NOTES

Chapter 1: The Next Industrial Revolution

1. Marine Conservation Biology Institute 1998, U.S. National Academy of Sciences and British Royal Society 1992.

2. Daily 1997.

3. Coral Reef Alliance 1998.

4. Worldwide Fund for Nature (Europe) 1998.

5. Costanza et al. 1997, using 1994 dollars in which the value was at least $33 trillion.

6. Details are in World Bank 1995 at 57–66, and 1997.

7. Deane & Cole 1969.

8. Vitousek et al. 1986, 1997.

9. International Labor Organization 1994.

10. Daly 1997.

11. Schmidt-Bleek et al. 1997.

12. Present at the Club in September 1996 were: Jacqueline Aloise de Larderel, Director, UNEP-IE, Paris; Willy Bierter, Director, Institut für Produktdauer-Forschung, Giebenach, Switzerland; Wouter van Dieren, President, Institute for Environment and Systems Analysis, Amsterdam; Hugh Faulkner, formerly Executive Director, Business Council for Sustainable Development; Claude Fussler, Vice President/Environment, Dow Europe; Mike Goto, Director, Institute of Ecotoxicology, Gakushuin University, Tokyo; Leo Jansen, Director, Dutch Sustainable Technology Programme; Ashok Khosla, President, Development Alternatives, New Delhi; Franz Lehner, President, Institute for Labor and Technology, Gelsenkirchen, Germany; Jim MacNeill, MacNeill & Associates, formerly Secretary General, Brundtland Commission, Ottawa, Canada; Wolfgang Sachs, Chairperson, Greenpeace Germany; Ken Saskai, Osaka University; Friedrich Schmidt-Bleek, Vice-President, Wuppertal Institute; Walter Stahel, Director, Institute de la Durabilité, Geneva; Paul Weaver, Director, Centre for EcoEfficiency and Enterprise, University of Portsmouth; Ernst Ulrich von Weizsäcker, President, Wuppertal Institute; Jan-Olaf Willums, Director, World Business Council for Sustainable Development, Geneva; Heinz Wohlmeyer, President, Austrian Association for Agroscientific Research; Ryoichi Yamamoto, President of MRS-Japan, Institute of Industry Science, University of Tokyo.

13. Gardner & Sampat 1998 at 26 provides a useful summary of many such initiatives.

14. Romm & Browning 1994.

15. Ayres 1989.

16. American Institute of Physics 1975, adjusted for progress and new insights since then.

17. Stahel & Reday-Mulvey 1981.

18. Friend 1996.

19. Stahel also coined the term "extended product responsibility" (EPR), which is cradle-to-cradle from the manufacturer's point of view. EPR is now becoming a mandated or voluntary standard in many European industries.

20. Stahel & Børlin 1987.

21. Emerson 1994 at 26.

22. As far as we know, the term "technical nutrient" was first used by Michael Braungart in a conversation with William A. McDonough.

23. Stahel 1981.

24. Womack & Jones 1996; Womack, personal communication, 28 February 1999.

25. *San Francisco Chronicle* 1998.

26. Kaplan 1994, 1997.

27. Yergin 1991.

28. Gleick 1998.

Chapter 2: Reinventing the Wheels

1. Those desiring a generic shorthand alternative to this term, a service mark of Rocky Mountain Institute, may use "ultralight hybrid."

2. James Womack, personal communication, February 23, 1999.

3. Williams, Moore & Lovins 1997.

4. This electricity is typically stored temporarily in a relatively small and lightweight "load-leveling device." This buffer-storage device also smooths out temporary fluctuations between the rates at which power is generated and required, decoupling the engine from the demands of driving and thus allowing the engine to become smaller.

5. Cumberford 1996, Brooke 1998, Lovins 1996a, Moore 1996, 1996a, 1997, Moore & Lovins 1995, Mascarin et al. 1995, Brylawski & Lovins 1995, 1998, Lovins et al. 1997, Cramer & Brylawski 1996, Fox & Cramer 1997, Williams et al. 1997.

6. Lovins 1996a, Fig. 1.

7. A nonproprietary current chronology is maintained at www.hypecarcenter.org.

8. Brooke 1998.

9. Designed for battery-electric cars like GM's EV-1, these high-pressure tires can grip the road well, despite the lighter car's pressing down less on them, because they're narrower — keeping the pressure on the contact patch about the same — and contain special gripping compounds like silica.

10. Mascarin et al. 1995, Lovins 1997, Lovins et al. 1997.

11. Brylawski & Lovins 1995, 1998, Lovins et al. 1997. Efforts to validate this hypothesis are under way.

12. Lugar & Woolsey 1999.

13. We describe here the Proton-Exchange Membrane (PEM) type of fuel cell because it has the clearest prospects of very low cost in high-volume production. Several other types of fuel cells are in commercial or experimental use, and some show promise of potentially low cost as well. See generally Cannon 1995, and, for the entire hydrogen transition strategy, Lovins & Williams 1999.

14. Port 1998.

15. Several independent studies (e.g., Lomax et al. 1997) have used standard industrial engineering techniques to calculate costs around $20–35/kW for the fuel-cell stack. Simplified accessories would increase this only modestly.

16. Williams et al. 1997.

17. This consists of a "reformer" — a thermochemical, often catalytic, reactor that extracts the hydrogen from a hydrocarbon fuel — and devices to remove residual carbon monoxide, sulfur, and any other impurities that could poison the fuel cell's catalyst.

18. Lovins & Lehmann 1999.

19. Directed Technologies, Inc. 1997.

20. James et al. 1997.

21. Bain 1997.

22. President's Council of Advisors on Science and Technology (PCAST) 1997 at 6–34.

23. Williams 1996.

24. Lovins & Lovins 1991, Lovins et al. 1981, Samuels 1981, *Automotive News* 1983, Goldenberg et al. 1983.

25. Such as the enclosed two-person Swiss Twike and S-LEM vehicles: www.twike.com and www.s-lem.ch/. By spring 1998, these makers were selling ten a week at SF12,000 each.

26. Such as the experimental Cyber-Tran: von Weizsäcker et al. at 124–125 and Plate 10; Dearian & Plum 1993, Dearian & Arthur 1997. CyberTran Development Co., 1223 Peoples Ave., Troy NY 12180, 518/276-2225, fax -6380, transit@transit21.com, www.cybertran.com.

27. Lovins 1998.

28. Lovins et al. 1997.

29. Today's propane and natural-gas feedstocks for polymer production could be replaced by vegetable carbohydrates: Lugar & Woolsey 1999. Henry Ford built a vegetable-composite car in 1941, and today's materials are better: *Carbohydrate Economy* 1998.

30. Lovins et al. 1997.

31. Cramer & Brylawski 1996, Fox & Cramer 1997.

32. This term, a combination of "fee" and "rebate," is credited to Dr. Arthur H.

Rosenfeld. The concept is credited to him, to Amory Lovins in the 1970s, and perhaps even earlier to IBM scientist Dr. Richard Garwin.

33. In 1989, the California legislature agreed, approving a "Drive+" feebate bill by a 7:1 margin, although outgoing governor Deukmejian vetoed it. Two years later, the Province of Ontario set the precedent by introducing a feebate supported by labor, automakers and dealers, other industry, environmentalists, and government, though like Austria's, the Ontario feebate is weak: Flavin & Dunn 1997 at 33–34.

34. A rebate of several thousand dollars for each 0.01-gallon-per-mile difference would pay about $5,000 to $15,000 of the cost of an efficient new car. That would rapidly get efficient, clean cars on the road and inefficient, dirty cars off the road: The dirtiest fifth of the car fleet produces perhaps three-fifths of its air pollution. Such "accelerated-scrappage" incentives have many variants.

35. Lovins et al. 1997. Hypercars are good news for such industries as electronics, systems integration, aerospace, software, petrochemicals, and even textiles with automated fiber-weaving techniques. Generally, while there would be some shifts in the types of work Hypercars provide, the total number and quality of jobs should improve, employment opportunities could be far more widely distributed by location and occupation, and some jobs should shift from manufacturing to the aftermarket — customization and upgrading businesses analogous to those in the computer industry. There would be less of the dangerous and mindless metal-bashing and the awkward, tedious assembly labor, more craft in lightweighting every part and optimizing all the software. In general, the dynamic new industries created should provide at least as many and as good jobs as are likely to be lost under current trends within the existing auto-related industries.

36. *Business Week* 1998.

37. Flavin & Dunn 1997 at 13–14.

38. Schafer & Victor 1997.

39. Johnson 1993.

40. MacKenzie et al. 1992, Ketcham & Komanoff 1992, Cobb 1998.

41. According to the 1996 annual Global Burden of Disease study by the World Health Organization, World Bank, and Harvard School of Public Health (Reuters 1997). In New York City, the leading cause of death among children aged 5–14 is pedestrian automobile accidents (Walljasper 1998).

42. Gibbs 1997.

43. *The Economist* 1997.

44. Case studies from Association for Commuter Transportation, ACTHQ@aol.com, 202/393-3497.

45. *Financial Times* 1998, Shoup 1997a; Prof. Donald Shoup, personal communication, 10 August 1998, Dept. of Urban Planning, UCLA, 310/825-5705.

46. Shoup 1997.

47. Buerkle 1998.

48. Id.

49. *The Economist* 1996.

50. Buerkle 1998; May & Nash 1996. (Flavin & Dunn 1997 mention Krakow as another interesting example.)

51. Gibbs 1997.

52. Newman & Kenworthy 1992; *cf.* Plowden & Hillman 1996.

53. *New Urban News* 1997, 1997a.

54. Durning 1996 at 24.

55. Komanoff & Levine 1994.

56. Gardner 1998.

57. Lowe 1990.

58. Komanoff & Levine 1994, Gardner 1998, Brown et al. 1997.

59. Gardner 1998 at 19, citing Todd Litman, Victoria (B.C.) Transport Policy Institute.

60. Gardner 1998 at 21–22.

61. von Weizsäcker et al. at 128–130, Petersen 1994; Stattauto.Hamburg.Reese@t-online.de.

62. The effects are of course wider and more complex: Cairncross 1997, Mokhtarian 1997.

63. North 1997.

64. Holtzclaw 1998.

65. Nivola 1999.

66. Gibbs 1997.

67. Seal-Uncapher et al. 1997 at 69.

68. Id., Kinsley & Lovins 1995.

69. Goldstein 1996.

70. Holtzclaw 1998, 1994, Holtzclaw & Goldstein 1991.

71. Tyson 1998.

72. Durning 1998.

Chapter 3: Waste Not

1. Womack & Jones 1996.
2. Anderson 1998.
3. Kranendonk & Bringezu 1993.
4. Liedtke 1993.
5. Wackernagel & Rees 1996.
6. Weber 1996.
7. Rathje & Murphy 1992 at 3–9.
8. Wernick & Ausubel 1995.
9. Private correspondence, Collins & Aikman, Inc.
10. Nadis & MacKenzie 1993.
11. Chemical Manufacturers Association 1993.
12. United States Bureau of the Census 1993.
13. USGS, 1995, http://h2o.er.usgs.gov/public/watuse/graphics/octo.html.
14. Water alone accounts for 1.2 million pounds per person per year. Most analyses of materials flow understandably leave water out because it dwarfs all other inputs and outputs and because it's ultimately more or less cyclic. Nevertheless, water as a material requires energy to move it to and from the processes required (Gleick 1994), and should be included in overall studies because the water is no longer potable or pure. At least 20 percent of water (3 billion tons) is so hazardous that it cannot be released into the environment and is injected into the ground.
15. *New York Times* 1995, Eckholm 1998.
16. *New York Times* 1996a; Mark Miringoff, personal communication, 914/332–6014, December 21, 1998. The index, reported with a two-year lag, was 76.9 in 1975 (for 1973) and 43.1 in 1998 (for 1996), up slightly from 37.5 in 1996 (for 1994).
17. Data from http://europa.eu.int/comm/dg05/empl&esf/docs/joint.htm.
18. Wilson 1996.
19. Mergenhagen 1996.
20. *San Francisco Chronicle* 1998a.
21. *Criminal Justice Newsletter* 1995.
22. Rowe 1996.
23. This occurred at a speech to The Conference Board given by Paul Hawken, February 1994, New York City.
24. Schor 1991.
25. L. Mishel et al. 1997.
26. By the late 1990s, half of all U.S. households, and about 80 percent of all African-American and Hispanic households, had less than three months' financial reserves.
27. *The Economist* 1996.
28. Lovins 1990.
29. Pear 1993.
30. *New York Times* 1994.
31. Pear 1993.
32. Brody 1995.
33. *New York Times* 1996.
34. Perlman 1998.
35. Drug Policy Foundation 1994.
36. Butterfield 1996.
37. Rowe 1996.
38. Daly 1997, 1998.
39. Halstead, Rowe, & Cobb 1995.
40. As quoted in Abramovitz 1998.

Chapter 4: Making the World

1. Other than in nuclear fission, where the mass difference is extremely small.
2. Interlaboratory Working Group 1997 at 4.35.
3. Sheldon 1994.
4. *Wall Street Journal* 1998; Stein et al. 1998.
5. Lovins 1998a.
6. Eng Lock Lee, personal communication, December 28, 1997 (he guided this and the following project); Zagar 1998; and proprietary data, respectively.
7. Robertson et al. 1997. We relied heavily on this reference, and discussion with its senior author, for much of the rest of this section.
8. Interlaboratory Working Group 1997 at 4.1, 4.35.
9. In the Air Sentry bistable-vortex design (Lab Crafters, Inc., 2085 5th Ave., Ronkonkoma, NY 11779, 516/471-7755, fax -9161). Further improvements of comparable size are available by complementary

means (Lunneberg 1998, p. 9, methods 3 and 4), raising the saving to 70–80 percent (J. Stein, E SOURCE, personal communication, 4 August 1998). Fume hoods often account for 50–75 percent of laboratories' total energy use.

10. The Sentry, from Progressive Technologies, 200 Ames Pond Dr., Tewksbury, MA 01876-1274, 978/863-1000.

11. Arbeus 1998.

12. Thompson 1998.

13. Interlaboratory Working Group at 4.39.

14. Id. at 4.43.

15. Dr. Michael Braungart, personal communication, February 8, 1998.

16. Amato 1998.

17. Service 1998, 1998a.

18. Jim McCloy, then head of strategic planning, Georgia Power Co., personal communication, late 1980s.

19. Interlaboratory Working Group at 4.36.

20. Wann 1990, Abe et al. 1998.

21. Atmospheric Pollution Prevention Division (USEPA) 1997.

22. See Pollard 1979.

23. Alternatively, at about 480°F by autoclaving olivine in steam (Kihlstedt 1977).

24. Benyus 1997 at 98ff.

25. Id. at 135.

26. *New York Times* 1998.

27. Prof. Dr. Hanns Fischer (personal communication, December 4, 1997), Physikalisch-Chemisches Institut der Universität Zürich, Winterthurerstraße 190, CH-8057 Zürich, Switzerland, fax ++ 41 1 + 362–0139, hfischer@pci.unizh.ch. We are indebted to Dow Europe's vice president, Dr. Claude Fussler, for this example. See Fischer 1991, 1991a, 1994, and Kating & Fischer 1995.

28. Brown & Levine eds. Interlaboratory Working Group 1997 at 4.41.

29. Full implementation of this project is currently on hold.

30. Bob Salter, Osmotek, PO Box 1882, Corvallis, OR 97339, 541/753-1297, rsalter@praxis.com, personal communications, 1998.

31. McDonough & Braungart 1998.

32. Foresight Institute, http://www.foresight.org/homepage.html.

33. This paragraph is paraphrased from Dr. Benyus's keynote address to the E SOURCE Members' Forum, October 8, 1998, Aspen, Colorado (www.esource.com).

34. Gardner & Sampat 1998 at 35, citing analyses by Walter Stahel's group.

35. Willis 1996.

36. Womack & Jones 1996 at 20.

37. Seissa 1991.

38. Perhaps a little sprue or flashing to be trimmed away and recycled, but far less than foundry and machining scrap for metals.

39. Roodman & Lenssen 1995 and RMI 1998 at 303.

40. Interlaboratory Working Group at 4.45.

41. Id. at 4.40.

42. Williams, Larson & Ross 1987 at 112.

43. Womack & Jones, 1996 at 316, n. 10.

44. Joel Makower (publisher of *Green Business Newsletter*, www.greenbiz.com), personal communication, February 3, 1998, citing company data.

45. The Design Council 1997 at 13.

46. OTA 1992 at 28.

47. Anderson (1998) says as much energy as the factory required, but ecometrics later discovered that the nylon saved was twice the amount originally thought (Jim Hartzfeld, personal communication, January 7, 1999).

48. Krol 1997; see also Young & Sachs 1994.

49. Id. at 3.

50. According to Warshall (1997), about 10 million pounds of floor carpet goes to the world's landfills every day.

51. Baldwin 1996.

52. Interagency Workgroup 1998 (citing a study by the Fraunhofer Institute in Stuttgart).

53. Interagency Workgroup 1998. The size estimate is due to Professor Robert Lund at Boston University (Deutsch 1998), and will doubtless be updated by the new Remanufacturing Industries Council International.

54. OTA 1992 at 41.

55. Originally dubbed "Phoenix," this business has been renamed Miller SQA,

standing for Simple, Quick, Affordable (www.sqa.net).

56. Deutsch 1998.

57. Interagency Workgroup on Industrial Ecology 1998.

58. Rocchi 1997 at 19.

59. McLean & Shopley 1996.

60. John Elter (VP New Business Development, Xerox Corporation), personal communication, November 1997. His 350 engineers designed the product after a week's wilderness course.

61. Deutsch 1998.

62. Nielsen & Elsbree 1997. Digital Equipment Corp., 111 Powdermill Rd, MSO2–3/C3, Maynard, MA 01754.

63. Gardner & Sampat 1998 at 37.

64. Id. at 45.

65. Graedel & Allenby 1996a at 99.

66. Rocchi 1997 at 20. The firm also developed a new type of soldering paste whose binder sublimes at soldering temperature. It can then be condensed and recovered, eliminating customers' need for a cleaning line.

67. McLean & Shopley 1996.

68. Gardner & Sampat 1998 at 46. This illustrates the importance of "industrial ecosystems," like the well-known archetype in Kalundborg, Denmark: If industries aren't close enough for one's waste actually to become another's food, the connectivity of their "ecosystem" is lost, and the potential food rots as waste.

69. *Green Business Letter* January 1998, reporting First American Scientific Corp.'s Kinetic Disintegration Technology.

70. Andreeva 1998.

71. *Automotive Industries* (1995) summarized from its 1928 coverage: "Ford used scrap lumber from shipping containers in his vehicles, cut smaller pieces for shipping containers, and ground the smallest scraps for cardboard. Tools were often reworked eight to ten times, mop pails were made from old paint cans and conveyor belt scraps were used in his cars to stop squeaks and rattles. . . . He dumped all metal scrap from rolling mills, billet trimmings, machine shop shavings and even nails into his furnaces, creating a steel mix of which nearly 50% was recycled."

72. Recycling steel takes one-third to two-thirds less energy than making it from ore, so two-fifths of crude steel worldwide is currently recovered from scrap. A similar switch to stackable, instead of single-use, packing crates that are returned and reused is heading for a 95 percent reusable container rate at Mitsubishi's Diamond Star Motors, and Mitsubishi Motor Manufacturing of America has reduced its use of wooden shipping containers by 99 percent, from 345 to 0.6 tons per year, by reusing wood and switching to steel: Kim Custer, Mitsubishi Motor Sales America (Cypress, CA), kcuster@mmsa.com, personal communications, 1995 and 1998.

73. Gardner & Sampat 1998 at 45.

74. The firm is developing a "reverse distribution network" to feed its 50,000-ton-a-year North Carolina plant. Since 1991, such innovation has helped the films business move from near failure to the top of a 57-firm marketplace while more than doubling its revenues. Goodman 1998.

75. Interagency Workgroup on Industrial Ecology 1998. Between 1970 and 1993–94, U.S. lead use rose by 15 percent, but recycling rose by 120 percent, use in gasoline was nearly eliminated, other dissipative uses were reduced, and in all, lead losses fell by 44 percent. Of course, a good goal would be to eliminate this toxic material altogether, as today's best technologies are very close to permitting.

76. From Phenix Biocomposites, Inc., St. Peter, Minnesota, 800/324-8187. Other interesting biomaterials are listed on p. 16 of the Summer 1997 *Whole Earth.*

77. Conventional packaging can be so complex that it's very hard or impossible to recycle. For example (OTA 1992), a standard snack-chips bag just two thousandths of an inch thick, can consist of nine layers — copolymer, polypropylene, copolymer, inks, polyethylene, aluminum metallization, copolymer, polypropylene, and copolymer. In contrast, a new technique (from Energy Conversion Devices in Troy, Michigan) can provide an excellent air barrier (to prevent oxidation of the food) with a silica coating just a few atoms thick on a single layer of fully biodegradable plastic. Put in a landfill, it soon decomposes into soil.

78. Roodman & Lenssen 1995 and RMI 1998 at 299.

79. For example, less steel to make the Hypercars, less cement to make the roads on which to haul the steel, less steel to make the steel and cement mills, et cetera. Using the 1970s technology still prevalent in much of the world, making a pound of nitrogen fertilizer requires not only operating energy equivalent to about five pounds of coal but also an initial plant investment of a pound of steel. Hauling and spreading it takes more work. Thus, organic farming and healthier soil mean less fertilizer, less energy, and less steel, then less transportation, road capacity, et cetera. Very little research has been done on the input-output structure of an economic equilibrium with radically reduced materials intensities.

80. American Institute of Physics 1975.

Chapter 5: Building Blocks

1. Browning 1992, Rocky Mountain Institute 1998.

2. Corbett 1981.

3. These three projects are among 84 featured in a book called *Green Development: Integrating Ecology and Real Estate* (RMI 1998).

4. Id. at 299, citing Roodman & Lenssen 1995 at 22.

5. RMI 1998 offers many examples.

6. Id.

7. Cramer-Kresselt Research 1996, cited at 2–10 in National Laboratory Directors 1997. See also Houghton 1995.

8. Romm & Browning 1994.

9. Browning 1997, 1997a.

10. Id., Romm & Browning 1994.

11. Romm & Browning 1994, Browning 1997.

12. A "ton" is a U.S. unit of the rate of cooling provided by an air conditioner or similar refrigerative system. Measured as 12,000 BTU per hour, or 3.52 thermal kilowatts, it is the rate at which cooling is delivered by melting a short (2,000-pound) ton of ice, the nineteenth-century cooling method, during a 24-hour period.

13. Houghton et al. 1992, Lovins 1992a.

14. Eley 1997.

15. Lovins 1992a.

16. Id.

17. At www.usgbc.org.

18. von Weizsäcker et al. 1997 at 191–197.

19. See www.pge.com/pec/act2/acsaasum.html.

20. In the Antioch building, it saved 38 percent, and cost one-sixth less than it saved.

21. Kerry Tremain (ktremain@earthlink.net), personal communication, May 29, 1999.

22. Lovins & Sardinsky 1988, Piette et al. 1989.

23. Jim Rogers PE, personal communications, February 5 and October 6, 1998 (jimrogers@mediaone.net, 508/256-1345, FAX -2226, 1 Blacksmith Rd., Chelmsford, MA 01824).

24. Komor 1996, Lovins & Heede 1990.

25. Franta & Anstead 1996.

26. Strong 1996 at 54.

27. See von Weizsäcker et al. 1997 at 62, Houghton et al. 1992 at 9. For the same building, the best design submitted in PG&E's Design Challenge, by ENSAR Group, would have saved about 87 percent of the total energy use. Other buildings described below have achieved 100 percent cooling reductions in hot climates.

28. Even in very large buildings, this is often feasible in hot climates, especially if the hottest days are also dry, and if the design uses displacement ventilation and one hundred percent outside air — both advantageous in many other respects.

29. *The Economist* 1998.

30. Froeschle 1998 and Lynn M. Froeschle AIA, personal communication, January 14, 1998.

31. RMI 1998 at 299 citing Roodman & Lenssen 1995 at 22.

32. *Environmental Building News* 1995.

33. RMI 1998 at 300–301.

34. Of ten recent case studies of recycling construction wastes, six showed unchanged and four showed reduced construction costs: *Environmental Design & Construction* 1998.

35. Id.

36. *Pacific Northwest Energy Conservation & Renewable Energy Newsletter*

1997. See also www.etbl.lbl.gov/aerosol-commercialaps.

37. Rosenfeld 1999.

38. Heederik 1998, Rosenfeld 1999, Aeroseal Inc. (www.aeroseal.com, Austin, TX, 512/445-2504).

39. Butti & Perlin 1980.

40. Lovins 1991b.

41. In Göteborg and Malmö, according to *Svenska Dagbladet,* July 30, 1998.

42. Boonyatikarn 1997.

43. www.pge.com/pec/act2/astansum.html.

44. See von Weizsäcker et al. 1997 at 25–26.

45. Atmospheric Pollution Prevention Division 1997.

46. Bancroft et al. 1991.

47. EPRI (www.kcpl.com/about/microwave.htm), updating Lamarre 1997.

48. For more details, see von Weizsäcker et al. 1997 at 33–36, and George et al. 1996 at 39.

49. Effective in 2001, though in April 1997, the Department of Energy relaxed this to 29 units. Nonetheless, by then, compared with the levels of efficiency prevailing in 1974 (but not counting the then-expected 6 percent annual growth in usage per refrigerator as they became bigger and fancier), the U.S. standards are expected to have saved the U.S. the equivalent of 45 one-thousand-megawatt power stations: Rosenfeld 1999.

50. See Shepard et al. 1990, Stickney 1992.

51. Nørgård 1989, summarized in von Weizsäcker et al. 1997 at 29–33.

52. von Weizsäcker et al. 1997 at 93, citing research by Walter Stahel.

53. Chelman 1998.

54. *New Urban News* 1997, 1997a, Walljasper 1998.

55. Durning 1996.

56. Oldenburg 1997.

57. Rosenfeld et al. 1996.

58. Rosenfeld 1999.

59. Id., n. 8.

60. Mott-Smith 1982.

61. Wassman 1999.

62. Rocky Mountain Institute 1998, Weissman & Corbett 1992.

63. Real Estate Research Corporation (RERC) 1974. See also Frank 1989.

64. Including roads (20 instead of 30 feet wide), driveways, street trees, sewers, water services, and drainage.

65. W. D. Browning, personal communication, January 6, 1999.

66. In Tannin (Orange Beach, Alabama): Chapman 1998. See also *Wall Street Journal* 1996, *New Urban News* 1997b, 1997c, RMI 1998.

67. Kinsley 1992.

Chapter 6: Tunneling Through the Cost Barrier

1. Design Council 1997a at 20.

2. Romm 1994.

3. Romm & Browning 1994.

4. Lovins 1995, 1996.

5. Lovins & Sardinsky 1988, Piette et al. 1989.

6. Mr. Lee is technical director of Supersymmetry Services Pte Ltd, Block 73 Ayer Rajah Crescent #07/06-09, 0513 Singapore, 65/777-7755, fax 779-7608.

7. More precisely, the Davis house would cost less to build if done as a normal construction project rather than a unique scientific experiment, and the Lovins house did cost less to build in 1983 with respect to its 99 percent saving of space-heating energy without its other savings.

8. Lovins 1991b.

9. Davis Energy Group 1994.

10. This phrase is due to solar designer Ed Mazria.

11. Lovins 1995. The air-conditioner downsizing was empirically confirmed elsewhere: RMI 1998 at 43, 50.

12. Including buildings (chapter 5), lighting systems (Lovins & Sardinsky 1998), motor systems (Lovins et al. 1989), hot-water systems (Bancroft et al. 1991), car design (chapter 2), and even computer design; see also Lovins 1993.

13. Lovins et al. 1989, Lovins & Sardinsky 1988.

14. See Lovins & Sardinsky 1988.

15. See Houghton et al. 1992 or Cler et al. 1997.

16. Berry 1981.

17. Alexander 1977.

Chapter 7: *Muda*, Service, and Flow

1. Womack & Jones 1996, summarized 1996a. See also Romm, who made many similar arguments (1994) and closely related them to clean production concepts.

2. Womack & Jones 1996. We are also grateful for Dr. Womack's helpful comments on this chapter; he is president of the Lean Enterprise Institute. www.lean.org.

3. Ohno 1988.

4. Womack & Jones 1996 at 66.

5. The mistake is caused by using the wrong metrics. As Womack & Jones remark (1996 at 60), "machines rapidly making unwanted parts during one hundred percent of their available hours and employees earnestly performing unneeded tasks during every available minute are only producing *muda*."

6. Womack & Jones 1996 at 216.

7. Naturalists have long known this: Haldane 1985, Colinvaux 1978.

8. Lovins & Lehmann 1999.

9. Womack & Jones 1996 at 24.

10. Womack, Jones, & Roos 1990.

11. Csikzentmihalyi 1990.

12. Lenssen & Newcomb 1996, citing Fédération Nationale de la Gestion des Equipements de l'Energie et de l'Environnement (FG&E) (undated).

13. Sprotte 1997 at 18.

14. For Otis Elevator's riposte, see Davis & Meyer 1998 at 24–25.

15. Lacob 1997 describes a next step.

16. Rocchi 1997 at 26.

17. See www.epa.gov/opptintr/greenchemistry/asrca98.htm.

18. Ron van der Graaf, director, Van Vlodrop Milieutechnologie (Vierlinghweg 32, 4612 PN Bergen op Zoom, Netherlands, ++31 164 + 265550, fax + 258125), personal communications, 1998.

19. Rocchi 1997 at 20.

20. Id. at 21.

21. Id. at 18.

22. Deutsch 1997.

23. Sprotte 1997.

24. Jan Agri (project manager, environmental Affairs, Electrolux, Stockholm), personal communications, March 9 and August 1, 1998, jan.agri@notes.electrolux.se.

25. Davis & Meyer 1998 at 14.

26. Id. at 21.

27. Id. at 183ff.

28. Agri, loc. cit. supra; Sjöberg & Laughran 1998.

29. Interface recommends that its carpet tiles be free-laid, but some installers may use an adhesive anyway. Around 1993, in an effort to mitigate fumes from broadloom installation, Interface had already introduced water-based glues, which were quickly adopted by most of the industry.

30. Personal communication, December 23, 1998.

31. Anderson 1998. The ultimate step, Anderson hopes, is to go back to the landfills and mine the 4 billion pounds of carpets arriving annually — a resource out of place.

32. Womack, personal communication, February 27, 1998.

33. Id. We are grateful for his important contribution to this discussion of stabilization of the business cycle.

34. James Womack, personal communication, February 27, 1998.

Chapter 8: Capital Gains

1. Meadows et al. 1972.

2. Ayres 1996a, 1998. Actually, the MIT team's model did include price feedback for resources, pollution cleanup, health care, and other investments. In the original resource submodel (Behrens 1973), for example, the price linkage was explicit: as *The Limits to Growth* explained at 63, that submodel "takes into account the many interrelationships among such factors as varying grades of ore, production costs, new mining technology, the elasticity of consumer demand, and substitution of other resources." *Limits* then gave an example (at 63–67) explaining the relationships between price, cost, and technology. Yet most readers ignored these references to price. That's partly because when submodels revealed no significant difference between modeling price feedback explicitly and doing so implicitly via lookup tables, the researchers adopted the condensed form for simplicity (Behrens 1973, Meadows & Meadows 1973, Meadows al. 1992 at 165).

3. What the press interpreted as predictions of resource depletion were explicitly presented as mathematical illustrations of exponential-growth arithmetic, and were absolutely correct on the assumptions stated. The prospects for and effects of increased reserves, for example, as a consequence of increased scarcity, price, exploration, and technology, were also clearly described at 62 and 66. The conclusion drawn about resource depletion was merely (66–67, emphasis altered) that "given present [1970–72] consumption rates *and the projected increase in these rates,* the great majority of the currently important nonrenewable resources will be extremely costly 100 years from now . . . regardless of the most optimistic assumptions about undiscovered reserves, technological advances, substitution, or recycling, *as long as the demand for resources continues to grow exponentially.*" That properly qualified statement was correct in 1972 and remains correct today. Unfortunately, many people got it mixed up with the initial illustrations.

4. "Reserves," as the MIT team was well aware, are an economic concept whose numerical size shifts over time: They are the part of the geological resource base whose location is known and that can be profitably extracted at present prices using present technologies.

5. *World Oil* 1997.

6. Meadows et al. 1972.

7. The MIT team's 1972 summary conclusions were not a prediction of anything but an explanation of choices and their consequences. The book specifically included, emphasized, and advocated a feasible transition to sustainability, based largely on strong and rapid improvements in resource productivity. That is, the authors issued a warning but also conveyed "a message of promise" that their analysis "justified . . . then and still justifies" twenty years later, but that in hindsight could now be even more strongly stated: Meadows et al. 1992 at xiii, xv–xvi. However, the fictitious "prophecy of doom" image dominated press coverage of the book and has shaped most people's perceptions of its message ever since.

8. Recer 1996, Ehrlich et al. 1997.

9. One economist who didn't believe this was invited to climb into a large bell jar with as much money as he wanted and see how long he'd last.

10. Calvin 1998.

11. A clear explanation of nonlinear response in social systems (Gladwell 1996) illustrates the concept from everyday experience: "Tomato catsup / In a bottle, / First none'll come, / and then the lot'll."

12. Stevens 1998.

13. Ayres 1995. Exceptionally, nuclear reactions do convert mass into energy, but so far as is known, their sum remains constant.

14. Technical readers will recognize this concept as "negentropy," rigorously analyzed by Nicolas Georgescu-Roegen in his dense text *Entropy and the Economic Process.*

15. Hillel 1991.

16. Gardner 1998a.

17. UNEP 1996.

18. Abramovitz 1998.

19. *San Francisco Chronicle* 1998c.

20. The primary references are reviewed in Brown et al. 1998 at 52.

21. Yoon 1998.

22. These organisms, such as algae, slime molds, and flagellates, have cell nuclei but are neither animals, plants, nor fungi.

23. Eisenberg 1998 at 27–28.

24. Id. at 23.

25. Stuart & Jenny 1999.

26. Eisenberg 1998. For the same reasons, the root system of one young rye plant was found to have 6,875 square feet of surface area — 130 times that of the aboveground plant — and the network of fungi in one ounce of rich forest soil, if it could be unraveled, could easily extend for two miles: Id. at 24.

27. As quoted by Margulis and Sagan 1997 at 18.

28. As quoted in Daily 1997.

29. Abramovitz 1998.

30. Gary Paul Nabhan and Steven Buchmann have formed the Forgotten Pollinators Campaign to educate the public about the growing threat human activities place on domestic crops and wild plants.

Forgotten pollinators include the 4–5,000 wild bees native to North America but also hummingbirds, butterflies, beetles, moths, bats, and even certain species of flies. The Forgotten Pollinators Campaign, Arizona-Sonora Desert Museum, 2021 N. Kinney Road, Tucson, AZ 85743; 520/883-3006, fax -2500, fpollen@azstarnet.com.

31. McHugh 1998.

32. Newman 1997.

33. De Groot 1994 (this is an amended and reworded rendition of de Groot's list of Regulation, Carrier, Production, and Information Functions); Cairns 1997 (which contains a very useful framework for understanding conditions for sustaining natural capital, based in part on the work of Dr. Karl-Henrik Robèrt, founder of The Natural Step).

34. The analysis published in *Nature* included sixteen specific biomes — geographical regions containing specific communities of flora and fauna — and identified the value of seventeen ecosystem services by economic activity within each biome. The biomes included marine and terrestrial environments: open ocean (33.2 million hectares), estuaries (180 million hectares), seaweed and algae beds (200 million hectares), coral reefs (62 million hectares), continental shelves (2.6 million hectares), lakes and rivers (200 million hectares), tropical forests (1,900 million hectares), temperate forests (2,955 million hectares), grasslands and rangelands (3,898 million hectares), tidal marshes and mangroves (165 million hectares), swamps and floodplains (165 million hectares). The economic values included net income, replacement cost, market value, resource production, real estate value in the case of cultural services, damage prevention, shadow prices, external costs mitigated, direct or estimated revenues in the case of recreation, avoided costs and damages, lost income in the case of erosion, restoration costs in cases of erosion control, option value, rents, opportunity costs, dockside prices for marine products, flood damage control, and energy flow analyses. One hundred seventeen prior studies, surveys, and papers were used as primary data and valuation sources for the paper. The study did not include the value of nonrenewable fuels and minerals or of the atmosphere itself.

35. Noss et al. 1995, Noss & Peters 1995.

36. We are indebted to Susan Meeker-Lowry, who made this point eloquently in a letter to the editor regarding Jane Abramovitz's article in *Worldwatch* cited earlier (Abramovitz 1998): "Nature doesn't provide us with services, like a waitress or mechanic or doctor. The diverse species and processes that make up ecosystems do what they do naturally. . . . Putting a price tag on it is terribly misleading, because in the end we cannot buy nature because we cannot create it."

37. Peter Raven, private correspondence, February 15, 1999.

38. As quoted in Hobsbawm 1996.

39. Daly at 22 in Jansson et al. 1994.

40. Id.

41. Myers 1998.

42. Id. and Roodman 1996.

43. World Bank 1995 at 48.

44. Rocky Mountain Institute first thoroughly analyzed federal subsidies to the U.S. energy sector for FY1986, then helped the Alliance to Save Energy update to FY1989. The only official assessments, whether by the U.S. government or by such international bodies as the International Energy Agency, OECD, UN, and World Bank, continue to omit most of the subsidies, partly on the specious grounds that some of them are also available to certain other industries (though not for, say, investments in saving energy). Transparency in subsidies is becoming somewhat greater in a few European countries.

45. *The Economist,* December 6, 1997. In fairness, the federal subsidies to the U.S. oil industry, unlike other fossil-fuel industries, are approximately offset by federal excise taxes collected on its retail products.

46. Myers 1998.

47. Roodman 1996.

48. U.S. Congress 1998; Friends of the Earth 1998.

49. Kinsella et al. 1999.

50. *The Economist,* December 13, 1997.

51. Id.

52. Sarah Gray, Farm Service Agency, USDA, personal communication, December 1998.

53. All these examples are from the World Bank (1995) at 55–65.

54. Caulfield 1989.

55. Zepezauer 1996.

56. Id.

57. Randy O'Toole, correspondence April 1998. The Thoreau Institute. www.ti.org. This number is an approximation of the annual losses from National Forest timber sales.

58. Bagby 1996.

59. Ayres 1996a, 1998.

60. Id.

61. Gardner & Sampat 1998 at 48.

62. Axelsson 1996.

63. Gardner & Sampat 1998 at 43.

64. Roodman 1998.

65. One of the best recent works in the area of tax shifts is Hammond et al. 1997.

66. Myers 1998; *San Francisco Chronicle* 1998b.

67. Anderson 1997.

Chapter 9: Nature's Filaments

1. McPherson 1994.

2. Walton 1999.

3. Warshall 1997 at 4–7, plus supplementary materials 8–21.

4. Niklas 1996 and Willis 1996.

5. Warshall 1997 at 6.

6. Id. at 7.

7. *Earth Impact* 1997, Harmony Catalog Newsletter, www.simplelife.com.

8. von Weizsäcker et al. at 88–89.

9. Chouinard & Brown 1997.

10. *Organic Cotton Directory 1998–99.*

11. Warshall 1997 at 7, 10.

12. Wernick & Ausubel 1995.

13. The Sustainable Forestry Working Group's 1998 U.S. case studies are available from Island Press, www.islandpress.org. See also Chipello 1998.

14. Nilsson 1997 at 121.

15. U.N. Food and Agriculture Organization 1995.

16. World Resources Institute 1994 at 15.

17. Or 20,000 acres per year with 5-day-a-week cutting. This assumes 117.4 ft^3 of wood is used per ton of pulp, a U.S. average of 1,550 ft^3 of wood per acre, and a large chemical pulp mill with a 1,000-short-ton-per-day production capacity. Based on figures cited in: Haynes 1990 at 52, 262.

18. Grieg-Gran et al. 1997.

19. According to the American Forest & Paper Association, www.afandpa.org, downloaded February 15, 1998.

20. International Institute for Environment and Development (IIED) 1995; summarized in Grieg-Gran et al. 1997; cited in Rice 1995 at 103.

21. Rainforest Action Network (RAN) 1995 at 10; and Recycled Paper Coalition 1993.

22. The Paper Task Force (Duke University, Environmental Defense Fund, Johnson & Johnson, McDonald's, The Prudential Insurance Company of America, Time Inc.) 1995 at 54. Summarized by Blum et al. 1997.

23. Lotspeich 1995 at 26.

24. Macht 1997. Hire Quality is at 773/281-6924.

25. Torben Petersen, information technology manager, Oticon A/S (Strandvejen 58, DK-2900 Hellerup, fax 45 39 27 79 00), personal communication, March 24, 1998.

26. Leica AG, CH-9435 Heerbrugg, Switzerland, fax ++ 41 71 + 727-3127.

27. BankAmerica 1997.

28. The DesignSuite catalog is described in Port 1998.

29. Dudley & Stolton 1996; cited in Brown 1997 at 68, n. 12. Prof. Paul Barten of the Yale School of Forestry and Environmental Studies estimates this as about 100 acres of pulp trees (personal communication, October 25, 1995).

30. Paper Task Force 1995 at 57–58.

31. Rice 1995 at 60; RAN 1995 at 10; Ayres & Ayres 1996 at 219; Friends of the Earth 1993.

32. IIED 1995, Richert & Venner 1994.

33. Puder 1992.

34. Brownstein et al. 1997, a report of a 1995–98 independent inquiry coordinated by RMI called the Systems Group on Forests, and seeking ways to reduce pressure on primary forests in a way that would also benefit forest-products companies. The

formula summarized here is heuristic, not exhaustive. For example, it doesn't include improving the weather-protection and hence the lifetime of outdoor structural wood, nor indirect methods, such as saving forests by using electricity more efficiently instead of flooding forests for hydroelectric dams. The formula's linear structure assumes that the variables are independent of one another, while in fact its eight terms have complex interactions through both price and physical (by-product, coproduct, et cetera) relationships. The terms of this formula also don't account for all of the kinds of pressure on forests: Forests are degraded or destroyed in many other ways than simply extracting fiber from them or clearing them for small farms. There are also ambiguities about where among the eight terms a given innovation should be classified, though that's probably not important so long as each option is counted once and only once.

35. Brownstein et al. 1997.

36. IIED 1995 reports partial duplexing cut AT&T's paper cost by about 15 percent.

37. Penzias 1995.

38. Warshall 1997.

39. Brownstein et al. 1997.

40. Calculated as (1 ÷ 0.9).

41. For example, from 3 to 15 m^3/ha-y wood production; *cf.* Sedjo 1994 at 11; these yields are within average or typical ranges. For example, the average U.S. harvest from natural forest, about 110 m^3/ha, is roughly one-sixth of the standing volume at harvest of a good New Zealand plantation of 30-year-old softwoods. Wood production at an average rate (over the stand life) of 20 m^3/ha-y is "routinely achievable in temperate softwoods (to produce about 700 m^3/ha at 30 years)" (Andy Pearce, Landcare Research New Zealand Ltd., personal communication, September 8, 1998).

42. *Cf.* EDF example in Paper Task Force Final Report at 57. Basis weight measures the amount of fiber per unit area.

43. For heuristic simplicity this term has been moved here from its usual position among the materials-cycle improvements.

44. Chapter 4, www.pge.com/pec/act2/adavssum.html, and Davis Energy Group 1994 at App. F.

45. Davis Energy Group 1994, PG&E 1993.

46. Gorman 1998.

47. www.bellcomb.com or 612/521-2425. The firm currently sells only smaller, non-building components, but has demonstrated the concept's suitability for small buildings.

48. *Composites News* 1995.

49. Machalaba 1998, Resource Conservation Alliance 1998.

50. For example, Eastman Kodak's pallet and stacking-pattern redesign saved over 7 million pounds of wood and $380,000 in a single year: *Inform Reports* Fall/Winter 1997.

51. At 1809 Carter Ave., Bronx, NY 10457, 212/222-7688, fax -2047.

52. RAN 1995 at 29–30.

53. American Forest & Paper Association 1994.

54. That's just for paper as such; by 1993, recycling was already over 50 percent for newspapers and nearly 60 percent for corrugated cardboard.

55. U.N. FAO 1998 (1996 data).

56. Warshall 1997 at 6. This comparison is uncorrected for differing moisture content, and uses removals data for 1991 from Haynes et al. 1995, table 34, at 41, using conversion factors from Haynes 1990, table B-7, at 262.

57. Joe Haworth, Sanitation District of Los Angeles County, 562/908-4202, personal communication, 1999.

58. *Boxboard Containers* 1993 at 44–45; *Pulp & Paper Week* 1993 at 24–28.

59. 59 Fountain St., Framingham, MA 01702, 508/620-0421, www.decopier.com.

60. The ink was first suggested as an experiment by German chemist Michael Braungart. Although practically possible, it has not been pursued as far as the authors know, primarily because of the institutional barriers to its acceptance.

61. Mann 1998 at 60; Horrigan et al. 1998.

62. Sedjo 1995 at 177–209 in Bailey ed. 1995 at 180. At p. 202 he gives total world

forest area as "just a bit below 4 billion hectares," or nearly 9.9 billion acres. Definitions and data on this point differ widely, and also change over time: Brown 1997 at 96 cites 8.5 billion acres of forests, excluding woodlands, which have trees but no closed canopy. For present purposes we adopt Sedjo's higher estimate.

63. This implies a productivity of 8 m^3/ha-y (114 ft^3/acre-y). *Average* U.S. temperate and boreal software forest productivity is only 2 (Roger Sedjo, Resources for the Future, personal communication, September 12, 1996) or 3 (Haynes 1990, 1986 data in Fig. 29 at 54) m^3/ha-y. However, fast-growing species and plantations commonly provide more than 20 m^3/ha-y — Northwest poplars can yield 30–50, Louisiana cottonwood 30–45 — and genetic engineering already well under way is expected to provide two to three and a half times higher productivity still (40–70 m^3/ha-y or 572–1,000 ft^3/acre-y). Consistent with Sedjo's line of reasoning, IIED found that plantations could in principle provide the world's entire pulpwood needs, about half the total industrial harvest, from an area of only 100 million acres, equivalent to the land area of Sweden plus Paraguay (IIED 1996 at 64–66). That's only 1 percent (they called it 1.5 percent) of world forest area, or about one-third the *present* area of tree plantations, or less than four times the present area of all high-yield ones.

64. Assuming 40–70 m^3/ha-y. The lower end of this range "is available . . . in some temperate and tropical hardwood plantations, especially eucalyptus both temperate and tropical" (Andy Pearce, loc. cit.), while the higher end may be achievable in "extremely short rotation pulpwood tropical plantations" whose long-term sustainability is not yet established. Warshall (1995) found that plantations recently occupied about 100–135 million ha, including 40 million ha of industrial plantations, of which 11–14 million ha were high-yielding. Plantations accounted for at most 4 percent of world forest area, but yielded about 34 percent of the total harvest.

65. Taking this loss to be 12.8 million ha/y: U.N. FAO 1997.

66. Sedjo 1997 at 10, 30.

67. However, Pearce (loc. cit.) correctly notes that a given forest cannot, in general, simultaneously reduce floods, recharge groundwater, *and* yield more surface water: "[T]he water balance is a fixed sum game and generally you can't have all three of these together." These services may, however, be provided to a significant degree in different places or times.

68. Krause et al. 1989 at I.3–49.

69. Pearce (loc. cit.) says that for 1.2 million hectares of New Zealand exotic softwood plantations, fiber value was about 40 percent of ecosystem value, but those plantations are about six times as productive of fiber as a typical U.S. natural forest, and being less ecologically diverse, may be presumed to have a lower natural capital value.

70. Wang & Hu 1998.

71. Warshall 1997 at 12.

72. Atchison 1995.

73. Smith 1997 at 76, citing U.N. Food & Agriculture Organization 1993.

74. Ayres 1993 at 6.

75. Warshall 1997 at 7.

Chapter 10: Food for Life

1. Naylor 1996 — the main source for the next three paragraphs.

2. Berry 1999.

3. Benyus 1997 at 20, 53.

4. U.N. FAO 1998. Nitrogen fertilizer now accounts for half the on-farm energy used to grow high-yield crops.

5. Ayres 1996 at 12. Berner & Berner 1996, at 101, show 158 million metric tons of human and 123 million metric tons of natural nitrogen fixation per year.

6. Conway 1997 at 33; see also 108–139.

7. Lal et al. 1998 at 17.

8. Id. at 18–19.

9. Soil scientists Lal et al. (1998 at 32) state that U.S. cropland's soil erosion rate fell by about one-third during the years 1982–92.

10. Lal 1995.

11. Eisenberg 1998 at 31.

12. Id. at 26.

13. Naylor 1996 at 117.

14. Id. at 111.

15. Sears 1935, Carter & Hale 1974, Hillel 1991.

16. Eisenberg 1998 at 31.

17. Reddy et al. 1997, at 47, citing WRI 1992. A further 1.8 billion acres is lightly degraded and can be restored by good soil conservation practices.

18. Naylor 1996.

19. Sedjo 1997 at 27. That drop was offset by more efficient processing later.

20. Diamond 1997 at 132.

21. Wes Jackson notes that about 85 percent of human caloric intake comes from a 65-million-year-old family of grasses, none of which happens to be poisonous.

22. Benyus 1997.

23. A few small nonprofit groups like Seed Savers Exchange (3076 N. Winn Rd., Decorah, IA 52101, http://nj5.injersey.com/~jceres/garden/sse.html) are making heroic efforts to preserve such biodiversity, but their resources are far smaller than the task.

24. Graedel & Allenby 1996 at 331.

25. National Research Council 1996.

26. Prof. David Pimentel (Cornell U.), personal communication, September 1998.

27. Specter 1998, citing estimates by the U.N. World Food Program.

28. Benyus 1997 at 18.

29. Id. In addition, nearly 50 weed species now resist herbicides (Conway 1997 at 209).

30. DeVore 1996 offers instructive examples.

31. *Gene Exchange* 1998, citing Gould et al. 1997 and Tabashnik et al. 1997, 1997a; Mellon & Rissler 1998. Beneficial insects can also be harmed: Halweil 1999.

32. Conway 1997 at 153.

33. Prof. Richard Harwood (Michigan State U.), personal communication, November 12, 1998.

34. That is about three-fifths as great as their consumption of iron and steel: Wernick & Ausubel 1995 at 470.

35. Daily & Ehrlich 1996.

36. Krause et al. 1989 at I.3–14.

37. Conway 1997, Lovins & Lovins 1991.

38. Successfully tested at the USDA Grain Marketing Research Laboratory, 1515 College Ave., Manhattan, KS 66502, 785/776-2728; contact agricultural engineer Harry Converse.

39. Bloome & Cuperus 1984.

40. von Weizsäcker et al. at 51–53, based on work by Wouter van Dieren and Geert Posma, and on personal communications with the former.

41. Wade 1981; see also UNDP 1996.

42. von Weizsäcker et al. at 117–121.

43. National Laboratory Directors 1997 at B-33.

44. Frantzen 1998, Lane 1998.

45. Eisenberg 1998 at 23, 29. See also Warshall 1999 and accompanying articles.

46. Epprecht 1998; see also Ho & Steinbrecher 1998, Ho et al. 1998, and www.ucsusa.org.

47. Prof. Robert M. Goodman (U. of Wisconsin), personal communication, October 7, 1998.

48. Bintrim et al. 1997.

49. Worster 1993.

50. Warshall 1999.

51. Lovins & Lovins 1991.

52. Krause et al. 1989 at I.3–32. Contrary to the conservative assumption made by Harmon et al. (1990), the data cited by Krause do show a 10 percent soil-carbon loss when the natural forest becomes managed.

53. Ross & Steinmeyer 1990.

54. Lal et al. 1998 at iv.

55. Id. at vi.

56. Id. at 83 estimate that the total carbon sequestration and offset potential from the roughly 337 million acres of U.S. cropland is 120–270 million metric tons of carbon per year, or 0.4–0.8 metric tons per acre per year.

57. Id.

58. For comparison, USDA/Beltsville test plots in the 1980s showed 0.2–0.6 percent carbon gain per year through light (40 t/ha-y) applications of compost and manure.

59. Id. at 92, Lal 1997.

60. Krause et al. 1989, p. I.3–20, Gardner 1998a.

61. Gardner 1998a.

62. Haruki Tsuchiya (personal communication, June 22, 1998) estimates that the animals' respiration emits 3 billion metric tons of CO_2 per year, compared with 2 billion

for the earth's human population, 5 billion for cars, and 21 billion for all fossil-fuel combustion.

63. Krause et al. 1989, EPA 1989.

64. Crutzen et al. 1986.

65. Soden 1988.

66. Browning 1987.

67. EPA 1989 at VII-270.

68. Krause et al. 1989 at I.3–19.

69. Gardner 1998a.

70. Id.

71. Savory & Butterfield 1999; Center for Holistic Management, 1010 Tijeras NW, Albuquerque, NM 87102, 505/842-5252, center@holisticmanagement.org.

72. Dana Jackson, Land Stewardship Project, personal communication, September 30, 1998; DeVore 1998.

73. DeVore 1998a.

74. Id.

75. Gardner 1998.

76. These more than doubled in rotational vs. continuous grazing in one Wisconsin experiment: Dansingburg & DeVore 1997.

77. Quoted in DeVore 1998.

78. NRC 1989. Similar economic benefits have been found in many hundreds of diverse U.S. and German farms: Brody 1985, Bechmann 1987, Bossel et al. 1986.

79. NRC 1989.

80. Jackson et al. 1984.

81. Conway 1997 at 200. The success of this approach naturally depends on addressing not only agricultural but also contextual social needs, especially the role of women, microcredit, and land tenure.

82. von Weizsäcker et al. at 99–101, The Land Institute 1993, Ecology Action 1993.

83. Benyus 1997 at 36–37, Fukuoka 1978.

84. Conway 1997 at 177–178.

85. Id. at 279.

86. Such as nitrogen-fixing blue-green alga *Anabaena azollae* in rice culture: Conway 1997 at 231–232.

87. Krause et al. 1989 at I.3–23, 24.

88. Benyus 1997 at 12–13.

89. Id. at 36–46.

90. Id. at 25.

91. von Weizsäcker et al. at 97–99, The Land Institute 1993.

92. Pimentel 1997.

Chapter 11: Aqueous Solutions

1. The rest of the freshwater 35 million cubic kilometers is in the polar icecaps and inaccessibly deep aquifers. See generally U.N. Commission on Sustainable Development (UNCSD) 1997.

2. Some 3.3 million people, three-fourths of them babies and children, die each year of diarrhea, and 1.5 billion people are infected with intestinal worms similarly spread by fecal-oral contamination: Simpson-Herbert 1996 at 47–53, citing World Health Organization 1995. In 1990, WHO estimated that 1.3 billion people in the developing world lacked access to safe and plentiful drinking water and 2.6 billion to adequate sanitation: http://206.168.2.226/information.html, downloaded January 14, 1998; UNCSD 1997; Gleick 1998 at 40. Pollution is often gross, large-scale, and industrial: In China, four-fifths of the major rivers are too toxic to support fish (Brown & Halweil 1998). In the United States in 1997, after decades of cleanup, only 16 percent of the 2,111 watersheds in the lower 48 United States had "good" water quality, 36 percent were "moderate," 21 percent had more serious problems, and 27 percent were indeterminate. (The U.S. Environmental Protection Agency's 1997 Index of Watershed Indicators is available at http://www.epa.gov/surf/iwi; Surf your Watershed is one level up [no iwi]. Additional instructions and hard copy [the Index is publication #EPA-841-R-97-010] are available from the National Center for Environmental Publications and Information, PO Box 42419, Cincinnati, OH 45242-2419, 513/489-8190, fax -8695.) The U.S. Department of Agriculture considers 46 percent of all U.S. counties, with 54 million people who drink water from underground, susceptible to groundwater contamination from farm chemicals, chiefly the herbicide atrazine and the insecticide aldicarb: *U.S. Water News,* November 1997. Half of all Americans rely on groundwater for their drinking water (Benyus 1997 at 19). Not surprisingly, U.S. imports of bottled water have more than doubled in the past decade (Kummer 1998).

3. Chao 1995, cited by Gleick 1998 at 70.

4. Brown et al. 1998 at 169.

5. Id. at 5–6.

6. Brown & Halweil 1998.

7. Gleick 1998 at 125–131, a compilation of five millennia of water conflicts.

8. Gleick 1994 reports that desalination, the last-resort technology for those lacking freshwater but rich in money and energy, provides only one-thousandth of the world's freshwater use. The economics of greatly increasing that fraction are discouraging. The minimum energy theoretically required to desalt a thousand gallons of seawater is 10.6 megajoules — the energy contained in ten ounces of oil. However, the best large-scale desalination plants operating in 1994 used about 30 times the theoretical limit, and are unlikely to improve by more than another threefold.

9. Postel et al. 1996.

10. Id., estimating a potential 10 percent increase in accessible runoff over the next 30 years, while population grows by about 45 percent.

11. In mixed current dollars: Rogers 1993.

12. Bredehoeft 1984 at 17.

13. Rogers 1993, paraphrased in Gleick 1998 at 6.

14. These two are somewhat analogous and often related: Gleick 1994.

15. Postel et al. 1996 estimate that the fraction of the earth's accessible water runoff appropriated for human use could rise from 54 percent in 1995 to more than 70 percent by 2025.

16. Gleick et al. 1995. Reisner (1986/93) estimated that enough water to meet the needs of Los Angeles's 13 million people was being used to irrigate California pastures for feeding livestock.

17. Jackson 1980.

18. The Ogallala provided one-tenth of America's total irrigation, and watered two-tenths of the nation's irrigated land.

19. Bredehoeft 1984 at 38–39.

20. Thanks to Dr. Wes Jackson of the Land Institute (Salina, KS 67401) for these insights. Prof. Jackie Giuliani of Antioch University (Los Angeles) notes that preparing and serving a single fast-food order of a hamburger, fries, and a soda requires over 1,500 gallons.

21. *U.S. Water News,* April 1992; the sample size exceeded 700 operations in four states.

22. Id.

23. Gleick 1998 at 10.

24. Solley et al. 1998.

25. Gleick 1998 at 12.

26. Brown & Halweil 1998.

27. Pinkham & Dyer 1993 at 9–10.

28. From 1.4 to 0.2 million acre-feet per year by 1991. Due to the 1992–96 drought, the depletion rate rebounded to 0.6–0.8 Maf/y by 1997, but steady efficiency improvements are continuing. Wayne Wyatt, High Plains Water District, 2930 Ave. Q, Lubbock, TX 79405, 806/762-0181, personal communication, February 16, 1998, and Laird & Dyer 1992 at 4–5.

29. Largely through canal lining and better management: Laird & Dyer 1992 at 5–7, Pinkham & Dyer 1994 at 10–12.

30. Gleick 1998 at 23.

31. For further case studies, see Gleick 1999.

32. Such designs as low-energy precision application can boost sprinkler efficiencies from 60–70 percent to 95 percent (Postel 1997).

33. Polak 1998, courtesy of RMI Director Dr. Michael Edesess.

34. DeSena 1997.

35. The Global Cities Project 1991 at 61. See generally Chaplin 1994.

36. *U.S. Water News* 1992.

37. Knopf 1999.

38. Patchett undated; *Midwest Real Estate News* 1992.

39. Jim Patchett, personal communications, 1997–98.

40. Installation is typically 4–23 times and maintenance 7–21 times cheaper, depending on local conditions.

41. Relatively clean but nonpotable water, filtered and recovered from sinks, bathtubs, showers, and clothes- and dishwashers.

42. Postel 1997, Jones 1993.

43. Osann & Young 1998; Pape 1998; *Australian Plumbing Industry* 1992; see also Ecos Catalog, "Tools for Low-Water and

Waterless Living," 152 Commonwealth Ave., Concord, MA 01742-2842, 978/369-3951.

44. Waterless Co. LLC, 1223 Camino del Mar, Del Mar, CA 92014, 800/244-6364, www.waterless.com.

45. A 42-unit retrofit to avoid replumbing an old building when replacing continuous-flow urinals saved 42–54,000 gal/unit-y, with a 3.4-year payback without or 1.7 y with a rebate from the Seattle Water Department: Nelson 1995.

46. Drangert 1997 in Drangert et al. 1997. A person excretes about 500 liters of urine and 50 liters of feces (3/4 water) per year.

47. This greatly complicates the safe, economical, and sustainable handling of both: Jönsson 1997, in Drangert et al. 1997.

48. According to "On-Site Waste Treatment — What Are the Benefits?" Clivus Multrum, Inc., 15 Union St., Lawrence, MA 01840, 978/725-5591, 800/962-8447, fax 978/557-9658, www.clivusmultrum.com/. Id. gives the ratio as about 36–360 in Swedish practice.

49. Simpson-Hebert 1996. The nutrients in a person's annual excreta roughly equal those required to grow enough cereals to feed that person for a year: Drangert et al. 1997; Jönsson 1997.

50. In developing countries, 95 percent of sewage is discharged untreated: World Resources Institute 1992. Even the wealthiest countries cannot afford tertiary treatment and safe disposal of industrially contaminated sludge.

51. Simpson-Hebert 1996.

52. Rogers 1997, Kalbermatten et al. 1982.

53. About 88 percent of N, 67 percent of P, and 71 percent of K: Jönsson 1997. Urine also releases far less ammonia if not exposed to an enzyme secreted by *Micrococcus urea,* a bacterium in feces.

54. Even if diluted 10:1 with water, one person's urine may be right for fertilizing as little as 10–20 square meters of intensive garden. Such a mixture of urine with household graywater is an essentially perfect fertilizer that can close the nutrient loop for growing a person's food: Drangert 1997 in Drangert et al. 1997.

55. Id.

56. For example, those from Energy Technology Laboratories, 2351 Tenaya Drive, Modesto, CA 95354, 800/344-3242, www.savewater.com.

57. The range depends on pressure; the vendor is ETL (previous note).

58. Omni Products, Chronomite Laboratories, 1420 W. 240th St., Harbor City, CA 90710, 800/447-4962, provides models with nominal flow rates of 1.5, 2.0, and 2.5 gpm.

59. U.S. models in early 1998 included Maytag's "Neptune" (http://neptune.maytag.com), Amana's "LTA85" (www.raytheon.com/rap/amana), and Frigidaire's "Gallery" (www.frigidaire). See Lamarre 1997a.

60. Posh Wash, evenings 503/257-9391.

61. *Consumer Reports* 1997.

62. Hart Industries of Laguna Hills, CA, now apparently defunct; but the idea seems feasible.

63. *U.S. Water News* April 1992 at 18.

64. Ian Michaels, New York City Department of Environmental Protection, Room 2454 Municipal Bldg, 1 Center St., New York, NY 10007.

65. Liebold 1995.

66. North American Residential End Use Study (see Nelson 1997).

67. Chernick 1988.

68. City of Boulder, "Water Conservation Facts and Tips," P.O. Box 791, Boulder, CO 80306, 303/441-3240.

69. Watersense and Northern Indiana Public Service Company are undertaking 1998 pilot installations of a programmable system, WatersOff!, that can trigger shutoff or notification on detecting major leaks (typically over 1 gpm) and can also recognize slow leaks (down to 0.05 gpm). Notification can be integrated with an emergency plumber call arranged by the utility. Kevin Shea, Watersense, Inc., 83 Second Ave., Burlington, MA 01801, 617/273-2733, kevinshea1@aol.com.

70. Fritz 1984–89.

71. *U.S. Water News* 1998.

72. Bill Ferguson, Water Development Planner, Public Works Dept., PO Box 1990, Santa Barbara, CA 93102, 805/564-5460.

73. Beth O'Connor, Utilities Market Services, City of Palo Alto, P.O. Box 10250, Palo Alto, CA 94303, 650/329-2549.

74. Preston 1994.

75. Vickers 1990.

76. John Wallace, Office Administrator, San Simeon Acres Community Services, Rt. 1, Box S17, San Simeon, CA 93452, 805/544-4011.

77. By an average of 0.22 ppm per year since 1987. Pinkham 1994 and personal communication, February 6, 1998, Ron Bishop, General Manager, Central Platte Natural Resource District, 215 N. Kaufmann Ave., Grand Island, NE, 308/385-6282.

78. Sharpe et al. 1984 at 12, Rubin 1982.

79. See also Postel 1992, citing Wilson 1997 at 10.

80. Gleick 1998 at 20–21.

81. Preliminary test data from Philip Paschke, Community Services Division, Seattle Public Utilities, 206/684-7666, personal communication, February 5, 1998. The site's operations manager is John Terry, 206/455-2000.

82. Dennis Brobst, Director, Water and Sewer Division, Calvert County, 175 Main Street, Prince Frederick, MD 20678, 410/535-1600.

83. von Weizsäcker et al. 1997 at 82–83.

84. Id. at 83, with thanks to Wendy Pratt of California Futures (Sacramento).

85. Alan Niebrugge, personal communication, 1994. Then Manager of Environmental Services. Contact Mike McMahan, GS Technologies, 8116 Wilson Road, Kansas City, MO 64125, 816/242-5638.

86. By Intel: http://www.intel.com/intel/other/ehs/management.html.

87. Using the new AWWA 44.6 gpcd average; a "nonconserving" household averages 64.6.

88. That's the rural Texas norm, although Dr. McElveen, a physician, uses ultraviolet light to treat the water.

89. *U.S. Water News* 1992a.

90. Wymer 1997.

91. For comparison, the canonical 133-year flood is 10 inches in 24 hours.

92. These can respond to local demand or be remotely "dispatched" by city water managers. Such dispatch of a "networked reservoir" could also empty cisterns in time for anticipated storms.

93. The TREES software package and related information are available from Tree People (12601 Mulholland Drive, Beverly Hills, CA 90210, 818/753-4600) or project administrator PS Enterprises (310/393-3703, fax -7012). TREES stands for Transagency Resources for Environmental and Economic Sustainability, and comprises diverse government, community, and environmental groups.

94. Jeff Wallace and Andy Lipkis, personal communication, October 30, 1998.

95. Re safety, see City of Los Angeles 1992, Warshall 1995a.

96. John Irwin, Thetford Systems, Inc., Box 1285, Ann Arbor, MI 48106. The project serves more than 1,100 people.

97. Joe Towry, Public Utilities Department, 290 16th St. N, St. Petersburg, FL 33713, 727/892-5095.

98. Chuck W. Carry, Sanitation Districts of Los Angeles County, Box 4998, Whittier, CA 90607.

99. Adler & Mace 1990; Prof. Avner Adin (Hebrew U. of Jerusalem, Div. of Environmental Science, personal communication, December 23, 1998).

100. *Sanitation and Disease,* quoted by David Venhuizen, PE (5803 Gateshead Drive, Austin, TX 78745, 512/442-4047, fax -4057, waterguy@ix.netcom.com).

101. Lovins & Lehmann 1999.

102. Clark & Tomlinson 1995.

103. Clark, Perkins, & Wood 1997 at 70–71; Clark 1997.

104. Venhuizen 1997 and in his 1996 paper "Is 'Waste' Water Reclamation and Reuse In Your Future?," http://www.geocities.com/RainForest/Vines/5240/FutureWaterUse.html, downloaded 5 February 1998.

105. Living Technologies, Inc., 431 Pine St., Burlington, VT 05401, 802/865-4460, fax -4438, http://www.livingmachines.com, jtodd@cape.com.

106. Wilson & Malin 1996 at 13–17.

107. Osann & Young 1998 at 27–52 present numerous case studies. Santa Monica's Baysaver Program, for example, returned about two dollars in savings per dollar invested, and has retrofitted nearly 60 percent of its toilets. For a general implementation guide, see Rocky Mountain Institute Water Program 1991.

108. Its goal of a 15 percent overall reduction was met by allocating 0–45 percent residential, 10–20 percent agricultural, and 15 percent commercial and industrial reductions depending on customers' current usage. Households that were already moderately water-efficient were therefore unaffected by the restrictions.

109. Larry Farwell, former Water Conservation Coordinator for the Goleta Water District, now a private consultant: 2476 San Marcos Pass Road, Santa Barbara, CA 93105, 805/964-8486, lfarwel@earthlink.net.

110. Per-capita consumption fell 16 percent during 1991–97: Osann & Young 1998 at 38.

111. CTSI Corporation, 2722 Walnut Ave., Tustin CA 92780, 714/669-4303; Chaplin 1995.

112. Osann & Young 1998 at 35, Gomez & Owens-Viani 1998. This effort installed over 750,000 new toilets just in the first four years.

113. Water Management, Inc. (117 Clarmont, Alexandria, VA 22304, 703/658-4300, fax -4311, www.watermgt.com) is a typical "water service company," or WASCO.

114. Jim Reed (Water Conservation Speciaiist, Denver Water, 1600 W. 12th Ave., Denver, CO 80254, 303/628-6347, www.state.co.use/gov+dir/oec), personal communication, February 3, 1998.

115. Jones & Dyer 1994; Jones et al. 1993 at 17–21.

Chapter 12: Climate

1. The fraction of total solar radiation that's intercepted by the earth's disk is 3×10^{-10}.

2. The earth also receives 0.018 percent of its warmth from heat flowing up from its interior, driven by radioactive decay, and 0.002 percent from the friction of the tides (moonpower). Berner & Berner 1996 at 10.

3. That is, about 2×10^{17} watts.

4. In 1990, fossil fuels accounted for about 87 percent of the world's commercial primary energy use. Noncommercial energy use added another estimated 11 percent to commercial energy use. Reddy et al. 1997 at 110.

5. This doesn't include 0.5–2.5 billion metric tons from deforestation and other net decreases in standing biomass. For these and other data in this simplified introduction to climatology, see Intergovernmental Panel on Climate Change (IPCC) 1990, 1992, 1996, 1996a, and continuing supplements.

6. This metaphor is provided by Matthias Schabel.

7. IPCC 1990.

8. Some of the best and most accessible descriptions of the history and science of global warming are contained in Weiner (1990) and Schneider (1997).

9. This does not mean that the *air* becomes warmer. Because downward reradiation of heat trapped by atmospheric CO_2 warms the surface, it cools the atmosphere equally, except near the surface where the air is directly heated by its proximity to the earth.

10. Approximately 30 percent of the increase during 1850–1990 came from such land-use changes as deforestation and ecological simplification, the rest from industry. Of the total increase, about 65 percent has come from the developed countries that currently comprise one-fifth of the world's population (Austin et al. 1998).

11. The average column of air contains water vapor equivalent to an inch of rain, removed by precipitation and replenished by evaporation every eleven days.

12. IPCC 1996. Satellite measurements now match surface measurements: Wentz & Schabel 1998, Hansen et al. 1998.

13. Stevens 1998a, citing a World Metereological Organization compilation of data from the NASA Goddard Institute for Space Studies, the British Meteorological Office, the U.S. National Climatic Data Center, the NASA Marshall Space Flight Center and University of Alabama, the International Research Institute (New York), and the Climatic Prediction Center (Washington, D.C.). Data from October 1998 were the latest available as this book went to press.

14. Flavin 1998.
15. McKibben 1998.
16. Vaughan & Doake 1996.
17. Kerr 1998.
18. Linden 1996 at 65.
19. Shindell et al. 1998.
20. Schneider 1997.
21. IPCC 1990, 1994, 1996.
22. Browne 1997.
23. The President's Council of Advisors on Science and Technology (PCAST) 1997.
24. Arrow et al. 1997; for a splendidly clear explanation of why theoretical models differ, see Repetto & Austin 1997.
25. Samuelson 1997.
26. E.g., Lovins et al. 1981, ICF 1990, Okken et al. 1991, Evans 1992, IPSEP 1993 & 1994–8, Koomey et al. 1991, Krause 1996, Brown & Levine 1997.
27. Detailed documentation on each of these matters, omitting only the newest developments such as Hypercars, is in the 188 references of an earlier survey paper in the journal of record: Lovins & Lovins 1991. Many older but still useful references are in its decade-earlier predecessor, Lovins et al. 1981.
28. NRC 1989, Lovins & Lovins 1991.
29. For example, just during 1990–96, while its earnings and stock prices soared, DuPont halved its total greenhouse gas emissions per unit of production, mainly by phasing out CFCs, of which it was the main manufacturer. During 1996–2002, it expects to save more than half the remaining greenhouse-gas emissions from its plants while continuing to decrease the greenhouse effects of its products per unit output (Krol 1997). During its first six months of operation at just one plant (the Sabine River Works in Texas), an "abater" that turns by-product nitrous oxide into air saved the equivalent of *7 billion* pounds of CO_2. That's the same as taking three million cars off the road. Meanwhile, Monsanto's Solutia spinoff found in 1997 that nitrous oxide is not just an unwanted, climate-threatening nuisance, but also a valuable reagent for turning benzene into competitively priced phenol — a classic conversion of lemons into lemonade.
30. There are six gases, each of which can be emitted less or stored or sequestered more. Either approach offers many methods — many kinds of efficiencies, process changes, substitutions, et cetera. Some methods also offer many different kinds of savings for the price of one: Lovins & Lovins 1991.
31. Lovins 1997a.
32. A 4- to 6-fold improvement over fifty years implies an average annual improvement by 2.8 to 3.6 percent. Americans actually reduced the primary energy used per dollar of real GDP by 3.4 percent per year during the years 1979–86. Preliminary data, not weather-corrected, for the short period 1997–99 suggest the possibility that comparably rapid savings may be starting to recur, driven this time not by price but by skill, attention, and competition.
33. Nelson 1993; now at KENTEC, Inc., 8118 Oakbrook Drive, Baton Rouge, LA 70810, 225/761-1838, fax -1872, kentech@compuserve.com.
34. Mills et al. 1991 (Swedish household refrigerators); U. of Lund data noted by T. B. Johansson, 1992, and recent industry data from Gunnar Hofstadius of ITT Flygt (personal communication, August 31, 1998) (industrial pumps); Howe et al. 1996 at 133, Fig. 8-8 (motors; the MotorMaster staff have privately confirmed the lack of efficiency/price correlation up to at least 200 hp); Houghton & Hibberd 1998 at 9, Fig. 6, for 5.4–20-ton packaged rooftop air-conditioning units. Valves are illustrated by the commonplace observation that full-port ball valves have far lower frictional head than globe valves but cost about half as much.
35. Howe et al. 1996.
36. Lovins et al. 1989, Fickett et al. 1990. This doesn't count the savings further downstream, which are usually larger and cheaper, and should be done first.
37. Interlaboratory Working Group 1997.
38. Lovins 1998a.
39. STMicroelectronics Vice President Murray Duffin (1998) has publicly presented a similar strategy.
40. Casten 1997.
41. Groscurth & Kümmel 1989.

42. Johansson et al. 1993, Romm & Curtis 1996.

43. Mansley 1995.

44. *Shell Venster*, Jan./Feb. 1998, the Shell external-relations newsletter, which states: "In 2050 a ratio 50/50 for fossil/renewables is a probable scenario, so we have to enter this market now!" *Cf.* Kassler 1994.

45. *The Economist* 1998a.

46. Flavin & Dunn 1997 at 47, citing California Energy Commission data from October 1997.

47. Brown et al. 1997 at 52; see also PCAST at 6-14; National Laboratory Directors at 2-38.

48. SERI 1990.

49. Interlaboratory Working Group 1997, e.g. at 1.14.

50. Sørensen 1979, Lovins et al. 1981, Reddy & Goldemberg 1990, Johansson et al. 1989 & 1993.

51. Flavin & O'Meara 1998 at 25.

52. Lovins & Lehmann 1999.

53. Johansson et al. 1993 at 23ff.

54. See also Prophet 1998.

55. Williams et al. 1997, Lovins 1998.

56. Edwards 1997.

57. *The Economist* 1998.

58. Keepin & Kats 1988, 1988a.

59. Bodlund et al. 1989.

60. Reddy & Goldemberg 1990.

61. Such studies are at scales ranging from California (Calwell et al. 1990) and New England (Krause et al. 1992) to western Europe (IPSEP 1993, 1994–98) and the world (Lovins et al. 1981, Goldemberg et al. 1988).

62. Reid & Goldemberg 1997, Flavin & Dunn 1997 at 26–29. See also Levine et al. 1993, Reddy et al. 1997, Yergin 1997.

63. Gadgil et al. 1991.

64. Lovins & Gadgil 1991.

65. Id.

66. Lovins 1976, Nash 1977.

67. Lovins & Lovins 1997.

68. For example, during the years 1983–85, ten million people served by Southern California Edison Company, aided by a comprehensive slate of financing, information, and other support, raised their electrical efficiency so quickly that if all Americans did as well, then *each year* they'd decrease the need for power supplies ten years later by about 7 percent. Implementing these savings would cost the efficiency about one-tenth as much as building today's cheapest new power stations. Lovins 1985 at 180–183, Fickett et al. 1990.

69. Interlaboratory Working Group 1997 at 2.10.

70. Jaffe & Stavins 1994, Sanstad & Howarth 1994, Krause 1996.

71. von Weizsäcker et al. at 143–209.

72. Todd 1997, Brandt 1997; Lovins & Lovins 1997 at n147.

73. Stewart 1997.

74. Clinton 1997.

75. David 1997 [David, G. 1997: Address to Earth Technologies Forum, October 26].

76. The total payroll of all U.S. coal miners is about $5 billion, or 1 percent of the nation's energy bills. This is less than spontaneous gains in energy efficiency *save* in any typical year. Americans pay about $24 billion a year for coal. If the miners' worst fears came true and coal consumption fell by half, then American consumers could afford to make good the miners' entire lost pay — with $9 billion a year left over. (For illustration, consumers could pay about $11.5 billion less each year for coal, pay $2.5 billion to cover the payroll of the out-of-work miners, and still have $9 billion left.) A more rigorous calculation would be much more sophisticated and opaque, but would give roughly the same answer.

77. Goodstein 1999.

78. DeCanio 1997.

79. *Christian Science Monitor* 1997.

80. Nitze 1997.

81. However, extensive European research suggests that a combination of price and market-transformation initiatives may interactively boost economic efficiency and welfare more than the sum of their parts: Krause 1996.

82. NREL 1997.

83. DeCanio 1997.

84. Carey 1998, Lovins 1999.

85. Cushman 1999. DuPont is now among the industries seeking an important

law to ensure credits for early emission reductions.

86. Climate Neutral Network, c/o Sue Hall, 509/538-2500, suehsea@gorge.net.

87. Such as Green Mountain Power, PO Box 850, South Burlington, VT 05402, 802/660-5672, www.gmpvt.com.

88. Lovins 1999, according to Dr. Richard Sandor, Vice Chair, Chicago Board of Trade (personal communication, December 2, 1998).

Chapter 13: Making Markets Work

1. *Cf.* Buchan 1997 at 239–240.

2. Lovins 1992, citing Kempton et al. 1992, Lutzenhiser 1992.

3. Korten 1999.

4. Schmidheiny & Zorraquin 1996.

5. Interlaboratory Working Group 1997.

6. Howe 1993.

7. DeCanio 1994.

8. The magic formula is: after-tax return on investment in percent per year equals (1 – marginal tax rate in decimal form) / (simple payback in years – 1). Thus if the total marginal tax rate (Federal, state, and local) totals, say, 36 percent or 0.36 (the value we assume), then the after-tax ROI corresponding to a two-year simple payback is (1 – 0.36) / (2 – 1) = 0.64, or 64 percent per year. Thus the ROI tends to infinity as the simple payback approaches one year, so for paybacks of one year or less, the ROI is conventionally set to infinity. For simplicity, the formula assumes an end-of-year convention about when investments are made and booked (a different timing assumption will change the result), and ignores such tax effects as the expensing of energy costs and capitalization of efficiency investments.

9. DOE 1997.

10. Implicit real annual discount rates for buying efficiency typically range around 30–60-plus percent: Rosenfeld & Hafemeister 1998; Koomey et al. 1991, Levine et al. 1995, Hausman 1979, Hartman & Doane 1986, Wolf et al. 1983.

11. Nadel 1990, Lovins 1994.

12. von Weizsäcker et al. at 166–167.

13. Udall 1997.

14. Lovins & Lehmann 1999.

15. Lovins & Gadgil 1991.

16. See also von Weizsäcker et al. at 155–176.

17. Proprietary engagements led by RMI and partly summarized in Lovins 1998a.

18. Rajendran 1997 and private data.

19. Audin & Howe 1994.

20. *Wall Street Journal* 1997.

21. Rosenfeld 1999, Mills 1995.

22. DeCanio 1993, 1994, 1994a, 1994b.

23. Lovins 1996.

24. Bradford 1998.

25. Moskovitz 1989, Lovins 1996.

26. Bradford 1998.

27. E.g., Sauer 1997, 1998.

28. CDA 1996.

29. Id.

30. EPA 1993.

31. DeCanio 1994b.

32. EPA 1993.

33. EPA 1998.

34. Geller & Nadel 1994.

35. Udall 1997.

36. Promoted by Byron Kennard, Executive Director, The Center for Small Business and the Environment, PO Box 53127, Washington, DC 20008, csbe2000@aol.com.

37. Lovins 1995a.

38. Arnold & Day (1998) provide a partial taxonomy of the business benefits of sustainable practices.

39. Tobias 1993. Their effort has so far been unsuccessful due to opposing lobbying efforts by industries that prefer their profits from present arrangements.

40. Gil Friend, personal communication, 1998.

41. Mills & Knoepfel 1997; Schanzenbacher & Mills 1997; and Mills 1997, http://eande.lbl.gov/CBS/Climate-insurance/GoingGreen.html.

42. Savory & Butterfield 1999. Describes a particularly comprehensive and ecologically based way to do this.

Chapter 14: Human Capitalism

1. Conway 1969, Harrisson 1965, Cheng 1963.

2. And may even help us live longer: longevity in 282 U.S. metropolitan areas has been much better correlated with relative than with absolute income, apparently reflecting links between psychosocial tensions and health (Lardner 1998).

3. This is a less modest restatement of the goals of Rocky Mountain Institute's Economic Renewal Project (1983–), which uses resource productivity and other principles to help build sustainable local economies from the bottom up. This often yields such important social side benefits as conflict resolution and leadership development. The project has shown its analytic and organizing process to be flexible and replicable, and has developed a variety of field-tested tools, including such workbooks and casebooks as Kinsley 1997, Hubbard & Fong 1995, and Cantrell 1991. A complete list of publications is at www.rmi.org.

4. Max-Neef 1992.

5. Some products even falsely pretend to satisfy a need, thereby retaining the opportunity to try again in other ways, or satisfy a need in ways that simultaneously prevent the satisfaction of other needs, creating still more market opportunities: Max-Neef 1992.

6. Midsized cities of 0.5 to 5 million hold four times as many of the world's people as do the megacities of 10 million or more: O'Meara 1998.

7. The population of the city itself quadrupled in 30 years, and by 1996 was 1.5 million out of the metro region's 2.4 million.

8. The following account draws on 1991–98 personal communications with Jaime Lerner and his former adviser Jonas Rabinovitch (now Senior Urban Development Adviser and Manager of the Urban Development Team at the United Nations Development Programme, jonas.rabinovitch@undp.org, fax 212/906-6973); the city's Portuguese-language website, www.curitiba.arauc.br; its 600-MB Portuguese/Spanish/English CD-ROM *Enciclopédia Cidade de Curitiba;* its video, *Good Morning, Curitiba;* the English-language brochures Curitiba 1997, Curitiba undated, and FAS undated; Lamounier & Figueiredo 1996; de Vega 1996; Rabinovitch 1992, 1993, 1995, 1996; Rabinovitch & Hoehn 1995 (which lists further readings); Rabinovitch & Leitman 1993, 1996; McKibben 1995 (the broadest and most accessible English-language treatment); Linden 1996; and O'Meara 1998. We are especially grateful for Jonas Rabinovitch's careful review of a draft of this chapter, but we alone are responsible for its content.

9. Linden 1996 at 62.

10. Having such a base for institutionalizing the continuous improvement of the city's strategy has proven invaluable. Now 200 strong, this independent nonprofit think tank has served as a vital incubator and reservoir of creativity, training three mayors and many of their senior advisors. (Rabinovitch joined in 1981 and rose to become its COO.) Starting with a 1965 strategic plan that won a public competition after wide public debate, IPPUC refined its fundamentals and details, ripening the plan until 1971 when, with Lerner's election, its implementation could begin.

11. Berry (1995 at 56): "If we are serious about conservation, then we are going to have to quit thinking about our work as a sequence of specialized and temporary responses to a sequence of specialized and temporary emergencies. We will have to recognize that our work is economic. We are going to have to come up with competent, practical, at-home answers to the humblest human questions: How should we live? How should we keep house? How should we provide ourselves with food, clothing, shelter, heat, light, learning, amusement, rest? How, in short, ought we to use the world?"

12. von Weizsäcker et al. at 126–128; photo, Plate 11. By mid-1998, 223 of these *estações tubo* were in use.

13. Linden 1996 at 62.

14. Linden (1996) reports that Lyons and Vancouver are among the cities considering surface subways.

15. The city is experimenting with innovative sewage-treatment methods and considering a dual-quality water supply and cistern collection, but until Lerner recently shifted to the Governorship, city/state issues prevented innovation in and decentralization of the water and wastewater systems.

16. The effort was launched by TV ads and school programs featuring actors dressed as the Leaf Family.

17. Available at www.product-life.org/history.htm. Stahel calls these last two steps "social ecology" and "cultural ecology."

18. At least, notes Rabinovitch, in the "formal city" for which good statistics exist: "It is impossible to have reliable data about the informal city, which changes on a daily basis and would present lower percentages. This fact is universal."

19. McKibben 1995 at 110.

20. Linden (1996 at 63–64) speculates that the rarity of examples like Curitiba's might reflect an unusual confluence of gifted leadership and prepared citizens.

21. Quoted id.

22. An aphorism of the late economist and iconoclast Professor Kenneth Boulding.

Chapter 15: Once Upon a Planet

1. Briscoe 1998.

2. Meadows 1994 at 25–30.

3. Meadows 1994.

4. Brower 1995 at 155–159. These are based on an endpaper published in 1975 in the *New York Times* entitled *The Third Planet: Operating Instructions* (300 Broadway, Suite 28, San Francisco, CA 94133-3312) and paraphrased here by permission.

5. D. Orr, personal communication, February 1, 1999.

6. Ayres 1992.

7. Holling, "New Science and New Investments for a Sustainable Biosphere," at 57 in Jansson et al. 1994, Callahan 1999.

8. Hart 1999.

9. Ayres 1995a.

10. Costanza, "Three General Policies to Achieve Sustainability," at 392 in Jansson et al. 1994.

11. Berry 1999.

12. von Weizsäcker 1994.