classes of Batteries.....	416
Summary	416
Chapter 21 Safety Issues	419
Overview	419
What Are Today's Hazards?.....	419
Who Has an Interest in Hybrid Safety?.....	420
Rescue of Occupants of Hybrid in a Wreck	420
Agencies Involved in Rescue.....	421
Rescue Equipment and Procedures	421
Built-In Safety	421
Safety for First Responders and during Dismantling	422
Battery Safety Switch.....	423
What Are Future Hazards?.....	423
Hydrogen Safety	424
Summary	424
Appendix 21.1: Lithium-Ion Battery Safety	425
Li-Ion Battery Protection in HEV Application	425
Cell-Level Safety Devices.....	425
Opening (Rupture) Lithium-Ion Battery	426
Causes of Battery Accidents: Triggers	426
Triggers: Overcharging or Overheating: Steps to Possible Disaster	
with Conventional Cell Chemistries	426
Triggers: Internal Short Circuit: Partial or Total.....	426
Positive Electrode.....	426
Negative Electrode	427
References	427
Chapter 22 Future	429
Introduction	429
Supply and Demand	429
Mitigation Measures.....	429
Asymmetric Risk.....	429
What Needs to Be Done?.....	430
Who Will Pay for It?.....	430

Incremental Costs of Mitigation.....	431
Painless (Almost) Mitigation Measures	431
Indicator for Alternate Fuels	431
Abiotic Oil.....	432
Uranium Argument	432
Alternate Fuels: Overview.....	432
“Fuel” for Transportation	432
Some Definitions	433
Perspective on Biofuels	434
Carbon/Hydrogen Ratio	434
Energy Out/Energy In	435
Coal.....	436
Coal Resources	437
Alternate Fuels: Details.....	437
Biomass and Alternate Fuels	437
Cellulosic Materials and Biofuels.....	437
Grassoline	438
Microorganisms in Alternate Fuels.....	438
Biodiesel Fuel	438
Alternate Fuels: Ethanol as a Fuel.....	439
Color Yellow	439
Energy Content.....	440
Combustion of Ethanol.....	440
Water in the Fuel	440
Emissions.....	440
Compression Ratio	440
Fuel Compatibility: Corrosion of Materials	441
Cold Weather Operation.....	441
Flame Arrestors.....	441
Dual-Fuel Vehicles	441
Transportation of Ethanol.....	442
Rocket Fuel	442
Can Ethanol Replace Gasoline?	442
Alternate Fuels: More Fuels	442
Methanol.....	442
Natural Gas.....	442
Natural Gas/Hydrogen Blends.....	443
Electricity as a Fuel	443
Alternate Fuels: Hydrogen as a Fuel	443
Hydrogen: Fuel of the Future	443
Hydrogen: Fuel of the Past	444
Critical Milestones	444
Production of Hydrogen	444
Hydrogen Storage	444
Hydrogen Storage: Clathrate Hydrates.....	445
Energy to Compress Hydrogen.....	445
Hydrogen Infrastructure.....	446
Simultaneity.....	446
Comparison with Gasoline	446
Past and Future.....	446
Past: 1890–1950.....	446

Future: 2000–2060	446
Gasoline/Diesel	447
Pure Electric	448
Hybrid	448
Fuel Cell Vehicle	448
Alternate Fuel, ICE.....	448
Kit Conversion Cars	448
Summary	448
Appendix 22.1: Physical Properties of Fuels.....	449
References	450
 Appendix A: Acronyms and Relevant Data.....	 451
 Appendix B: Global Warming	 457
Reference	458
 Index	 459