

Figures

1.1	Simple Salter cycle	9
3.1	The materials life cycle	66
3.2	US economic system as a whole from a mass flow perspective (1993 in MMT)	68
3.3a	Total major inputs to GDP (fuels, metals, construction, chemicals and biomass): in terms of mass (USA, 1900–2004)	73
3.3b	Total major inputs to GDP (fuels, metals, construction, chemicals and biomass): in terms of exergy (USA, 1900–2004)	73
3.4a	Major inputs of fossil fuels (coal, petroleum, natural gas and NGL): mass/capita and exergy/capita (USA, 1900–2004)	74
3.4b	Major inputs of chemicals to GDP: mass/capita and exergy/capita (USA, 1900–2004)	74
3.4c	Major inputs of construction to GDP: mass/capita and exergy/capita (USA, 1900–2004)	75
3.4d	Major inputs of metals to GDP: mass/capita and exergy/capita (USA, 1900–2004)	75
3.4e	Major inputs of biomass to GDP: mass/capita and exergy/capita (USA, 1900–2004)	76
3.4f	Total major inputs to GDP (fuels, metals, construction, chemicals and biomass): mass/capita and exergy/capita (USA, 1900–2004)	76
3.5a	Major inputs to GDP of fossil fuel: mass/GDP and exergy/GDP (USA, 1900–2004)	81
3.5b	Major inputs to GDP of chemicals, major organic and inorganic: mass/GDP and exergy/GDP (USA, 1900–2004)	81
3.5c	Major inputs to GDP of construction materials: mass/GDP and exergy/GDP (USA, 1900–2004)	82
3.5d	Major inputs to GDP of metals: mass/GDP and exergy/GDP (USA, 1900–2004)	82
3.5e	Major inputs to GDP of biomass: mass/GDP and exergy/GDP (USA, 1900–2004)	83
3.5f	Total major inputs to GDP (fuels, metals, construction, chemicals and biomass): mass/GDP and exergy/GDP (USA, 1900–2004)	83

3.6	Exergy intensities: fossil fuels and total (USA, 1900–2005)	84
3.7a	Inputs of exergy by source (USA, 1900–2004)	85
3.7b	Inputs of exergy by source (Japan, 1900–2004)	86
3.8a	Exergy input sources as percent of total exergy input (USA, 1900–2004)	86
3.8b	Exergy input sources as percent of total exergy input (Japan, 1900–2004)	87
4.1a	Percent of coal exergy consumed by type of end-use (USA, 1900–2004)	93
4.1b	Percent of coal exergy consumed by type of end-use (Japan, 1900–2004)	93
4.2a	Percent of petroleum and NGL exergy consumed by type of end-use (USA, 1900–2004)	94
4.2b	Percent of petroleum and NGL exergy consumed by type of end-use (Japan, 1900–2004)	94
4.3a	Percent of natural gas exergy consumed by type of end-use (USA, 1900–2004)	95
4.3b	Percent of natural gas exergy consumed by type of end-use (Japan, 1900–2004)	95
4.4a	Percent of total fossil fuel exergy consumed by type of end-use (USA, 1900–2004)	96
4.4b	Percent of total fossil fuel exergy consumed by type of end-use (Japan, 1900–2004)	96
4.5	Developments in petroleum ‘cracking’ fractions (USA, 1910–72)	99
4.6	Petroleum utilization efficiency: percent used as fuel for prime movers (USA, 1900–82)	100
4.7	Percent of crude oil cracked to produce gasoline (USA, 1910–72)	100
4.8	Farm mechanization: substitution of machinery for animals	101
4.9	Performance of steam engines: fuel consumption and thermal efficiency	102
4.10	Sources of mechanical drive in manufacturing establishments (USA, 1869–1939)	103
4.11	Substitution of diesel for steam locomotives in the USA, 1935–57	105
4.12	Index of total electricity production by electric utilities (1902 = 1) and average energy conversion efficiency (USA, 1902–98)	106
4.13a	Household electrification (I) (percent of households)	107
4.13b	Household electrification (II) (percent of households)	107

4.14	Compression ratio in auto engines (USA, 1926–75)	108
4.15	Internal combustion engine efficiency	109
4.16	Breakdown of energy requirements for a typical mid-size automobile	110
4.17	Exergy consumption by industrial processes (USA, 1880–2000)	116
4.18	Secondary electrical work by function as percentage of total secondary electrical work (USA, 1902–2000)	122
4.19	Efficiencies in performance: secondary work from electricity by function (USA, 1900–2000)	123
4.20	Vehicle fuel rates and energy conversion efficiency	124
4.21a	Energy (exergy) conversion efficiencies (USA, 1900–2004)	128
4.21b	Energy (exergy) conversion efficiencies (Japan, 1900–2004)	128
4.22	Useful work (U) for the USA and Japan, 1900–2004	129
4.23	Aggregate efficiencies for the USA and Japan, 1900–2004	129
4.24a	Primary work and primary work/GDP ratio (USA, 1900–2005)	130
4.24b	Primary work and primary work/GDP ratio (Japan, 1900–2005)	130
5.1	Production-consumption systems	138
5.2	Cost of power per hour as multiple of hourly wage	148
6.1	Substitutability in aggregate production functions	180
6.2	The production frontier as a turbulent cloud	184
6.3a	GDP and factors of production (USA, 1900–2005)	188
6.3b	GDP and factors of production (Japan, 1900–2005)	188
6.4	US GDP, 1900–2000 (actual versus three-factor Cobb-Douglas function)	189
6.5	Technological progress function and Solow residual (USA, 1900–2005)	189
7.1	Exergy to GDP ratio (USA and Japan, 1900–2005, excluding 1941–7)	198
7.2	Useful work (U) to GDP ratio (USA and Japan, 1900–2005, excluding 1941–7)	199
7.3	Exergy to work efficiencies (f) (USA and Japan, 1900–2005, excluding 1941–7)	200
7.4a	Empirical and estimated GDP (USA, 1900–2005, excluding 1941–8)	206
7.4b	Empirical and estimated GDP (Japan, 1900–2005, excluding 1941–8)	207
7.5a	Cobb-Douglas residuals (USA and Japan, 1900–2005, excluding 1941–8)	208

7.5b	LINEX residuals (USA and Japan, 1900–2005, excluding 1941–8)	208
7.6a	Parameters of the LINEX function (USA, 1900–2005)	209
7.6b	Parameters of the LINEX function (Japan, 1900–2005)	209
7.7a	Elasticities of factors of production – LINEX function (USA, 1900–2005, excluding 1941–7)	212
7.7b	Elasticities of factors of production – LINEX function (Japan, 1900–2005, excluding 1941–7)	212
8.1	Simulated labor hire and fire rate (USA, 1900–2000)	238
8.2	Simulated and empirical labor (USA, 1900–2000)	239
8.3	Simulated and empirical capital (USA, 1900–2000)	240
8.4	Energy intensity of capital (USA, 1900–2000)	241
8.5	Energy intensity of GDP (USA, 1900–2000)	242
8.6	Logistic and bi-logistic S-curve fits to the trend of aggregate technical efficiency in the USA, 1900–2000	244
8.7	Rate of change of aggregate technical efficiency of primary exergy conversion (USA, 1900–1998)	245
8.8	Sensitivity test results varying the fractional decay rate of output exergy intensity	247
8.9	Sensitivity test results varying both the fractional rate of output exergy intensity and selected parameters of the bi-logistic curve controlling the rate of efficiency growth	248
8.10	Historical (1950–2000) and forecast (2000–50) GDP for alternate rates of decline of the energy intensity of output, USA	249
8.11	Historical (1950–2000) and forecast (2000–50) technical efficiency of energy conversion for alternate rates of technical efficiency growth, USA	249
8.12	Historical (1950–2000) and forecast (2000–50) GDP for alternate rates of technical efficiency growth, USA	250
9.1	Plot of GDP gap against energy policy gap, all countries, all years	267
9.2	Fitted results from regression 4 (Table 9.3)	271
9.3a	Development tracks of countries in group 2	273
9.3b	Development tracks of countries in group 3	273
9.3c	Development tracks of countries in group 4	274
9.3d	Development tracks of countries in group 8	274
9.4a	Weighted regressions for group 4 (oil factor = 0.10)	278
9.4b	Weighted regressions for group 8 (oil factor = 0.10)	278
9.5a	Weighted regressions for group 4 (oil factor = 0.15)	279
9.5b	Weighted regressions for group 8 (oil factor = 0.15)	279
9.6a	Development tracks of group A countries	281

9.6b	Development tracks of group C countries	281
9.7a	Development tracks of catch-up countries (oil factor = 0.00)	282
9.7b	Development tracks of catch-up countries (oil factor = 0.10)	282
9.7c	Development tracks of catch-up countries (oil factor = 0.15)	283
9.7d	Development tracks of catch-up countries (oil factor = 0.20)	283
9.7e	Development tracks of catch-up countries (oil factor = 0.25)	284
9.8a	Simulation results for catch-up countries (oil = 0.00)	286
9.8b	Simulation results for catch-up countries (oil = 0.10)	286
9.8c	Simulation results for catch-up countries (oil = 0.15)	287
9.8d	Simulation results for catch-up countries (oil = 0.20)	287
9.8e	Simulation results for catch-up countries (oil = 0.25)	288
9.9a	Changes of catch-up elasticity of GDP with respect to EP for two models using weighted regression results	289
9.9b	Changes of catch-up elasticity of EP with respect to GDP for two models using weighted regression results	290
9.10	Development trajectory (GDP versus EP) of the USA from 1960–2001	291
9.11	Annual percentage change in US GDP and EP indices, 1960–2001	292
C.1	Relationship between GDP and electrification for 1997–2001	345
C.2	Relationship between GDP and urbanization for 1997–2001	345
C.3a	Processes of urbanization and electrification (France and Japan, 1960–2001)	346
C.3b	Processes of urbanization and electrification (Brazil and China, 1971–2001)	346
C.3c	Processes of urbanization and electrification (India and Indonesia, 1971–2001)	347
C.3d	Processes of urbanization and electrification (Sweden and UK, 1960–2001)	347
C.3e	Processes of urbanization and electrification (USA 1960–2001)	348