

Contents

Preface			χV		1.13		re the World Leaders in	19	
Acknowledgments					1 14	Renewable Energy? 14 What Is Our Likely Energy Future?			
Author			xix		1,17		! What Is Projected for Future Employment	21	
1	Intro	duction	1				in the Renewable Energy Field?	22	
	1.1	Why Another Book on Energy?	1		1 15	Compl	exities in Charting the Best	<i>L L</i> .	
	1.2	Why Is Energy So Important to			1.10		for the Future	24	
		Society?	1				Example 3: How the	- fam. 1	
	1.3	Exactly What Is Energy?	2			1.10.1	Usage of Wind Power to		
	1.4	Might There Be Some New Forms					Offset Coal-Fired Plants		
		of Energy Not Yet Known?	4				Can Generate More		
	1.5	What Are the Units of Energy?	5				Emissions Not Less	26	
	1.6	Laws of Thermodynamics	7		1.16	Summ		26	
		1.6.1 Example 1: Calculating			Prob			26	
		Energy When Power Varies				rences		28	
		in Time	8						
		What Is an Energy Source?	8	2	Foce	il Fuels		29	
	1.8	What Exactly Is the World's		han					
		Energy Problem?	9		2.1	Introdu		29	
		1.8.1 Climate Change	10		0.0		Carbon Cycle	31	
		1.8.2 Is Human Population			2.2	Coal	Commonition of Cool	31	
		Growth the Root Cause					Composition of Coal	32	
		of Our Energy and	10			2.2.2	Example 1: Energy Content	34	
		Environmental Problem?	10			222	of Coal Formation of Coal	34	
	1.0	1.8.3 How Much Time Do We Have?	12				Resource Base	36	
	1.9	How Is Green or Renewable	10				Electricity Generation	30	
	1 10	Energy Defined?	13			2.2.5	from Coal	37	
	1.10	Why Has Renewable Energy and					2.2.5.1 Example 2:	57	
		Conservation Been Neglected	1 /				Efficiency of a		
	1 1 1	Until Fairly Recently?	14				Coal-Fired Power		
	1.11	Does Energy Efficiency Really Matter?	16				Plant	38	
			10				2.2.5.2 Rankine Cycle	39	
		1.11.1 Example 2: Which Solar Panels Are Superior?	16			226	Conversion of Coal		
	1 10	Which Renewable Energy Sources	ΤÜ			2,2.0	to a Transportation Fuel	40	
	1.12	Hold the Greatest Promise?	17			2.2.7	Coal Mining	41	
		riola life diealest i lolllise:	Τ/					,	

	2.2.8	2.2.8 Environmental Impacts of		3	Nucl	ear Power	65
		Coal	42		3.1	Introduction	65
		2.2.8.1 Atmospheric				Early Years	65
		<i>Emissions</i>				Discovery of the Atomic Nucleus	67
		from Coal			3.4	Mathematical Details of the	07
		Power Plants	43		3.4		70
		2.2.8.2 Other	, -			Rutherford Scattering Experiment	70
		Atmospheric				3.4.1 Example 1: Setting an	
		Emissions				Upper Limit to the Nuclear	70
		Including			0.5	Size	72
		Radioactivity	44		3.5	Composition and Structure of the	70
		2.2.8.3 Waterborne	44			Atom and Its Nucleus	73
					3.6	Nuclear Radii	74
		Pollution and	4.4			Nuclear Forces	75
		Acid Rain	44		3.8	Ionizing Radiation and Nuclear	
		2.2.8.4 Example 3:				Transformations	76
		Connection			3.9	Nuclear Mass and Energy	78
		between Acidity			3.10	Nuclear Binding Energy	79
		and pH Levels	45		3.11	Energy Released in Nuclear Fusion	80
		2.2.8.5 Impacts on the				3.11.1 Example 2: Estimating	
	_	Land	46			the Energy Released in	
	2.2.9	Carbon Sequestration and				Fusion	80
_		"Clean" Coal	46		3.12	Mechanics of Nuclear Fission	81
2.3	Petrole	eum and Natural Gas	48			3.12.1 Example 3: Estimating	_
	2.3.1	History of Petroleum Use	48			the Energy Released in	
	2.3.2	Resource Base of Oil and				Fission	82
		Gas	49		3 13	Mechanics of Nuclear Fusion	82
	2.3.3	Formation and Location of			5.15	3.13.1 Example 4: Find the	02
		Oil and Gas	50			Temperature Needed to	
	2.3.4	Are Coal, Oil, and Gas				Initiate d–d Fusion	84
		Really Fossil Fuels?	52		211		84
	2.3.5	Peak Oil	54			Radioactive Decay Law	
		2.3.5.1 Example 4: How	•			Health Physics	85 86
		Many Years Are				Radiation Detectors	86
		Left?	55		3.17	Radiation Sources	86
	236	Petroleum and Natural Gas	30			3.17.1 Example 5:	
	2.0.0	Processing Processing	56			Comparison of Two	0.77
		2.3.6.1 Extraction of Oil	50			Radioactive Sources	87
		and Gas	56		3.18	Impacts of Radiation on Humans	88
		2.3.6.2 Refining of Gas	50			3.18.1 Safe Radiation Level and	
		-	E 7			Cancer Risks	88
	227	and Oil	57			3.18.2 Relative Risk	89
	2.3./	Gas and Oil Power Plants	58		3.19	Summary	90
		2.3.7.1 Example 5: A			Prob	lems	90
		Binary Cycle			Refe	rences	92
	000	Plant	59				
	2.3.8	Environmental Impacts of					
0.4	0	Oil and Gas	59	4	Nuc	lear Power	93
2.4	Sumn	nary	62	1°			
	lems		62			Introduction	93
<i>Kete</i>	rences		64		4.2	Early History	94

	4.3	Critical Mass	96			5.2.2 Example 2: Best	
		4.3.1 Neutron Absorption by				Wavelengths of Light for	
		Uranium Nuclei	97			Photosynthesis	138
		4.3.2 Why Does Density Matter			5.3	Biofuel Classifications	139
		in Determining Critical				5.3.1 Choice of Feedstock for	
		Mass?	98			Biofuels	139
		4.3.2.1 Example 1:				5.3.2 Biofuel Production	
		Estimation of				Processes	143
		Critical Mass	98			5.3.3 Example 3: Loss	
	4.4	Nuclear Weapons and Nuclear	-			of Energy When	
	,	Proliferation	100			Combustible Material	
	4.5	World's First Nuclear Reactor	103			Is Moist	145
	4.6	Nuclear Reactors of Generations	100			5.3.4 Generation of Biofuels	145
	7.0	I and II	105		5.4	Other Uses of Biofuels and	110
	4.7	Existing Reactor Types	106		J. T	Social–Environmental Impacts	147
	7./	4.7.1 Choice of Moderator	106			5.4.1 Biofuels from Wastes and	17/
		4.7.1.1 Example 2: How	100			Residues Residues	148
		•				5.4.2 Agricultural Wastes	148
		Much Energy Does a Neutron Lose					. 140
						5.4.3 Central Role of Agriculture in a Sustainable Future	140
		on Average during	107				149
		Elastic Collisions?	107		<i>E E</i>	5.4.4 Vertical Farming	150
		4.7.2 Choice of Fuel	108			Artificial Photosynthesis	151
	4.0	4.7.3 Choice of Coolant	110			Summary	152
	4.8	Reactor Accidents	111		Prob		152
		4.8.1 Fukushima	111		Refei	rences	154
		4.8.2 Chernobyl	112				
		4.8.2.1 Causes of		6	Cent	hermal Energy	155
		Chernobyl	114	0			100
		4.8.3 Reactor Accidents: Three			6.1	Introduction and Why Geothermal	1.55
		Mile Island	115			Is Important	155
	4.9	Front End of the Fuel Cycle:				6.1.1 History and Growth of	
		Obtaining the Raw Material	116			Usage	155
	4.10	Back End of the Fuel Cycle:				6.1.2 Geographic Distribution	155
		Nuclear Waste	117			6.1.3 Sources of the Earth's	
		4.10.1 Shipping Nuclear Waste	119			Thermal Energy	156
	4.11	Economics of Large-Scale				6.1.4 Comparison with Other	
		Nuclear Power	121			Energy Sources	157
	4.12	' Small Modular Reactors	124		6.2	Geophysics of the Earth's	
	4.13	Nuclear Fusion Reactors	126			Interior	158
	4.14	Summary	128		6.3	Thermal Gradient	159
	Prob	lems	129		6.4	Characterization and Relative	
	Refe	rences	131			Abundance of the Resource	161
						6.4.1 Impact of the Thermal	
genes	m' (•	100			Gradient	161
5	Biofu	ueis	133			6.4.2 Example 1: Relative	
	5.1	Introduction	133			Energy Content for Two	
	5.2	Photosynthesis	135			Gradients	162
		5.2.1 Example 1: Efficiency of				6.4.3 Questioning Our	
		Photosynthesis	137			Assumptions	162

		6.4.4	Other Geologic Factors			7.2.1	v-Cubed	
			Affecting the Amount of				Dependence of Power on	
			the Resource	164			Wind Speed	187
		6.4.5	Hot Dry Rock Formations	164		7.2.2	Wind Speed	
	6.5	Geoth	ermal Electricity Power				Distributions	188
		Plants		166		7.2.3	Wind Speed as a	
		6.5.1	Example 2: Efficiency				Function of Height	191
			of a Geothermal Power			7.2.4	Example 1: Turbine	
			Plant	167			Power versus Height	192
	6.6	Reside	ential and Commercial		7.3	Power :	Transfer to a Turbine	193
			ermal Heating	167	7.4		Types and Terms	195
			Economics of Residential			7.4.1	Lift and Drag Forces and	
			Geothermal	169		-	the Tip-Speed Ratio	195
	6.7	Sustai	nability of Geothermal	170		7.4.2	Example 2: The Cup	100
			Depletion of a Geothermal	2, 0		, , , , , _	Anemometer	196
			Field	170		7.4.3	Horizontal versus Vertical	150
		6.7.2	Example 3: Lengthening	1,0		7.4.0	Axis Turbines	197
		0	the Lifetime	171		7.4.4	Number of	197
		6.7.3	Example 4: A 100 MW	1,1		7.7.7	Turbine Blades, and	
			Power Plant	172	1		Solidity	199
	6.8	Enviro	nmental Impacts	172		7.4.5	Variable and Fixed	199
			Released Gases	172		7.7.5	Rotation Rate Turbines	202
			Impact on Land and	1,2	7.5	Control	ling and Optimizing Wind	202
		0.0.2	Freshwater	173	7.5		Performance	202
		683	Do Heat Pumps Cut Down	175		7.5.1	Example 3: Turbine	202
		0.0.0	on CO ₂ Emissions?	174		7.5.1	Power and Typical Blade	
	6.9	Econo	mics of Geothermal	1/4			Diameter	204
	0.5	Electri		174		7.5.2		204
			Drilling Costs	174		7.5.2	Maximizing Power below	204
			Beating the Exponential?	174		752	the Rated Wind Speed	204
			Why the Exponential	1/5		7.5.3	Limiting Power	
		0.5.5	Dependence of Cost on				above the Rated Wind	200
			•	176	7.0	Ela aboi a	Speed	206
		601	Well Depth?	176	7.6		al Aspects and Grid	000
		0.9.4	Is Spallation Drilling the	176		Integrat		206
		605	Answer?	176	~ ~		Asynchronous Generator	207
		0.9.5	Why Spallation		7.7	Small V		210
			Drilling Cost Might			7.7.1	Example 4: Comparing	
			Be a Linear Function	177	7.0	011	Two Turbines	211
	C 10	Cuman	of Depth	177	7.8	Offshore		211
		Summ	iary	178			mental Impacts	212
	Prob			179	7.10		al Designs and	
	кете	rences		181		Applica		214
							Airborne Turbines	214
7	Wine	l Powe	r.	183			Wind-Powered Vehicles	215
,						7.10.3	Directly Downwind	
	7.1		uction and Historical Uses	183	_		Faster-than-the-Wind	216
	7.2		Characteristics and		Prob			216
		Resou	rces	185	Refer	rences		218

8	Hydr	opower		219		9.5	Availabi	lity of Solar Radiation	
	8.1	=	tion to Hydropower	219			on Earti	=	258
	· · ·	8.1.1	Advantages of Hydropower				9.5.1	Example 2: Finding	
		8.1.2	Basic Energy Conversion					the Number of Daylight	
			and Conservation					Hours	258
			Principles	221		9.6	Optimu	m Collector Orientation	
		8.1.3	Impulse Turbines	223			and Tilt		260
		8.1.4	Design Criteria for			9.7		ouse Effect	261
			Optimum Performance	224			9.7.1	Expected Average Surface	
		8.1.5	Example 1: Designing a					Temperature of the Planet	261
			Pelton Turbine	225			9.7.2	Natural Greenhouse Effect	262
		8.1.6	Reaction Turbines	226			9.7.3	Climate Change	
		8.1.7	Turbine Speed and					Feedbacks	264
			Turbine Selection	228				9.7.3.1 Positive	
		8.1.8	Specific Speed	229				Feedbacks	265
		8.1.9	Pumped Storage					9.7.3.2 Negative	
			Hydroelectricity	231				Feedbacks	265
		8.1.10	Small Hydro	232			9.7.4	Four Greenhouse Gases	266
	8.2	Wave, Ti	idal, and Ocean Thermal				9.7.5	Global Temperature	
		Power R	Pesources Personal Pe	234				Variation and Its Causes	268
		8.2.1	Wave Motion and Wave				9.7.6	Climate Projections	
			Energy and Power	235				for the Coming Century	270
		8.2.2	Example 2: Power of a				9.7.7	"Tipping Points" in the	
			Wave	236				Climate System	271
		8.2.3	Devices to Capture Wave				9.7.8	Categories of	
			Power	236				Positions in the Global	
	8.3	Introduc	tion to Tidal Power and					Warming Debate	272
		the Caus	se of the Tides	238			9.7.9	Arguments of Global	
		8.3.1	Tidal Current Power	241				Warming Skeptics and	
		8.3.2	Impoundment (Barrage)					Deniers	273
			Tidal Power	242			Summa	ry	277
		8.3.3	Dynamic Tidal Power	242		Probl			277
	8.4		Thermal Energy Conversion	244		Keter	rences		279
	8.5	Social a	nd Environmental Impacts						
		of Hydro	•	245	10	Solar	al	281	
	8.6	Summai	ry	246	 •		Introduc		281
	Prob			246				ater-Heating Systems	282
	Refer	rence		247				ater-rieating Systems te Collectors	283
								ed Collectors	284
9	Solar	r Radiati	on and Earth's Climate	249				r and System Efficiency	286
	9.1	Introduc	tion	249		10.5		Example 1: A Flat-Plate	200
	9.2		nagnetic Radiation	250			10.5.1	versus an Evacuated Tube	
	9.3		Spectra	251				Collector	288
	0.0		Blackbody Spectrum	251		10.6	Therma	Losses in Pipes	289
	9.4		t Motion of the Sun			10.0		Example 2: Thermal	203
		in the Si		254			± 0.0.1	Loss in a Pipe	290
		9.4.1	Example 1: Finding the	_~ '		10.7	Water T	anks and Thermal	
		_	Solar Declination	257			Capacit		291

	10.7.1	Example 3: Insulating a Hot Water Tank to			11.6		l Properties of a	
		Reduce Thermal Losses	291		11.7	Solar Ce	ey of Solar Cells and	328
10.8	Passive S	Solar Hot Water System	292		11./	Solar Sy		329
	10.8.1	Example 4: Finding	232			11.7.1		329
		the Fluid Flow Rate in				11.7.2	Temperature	329
		a Thermosiphon Hot				11.7.2	Dependence of	
		Water Heater	294				Efficiency	330
10.9	Swimmin	ng Pool Heating	295				11.7.2.1 Example 3:	330
10.10		eating and Cooling	296				Impact of	
		plications Well Suited					Temperature	
		pping Nations	297				on Efficiency	,
		Crop Drying	298				and Power	
		Water Purification	299				Output	330
		Solar Cooking	300			11.7.3	Spectral	330
10.12		y Generation	300			11.7.0	Efficiency and Choice	
		Concentration Ratio					of Materials	330
		and Temperature	301			11.7.4	Efficiency of	330
	10.12.2	Parabolic Dish				11.7.7	Multijunction Cells	332
		Systems and "Power			11.8	Efficienc	y of Solar Systems	332
		Towers"	304		11.9		nection and Inverters	333
	10.12.3	Solar Chimneys	306				pes of Solar Cells	334
10.13	Summary	/	308				Thin Films	334
		Heat Transfer					Dye-Sensitized Cells	334
	lechanisn		309		11.11		nental Issues	336
	10.A.1	Conduction	309			Summar		336
	10.A.2	Convection	310				Quantum Mechanics	330
	10.A.3	Radiation	311				rmation of Energy	
	10.A.4	Example 5: Validity				ands	mation of Energy	336
		of the First-Order			_	11.A.1	Finding Energy Levels	550
		Approximation	312				and Wavefunctions	337
	10.A.5	Mass Transport	312			11.A.2	Coupled Systems	337
Problem	7S	•	313				and Formation of	
Referei	nces		315				Energy Bands	339
					Problem	ns		341
n: .					Referen			342
Photov			317					0 12
11.1	Introducti	on	317				•	
11.2	Conducto	rs, Insulators, and		12	Energy	Conserv	ation and Efficiency	343
	Semicono	luctors	319		12.1	Introduct	ion	343
	11.2.1	Example 1: Using				12.1.1	Example 1: What Went	0.0
			321				and the second s	346
11.3		g the Conductivity of			12.2	Factors E	Besides Efficiency	0.10
			322				ng Energy-Related	
		Example 2: Effect of				Choices	=	347
		Doping on Conductivity	324					347
	pn Junctio		325				More Efficient Solar	J 17
11.5	Generic P	hotovoltaic Cell	327					349
							-	J . J

12.3 Lowest of 12.3.1	of the Low Residentia		349 349	13	-	g <mark>y Stora</mark> Energy S		ansmission	371 371
12.3.2 12.3.3		2: Lighting Cost	352		10.1	13.1.1	Introducti	on al and Thermal	371
	Compariso		354			13.1.2	Energy St		373
		anagement	356					Pumped Hydro	374
	Cogenerat		357					Thermal Storage	
		ectric Effect:						Compressed	
		lay to Use						Air Energy	
	Cogenerat		358					Storage	375
	Conservat						13.1.2.4	Flywheel	
	and Effici	-	250					Energy Storage	378
	Transporta		359			13.1.3	Electric a	nd Magnetic	
	12.3.7.1	Thermoelectric	260				Energy St		383
	12272	Energy Recovery Example 3:	300				13.1.3.1		383
	12.3.7.2	What						•	389
		Efficiency of a						Fuel Cells	391
		Thermoelectric				13.1.4		Storage and	
		Generator Is				1015	Cars Powe	-	392
		Needed?	361			13.1.5	-	owered Electric	205
	12.3.7.3	Regenerative	001			1216	Cars	Chamama	395
	12/0///0	Brakes					Magnetic	_	396
		and Shock					Nuclear E		397
		Absorbers	361				Antimatte Summary		398 399
	12.3.7.4	Improving			122		Summary Transmissio		399
		Engine			13.2		Introducti		399
		Efficiency	361			10.2.1		Electricity	399
	12.3.7.5	Lighter and					10.2.1.1	Transmission	399
		Smaller Vehicles	362				13.2.1.2	Alternating	055
		Alternate Fuels	362				10.2.1.2	Current	
	12.3.7.7	Alternatives						Transmission	
		to the Internal						and Distribution	400
		Combustion					13.2.1.3	Alternating	
		Engine	363					versus Direct	
	12.3.7.8	~						Current	401
		Automobiles					13.2.1.4	High Voltage	
		and Trucks Less						Transmission	
		or Using Them	262					Lines	403
12 1 Obotoolo	o to Effici	More Efficiently	363					Skin Effect	404
12.4 Obstacle Conserva		ericy ariu	364				13.2.1.6	Direct Current	
12.5 Is Energ		17	304					Power	
		y Ultimately Futile?	367				10017	Transmission	405
	Jevon's Pa	-	367				13.2.1.7	Example 6:	
12.6 Summar		aradon	368					Power Losses	
Problems Problems		369					with HVAC and		
References			370					HVDCTransmissio	
								Lines	406

	13.2.1.8 Problems with the Grid	407	14.2.3 United States 14.3 How Much Time Does the World	420
	13.2.1.9 Goals for a	407	Have to Move Away from Fossil	
	Smart Grid	409	Fuels?	422
	13.2.2 Summary	410	14.4 How Has Public Opinion Evolved?	424
	Problems	411	14.4.1 Climate Change	424
	References	412	14.4.2 Renewable Energy	426
			14.4.3 Nuclear Power	426
14	Climate and Energy: Policy, Politics,		14.5 Best Way Forward	427
- •	and Public Opinion	415	14.6 Summary	430
	•		14.7 Some Concluding Thoughts	430
	14.1 How Important Are International	415	Problems	432
	Agreements?	415	References	432
	14.2 What Are the Top-Three GHG	410		
	Emitters Doing?	419	Appendix	435
	14.2.1 China	419	land an	407
	14.2.2 India	420	Index	437