Resource Letter PSEn-1: Physics and Society: Energy

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ABSTRACT

This Resource Letter provides a guide to the physics-related literature about energy-and-society. Journal articles, books, and websites are cited for the following topics: general references, textbooks, other pedagogical resources, population growth, fossil fuels, global warming, nuclear power, side effects of nuclear power, fusion power, renewable resources (including hydroelectric, biofuels, wind, photovoltaics, direct solar, geothermal, hydrogen, and energy storage), energy efficiency, and transportation efficiency.

I. INTRODUCTION

A 1996 American Physical Society National Policy Statement said in part:

> Our nation's complacency about the energy problem is dangerous. …Such complacency is short-sighted and risky. Low-cost oil resources outside the Persian Gulf region are rapidly being depleted, increasing the likelihood of sudden disruptions in supply. Energy-related urban air pollution has become a world-wide threat to human health. Atmospheric concentrations of CO_2, other greenhouse gases and aerosols are climbing; this will cause changes in temperature, precipitation, sea level, and weather patterns that may damage both human and natural systems.
>
> The Council of the American Physical Society urges continued and diversified investments in energy research and development, as well as policies that promote efficiency and innovation throughout the energy system. Such investments and policies are essential to ensure an adequate range of options in the decades ahead. Our national security, our environmental well-being, and our standard of living are at stake. (See http://www.aps.org/statements/index.cfm.)

The APS statement still rings true, and is in fact even more urgent today than it was in 1996. People need to understand the social ramifications of energy, and so teachers of physics—a field that certainly includes energy as a major subtopic—need to teach it. If physicists don't teach energy and society (as I will call this field), it's hard to imagine who will. Hence, this Resource Letter. It surveys books and articles that provide physics teachers and others with the resources needed to understand and teach the main energy-and-society topics. As E. O. Wilson (Ref.

35) points out, it will be difficult to pull civilization through the coming century. To pull through, it's essential that all students--scientists and nonscientists alike--understand at least some of the many physics-related social issues that confront us. Among these issues, energy is one of the most fundamental. As John Holdren puts it:

> Energy is the most difficult part of the environment problem, and environment is the most difficult part of the energy problem. The core of the challenge of expanding and sustaining economic prosperity is the challenge of limiting, at affordable cost, the environmental impacts of an expanding energy supply. (Ref. 64)

You can help by becoming more aware of, and by teaching, this issue. One way to teach energy and society is to develop an entire course devoted to the topic. There are many such courses today, and several textbooks for such courses (Refs. 1-5).

Another way is to insert energy-and-society topics into a more general physics course. The topics in this Resource Letter can fit comfortably into physics courses and could be inserted into lectures and discussions. Don't save these topics until the end of the course; insert them as soon as students understand the relevant physics, so that they can see the connections between physics and society. Energy-and-society topics can range from a few minutes devoted to photovoltaic cells during a lecture about the photoelectric effect, to 15 minutes about automobile engine efficiencies during a discussion of the second law of the thermodynamics, to a 50-minute lecture on global warming following presentation of the electromagnetic spectrum.

Energy and society is a broad and hugely interdisciplinary field, spilling out into physics, engineering, chemistry, economics, sociology, psychology, political science, ethics, religion, and history. This makes the field immensely interesting but difficult to organize, and makes it hard to select a limited number of representative references. I've tried to choose only selections with a close connection to physics and, of course, only those with something substantial to contribute.

Energy and society is a rapidly evolving field. Current data, technologies, and the underlying science, can change significantly in a short time. Although I've included older articles when they are still relevant, I've omitted a lot of older material for this reason.

This Resource Letter's organization reflects the diversity of its topic. Section II lists the most important journals. Section III lists general references that span most of the field, with subsections on textbooks, other pedagogical references, other general references, and population growth. The remaining four sections are categorized by energy resources: fossil, nuclear, renewable, and efficiency (which is not a resource but acts in many ways like a resource). Section IV concentrates on fossil fuels, with a separate subsection on global warming--the major side effect of fossil fuels. Global warming also crops up in several references in Sections V, VI, and VII. Section V covers nuclear energy, with subsections on nuclear power (energy from fission), the side effects of nuclear power (reduction in global warming, nuclear proliferation and nuclear terrorism, radioactive waste, and accidents), and fusion power. Section VI covers renewable energy with a separate subsection devoted to individual renewables (hydroelectric, biomass, wind, photovoltaic, direct solar, geothermal, hydrogen, and energy storage). Section VII covers energy efficiency with a separate subsection on transportation efficiency. Since this Resource Letter is organized by energy resources rather than by end uses, any particular end use can show up in many places; transportation, for example, shows up not only in Section VII but also in Sections III, IV, and VI.

II. JOURNALS, INCLUDING ANNUALS

American Journal of Physics

Annual Review of Environment and Resources, titled *Annual Review of Energy* during 1976-1990; titled *Annual Review of Energy and the Environment* during 1991-2002

Environment, a journal of science and policy for sustainable development

Environmental Research Letters, an open-access journal published at http://www.iop.org/EJ/erl

National Geographic

Nature

Physics and Society, newsletter of the American Physical Society's Forum on Physics and Society, archived at http://www.aps.org/units/fps/index.cfm

Physics Today

Science

Scientific American

State of the World, annual collection of articles updating areas of environmental concern, from the Worldwatch Institute

Teachers Clearinghouse for Science and Society Education Newsletter, soon to be available on the web at http://www.physics.rutgers.edu/~lindenf/pse/

Vital Signs, annual report of global environmental data, from the Worldwatch Institute

WorldWatch, a bimonthly magazine from the Worldwatch Institute; news items and articles related to the goal of a sustainable world

III. GENERAL REFERENCES

A. Energy and Society Textbooks

The following textbooks provide comprehensive treatments of energy and society. They typically include chapters on energy resources, production, transmission, end uses, and environmental effects, interspersed with chapters on the underlying physics. Except for Ref. 5, they are conceptual (quantitative but with little or no algebra) and designed for nonscientists' courses in energy and society, technology and society, environmental science, or physical science.

1. **Renewable Energy: Power for a Sustainable Future**, edited by G. Boyle (Oxford University Press, Oxford, UK, 2nd edition 2004); **Energy Systems and Sustainability: Power for a Sustainable Future**, edited by G. Boyle, B. Everett, and J. Ramage (Oxford University Press, Oxford, 2003). These textbooks for an undergraduate course at the United Kingdom's Open University address the question of supplying energy cleanly, safely, and sustainably in view of increasing population, increasing industrialization, and global warming. The first volume covers a wide variety of renewable energy systems. The second volume covers all primary energy sources and their associated technologies, the physical forms of energy, energy economics, environmental impacts, and the sustainability of each major energy technology. There are no exercises or problems. (E)
2. **Energy: Physical, Environmental, and Social Impact**, G.J. Aubrecht (Prentice Hall, Englewood Cliff, NJ, 3rd edition 2006). This book's three major parts deal with fossil, nuclear, and solar energy resources and their consequences. There are individual chapters on overpopulation, energy efficiency, mineral resources, recycling, fossil-fuel pollution, transportation, climate change, nuclear-power risks, and the energy cost of agriculture. The final chapter presents the book's bottom line: alarm bells of overpopulation and overexploitation are sounding worldwide. Each chapter includes a list of key terms, a summary, problems, and questions. (E)
3. **Energy: Its Use and the Environment**, R.A. Hinrichs and M. Kleinbach (Thomson Brooks/Cole, Belmont, CA, 4th edition 2006). This book covers all the major energy resources, transmission, efficiency, and environmental effects. Each chapter includes worked examples, a reading list, questions, numerical problems, and hands-on activities. (E)
4. **Energy and Society: An Introduction**, H.H. Schobert (Taylor & Francis, New York, 2002). This book is best described as a history of technology. Its

37 chapters include human energy, fire, waterwheels, wind energy, steam-electric power, transportation, six chapters on fossil fuels including separate chapters on diesel and jet fuel and gasoline, three chapters on nuclear power including fusion, chapters on environmental effects, and three chapters on renewables (biomass, wind, solar). There are no exercises or problems. (E)

5. **Sustainable Energy: Choosing Among Options**, J.W. Tester, E.M. Drake, M.J. Driscoll, M.W. Golay, W.A. Peters (MIT Press, Cambridge, MA, 2005). This calculus-based textbook for advanced undergraduates and graduate students provides tools for solving the problem of providing energy cleanly, safely, and sustainably. Chapters 1-6 include sustainability, evaluation of resources, measuring performance, and environmental effects. Chapters 7-15 cover energy sources: fossil, nuclear, biomass, geothermal, hydro, solar, ocean, and wind. Chapters 16-21 cover storage, distribution, electric power, end uses, and complex systems analysis. Each chapter includes problems, recommended reading, and web sites. (A)

B. Other Pedagogical Resources

6. **Active Physics: Light Up My Life**, A. Eisenkraft, project director (It's About Time, Inc., Armonk, NY, 2000). This module of the "Active Physics" series focuses on better energy utilization. Developed by physicists and educators working with the American Association of Physics Teachers, the inquiry-based one-year secondary-school Active Physics course is based on seven independent short modules. It could be used as a 9th-grade "physics first" course. The modules are full of interactive activities and exercises. (E)
7. **Physics: Concepts & Connections**, A. Hobson (Pearson Prentice Hall, Upper Saddle River, NJ, 4th edition 2007). This conceptual-physics textbook for nonscience college students covers the big ideas of physics, emphasizing modern physics and societal connections. It includes a chapter on the energy future plus sections on the automobile, transportation efficiency, resource use, exponential growth, ozone depletion, global warming, radiation risks, and risk assessment. Each chapter includes "concept checks," review questions, conceptual exercises, and problems. (E)
8. **Environmental Physics**, E. Boeker and R. van Grondelle (John Wiley & Sons, Chichester, UK, 1995). This calculus-based textbook for upper-level undergraduate physics students includes a long chapter on "Energy for Human Use" (heat transfer, fossil fuels, energy conversion, renewable sources, and nuclear energy), plus chapters on environmental spectroscopy, climate change, the transport of pollutants, noise, and energy policy. Each chapter includes exercises. (A)

9. “Science and Society Test X: Energy Conservation,” D. Hafemeister, Am. J. Phys. **55** (4), 307-315 (April 1987); “Science and Society Test VII: Energy and Environment,” D. Hafemeister, Am. J. Phys. **50** (8), 713-720 (August 1982); “Science and Society Test VI: Energy Economics,” D. Hafemeister, Am. J. Phys. **50** (1), 29-38 (January 1982); “Science and Society Test IV: The 94th Congress,” D. Hafemeister, Am. J. Phys. **47** (8), 671-677 (August 1979); “Science and Society Test for Scientists: Transportation,” D. Hafemeister, Am. J. Phys. **44** (1), 86-90 (January 1976); “Science and Society Test for Scientists: The Energy Crisis,” D. Hafemeister, Am. J. Phys. **42** (8), 625-641 (August 1974). Hafemeister’s series of “science and society tests” aim at a middle, “sophmore physics” level between qualitative discussion and sophisticated analysis. These six articles from the series deal with energy-related topics such as energy efficiency, passive solar energy, photovoltaics, utility load management, economics, car efficiency standards, uranium enrichment, the greenhouse effect, nuclear reactor accidents, radon in buildings, acid rain, freeway noise, and the 55 mph speed limit. (A)
10. "Statistics of Measurements of Automobile Fuel Efficiency," A. Bartlett, The Physics Teacher **41**, 472-477 (November 2003). Bartlett explains how to accurately measure your car’s gasoline efficiency, how to compare with official mileage estimates, the effect of country versus urban driving, yearly averages, and rms deviations. These measurements and calculations are suitable for secondary school students. (E)
11. "Energy Flow Diagrams for Teaching Physics Concepts," A. Hobson, The Physics Teacher **42**, 113-117 (February 2004). Every physical process is an energy transformation. Energy flow diagrams show these transformations visually and approximately quantitatively. Even for complex processes, these diagrams show the physical fundamentals in a meaningful manner. Examples include energy flow through a heat engine, a leaf, an automobile, Earth without greenhouse gases, and Earth with greenhouse gases (thus illustrating the greenhouse effect). (E)
12. “Introductory Experiment to Determine the Thermodynamic Efficiency of a Household Refrigerator,” A. Bartlett, Am. J. Phys. **44** (6), 555-559 (June 1976). Introductory laboratory students can determine all energy flows, hence the coefficient of performance, of a household refrigerator, and compare with an ideal Carnot refrigerator. Concepts include the 1st and 2nd laws of thermodynamics, and energy transfer by thermal conduction. (I)
13. “Inexpensive Photovoltaic Solar Radiometer,” F. Kisser, Am J. Phys. **49** (5), 439-442 (May 1981). Using a solar cell as sensor, undergraduate physics students can construct a low-cost instrument to measure instantaneous and

integrated solar flux. Students examine a variety of aspects of solar measurements. (A)

14. "Illuminating Physics With Light Bulbs," H.S. Leff, The Physics Teacher **28** (1), 30-35 (January 1990). Leff shows how to analyze incandescent light bulbs using data that precollege through advanced undergraduate students can take in supermarkets. Topics include bulb efficiency and "efficacy" (in lumens/watt), an analysis of filament temperatures, deducing how a 3-way bulb works, and the statistics of light bulb lifetimes. (A)
15. "Compact Fluorescent Light Bulbs," L. Hodges, The Physics Teacher **30** (2), 90-91 (February 1992). Following up on Ref. 14, how do the efficacy, lifetime, energy consumption, and total costs of compact fluorescent bulbs and incandescent bulbs compare? Compact fluorescents come in at less than half the total cost of incandescent bulbs. (I)

16. Website of New York State's National Energy Education Development Project (NEED). NEED promotes an energy-conscious and educated society by creating networks of students, educators, business, government, and community leaders to design and deliver objective, multi-sided energy education programs, curriculum materials, and professional development; http://www.need.org.

C. Other General References

The following references discuss the full range of energy resources: fossil, nuclear, renewables, and efficiency.

17. **Energy At the Crossroads: Global Perspectives and Uncertainties**, V. Smil, (MIT Press, Cambridge MA, 2003). This overview covers long-term trends, energy linkages (to economics, environment, war), forecasting (Smil is against it), fossil-fuel futures, nonfossil energies, and possible futures. The final chapter comments on where we are and where we might be going. For a similar but shorter overview, see V. Smil, "Energy in the Twentieth Century: Resources, Conversions, Costs, Uses, and Consequences," Annual Review of Energy and the Environment **25**, 21-51 (2000). (I)
18. **World Energy Assessment: Energy and the Challenge of Sustainability**, edited by J. Goldemberg (U.N. Development Programme, New York, 2000); available at http://www.undp.org/energy/; a 2004 update is available at the same website. Vaclav Smil (Ref. 17) calls this book "the most far-reaching comprehensive assessment of world energy prospects." It demonstrates that current economic development is unsustainable and that different energy policies are needed. Its four parts cover energy and global issues (social,

environmental, health, security); resource and technology options (end-use efficiency, renewable energy, advanced technologies); sustainable futures (energy scenarios, developing countries); and where we go from here (economic policy, sustainable development). (I)

19. **Energy: Science, Policy, and the Pursuit of Sustainability**, edited by R. Bent, L. Orr, and R. Baker (Island Press, Washington, 2002). These seven chapters by different authors form an integrated interdisciplinary whole. Chapters 1-3 cover physical dimensions of sustainability, including exponential growth, trends in energy demand, and social and environmental impacts of energy resources. Chapters 4-7 are unique in presenting the human dimension, including social factors shaping resource use, the difficulty of pursuing sustainable policies in a democratic society, the environmental context of economics, and the rights of future generations. (E)
20. **The Energy Sourcebook: A Guide to Technology, Resources, and Policy,** edited by R. Howes and A. Fainberg (American Institute of Physics, New York, 1991). This well-integrated and technically-accurate set of essays by different authors, nearly all physicists, surveys a wide variety of source and end-use technologies, including conventional and unconventional fossil, fission, fusion, photovoltaics, solar-thermal, hydroelectricity, geothermal, ocean-thermal, biomass, wind, energy storage, transportation, agriculture, and efficiency. Each essay includes advantages, disadvantages, and environmental and other impacts. (I)
21. **Encyclopedia of Energy, Technology, and the Environment**, edited by A. Bisio and S. Boots, (John Wiley & Sons, New York, 1995). This is a 3000-page, 4-volume encyclopedia by over 200 experts. Its size alone indicates the extent of energy and environmental issues. As a typical example, the 72-page entry on "nuclear power" includes substantial essays on decommissioning power plants, managing nuclear materials in view of proliferation concerns, and nuclear power-plant safety, each with an extensive bibliography. There is a 40-page index. (I)
22. **National Energy Policy: Reliable, Affordable, and Environmentally Sound Energy for America's Future**, National Energy Policy Development Group headed by Vice President Dick Cheney (U.S. Government Printing Office, Washington, 2001); available at http://www.energy.gov/about/nationalenergypolicy.htm. This document lays out the Bush Administration's energy policy, emphasizing energy production and relaxation of regulations that might limit production, while also supporting environmental and efficiency measures. (E)
23. **Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges,** National Commission on Energy Policy (National

Commission on Energy Policy, 2004); available at http://www.energycommission.org. This report by 16 Commissioners from varied walks of life, led by energy/environment expert John Holdren, former Environmental Protection Agency Administrator William Reilly, and Exelon Corp. CEO John Rowe, was funded by the William and Flora Hewlett Foundation. Its six chapters deal with oil security, climate change, energy efficiency, expanding energy supplies, strengthening the energy-supply infrastructure, and better energy technologies for the future. Its central themes are the strains (of supply, security, and environment) affecting the global oil system, the threat of global warming, and improved energy technology. (E)

24. **A Responsible Energy Plan for America,** Natural Resources Defense Council (NRDC, 2005); available at http://www.nrdc.org/. This report presents itself as an alternate vision to the Bush Administration's national energy policy (Ref. 22), one that emphasizes energy efficiency and environmental preservation rather than (as in the administration's policy) maximum energy production. Its three chapters discuss efficiency-based reductions in demand, meeting electricity demands through renewable technologies and efficiency, and the responsible extraction and use of natural gas. Its main message is that we should turn to greater energy efficiency and renewable energy sources sooner rather than later. (E)

25. "Resource Letter ERPEE-1: Energy: Resources, Production, and Environmental Effects," R.H. Romer, Am. J. Phys. **40** (6), 805-829 (June 1972). This Resource Letter includes 248 references from the pre-1972 period, with sections on general references, nuclear power regulation, fission wastes, biological effects of radiation, fuel cycles and economics, fossil fuels, thermal pollution, and one section combining nuclear fusion, solar energy, and other energy sources. (I)

26. "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet," M.L. Hoffert, *et al*. Science **298**, 981-987 (November 1, 2002). This broad but detailed overview by 18 experts covers many possibilities for solving the world's energy and global warming problems, including efficiency, decarbonization, sequestration, fission, fusion, and "climate engineering." The authors argue that the required energy sources do not exist at present, even as pilot plants, and that revolutionary, rather than evolutionary, technology changes are needed. Three letters commenting on this article, along with the authors' response, appeared in Science **300,** 581-584 (2003). (A)

27. "Special Issue: Energy's Future: Beyond Carbon," Scientific American **295** (3), 46-114 (September 2006). Articles include "A Climate Repair Manual," G. Stix; "A Plan to Keep Carbon in Check," R.H. Socolow and S.W. Pacala;

"Fueling Our Transportation Future," J.B. Heywood; "An Efficient Solution," E.K. Jochem; "What to Do about Coal," D.G. Hawkins, D.A. Lashof, and R.H. Williams; "The Nuclear Option," J.M. Deutch and E.J. Moniz; "The Rise of Renewable Energy," D. M. Kammen; "High Hopes for Hydrogen," J. Ogden; "Plan B for Energy," W.W. Gibbs. (E)

28. "Special Issue: The Energy Challenge," edited by S. Benka, Physics Today **55** (4), 38-75 (April 2002). Articles include Benka's introductory essay with a list of related readings in Physics Today; "Meeting Energy Challenges: Technology and Policy," E. J. Moniz and M. A. Kenderdine; "Physics in Oil Exploration," B. Clark and R. Kleinberg; "New Designs for the Nuclear Renaissance," G.H. Marcus and A.E. Levin; "Renewable Energy: Progress and Prospects," S.F. Baldwin; and "Hydrogen: The Fuel of the Future?" J.M. Ogden. (A)

29. "Energy Resources and Global Development," J. Chow, R.J. Kopp, and P.R. Portney, Science **302**, 1528-1531 (November 28, 2003). This is a survey of the global availability and consumption of primary energy resources, and the economic and environmental consequences of energy consumption. Fossil fuel will not run short for 25-50 years. As economies grow, adoption of environmentally benign energy technologies will depend on politics and economics. (A)

30. "The Inconvenience of Truth: The Movie and The Book," "Two Prominent Publications Address Global Warming," "Harvard Hosts Energy Lectures," "Infrared Cameras Monitor Heat Loss," "Drell and Garwin on Nuclear Proliferation," "The Importance of Teaching 'Physics for All'," "Science and Engineering Indicators 2006," "ITER: Next Step for Fusion Energy," "Education and Outreach on Federal Agency Websites," "LEED Certification Leads the Way to Sustainable Living," "How to Detect Illicit Uranium," "Forthcoming Science and Society Education Meetings," "Science and Society Educational Resources: Recommendations and Reviews," J.L. Roeder, Teachers Clearinghouse for Science and Society Education Newsletter **25** (2), 1-40 (Fall 2006); available at http://www.physics.rutgers.edu/~lindenf/pse/ Appearing three times per year, this publication reviews meetings, talks, books, articles, and news items relevant to science and society education. (E)

31. Websites covering a wide range of energy topics: American Physical Society, Panel on Public Affairs, background papers on energy, http://www.aps.org/policy/reports/popa-reports/index.cfm. U.S. Energy Information Administration, http://www.eia.doe.gov. Union of Concerned Scientists, http://www.ucsusa.org/. International Energy Agency, http://www.iea.org/. World Resources Institute, information on global problems, http://www.wri.org/; see especially the section labeled "Climate, energy & transport" at http://www.wri.org/climate/ .

D. Population Growth

The energy used by a particular nation is usually considered to be proportional to three factors: the nation's population, its gross national product per capita, and a technology factor that expresses the amount of energy needed to create one unit of gross national product. Economic and technological factors are discussed in many of the references in this Resource Letter, but unfortunately most articles overlook the population factor. Since population growth is so important in every aspect of energy and society, this subsection covers this topic.

32. **The Essential Exponential**, A.A. Bartlett (Center for Science, Mathematics & Computer Education, University of Nebraska, Lincoln, 2004). Populations tend to grow exponentially. Bartlett has written extensively exponential growth, and dedicates this collection "to children everywhere," because "you deserve a world in which everyone understands the implications of the exponential function." The book contains 34 previously published articles, plus Bartlett's reflections on a lifetime of speaking about this topic, grouped under the headings of energy, population, resources, related articles by M. King Hubbert and L. David Roper, the arithmetic of growth, and the exponential function. For those who cannot easily access this book, one of its most relevant articles on energy is "Forgotten Fundamentals of the Energy Crisis," A. Bartlett, Am. J. Phys. **46** (9), 876-888 (Sep. 1978). (A)
33. **Beyond Malthus: Nineteen Dimensions of the Population Challenge**, L.R. Brown, G. Gardner, B. Halweil (W.W. Norton & Company, New York, 1999). The 19 dimensions are grain production, fresh water, biodiversity, energy, fish catch, jobs, disease, cropland, forests, housing, climate change, materials, urbanization, protected natural areas, education, waste, conflict, meat production, and income. This is a sobering presentation. (E)
34. **Beyond Six Billion: Forcecasting the World's Population**, National Research Council (National Academy of Science, Washington, DC, 2000). This report to the public is the result of a collaborative effort by 19 members of the NRC's Committee on Population. Following a useful executive summary, topics include the accuracy of past projections, transitional and post-transition fertility, mortality, migration, and the uncertainty of population forecasts. Each chapter includes recommended research priorities. (I)
35. "The Bottleneck," E. O. Wilson, Scientific American **286** (2), 82-91 (February 2002). The author of *The Future of Life* (from which this essay is excerpted) and *Consilience* writes about the social changes necessary to sustain human life into the indefinite future, the differing views of economists and

environmentalists, and the consequences of 20th century population growth. We are passing through a "bottleneck" of difficulties in which environmental issues may be more important than economic issues. (I)

36. "Perceiving the Population Bomb," A.R.B. Ferguson, WorldWatch **14** (4), 36-38 (July-August 2001). Arguing that the population bomb went off in 1940, because that is when world population went beyond sustainable carbon emissions, Ferguson tallies the "collateral damage [that] has been steadily accruing ever since." He commends Paul Ehrlich, Albert Bartlett, and others for perceiving the problem, and laments that, even today, "there are few ready to listen to those who have... been toiling to awaken the world to our perilous situation." (E)

37. "Basic Choices and Constraints on Long-Term Energy Supplies," P.B. Weisz, Physics Today **57** (7), 47-52 (July 2004). This analysis of the effect of population growth on energy-resource demand concludes that even large energy-conservation efforts will be quickly nullified by population growth. Weisz analyzes the effect of population growth and steadily increasing demand on the longevity of remaining fossil and nuclear resources and on the extent (land requirements, etc.) of renewable resources required to provide sustainable energy for everybody. (A)

38. "Thoughts on Long-Term Energy Supplies: Scientists and the Silent Lie," A.A. Bartlett, Physics Today **57** (7), 53-55 (July 2004). Bartlett faults physicists for failing to note that population growth is a major cause of energy-resource problems and other societal problems, and that these problems cannot be solved without stopping population growth. This and Weisz's article (Ref. 37) generated many letters to the editor that were published, together with Bartlett's and Weisz's replies, in Physics Today **57** (11), 12-20 (November 2004). (E)

39. "Human Population Grows Up," J.E. Cohen, Scientific American **293** (9), 48-55 (September 2005). Global population continues to grow rapidly, while slowing. Nearly all of the increase is occurring in undeveloped nations. 50 percent of the increase will occur in just nine nations, led by India. 51 nations or areas will lose population. It is difficult to estimate Earth's carrying capacity using such one-dimensional indicators as the "ecological footprint," and consequently the numerical estimates range from one billion to 1000 billion. No scientific estimate of sustainable population size exists. These points and others are elaborated in much greater detail in Cohen's book, *How Many People Can the Earth Support* (W. W. Norton & Company, New York, 1995). (E)

IV. FOSSIL ENERGY

A. Fossil-fuel Production, Consumption, and Resources

40. **The Prize: The Epic Quest for Oil, Money, and Power**, D. Yergin, (Simon & Schuster, New York, 1991). The definitive history of the oil industry, this book recounts the industry's rise and its impact on global politics, war, economics, trade, and society. Yergin traces oil's role in the rise of large corporations, in global power struggles, and in modern culture. *The Prize* won the 1992 Pulitzer Prize for general nonfiction. (E)
41. **Winning the Oil Endgame: Innovation for Profits, Jobs, and Security**, A.B. Lovins, *et al*. (Rocky Mountain Institute, Snowmass, CO, 2006); available at http://www.oilendgame.com/ReadTheBook.html. This roadmap for getting the USA completely and profitably off oil advocates using oil much more efficiently, substituting biofuels and saved natural gas for oil, and optionally substituting hydrogen for oil. To accomplish this, Lovins proposes market-oriented policies without taxes or mandates. A $180-billion investment over a decade will yield $130-billion savings every year by 2025, while revitalizing industry, creating jobs, rebalancing trade, increasing national security, and helping the environment. (I)
42. **Blood and Oil: The Dangers and Consequences of America's Growing Dependency on Imported Petroleum**, M.T. Klare (Henry Holt and Co., New York, 2004). In this historical assessment of petroleum's critical role in American foreign and military policy, Klare argues for reducing America's dependence on foreign oil, lest we continue paying for oil with blood. Klare's previous book, *Resource Wars: The New Landscape of Global Conflict* (Henry Holt and Co., New York, 2001), offers a broader look at the connections between war and natural resources, including oil, water, minerals, and timber. (E)
43. **Coal Utilisation: Technology, Economics and Policy**, L. Grainger and J. Gibson (Halsted Press, New York, 1981). Each chapter of this coal industry overview can be read independently. Introductory topics include coal's physical nature, resource extent, mining, and uses. This is followed by detailed chapters on combustion, carbonization, gasification, liquefaction, chemicals from coal, and chapters on the economics of each of these processes. A concluding section on energy policy covers distribution of coal to users, coal's relationship to nuclear power and other energy sources, and coal's role in world energy strategies. (A)
44. "King Coal's Weakening Grip on Power," S. Dunn, WorldWatch **12** (5), 10-19 (September-October 1999). Coal is increasingly recognized as a leading threat to health and the environment; there is a growing consensus that it's time to replace it with cleaner, and ultimately cheaper, alternatives. After discussing

health hazards, environmental damage, carbon emissions, and job losses in the industry, the article discusses two key policies to reduce coal use: removing subsidies, and energy taxation, so that the price of coal reflects its true environmental and human costs. (E)

Fossil fuels are finite resources. A vast literature is devoted to determining how much remains to be produced, how long it will last, and the consequences of declining supplies. In the case of oil, the predicted date of the peak of world production is an important issue, because oil prices are expected to increase following the peak. M. King Hubbert's famous prediction in 1956, that U.S. oil production would peak around 1970, was scoffed at but has proved accurate. Predictions range from 2005-2006 (Ref. 46) to at least 25-30 years (Cavaney in Ref. 48), and predictions about what will happen after the peak range from rapid changes in the American way of life (see http://www.endofsuburbia.com/) to a lengthy and relatively smooth transition (http://www.cera.com/home/). Refs. 45-52 discuss this issue.

45. **Out of Gas: The End of the Age of Oil**, D. Goodstein (W.W. Norton, New York, 2004). This book's first and also last sentence read as follows: "Civilization as we know it will come to an end sometime in this century unless we can find a way to live without fossil fuels." In the first and last chapters, Goodstein discusses the quickly approaching fossil-fuel crisis, and the related peril to Earth's climate. The intervening three chapters discuss the physics and history of energy, electromagnetism, and Goodstein's specialty, thermodynamics. (E)

46. **Beyond Oil: The View from Hubbert's Peak**, K.S. Deffeyes (Hill & Wang, New York, 2005). Deffeyes's first paragraph states that world oil will peak in 2005-2006. After presenting his arguments for this prediction, Deffeyes examines alternative future resources: natural gas, coal, oil sands, oil shale, uranium, and hydrogen as an energy carrier. The final chapter deplores the present state of U.S. science education in which students substitute softer "environmental" courses for "the hard stuff." (E)

47. "Risks of the Oil Transition," A.E. Farrell and A.R. Brandt, Environmental Research Letters **1**, 6 pages, (October-December 2006); available at http://iop.org/EJ/erl. Rather than an economic crisis following the global peak in "conventional" oil (from wells), the peak will be accompanied by a transition to tar sands, heavy oil, gas-to-liquid synfuels, coal-to-liquid synfuels, and oil shale, all of which can be produced at $40-$50 per barrel. Instead of a sudden shock, there will be economic, security, and environmental problems as we negotiate this transition. The main dangers will be environmental. Using just a

quarter of the world's coal as coal-to-liquid would increase atmospheric greenhouse gas concentrations by about 300 parts per million. (A)

48. "Peak Oil Forum," K. Aleklett, R. Cavaney, C. Flavin, R.K. Kaufmann, and V. Smil, WorldWatch **19** (1), 9-24 (January-February 2006). Here are five articles on when conventional oil will reach peak production. Aleklett predicts before 2020, Cavaney says more than 30 years, Flavin makes no prediction, Kaufmann predicts "in my lifetime (I am 48)," and Smil (Ref. 17) predicts 20 years with large supplies remaining available until 2050. For letters in response, see WorldWatch **19** (3), 3-10 (May-June 2006). (E)
49. "News Focus: Bumpy Road Ahead for World's Oil," Richard A. Kerr, Science **310**, 1106-1108 (November 18, 2005). Tight oil supplies will ease in the short run, but conventional production outside the OPEC nations will stall within a decade. OPEC may not respond with increased production. Some forecasts see OPEC and world production peaking by 2018, while others see OPEC expanding production to keep supply above demand through 2025. Unconventional oil (heavy oil, oil sands, oil from coal) might fill any supply-demand gaps. (E)
50. "Oil: Never Cry Wolf--Why the Petroleum Age Is Far from Over," L. Maugeri, Science **304**, 1114-1115 (May 21, 2004). Estimates of oil resources don't include nonconventional oils (oil sands and heavy oils). These resources are huge and the costs of extraction are falling even as oil prices rise. Low oil prices have discouraged investment in exploration for 20 years, but investments will resume with rising prices. "Crying wolf" over oil resources causes a politically harmful obsession with oil security. (I)
51. "News Focus: USGS Optimistic on World Oil Prospects," R.A. Kerr, Science **289**, 237 (July 14, 2000). A new U.S. Geological Survey (USGS) predicts rising conventional oil production for 25 more years. Most industry experts predict that improved technology will hold off the peak in world oil production and keep prices down, perhaps until midcentury. However, U.S. consumption keeps rising while U.S. production will keep falling, so the U.S. will depend increasingly on foreign oil. (E)
52. "News Focus: Gas Hydrate Resource: Smaller But Sooner," R.A. Kerr, Science **303**, 946-947 (February 13, 2004). Gas hydrate (methane trapped in subsurface ice) has been discovered on the deep sea floor and in Arctic permafrost. If 1% of it were commercially extracted, the world would be awash in natural gas. The first controlled attempt to produce gas from hydrate, in 2002, was a success. Gas hydrate might be produced within 10 to 20 years, and could make a significant contribution in 30 years. See also "News Report: Ocean Project Drills for Methane Hydrates," Dennis Normile, Science **286**, 1456 (19 Nov. 1999). (E)

53. Websites about fossil fuels: American Petroleum Institute (oil and natural gas), http://www.api.org. World Coal Institute, http://www.worldcoal.org/. American Coal Council, http://www.americancoalcouncil.org/. American Coal Foundation (education of teachers and students), http://www.teachcoal.org/. Cambridge Energy Research Associates, chaired by D. Yergin (Ref. 40), http://www.cera.com/home/.

B. Global Warming and Other Side Effects of Fossil Fuels

As John Holdren's statement in Part I emphasizes, energy and environment are closely intertwined. Among the energy-related environmental issues, global warming looms largest. Quoting Holdren again (Ref. 64), "Over the next several decades, [climate change] will come to be understood as the most dangerous and the most intractable of the environmental impacts of human activity." From the enormous literature on the many aspects of climate change, I've included here only items related to carbon emissions from fossil fuels. Global warming also crops up in other places in the remainder of this Resource Letter.

54. **Global Warming: The Complete Briefing**, J. Houghton (Cambridge University Press, Cambridge, UK, 3rd edition 2004). This textbook, by the co-chair of the scientific assessment working group for all three reports of the Intergovernmental Panel on Climate Change, is based on those reports, is written for a nontechnical audience, includes end-of-chapter exercises, and is suitable for the general public and for environmental courses. It includes chapters on the greenhouse effect, past climates, modeling, current and future warming, impacts, uncertainties, a climate-stabilization strategy, and the energy future. (I)
55. **Climate Protection Strategies for the 21st Century: Kyoto and Beyond**, German Advisory Council on Global Change (WBGU, Berlin, 2003); available at http://www.wbgu.de/wbgu_sn2003_presse_engl.html. This compact document is an integrated global strategy for avoiding dangerous warming. Temperatures should be held to 2°C above pre-industrial times, by keeping CO_2 concentrations below 400-450 ppm. The socially-just pathway to this limit is "contraction and convergence" whereby the world contracts emissions to arrive by 2050-2100 at 400-450 ppm, while converging on globally equal per-capita emission rights. The report works out the detailed implications (energy resources, economics, etc.) of this strategy. (A)
56. **The Revenge of Gaia: Earth's Climate Crisis and the Fate of Humanity**, J. Lovelock (Basic Books, New York, NY, 2006). Lovelock originated the

Gaia hypothesis that Earth is a self-regulating feedback system similar to a complex organism. Earth struggles to keep herself cool enough for her many forms of life while humans, ruling the planet for their benefit alone, are adding too much carbon to the system. Lovelock, a respected biophysicist and Fellow of the Royal Society, advocates a rapid and massive expansion of nuclear power to replace fossil sources, predicting that our present course will soon set Earth on an irreversible path toward an inhospitable climate regime. (I)

57. **The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future**, R.A. Alley (Princeton University Press, Princeton, NJ, 2000). A leading climate researcher tells the history of global climate changes as revealed by the annual rings of ice from cores drilled in Greenland and Antarctica. This book comprises 6 chapters on reading the 420,000-year ice record, four chapters on the fluctuations, freezes, and mild spells shown by this record, three chapters on how the climate works, and three chapters viewing the possible future. (I)
58. **Climate Change Policy: A Survey**, edited by S.H. Schneider, A. Rosencranz, and J.O. Niles (Island Press, Washington, DC, 2002). This book addresses the political-, economic-, and social-policy challenges presented by climate change. Each of its 20 chapters is an essay on an aspect of global-warming policy, including science and impacts, economics, government policy, forests, agriculture, development, equity, and energy choices, with extensive discussion of developments following from the 1997 Kyoto Protocol. (I)
59. **The Discovery of Global Warming**, S.R. Weart (Harvard University Press, Cambridge, MA, 2003). This is a history of global-warming research, from the perspectives of climate science, other scientific fields, the media, politics, and 20th-century history. Weart recounts, for example, Charles Keeling's measurements of CO_2 in the atmosphere, perhaps the most important geophysical measurement of the 20th century; and the point in the late 1990s when scientists realized that global warming may have risen above the noise in Earth's climate system. (E)
60. **An Inconvenient Truth**, a film directed by Davis Guggenheim, starring Al Gore, available on DVD at http://www.amazon.com. **An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It**, Al Gore (Rodale Books, Emmaus, PA, 2006). This widely-viewed film and the accompanying book are based on Al Gore's slide show about global warming and flashbacks of his life. Gore's message that global warming is dangerous and that we'd better address it soon comes through loud and clear. The science is accurate with a few exceptions, most importantly in the causal connection the film makes between global warming and increased hurricane strengths, a connection that is suspected but not established scientifically. (E)

61. "Earth System Analysis for Sustainability," H.J. Schellnhuber, P.J. Crutzen, W. C. Clark, J. Hunt, Environment **47** (8), 10-25 (October 2005). This large view proposes a "new contract between science and society" because "the sustainability of modern civilization is at risk." This contract involves a "fundamental shift in humankind's research agenda" toward "questions about … a sustainable future." Highlights: the term "the Anthropocene" (introduced by Crutzen in 2000) for the current human-dominated era, a diagram of the "coevolutionary" history of life and the environment, a map locating the instabilities of global change, and a diagram showing feedback loops between environmental and development policies. (I)
62. "Solving the Climate Problem: Technologies Available to Curb CO_2 Emissions," R. Socolow, R. Hotinski, J.B. Greenblatt, S. Pacala, Environment **46** (10), 8-19 (December 2004). Carbon emissions during 1954-2004 form a straight-line graph sloping upward. We could avoid a dangerous doubling of atmospheric carbon by flattening this path from 2004 until 2054 at its 2004 value of 7 billion gigatons of carbon per year, and then reducing emissions. This article offers 15 independent carbon-reduction strategies, any 7 of which would provide the required flattening, each based on proven technology. For a condensed version, see "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," S. Pacala and R. Socolow, Science **305**, 968-971 (12 Aug. 2004). (I)
63. "Earth's Energy Imbalance: Confirmation and Implications," J. Hansen et al, Science **308**, 1431-1435 (June 3, 2005). NASA's climate model, driven by increasing greenhouse gases and other imposed changes on Earth's climate, calculates that Earth is now absorbing 0.85 ± 0.15 W/m^2 more energy than it is emitting to space. This is confirmed by measurements of increasing ocean heat content. The imbalance implies that 0.6 ^{o}C of additional warming is still in the pipeline and will occur even if atmospheric composition and other imposed changes remain fixed at today's values. (A)
64. "The Energy-Climate Challenge," J.P. Holdren, Environment **43** (5), 8-21 (June 2001). Holdren analyzes the climate-change implications of business-as-usual and the magnitude of the changes that will be required to avoid dangerous climate change. He recommends a general strategy and an action program that includes expanded research, family planning, incentives for carbon reduction, and a global framework of commitments to emissions reductions. "The cost of the needed steps almost certainly would be small compared with the cost of the environmental and economic damages averted." (I)
65. "Climate Change and Its Consequences," F.S. Rowland, Environment **43** (2), 28-34 (March 2001). The 1995 Nobel Prize winner in Chemistry for work on stratospheric ozone depletion discusses recent changes in atmospheric

composition, the natural and human-enhanced greenhouse effects, the recent global temperature increase, modeling the atmosphere, feedback effects, cloud effects, possible outcomes by 2100, and recommendations. (I)

66. "The Heat is On: A Survey of Climate Change," The Economist **380** (8494), 24 supplementary pages following p. 50 (September 9-15, 2006). This special report includes 12 articles on global warming, stressing such economic issues as carbon trading, the costs of global warming, the costs of mitigation, environmental consciousness in business, and economic solutions. (E)

67. "Special Issue: Global Warming: Bulletins from a Warmer World," National Geographic **206** (3), 2-75 (September 2004). This collection includes: "The Heat Is On," T. Appenzeller and H. Schultz; "Geo-Signs: The Big Thaw," D. Glick; "Eco-Signs: No Room to Run," F. Montaigne; and "Time Signs: Now What?" V. Morell. Rising CO_2 levels, rising temperatures, retreating glaciers, fracturing ice shelves, rising sea levels, increasing wildfires, shrinking lakes, lingering droughts, precipitation increases, warming winters, changing habitats, spreading diseases, declining snowpacks, exotic species invasions, disappearing species, and the human role in all this, told in words and photographs. (E)

68. "Resource Letter GW-1: Global Warming," J.W. Firor, Am J. Phys. **62** (6), 490-495 (June 1994). This Resource Letter comprises 120 references from the pre-1994 period, with sections on general references, global-warming history, sources of greenhouse gases, climate models, uncertainties, the greenhouse debate, past climate changes, sea-level rise, impacts, and economics and policy issues. (I)

69. "Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption," D. O'Rourke and S. Connolly, Annual Review of Energy & the Environment **28**, 587-617 (2003). The authors review existing data and research on the global distribution of environmental, social, and health impacts of oil extraction, transport, refining, and consumption. They focus on the distribution of these burdens among socioeconomic and ethnic groups, communities, countries, and ecosystems. (I)

70. "An Introduction to Global Warming," J.R. Barker and M.H. Ross, Am. J. Phys. **67** (12), 1216-1226 (December 1999). Barker and Ross present the physics of global warming using a simplified one-dimensional model of energy flows. Section VI is a useful list of the degree of certainty associated with the various predictions of climate change caused by global warming. (A)

Refs. 71-73 discuss carbon sequestration--capturing and storing CO_2 emissions from fossil fuels to reduce global warming.

71. "Can We Bury Global Warming?" R.H. Socolow, Scientific American **293** (1), 49-55 (July 2005). Pumping CO_2 underground to avoid global warming is feasible if several challenges can be met. Socolow describes the technology of CO_2 capture from present and future coal-based generating plants, and sequestration technology for underground storage. Storage capacity can probably accommodate much of the CO_2 from 21st-century generating plants. (E)

72. "Capturing Greenhouse Gases," H. Herzog, B. Eliasson, and O. Kaarstad, Scientific American **282** (2), 72-79 (February 2000). Spurred by a $50 per tonne CO_2 tax on offshore gas mining operations, a Norwegian company is sequestering CO_2 from North Sea natural gas mining operations by pumping it into the pores of a sandstone layer 1000 meters below the seabed. This article describes the technologies, safety, and feasibility of this and other proposed CO_2 sequestration schemes. (E)

73. "Prospects for Carbon Capture and Storage Technologies," S. Anderson and R. Newell, Annual Review of Environment & Resources **29**, 109-142 (2004). Carbon capture and storage underground or in the ocean is technically feasible, at current costs of $200-250 per tonne of carbon. Storage in depleted oil and gas reservoirs appears most feasible in the near term, while deep aquifers appear more attractive in the longer term; ocean storage poses greater technical and environmental uncertainty. (A)

74. Websites about global warming: Intergovernmental Panel on Climate Change, with summaries of all IPCC reports, http://www.ipcc.ch. Environmental Protection Agency website on global warming, www.epa.gov/globalwarming/. EPA's state-by-state global warming impact report, http://yosemite.epa.gov/oar/globalwarming.nsf/content/ImpactsStateImpacts.html.

V. NUCLEAR ENERGY

Global warming has recently prompted a reassessment of nuclear power, because nuclear power provides large-scale electricity without greenhouse gases. Nuclear enthusiasts are predicting a new era for nuclear power, many environmentalists are becoming more friendly toward nuclear power, and all observers are cooling toward coal power unless accompanied by carbon sequestration.

A. General References on Nuclear Power

Here, "nuclear power" means energy obtained from fission. Fusion power is discussed in a separate subsection.

75. **Nuclear Energy: Principles, Practices, and Prospects**, D. Bodansky (Springer-Verlag, New York, 2nd edition 2004). Developed from teaching notes for a physics course on energy production and consumption, this book is a comprehensive account for scientists and engineers. Chapters cover the motivation for nuclear energy, the history of nuclear power, radioactivity, radiation exposure, nuclear reactions, fission, chain reactions, types of reactors, the nuclear-fuel cycle, nuclear waste (4 chapters), reactor safety, accidents, future reactors, nuclear weapons and terrorism, nuclear-weapons proliferation, electricity costs, and prospects for nuclear energy. (A)
76. **The Future of Nuclear Power: An Interdisciplinary MIT Study**, J. Deutch and E.J. Moniz (study co-chairs), with S. Ansolabehere, M. Driscoll, P.E. Gray, J.P. Holdren, P.L. Joskow, R.K. Lester, and N.E. Todreas (Massachusetts Institute of Technology, Cambridge, MA, 2003); available at http://web.mit.edu/nuclearpower/. This study's point of departure is global warming. The study offers a scenario where global nuclear generating capacity would expand threefold, to 1000 gigawatts, by 2050. Such a deployment would avoid an annual 1.8 billion metric tons of carbon emissions from coal plants, about 25% of the increment in carbon emissions otherwise expected in the business-as-usual scenario. Chapters include fuel cycles, economics, safety, nuclear waste, nonproliferation, public understanding, and three chapters of recommendations. (I)
77. **Megawatts and Megatons: A Turning Point In the Nuclear Age?** R.L. Garwin and G. Charpak, (Alfred A. Knopf, New York, 2001). This is a discussion of nuclear power and nuclear weapons, including how nuclear reactors and nuclear weapons work, reactor types, biological effects of radiation, safety and nuclear accidents, nuclear power's future, reducing greenhouse-gas emissions, comparing nuclear power with other energy sources, and arms control. The authors support nuclear power while opposing fuel reprocessing, opposing breeder reactors, and favoring renewables and energy efficiency. (I)
78. **Too Cheap to Meter: An Economic and Philosophical Analysis of the Nuclear Dream**, S.M. Cohn (State University of New York Press, Albany, 1997). The nuclear industry once dreamed of producing electricity so cheaply there would be no need to bill customers. This book chronicles the rise and fall of the nuclear industry in social context, with a view to the future. The first half looks at who promoted nuclear power, how they did it, and why costs and

hazards were underestimated. The second half looks at current debates as seen in historical perspective. (I)

79. "News Focus: Rethinking Nuclear Power," Science **309**, 1168-1179 (August 19, 2005). This collection includes: "Is the Friendly Atom Poised for a Comeback?" E. Marshall; "Nuclear Industry Dares to Dream of a New Dawn," D. Clery; "Asia's Demand for Electricity Fuels a Regional Nuclear Boom," G. Yidong and D. Normile; and "Lingering Nuclear Waste," M. Inman. These articles suggest that nuclear power is poised for a comeback. They discuss new safer reactor designs, nuclear waste plans, and reprocessing. (I)

80. "Why Nuclear Power's Failure in the Marketplace Is Irreversible (Fortunately for Nonproliferation and Climate Protection)," A.B. Lovins, Physics & Society **30** (4), 8-11 (October 2001); available at http://www.aps.org/units/fps/index.cfm. Asserting that "nuclear power has suffered the greatest collapse of any enterprise in the industrial history of the world," Lovins argues that the reason for this disappointment is not public concern but unfavorable economics. The providers of electricity services are, in order of increasing cost: end-use efficiency, combined-cycle gas turbines, wind turbines, co-generation microturbines, coal, and, most expensively, nuclear power. The demise of nuclear power offers a unique opportunity to inhibit nuclear proliferation. (I)

81. "Nuclear Energy in the 21st Century: Examination of a Contentious Subject," P.W. Beck, Annual Review of Energy & the Environment **24**, 113-137 (1999). Beck studies the way beliefs are formed, the history of nuclear power, and the 21st-century energy scene, to test the opposing views about nuclear power. The article concludes that both views are flawed, but there is a strong case for keeping the nuclear option open. Such expansion requires public cooperation, international collaboration, and successful research and development. (I)

82. "Understanding Plutonium Production in Nuclear Reactors," B.C. Reed, The Physics Teacher **43** (4), 222-224 (April 2005). The amount of plutonium produced annually in a nuclear reactor can be estimated based on simplifying assumptions and knowledge of relevant reaction cross sections. One finds a typical production rate of ~100 kg/yr, which is in line with published estimates. This article is suitable for undergraduate physics students. (A)

83. "Brave Nuclear World," K. Charman, WorldWatch, **19** (3), 26-31 (May-June 2006); and **19** (4), 12-18 (July-August 2006). This is a critical look at nuclear power in light of nuclear proponents' claim that they have the solution to global warming. Charman argues that nuclear power cannot make a significant dent in carbon emissions, is too expensive, is too accident-prone despite recent innovations such as passive safety designs, and has an unsolved nuclear-waste problem that cannot be solved by reprocessing. (E)

84. "Oil, CO_2, and the Potential of Nuclear Energy," R.W. Albrecht and D. Bodansky, Physics & Society **34** (1), 12-14 (January 2005); available at http://www.aps.org/units/fps/index.cfm. This article studies the potential of nuclear power to address our energy problems sustainably; it includes the relevance of nuclear power, weapons proliferation, terrorism, and future (Generation IV) reactors. (I)

The following references look primarily at new types of reactors.

85. **Nuclear Energy: Present Technology, Safety, and Future Research Directions: A Status Report**, J. Ahearne, R. Bennett, R. Budnitz, D. Kammen, J. Taylor, N. Todreas, B. Wolfe (American Physical Society, Panel On Public Affairs, College Park, MD, 2001); available at http://www.aps.org/policy/reports/popa-reports/index.cfm. This report aims to further the development of new, safe, environmentally sound nuclear reactors. It discusses several new designs: advanced light-water and boiling-water reactors; advanced reactors built, under construction, or in the design phase; the Pebble Bed Modular Reactor; new high-temperature gas reactors; and the "Generation IV Initiative" to develop and deploy next-generation systems by 2030. The last section deals briefly with nuclear waste as well as terrorist and proliferation threats. (A)

86. "Next-Generation Nuclear Power," J.A. Lake, R.G. Bennett, and J.F. Kotek, Scientific American **286** (1), 72-79 (January 2002). New, safer, and more economical nuclear reactors could satisfy many of our energy needs while combating global warming. The article covers gas-cooled reactors, water-cooled reactors, "fast-spectrum" (or high-energy neutron) reactors, and open and closed fuel cycles, all with detailed diagrams. There is also a primer on conventional pressurized water reactors, and a box discussing the security of nuclear-power plants from terrorists. (E)

87. "Advanced Nuclear Reactors--Their Use in Future Energy Supply," J.F. Ahearne, Physics & Society **35** (2), 2-6 (April 2006); available at http://www.aps.org/units/fps/index.cfm. This article surveys 11 recently deployed "Generation III" designs, along with possible future "Generation IV" designs. Topics include once-through *versus* closed-fuel cycles, construction costs, nuclear-weapons proliferation, reprocessing, waste storage, uranium supplies, safety, and public attitudes. (A)

88. "The Pebble-Bed Modular Reactor (PBMR): Safety Issues," E.S. Lyman, Physics & Society **30** (4), 16-19 (October 2001); available at http://www.aps.org/units/fps/index.cfm. The U.S. nuclear industry is hanging its hopes on a radically different type of plant, the PBMR. The article discusses

its design, safety features, safety uncertainties, fuel performance, and waste disposal. (I)

B. Side Effects of Nuclear Fuels

Like fossil fuels, nuclear power has substantial side effects. One of these is definitely positive: To the extent that it substitutes for fossil fuels, nuclear power alleviates global warming. The main negative side effects are nuclear proliferation and nuclear terrorism, radioactive waste, and power-plant accidents.

Refs. 89-91 discuss nuclear power and global warming. This topic is also discussed in several of the above references on global warming, and in Ref. 95.

89. "Global Warming and Nuclear Power," R.A. Meserve, Science **303**, 433 (January 23, 2004). Paradoxically, those who should be the strongest nuclear-power advocates--environmentalists--are not advancing the most compelling argument for it: global warming. The challenges of safety, waste, and weapons proliferation can be met. Nuclear power must at least be a bridging technology until other carbon-free options are more readily available. (E)
90. "A Nuclear Solution to Climate Change," W.C. Sailor, D. Bodansky, C. Braun, S. Fetter, and B. van der Zwaan, Science **288**, 1177-1178 (May 19, 2000). This article presents a 2050 energy scenario that assumes 50% increases in population and per capita energy consumption, while holding CO_2 concentrations to 550 ppm. The energy comes, in equal amounts, from fossil, renewables, and nuclear, the latter requiring 4000 gigawatt-scale reactors. The article discusses safety, reactor designs, economics, waste disposal, nuclear proliferation, and nuclear power's contribution to solving global warming. (I)
91. "Playing Politics With Energy Policy: The Phase-out of Nuclear Power in Sweden," R.E. Lofstedt, Environment **43** (4), 20-33 (May 2001). Do nations like Sweden, Germany, and Italy really wish to revert to coal as a way toward a greener society, when a carbon-free source is already in place? This article studies the effect on global warming of Sweden's planned nuclear-power phaseout. A phaseout will increase Sweden's imports of coal-generated electricity, causing increased carbon emissions. Sweden, where polls show the population considers global warming to be more dangerous than nuclear power, is reassessing its planned phaseout. (I)

Refs. 92-97 discuss nuclear proliferation and nuclear terrorism, often considered to be the most serious side effect of nuclear power.

92. **The Four Faces of Nuclear Terrorism**, C.D. Ferguson and W.C. Potter, (Center for Nonproliferation Studies, Monterey Institute of International Studies, Monterey, CA, 2004). Nuclear terrorists are a growing threat. Who, and how capable, are they? What motivates them? The authors devote a chapter to each of four paths to nuclear terrorism. In order of decreasing damage but increasing likelihood, these are: Seizing a nuclear bomb, making a bomb, releasing radiation from a nuclear-power plant or other facility, and dispersing radiation with a dirty bomb. The final chapter is a point-by-point plan for meeting these challenges. (E)

93. **Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk**, Nuclear Energy Study Group of the American Physical Society Panel On Public Affairs (APS, College Park, MD, 2005); available at http://www.aps.org/policy/reports/popa-reports/index.cfm. Proliferation, rather than safety, waste, or economics, is nuclear power's greatest risk. This study examines the technological steps the U.S. can take to increase nuclear power's proliferation resistance. Although nuclear power cannot be made proliferation proof, it can be made proliferation-resistant by strengthening the federal safeguards program, incorporating proliferation resistance into new reactor designs, not reprocessing spent fuel at the present time, and other measures. (I)

94. "Plutonium and Reprocessing of Spent Nuclear Fuel," F.N. von Hippel, Science **293**, 2397-2398 (September 28, 2001). The Bush Administration is considering foregoing the nation's once-through nuclear-fuel policy and embracing reprocessing and breeder reactors. Reprocessing and breeder-development programs were launched during the 1960s and 1970s and found to be economically unfeasible. They were rejected in 1974 after India's nuclear test made with plutonium separated with U.S.-supplied reprocessing technology. "Pyroprocessing" techniques are also not proliferation resistant. We should stick to the once-through fuel cycle. (I)

95. "Nuclear Power, Nuclear Proliferation, and Global Warming," H.A. Feiveson, Physics & Society **32** (1), 11-14 (January 2003); available at http://www.aps.org/units/fps/index.cfm . What proliferation risks will be posed by an expansion of nuclear power large enough to significantly reduce global warming, such as an expansion by 3000 gigawatts (cf. Ref. 90)? The expansion will go mostly into developing countries, letting the nuclear genie out of the bottle in many nations. Pressures for reprocessing will pose proliferation risks. Even without reprocessing, uranium enrichment would require ~200 bomb-capable enrichment plants. The most plausible solution is large international nuclear-energy parks that would export electricity, hydrogen, or small, sealed reactors. But is this realistic? (I)

96. "Bombs, Reprocessing, and Reactor Grade Plutonium," G.E. Marsh and G.S. Stanford, Physics & Society **35** (2), 7-10 (April 2006); available at http://www.aps.org/units/fps/index.cfm. The authors present the case for reprocessing nuclear fuel to recover fissionable plutonium while consuming long-lived waste elements in "fast reactors" so that the remaining waste will be toxic for only a few hundred years, greatly simplifying waste management. Much of the world is going ahead with reprocessing; the U.S. should participate in and help guide it. Reprocessing can be proliferation-proof. (A)

97. "Illicit Trafficking of Weapons-Usable Nuclear Material: Facts and Uncertainties," L. Saitseva and F. Steinhausler, Physics & Society **33** (1), 5-8 (January 2004); available at http://www.aps.org/units/fps/index.cfm. This article tabulates and discusses 25 credible trafficking incidents involving highly-enriched uranium and weapons-grade plutonium, and discusses our current knowledge about illicit trafficking and uncertainties in that knowledge. (I)

Refs. 98-102 discuss radioactive waste.

98. "Special Issue: Radioactive Waste," Physics Today **50** (6), 22-62 (June 1997). This collection includes an overview by J.F. Ahearne; "Radioactive Waste: The Size of the Problem," J.F. Ahearne; "Nuclear Waste Disposal: The Technical Challenges," K.D. Crowley; "Hazards of Managing and Disposing of Nuclear Waste," W. E. Kastenberg and L.J. Gratton; "Unresolved Problems of Radioactive Waste: Motivation for a New Paradigm," D.W. North; and "Nuclear Waste Management Worldwide," C. McCombie. These articles review the technical problems and risks of nuclear-waste disposal, outline the reasons why the problem has not really been answered anywhere in the world, and suggest possible new approaches. (A)

99. "International Nuclear Waste Transportation: Flashpoint, Controversies, and Lessons," K. O'Neill, Environment **41** (4), 12-15, 34-39 (May 1999). Opposition to nuclear waste transport remains high, although health and environmental concerns suggest that transport should continue. Yucca Mountain will require 100,000 shipments through 43 states over 30 years using several transportation methods. Although the present solution of keeping spent fuel at reactors is inadequate, there is no consensus to do anything else. To reach consensus, regulatory officials must be more open, promote public dialogue, and trust the public. (E)

100. "The Status of Nuclear Waste Disposal," D. Bodansky, Physics & Society **35** (1), 4-6 (January 2006); available at http://www.aps.org/units/fps/index.cfm. Bodansky discusses the nature of nuclear wastes, reprocessing options

including "pyroprocessing," removal and reuse of plutonium and uranium, breeder reactors, and the Yucca Mountain repository including its calculated performance in comparison with current EPA limits. If the Yucca Mountain project is defeated, it may be a long time before support can develop for an alternative. (I)

101. "Dismantling Nuclear Reactors," D. Wald, Scientific American **288 (**3), 60-69 (March 2003). The environmental reclamation of nuclear power sites is imperative for nuclear power's revival. The Maine Yankee plant provides a case study of decommissioning. Maine law states that an exposed individual can receive no more than 10 millirem per year above background exposure. Since background averages 300 millirem per person per year nationally, this criterion requires plant managers to determine what normal background was in that area lest they end up removing radionuclides that would have been present had the plant never been built. (E)

102. "Proof of Safety at Yucca Mountain," L.J. Carter and T.H. Pigford, Science **310**, 447-448 (October 21, 2005). The major problem of the Yucca Mountain nuclear-waste repository is its lack of proof of safety for 500,000 years. The repository must heed the recommendations of a National Academy of Sciences finding that such proof is necessary and feasible, but the present repository design cannot meet this recommendation. A new repository design is proposed. (I)

The following references discuss nuclear power's two most serious accidents.

103. **Three Mile Island: A Nuclear Crisis in Historical Perspective**, J.S. Walker (University of California Press, Berkeley, CA, 2004). The opening 3 chapters discuss the nuclear-power debate, the regulation of nuclear power, and accident prevention by a layered "defense in depth" that includes emergency core cooling. The next five chapters, the book's centerpiece, are a blow-by-blow account of each of the five most crucial days of the accident. The last two chapters discuss the immediate aftermath and long-term effects. Written in accurate but nontechnical prose. (E)

104. "Return to the Inferno: Chornobyl After 20 Years," R. Stone, Science **312**, 180-182 (14 April 2006). Twenty years after the world's worst nuclear accident, the population of the hardest-hit parts of Belarus, Ukraine, and Russia have become an involuntary experiment on how radiation affects human health. About 100 times the amount of radiation released at Hiroshima and Nagasaki settled on these areas. Health experts track diseases, while engineers prepare to

slide a steel arch--the world's biggest movable structure--over the disintegrating shelter now enclosing the ruins. (I)

105. "Nuclear Power After Chernobyl," J.F. Ahearne, Science **236**, 673-679 (May 8, 1987). Ahearne describes the causes and progress of the accident, and compares it with Three Mile Island. Similarities include operator and industry complacency, deliberate negation of safety systems, and operators' lack of understanding, demonstrating the critical importance of the human element. The accident affects U.S. nuclear-power research, regulation, reactor designs, and public attitudes. (I)

C. Fusion Power

Energy problems loom so large that most observers believe it's essential to be at least on the road to solving them within a few decades. But even by the most optimistic estimates, practical power from nuclear fusion will not begin to be available for several decades. Thus, most experts consider fusion to be so far in the future, or so technically problematic, as to be largely irrelevant to today's energy-and-society problem. Although only two references on fusion are listed below, Refs. 1-4, 17, 18, 20, 21, and 110 also contain sections on fusion.

106. "ITER's $12 Billion Gamble," D. Clery, Science **314**, 238-242 (13 October 2006). The planned International Thermonuclear Experimental Reactor must successfully run a gantlet of technical challenges if fusion is to fulfill its promise. This article discusses these challenges, the many unknowns, how a "tokamak" reactor works, and the history of fusion. (I)

107. "Fusion: The Way Ahead," R. Pitts, R. Buttery, and S. Pinches, Physics World **19** (3), 20-26 (March 2006). This article discusses the need for fusion power, how a tokamak fusion reactor works, the difficulties of making it work, the Joint European Torus experimental reactor, and the planned International Thermonuclear Experimental Reactor. It is hoped that ITER will achieve full power deuterium-tritium operation by 2021, and that construction on a demonstration power plant can begin in 2025 with operation perhaps 10 years later. (I)

VI. RENEWABLE ENERGY

Renewable energy (resources that are replaced by natural processes within a human lifetime) offers an endless supply but at a limited sustainable rate, with greatly reduced or zero greenhouse-gas emissions and few other harmful side effects. For this and other reasons, most renewable forms of energy have expanded rapidly in recent years, especially wind (24% worldwide growth in 2005), photovoltaics (45%), and biofuels (19%).

A. General References On Renewable Resources

108. **Clean Energy Blueprint**, S. Clemmer, D. Donovan, A. Nogee, J. Deyette (Union of Concerned Scientists, with the American Council for an Energy-Efficient Economy and the Tellus Institute, Cambridge, MA, 2001); available at http://www.ucsusa.org/assets/documents/clean_energy/ACFjtMhdd.pdf. This is a guide, with proposed legislation, to a sustainable U.S. electricity supply by 2020, based on renewables and efficiency. As compared with the Bush Administration's "business-as-usual" proposal (Ref. 22), this plan reduces natural gas by 31% and coal by 60%, avoids 975 new power plants, retires 180 coal plants and 14 nuclear plants, reduces carbon emissions by two-thirds, and saves $440 billion. (I)
109. **Eco-Economy: Building an Economy for the Earth**, L.R. Brown (W.W. Norton, New York, 2001). Brown argues that the fossil-fueled, car-centered, throwaway economic model cannot work, by showing what would happen if China fully adopted it. He describes a restructuring for sustainability: wind farms replace coal plants, hydrogen-fuel cells replace gasoline engines, and cities are designed for people instead of for cars. Tools include tax shifting, subsidy shifting, ecolabeling, tradable permits, and support for fiscal restructuring. He describes glimpses, now appearing around the world, of this new economy. (E)
110. **Prospects for Sustainable Energy: A Critical Assessment**, E.S. Cassedy (Cambridge University Press, Cambridge, UK, 2000). Cassedy describes and assesses solar, biomass, windpower, hydroelectric power, energy storage, geothermal energy, ocean energy, nuclear fusion, and hydrogen fuel from renewable resources. Two concluding chapters summarize these assessments and discuss research and development of these technologies. (I)
111. **The New Ecological Home: The Complete Guide to Green Building Options**, D.D. Chiras (Chelsea Green Pub. Co., White Water Junction, VT, 2004). Shelter comes at great cost to the planet. "Green" techniques can provide comfortable, affordable, beautiful homes at low economic and ecologic cost. Although not quite a "how-to" book, this book contains practical information on techniques, materials, and products. Energy-related chapters include energy-efficient design and construction, earth-sheltered architecture, passive heating and cooling, electricity from the sun and wind, sustainable water and waste, and a guide to publications and organizations. (E)

112. **Solar Energy: Fundamentals, Design, Modeling and Applications**, G.N. Tiwari (Alpha Science International Ltd., Pangbourne, UK, 2002). This practical guide to understanding and working with solar-energy systems includes principles of heat transfer, flat-plate collectors, evacuated collectors, water heating systems, air heaters, crop drying, solar concentrators, solar distillation, solar houses, other smaller applications, energy storage, and economic analysis of solar systems. (A)

113. "Resource Letter SE-1: Solar Energy," D.K. McDaniels and M.J. Throop, Am. J. Phys. **44** (5), 409-416 (May 1976). 100 references from the pre-1976 period, comprising general references, heating and cooling, large scale electric power, photovoltaic devices, energy storage, and miscellaneous topics. (I)

114. "Resource Letter SE-2: Solar Energy," L. Hodges, Am. J. Phys. **50** (10), 876-881 (October 1982). 140 references mainly from 1976-1982 (see also Ref. 113), comprising solar heating and cooling, other solar technologies, socioeconomic issues, and pedagogy. (I)

115. "Renewable Energy: A Viable Choice," A.V. Herzog, T.E. Lipman, J.L. Edwards, and D.M. Kammen, Environment **43** (10), 8-20 (December 2001). Solar, wind, biomass, and efficiency are poised to play a major domestic role. National energy policy should be formulated around renewables, which have seen too few incentives and too little research. Energy efficiency has already contributed a great deal, and is the single best way to improve the U.S. energy economy. Policy options include research funding, tax incentives, efficiency standards, a renewable-portfolio standard, small-scale generation, cogeneration, and cost-benefit analysis. (I)

116. "Promoting Appropriate Energy Technologies in the Developing World," D.M. Kammen, Environment **41** (5), 10-15, 34-41 (June 1999). Small, decentralized, and renewable energy systems (e.g. biogas, photovoltaics, wind) offer a viable alternative to carbon-intensive sources and could provide sustainable development in developing nations. But there has been a pattern of neglect and underinvestment in such systems. There are now opportunities for large returns, but ill-conceived actions could harm the deployment of clean energy systems. Scholarly attention to these problems is notable primarily for its absence. (I)

117. "Special Section: Energy," edited by R. Stone and P. Szuromi, Science **285**, 677-711 (July 30, 1999). This collection about renewables and efficiency comprises: "Bright Future—or Brief Flare—for Renewable Energy?" K.S. Brown; "U.S. Supercars: Around the Corner, or Running on Empty?" D. Malakoff; "Bringing Fuel Cells Down to Earth," R.F. Service; "Turning Engineers Into Resource Accountants," J. Kaiser; "A Realizable Renewable

Energy Future," J.A. Turner; "Underinvestment: The Energy Technology and R&D Policy Challenge," R.M. Margolis and D.M. Kammen. (I)

118. "Renewable Energy Gains Momentum: Global Markets and Policies in the Spotlight," E. Martinot, Environment **46** (6), 26-42 (July-August 2006). The installed global capacity of renewable energy, excluding large hydropower, is now almost half that of nuclear power. This article is a broad worldwide look at renewable technologies and cost trends, trends in capacities in specific nations and groups of nations, policy targets, and promotion policies. (I)

119. Websites about renewables: National Renewable Energy Laboratory in Golden, Colorado http://www.nrel.gov/. Energy Efficiency and Renewable Energy division of the U.S. Department of Energy http://www.eere.energy.gov. Renewable and Appropriate Energy Laboratory, University of California at Berkeley http://rael.berkeley.edu/.

B. Specific Renewable Resources and Related Topics

The following specific renewable resources are also discussed in the preceding general references on renewable resources. Refs. 120-122 discuss hydroelectric energy.

120. **Dams and Development: A New Framework for Decision-Making**, Report of the World Commission on Dams (Earthscan Publications Ltd, London and Sterling, VA, 2000); available at http://www.dams.org/report/contents.htm. This wide-ranging report states that dam benefits "in too many cases" have been gained at "an unacceptable and often unnecessary price." The costs of most of the world's 45,000 large dams have outweighed their benefits. And, because of carbon emissions from rotting vegetation, hydropower is not necessarily cleaner than fossil fuels. Dam critics have called on funding agencies stop supporting dam-building until they have adopted this report's recommendations; the World Bank has already cut back its support. (I)

121. "Neither Temples Nor Tombs: A Global Analysis of Large Dams," S. Khagram, Environment **45** (4), 28-37 (May 2003). The debate over large dams is at a stalemate. There is praise for their provision of irrigation, electricity, water supply, flood control, navigation, and recreation, but criticism of their social and environmental costs, population displacement, reduction in floodplain and delta productivity, and losses of freshwater biodiversity. Are benefits greater than costs? We should focus less on building new dams and more on improving the functions of existing dams. Several suggestions are given for improving decision-making processes. (I)

122. "It's Not Easy Being Green: Environmental Technologies Enhance Conventional Hydropower's Role in Sustainable Development," P.A. March, Annual Review of Energy and the Environment **24**, 173-188 (1999). For sustainable development, the hydropower industry must address environmental concerns. March discusses new design and control of turbines to improve dissolved oxygen levels, fish survival, collaboration of stakeholders, and balance between environmental and economic considerations. (I)

Refs. 123-126 discuss biofuels.

123. **Biomass Energy: Resources, Links, Constraints**, V. Smil (Plenum Press, New York, 1983). Is biomass energy worth it? To what extent should it be used? What would be the real cost? Where should we concentrate our efforts? Where should we abstain? Smil (Ref. 17) looks at forest resources, trees for energy, crop residues, fuel crops, aquatic plants, and animal wastes. (I)

124. **Biorenewable Resources: Engineering New Products from Agriculture**, R.C. Brown (Iowa State Press, Ames, Iowa, 2003). This is a textbook for science and engineering undergraduates seeking a broad perspective on biomass resources. It includes the biorenewable-resource base, production of biorenewable resources, products, conversion of resources into heat and power, processing into chemicals and fuels, processing into natural fibers, environmental impact, and economics. (A)

125. "The Potential of Biomass Fuels in the Context of Global Climate Change: Focus on Transportation Fuels," H.S. Kheshgi, R.C. Prince, and G.Marland, Annual Review of Energy and the Environment **25**, 199-244 (2000). Biomass-transportation fuels to reduce carbon emissions are limited by land area and conversion efficiencies. Biomass could be a net zero-carbon-emission source, but the energy required to produce biomass is often a net source of carbon. This review focuses on current large-scale applications, such as the U.S. corn-ethanol system, and at opportunities for improving efficiencies. Technologies include cellulosic biomass and conversion of biomass into electricity, hydrogen, or alcohols for vehicles. (A)

126. "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower," D. Pimentel and T.W. Patzek, Natural Resources Research **14** (1), 65-76 (March 2005). Energy outputs from ethanol produced using corn, switchgrass, and wood biomass, and from biodiesel using soybeans and sunflower, are found to be less than the respective fossil energy inputs. For example, corn ethanol requires 29% more fossil energy than the fuel produced, and switch grass requires 45% more. The authors include such factors as energy used in pesticide and fertilizer

production, running farm machinery, and irrigating, grinding, and transporting the crop. (I)

Refs. 127-131 discuss energy from wind. A major breakthrough in wind energy technology is the development, by China, of magnetically levitated wind turbines to reduce friction and enable start-up at wind speeds of 1.5 m/s and continuous operation at average wind speeds of 3 m/s. This will increase the capacity and reliability of wind energy, and permit installations in new locations. This development has not yet been reported in the permanent literature, but information is available at http://www.worldwatch.org/node/4217.

127. "Wind Power: Obstacles and Opportunities," M.J. Pasqualetti, Environment **47** (7), 22-38 (September 2004). This survey of U.S. wind energy includes history, wind resources, distribution of installed capacity among states and European nations, wind-speed requirements, costs, public attitudes, siting issues, offshore wind turbines, sizes of wind turbines, economics, tax issues, and bird mortality. Pasqualetti recommends more care in siting, choosing only highly suitable sites such as □idwestern farms where few residents will see the turbines and farmers can earn income. (E)

128. "Exploiting Wind Versus Coal," M.Z. Jacobson and G.M. Masters, Science **293**, 1438 (August 24, 2001). This brief article compares wind-energy costs with coal-energy costs. Coal costs 3.5-4¢/kWh, but health and environment costs bring the total to 5.5-8.3¢/kWh. Wind costs 3-4¢/kWh. A letter responding to this article, and the authors' rebuttal, appear in Science **294**, 1000-1002 (November 2, 2001). (I)

129. "Windpower: A Turn of the Century Review," J.G. McGowan and S.R. Connors, Annual Review of Energy and the Environment **25**, 147-197 (2000). Wind energy expanded five-fold during the 1990s, mostly in Europe where governmental policies provided a sheltered market. This article reviews developments in turbine design (rotors, blades, drive train, generators, controls, towers), land use and environmental design, wind-resource considerations, future windpower deployment, and industry trends. (A)

130. "Energy From the Wind," D.G. Pelka, R.T. Park, and R. Singh, Am. J. Phys. **46** (5), 495-498 (May 1978). Using introductory physics concepts (fluid mechanics, momentum and energy conservation), the maximum mechanical energy that can be extracted by a wind turbine is shown to be 16/27, or 59%, of the power available in the wind. An estimate is made of the total electric power which could be generated in the U.S. from wind. (I)

131. "Windmills," R.E. Alley, Jr., The Physics Teacher **19**, 590-595 (December 1981). Alley presents the history and engineering design of windmills. (E)

Refs. 132-135 discuss photovoltaic energy.

132. **The Solar Electric House: Energy for the Environmentally-Responsive, Energy-Independent Home**, S.J. Strong with W.G. Scheller (Sustainability Press, Still River, MA, 1993). Strong has designed more than 100 photovoltaic systems including the world's first solar electric neighborhood of 30 PV-powered homes in the Town of Gardner, MA. This book provides information about building a photovoltaic home, including systems options, economics, stand-alone and utility-connected systems, descriptions of key components, how to determine electricity requirements, and how to design a solar-electric house. (I)

133. "Is It Time to Shoot for the Sun?" R.F. Service, Science **309**, 548-551 (July 22, 2005). The U.S. Department of Energy is working to kindle support for a crash program to make the basic scientific breakthroughs needed to transform photovoltaics from a small player into the world's leading power source. At $0.25-0.50 per kWh for photovoltaics, compared to wind power's $0.05-0.07, natural gas's $0.025-0.05, and coal's $0.01-0.04, the biggest hurdle is cost. The article describes several priorities for photovoltaic energy research. (I)

134. "Photovoltaics: Energy for the New Millennium," T. Surek, Physics and Society **30** (1), 7-9 (January 2001); available at http://www.aps.org/units/fps/index.cfm. Progress, status, research directions, markets, and applications of PV technologies. (A)

135. **The Power of the Sun**, a film distributed by UCSB Bookstore, University of California, Santa Barbara, CA 93106; produced by 1998 Chemistry Nobelist Walter Kohn, 2005; excerpts at http://powerofthesun.ucsb.edu/index.html. This 56-minute film is narrated by John Cleese and accompanied by a 22-minute science-education film for high-school and college students. Focusing mainly on photovoltaics, the film tours the history of solar power from wave-particle duality to the first solar-powered batteries, to current solar panels. Kohn has a message: "I am convinced that energy is one of the make-or-break challenges of our times." (E)

The following reference discusses active and passive solar techniques.

136. **Solar Retrofit: Adding Solar to Your Home**, D.K. Reif (Brick House Publishing Company, Andover MA, 1981). A do-it-yourself primer and construction manual to time-tested passive and active solar techniques. Topics include how to choose a solar system; direct solar strategies; the thermosiphoning air panel; the attached solar greenhouse; the horizontal air-

flow active collector; improving performance with reflectors, wind barriers, summer shading, and solar-window greenhouses; and fundamentals of heat loss, solar-heat gain, and heat storage. (I)

Geothermal energy is usually classified as a renewable because deep-lying hot rock, and ground source heat pumps to provide heating, cooling, and hot water, represent nearly inexhaustible sources of energy.

137. "Geothermal Energy From the Earth: Its Potential Impact as an Environmentally Sustainable Resource," J.E. Mock, J.W. Tester, and M.P. Wright, Annual Review of Energy & the Environment **22**, 305-356 (1997). This article reviews geothermal technology in terms of its current impact and future potential as an energy source. In 1997, 7 GW of electric base-load capacity and 15 GW of thermal-heating capacity were in commercial use worldwide. The potential for growth is reviewed for the major geothermal resources including hydrothermal, hot dry rock, and magma. (I)

Like electricity, hydrogen is an energy transfer and storage medium. Although it's not a naturally-occurring energy resource at all, hydrogen is an important piece of the energy puzzle that can work well with many energy resources, especially the renewables, and is usually classified with the renewables. Refs. 138-147 are selected from the many recent articles on hydrogen.

138. **Tomorrow's Energy: Hydrogen, Fuel Cells, and the Prospects for a Cleaner Planet**, P. Hoffmann (MIT Press, Cambridge, MA, 2001). Does hydrogen hold the solution to concerns about fossil-fuel resources, pollution, and global warming? Although the conversion to a hydrogen-based economy would be complex, Hoffman argues that environmental and health benefits would far outweigh costs. Topics include the history of hydrogen, producing hydrogen, primary energy resources to make hydrogen, fuel cells, hydrogen in aerospace, hydrogen as utility gas, safety of hydrogen, and the next 100 years. (I)

139. **Twenty Hydrogen Myths**, A. Lovins (Rocky Mountain Institute, Old Snowmass, CO, 2003); available at http://www.rmi.org. This primer on basic hydrogen facts weighs competing opinions and corrects twenty widespread misconceptions. It argues that a transition to a hydrogen economy is warranted and could yield important national and global benefits. (I)

140. **Fuel Cell Systems Explained**, J. Larminie and A. Dicks (John Wiley & Sons, Hoboken, NJ, 2003). This is a technical and practical guide to the

principles, design, and application of fuel cell systems, for engineers and scientists. (A)

141. "The Hydrogen Initiative," American Physical Society Panel on Public Affairs (APS, One Physics Ellipse, College Park, MD, March 2004); available at http://www.aps.org/policy/reports/popa-reports/index.cfm. President Bush has proposed a $1.2-billion initiative to develop a hydrogen-fueled car and supporting infrastructure by 2020. Major scientific breakthroughs are needed for success. Basic science and "bridge" technologies should be given greater attention. The initiative should not displace research into promising energy efficiency and renewable energy areas. (I)

142. "The Hydrogen Economy," G.W. Crabtree, M.S. Dresselhaus, and M.V. Buchanan, Physics Today **57** (12), 39-44 (December 2004). If hydrogen-based energy is to be widely used, basic research must provide breakthroughs in understanding, materials, and design. To achieve benefits, we must produce hydrogen from nonfossil resources such as water, using renewable energy. A host of problems remain to be solved before hydrogen fuel cells can compete with gasoline. (A)

143. "Special Issue: Toward a Hydrogen Economy," Science **305**, 917 and 957-976 (August 13, 2004). This collection comprises: "The Hydrogen Solution," D. Kennedy (editorial); "Not So Simple," R. Coontz and B. Hanson; "The Hydrogen Backlash," R.F. Service; "The Carbon Conundrum," R.F. Service; "Revving up for H_2," A. Cho; "Will the Future Dawn in the North?" G. Vogel; "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," S. Pacala and R. Socolow; "Sustainable Hydrogen Production," J.A. Turner; and "Hybrid Cars Now, Fuel Cell Cars Later," N. Demirdoven and J. Deutch. (I)

144. "Cleaning the Air and Improving Health with Hydrogen Fuel-Cell Vehicles," M.Z. Jacobson, W.G. Colella, and D.M. Golden, Science **308**, 1901-1905 (June 24, 2005). How would air quality and CO_2 emissions change if the nation converted to hydrogen fuel-cell vehicles (HFCVs)? A computer-based model compares five scenarios: an August 1999 baseline, all (i.e. the entire fleet) hybrids, and three all HFCV scenarios with hydrogen produced by steam reforming of natural gas, wind-powered electrolysis, and coal gasification. All four alternatives yield significant improvements in air quality, health, climate, and costs. HFCVs using wind-powered electrolysis offered the greatest environmental and other benefits. (A)

145. "Rethinking Hydrogen Cars," D.W. Keith and A.E. Farrell, Science **301**, 315-316 (July 18, 2003). Arguing against a long-term project to adopt hydrogen-fueled vehicles, this article finds that for several future decades the

most cost-effective method to reduce CO_2 emissions from cars will be to increase fuel efficiency. (I)

146. "Prospects for Building a Hydrogen Energy Infrastructure," J.M. Ogden, Annual Review of Energy & the Environment **24**, 227-279 (1999). Ogden reviews the current status of technologies for hydrogen production, storage, transmission, and distribution; describes likely areas for technological progress; and discusses the implications for developing hydrogen as an energy carrier. (A)

147. "Fuel Cells: Reaching the Era of Clean and Efficient Power Generation in the Twenty-First Century," S. Supramaniam, R. Mosdale, P. Stevens, C. Yang, Annual Review of Energy & the Environment **24**, 281-328 (1999). This article covers fundamental electrochemical and performance aspects of fuel cells, fuel-cell research and development, competing technologies, and prospects for applications and commercialization. Significant research is still necessary, but could lead before long to widespread use. (A)

Energy storage, covered in the next reference, acts in many ways like an energy resource and is often used in conjunction with renewable resources. For example, an effective energy-storage system is often considered essential to the wide use of intermittent resources such as wind and photovoltaics.

148. **Fundamentals of Energy Storage**, J. Jensen, B. Sorensen (John Wiley & Sons, New York, 1984). This textbook and energy planning manual evaluates options for energy storage. Part I outlines the fundamentals of energy-storage for buildings, transportation, and utilities. Part II provides theoretical and technical details for mechanical, electromagnetic, fossil, biomass, chemical, electrochemical, nuclear, and heat storage. Part III surveys several applications including management of reject heat, automotive energy storage, and residential systems with active or passive storage. (A)

VII. ENERGY EFFICIENCY AND CONSERVATION

Here, "energy efficiency" means measures taken to reduce energy use while getting the same energy services, and "energy conservation" means lifestyle changes that save energy. Replacing incandescent bulbs with compact fluorescents is an example of efficiency, while commuting on a bicycle instead of in a car is an example of conservation. Energy efficiency acts like an energy resource. In fact, there is evidence that, by 2000, efficiency measures that were added since 1975 were contributing as much in energy services as oil and gas combined (Ref. 7, page 416).

Many experts consider a combination of renewable resources with energy efficiency and conservation to be the key to providing sustainable energy services to a growing and aspiring world population while maintaining a healthy environment. Thus, it's not surprising that many of the above references on Renewable Energy also discuss energy efficiency.

Section A below covers energy efficiency and conservation outside of the transportation domain; Section B covers transportation.

A. Energy Efficiency and Conservation

149. **Natural Capitalism**, P. Hawkens, A. Lovins, L.H. Lovins (Little, Brown & Co., Boston, 1999). This book explains how to solve global warming at a profit. The world is on the verge of a new industrial revolution of ecologically-sound development that will transform commerce. Traditional capitalism neglects to assign monetary value to its largest stock of capital, namely, natural resources. Natural capitalism takes account of these stocks. Companies are saving money through novel technologies and efficient business practices. This book details many specific examples. See also "More Profit With Less Carbon," A. Lovins, Scientific American **293** (3), 74-83 (Sep. 2005). (E)
150. **The Natural Wealth of Nations: Harnessing the Market for the Environment**, D.M. Roodman (W.W. Norton & Co., New York, 1998). Roodman offers market-based solutions to environmental problems by showing how we can turn the power of market economies away from environmentally destructive practices and toward protecting natural wealth and human health. These solutions include cutting subsidies for environmentally harmful activities like driving and mining, and "shifting" taxes off of payrolls and on to harmful activities. (E)
151. **Efficient Use of Energy**, Edited by K.W. Ford, G.I. Rochlin, R.H. Socolow, D.L. Hartley, D.R. Hardesty, M.Lap, J.Dooher, F. Dryer, S. M. Berman, and S. D. Silverstein (American Institute of Physics, New York, 1975). This book offers basic physics perspectives, rooted in thermodynamics, on home energy systems, automobile fundamentals (power train, tires, internal combustion engines), selected industrial processes, fuels and combustion, windows, and indoor climate control. (A)
152. "Technologies to Reduce Carbon Dioxide Emissions in the Next Decade," A.H. Rosenfeld, T.M. Kaarsberg, and J.Romm, Physics Today **53** (11), 29-34 (November 2000). This article discusses several energy-saving technologies in buildings (low-emissivity window coatings), industry (combined heat and power systems), and transportation (gasoline-electric hybrid cars). Figure 4,

showing vehicle fuel economies and federal fuel economy standards during 1975-2000, is enlightening. (I)

153. "Special Issue: Cities That Work," WorldWatch **11** (5), 9-27 (September-October 1998). This collection on saving energy in cities comprises "How Mid-Sized Cities Can Avoid Strangulation," M. O'Meara (how Curitiba, Brazil, and Portland, Oregon, managed sprawl and congestion with city planning and mass transit); "When Cities Take Bicycles Seriously," G. Gardner (by making room for bikes, cities find a remedy for urban car problems); "Solar Power Markets Boom," C. Flavin and M. O'Meara (cities around the world are installing photovoltaic power on rooftops). (E)

154. "Engineering-Economic Studies of Energy Technologies to Reduce Greenhouse Gas Emissions: Opportunities and Challenges," M.A. Brown, M.D. Levine, J.P. Romm, A.H. Rosenfeld, and J.G. Koomey, Annual Review of Energy and the Environment **23**, 287-385 (1999). This paper compares four studies of the potential for energy technologies to reduce greenhouse-gas emissions. These studies document that many cost-effective technologies remain underutilized in every end-use sector. Large carbon reductions are possible at incremental costs that are less than the value of the energy saved. A national commitment involving tax incentives, emissions trading, and mandated energy reductions is needed to exploit these opportunities. (I)

155. "EER, COP, and the Second Law Efficiency for Air Conditioners," H.S. Leff and W.D. Teeters, Am. J. Phys. **46**(1), 19-22 (January 1978). Refrigerators and air conditioners use a significant fraction of our electrical energy. This article discusses the thermodynamics of air conditioners, including their energy efficiency, 2nd law efficiency, and coefficient of performance. (I)

The next four references discuss lighting efficiency.

156. "The Promise and Challenge of Solid-State Lighting," A. Bergh, G. Craford, A. Duggal, and R. Haitz, Physics Today **54** (12), 42-47 (December 2001). Solid-state devices will provide inexpensive, environmentally friendly illumination that will transform the way we thinking about lighting. This article discusses the physics and technology of light-emitting diodes and organic LEDs, the history of their performance (especially their energy efficiency), and their economics. (I)

157. "The Specter of Fuel-Based Lighting," E. Mills, Science **308**, 1263-1264 (May 27, 2005). Much of the developing world lacks electricity and resorts to fuel-based lighting such as kerosene and candles. They could have cheap electric lighting while leapfrogging current more expensive and inefficient technology by installing white LEDs run on AA batteries charged by a solar

array “the size of a paperback novel.” This would significantly reduce fossil fuel demands and CO_2 emissions. (I)

158. “Organic LEDs Look Forward to a Bright, White Future,” R.F. Service, Science **310**, 1762-1763 (December 16, 2005). Today’s LEDs remain too costly for general-lighting use. The first white organic LEDs should be on the market in 2007. Their efficiency, measured in lumens per watt, is already 4 times that of fluorescent bulbs and is approaching that of non-organic LEDs, and since they consist of simple polymers they should be cheap. (I)

159. “Efficiency and Efficacy of Incandescent Lamps,” D.C. Agrawal, H.S. Leff, and V. J. Menon, Am. J. Phys. **64** (5), 649-654 (May 1996). Planck’s radiation formula is used to find the energy efficiency as a function of filament temperature, and the “efficacy” (in lumens/watt), of incandescent bulbs. Efficiencies of 2% to 13% are found. (A)

160. Websites about energy efficiency: American Council for an Energy-Efficient Economy, http://www.aceee.org/. Rocky Mountain Institute, http://www.rmi.org/. U.S. Bureau of Transportation Statistics, http://www.bts.gov. Victoria Transportation Policy Institute, http://www.vtpi.org/. Energy Star, a government program to help consumers save money and protect the environment through energy efficiency, http://www.energystar.gov/index.cfm?c=home.index.

B. Transportation Efficiency and Conservation

Transportation devours two-thirds of the oil consumed in the United States, and the situation is similar in most other industrialized nations. Since oil is central to the problems of energy and the environment, it is especially important that transportation be as energy efficient as possible. Consequently, much has been written about saving transportation energy, not only through fuel efficiency but also through lifestyle changes such as reduced automobile use, alternate transportation modes, and reduced suburban sprawl. This subsection explores these issues. Refs. 138-147, on hydrogen, also deal mostly with transportation systems.

Refs. 161-163 address the problem of automobile overuse, while Ref. 164 takes a global view of the “external costs” of driving.

161. **The Geography of Nowhere: The Rise and Decline of America’s Man-Made Landscape**, J.H. Kunstler (Simon & Schuster, New York, 1993). Kunstler explains how American towns turned into car-dependent suburbs, and how they might be turned back into humane communities. Proposed remedies include sound planning principles, and an end to “compulsive commuting, the

unreality of the suburb, the alienation of downtown, the vulgarity of the highway strip, and the destruction of our countryside." Much of the book tells the history of transportation in America. A central chapter describes three contrasting cities: Detroit; Portland, Oregon; and Los Angeles. (E)

162. **Asphalt Nation: How the Automobile Took Over America and How We Can Take It Back**, J.H. Kay (Crown Publishers, New York, 1997). Kay analyzes the automobile's pervasive yet subtle control over most dimensions of American life, and calls for a revolution to reverse automobile dependency. Citing successful efforts in many cities, she shows that radical change is possible. Like Ref. 161, much of the book discusses the history of America's relationship with the car. Kay's recommended solutions include rational city planning, mass transit, intercity rail, de-paving, and an end to automobile subsidies. (E)

163. **Sustainability and Cities: Overcoming Automobile Dependence**, P. Newman and J. Kenworthy (Island Press, Washington, DC, 1999). This is a careful analysis of a wide range of car-related urban issues and their solutions, with many real-life examples. The authors argue that cities are a necessary focus for global sustainability issues. They make the case that a city's character results from how it manages transportation, and that we can achieve sustainability only by overcoming car dependence. (I)

164. "A Lighter Tread? Policy and Technology Options for Motor Vehicles," W. Harrington and V. McConnell, Environment **45** (9), 22-38 (November 2003). This article analyzes the private and social costs of vehicle use. Automobiles have many "external" costs including air pollution, congestion, accidents, global warming, and urban sprawl. How can we measure and manage these costs? Based on a survey of studies, the authors find that the external costs of driving are 13-68 cents per mile, equivalent to $3-$17 per gallon. The article discusses how new technology, management of transportation infrastructure, and economic and tax policy can attain a more sustainable transportation future. (I)

Refs. 165-168 look at reducing oil consumption by improving engine efficiencies and switching to more renewable fuels.

165. **Drilling In Detroit: Tapping Automaker Ingenuity to Build Safe and Efficient Automobiles**, D. Friedman, J. Mark, P. Monahan, C. Nash, C. Ditlow (Union of Concerned Scientists, Cambridge, MA, 2001); available at http://www.ucsusa.org/clean_vehicles/fuel_economy/drilling-in-detroit.html. The efficiency of cars and light trucks is at its lowest point in 20 years. Increasing efficiency to 40 mpg by 2012 and to 55 mpg by 2020 is feasible and

can yield significant benefits to consumers, the economy, and the environment without sacrificing passenger safety during collisions. (I)

166. "Hybrid Vehicles Gain Traction," J.J. Romm and A.A. Frank, Scientific American **294** (4), 72-79 (April 2006). Highly efficient hybrid vehicles have increased in popularity. Their cost should decline as battery technology improves and more vehicles are produced. Plug-in hybrids will travel 600-1000 miles on one tank and one battery charge. The article lists specifications for ten different 2006 hybrid models. (E)

167. "Fuel Efficiency and the Economy," R.H. Bezdek and R.M. Wendling, American Scientist **93** (2), 132-139 (March-April 2005). The National Research Council has identified many technologies that could improve vehicle fuel efficiency. This study models the gains that could be obtained by increased gasoline-mileage standards, using input-output analysis which takes account of feedbacks between different parts of the economy. Such standards could save consumers money, would not harm the economy, and would lead to a net increase in jobs. A modest increase in standards would slow down our rate of increase of oil consumption, while a 50% increase by 2015 would hold total consumption level while adding 350,000 more jobs to the economy. (I)

168. "Partmerships for Sustainable Mobility: The Pilot Region of Basel," S.F. Lienin, B. Kasemir, R. Stulz, and A. Wokaun, Environment **47** (3), 22-35 (April 2005). Switzerland plans to reduce its per-capita energy consumption by 60% to 2000 watts per capita (the current global average) by 2050. To demonstrate sustainable mobility, the Swiss city of Basel is producing methane and hydrogen from natural gas for use in hybrid and fuel-cell vehicles. The plan is to eventually obtain the needed methane and hydrogen from biomass. (I)

Refs. 169-171 explain how automobile engines, hydrogen fuel-cell cars, and magnetically levitated vehicles work.

169. "A Physicist's View of the Automobile Engine," B.J. Feldman, The Physics Teacher **42** (9), 543-547 (December 2004). Feldman discusses the thermodynamics of the 4-stroke Otto cycle, science-and-society interactions since 1970, the chemistry of pollutants, catalytic converters, fuel-injection engines, and hybrid technology. Students appreciate the application of thermodynamics to an object, such as the automobile, that is an integral part of their lives. (A)

170. "Hydrogen Fuel Cell Automobiles," B.J. Feldman, The Physics Teacher **43** (8), 492-495 (November 2005). This article discusses how hydrogen fuel cells work, and the advantages and disadvantages of hydrogen fuel-cell cars, and

concludes that this technology is worth investigating but should not be used to avoid considering alternative approaches. (I)

171. "Magnetic Levitation," T D. Rossing and J.R. Hull, The Physics Teacher **29** (9), 552-562 (December 1991). This article explains the basic physics of magnetic levitation and how to measure the "lift" and "drag" forces. The authors describe the history of maglev vehicles and apply the preceding physics to maglev vehicles and magnetic bearings. (I)

Refs. 172-174 discuss the most efficient form of transportation among all machines and all animals (Ref. 174): the bicycle.

172. "Bicycling Boom in Germany: A Revival Engineered by Public Policy," J. Pucher, Transportation Quarterly **51** (4), 31-46 (Fall 1997). Bicycling has increased dramatically in Germany during two decades, mitigating roadway congestion and pollution. This resurgence of bicycling is due almost entirely to policies enhancing the safety, speed, and convenience of bicycling while making auto use more difficult and expensive. With the right policies, bicycling can be increased almost anywhere. (E)

173. "Bicycling Renaissance in North America? Recent Trends and Alternative Policies to Promote Bicycling," J. Pucher, C. Komanoff, and P. Schimek, Transportation Research **33-** (7/8), 625-654 (September 1999). The number of U.S. bicycle trips doubled during 1989-1999. The potential for further growth is enormous. Bicycling's share of U.S. trips remains far lower than levels in northern Europe, because there is no tradition of cycling for utilitarian purposes and because of the marginal status of cyclists in a car-based transport system. As long as car use remains cheap and transportation policy remains dominated by motoring, bicycling for daily travel will not flourish in North America. (E)

174. "Bicycle Technology," S.S. Wilson, Scientific American **228** (3), 81-91 (March 1973). This humane and efficient machine played a central role in the evolution of the ball bearing, the pneumatic tire, the automobile, and the airplane. A human on a bicycle ranks first in efficiency among traveling animals and machines when measured in kilogram-kilometers (total weight of the animal plus its vehicle, times the distance traveled) per unit of energy. (E)

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