RENEWABLE ENERGY SOURCES

Antonia V. Herzog, Timothy E. Lipman, Daniel M. Kammen
Energy and Resources Group, Renewable and Appropriate Energy Laboratory (RAEL), University of California, Berkeley, U.S.A.

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Summary

The potential of renewable energy sources is enormous as they can in principle meet many times the world's energy demand. Renewable energy sources such as biomass, wind, solar, hydropower, and geothermal can provide sustainable energy services, based on the use of routinely available, indigenous resources. A transition to renewables-based energy systems is looking increasingly likely as their costs decline while the price of oil and gas continue to fluctuate. In the past 30 years solar and wind power systems have experienced rapid sales growth, declining capital costs and costs of electricity generated, and have continued to improve their performance characteristics. In fact, fossil fuel and renewable energy prices, and social and environmental costs are heading in opposite directions and the economic and policy mechanisms needed to support the widespread dissemination and sustainable markets for renewable energy systems are rapidly evolving. It is becoming clear that future growth in the energy sector will be primarily in the new regime of renewable energy, and to some extent natural gas-based systems, not in conventional oil and coal sources. Because of these developments market opportunity now exists to innovate and to take advantage of emerging markets to promote renewable energy technologies, with the additional assistance of governmental and popular sentiment. The development and use of renewable energy sources can enhance diversity in energy supply markets, contribute to securing long term sustainable energy supplies, help reduce local and global atmospheric emissions, and provide commercially attractive options to meet specific energy service needs, particularly in developing countries and rural areas helping to create new employment opportunities there.

1. Introduction

Conventional energy sources based on oil, coal, and natural gas have proven to be highly effective drivers of economic progress, but at the same time damaging to the environment and to human health. Furthermore, they tend to be cyclical in nature, due to the effects of oligopoly in production and distribution. These traditional fossil fuel-based energy sources are facing increasing pressure on a host of environmental fronts, with perhaps the most serious challenge confronting the future use of coal being the Kyoto Protocol greenhouse gas (GHG) reduction targets. It is now clear that any effort to maintain atmospheric levels of CO_2 below even 550 ppm cannot be based fundamentally on an oil and coal-powered global economy, barring radical carbon sequestration efforts.

The potential of renewable energy sources is enormous as they can in principle meet many times the world's energy demand. Renewable energy sources such as biomass, wind, solar, hydropower, and geothermal can provide sustainable energy services, based on the use of routinely available, indigenous resources. A transition to renewables-based energy systems is looking increasingly likely as the costs of solar and wind power systems have dropped substantially in the past 30 years, and continue to decline, while the price of oil and gas continue to fluctuate. In fact, fossil fuel and renewable energy prices, social and environmental costs are heading in opposite directions. Furthermore, the economic and policy mechanisms needed to support the widespread dissemination and sustainable markets for renewable energy systems have also rapidly evolved. It is becoming clear that future growth in the energy sector is primarily in the new regime of renewable, and to some extent natural gas-based systems, and not in conventional oil and coal sources. Financial markets are awakening to the future growth potential of renewable and other new energy technologies, and this is a likely harbinger of the economic reality of truly competitive renewable energy systems.

In addition, renewable energy systems are usually founded on a small-scale, decentralized paradigm that is inherently conducive to, rather than at odds with, many electricity distribution, cogeneration (combined heat and power), environmental, and capital cost issues. As an alternative to custom, onsite construction of centralized power plants, renewable systems based on PV arrays, windmills, biomass or small hydropower, can be mass-produced "energy appliances" capable of being manufactured at low cost and tailored to meet specific energy loads and service conditions. These systems can have dramatically reduced as well as widely dispersed environmental impacts, rather than larger, more centralized impacts that in some cases are serious contributors to ambient air pollution, acid rain, and global climate change.

Renewable energy sources currently supply somewhere between 15 percent and 20 percent of the world's total energy demand. The supply is dominated by traditional biomass, mostly fuel wood used for cooking and heating, especially in developing countries in Africa, Asia and Latin America. A major contribution is also obtained from the use of large hydropower; with nearly 20 percent of the global electricity supply being provided by this source. New renewable energy sources (solar energy, wind energy, modern bio-energy, geothermal energy, and small hydropower) are currently contributing about two percent. A number of scenario studies have investigated the potential contribution of renewables to global energy supplies, indicating that in the second half of the 21st century their contribution might range from the present figure of nearly 20 percent to more than 50 percent with the right policies in place.

2. Biomass Energy

2.1 Introduction

Biomass is the term used for all organic material originating from plants (including algae), trees and crops and is essentially the collection and storage of the sun's energy through photosynthesis. Biomass energy, or bioenergy, is the conversion of biomass into useful forms of energy such as heat, electricity and liquid fuels.

Biomass for bioenergy comes either directly from the land, as dedicated energy crops, or from residues generated in the processing of crops for food or other products such as pulp and paper from the wood industry. Another important contribution is from post consumer residue streams such as construction and demolition wood, pallets used in transportation, and the clean fraction of municipal solid waste (MSW). The biomass to bioenergy system can be considered as the management of flow of solar generated materials, food, and fiber in our society. These inter-relationships are shown in Figure 1, which presents the various resource types and applications, showing the flow of their harvest and residues to bioenergy applications. Not all biomass is directly used to produce energy but rather it can be converted into intermediate energy carriers called biofuels. This includes charcoal (higher energy density solid fuel), ethanol (liquid fuel), or producer-gas (from gasification of biomass).

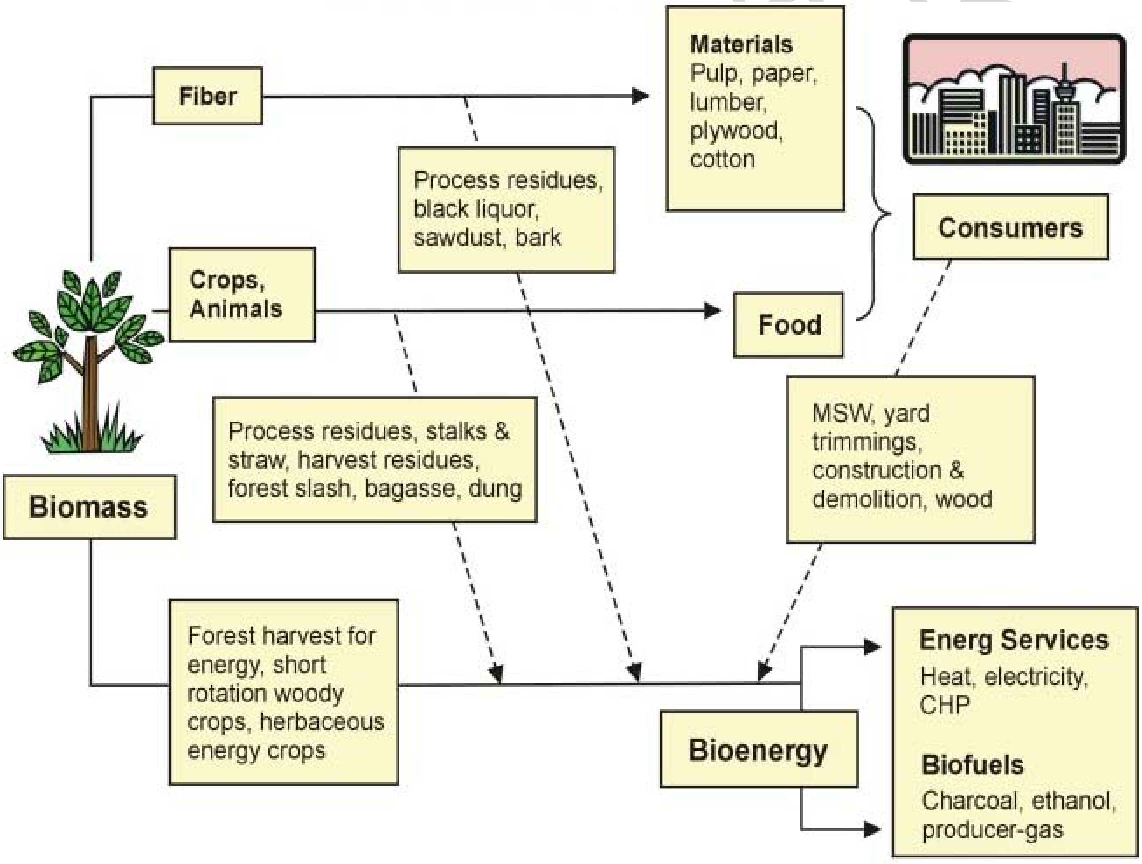

Figure 1: Biomass and bioenergy flow chart
(Source: R.P. Overend, NREL, 2000)

Biomass was the first energy source harnessed by humans, and for nearly all of human history, wood has been our dominant energy source. Only during the last century, with the development of efficient techniques to extract and burn fossil fuels, have coal, oil, and natural gas, replaced wood as the industrialized world's primary fuel. Today some 40 to 55 exajoules (EJ = 10^{18} joules) per year of biomass is used for energy, out of about

450 EJ per year of total energy use, or an estimated 10-14 percent, making it the fourth largest source of energy behind oil (33 percent), coal (21 percent), and natural gas (19 percent). The precise amount is uncertain because the majority is used non-commercially in developing countries.
Biomass is usually not considered a modern energy source, given the role that it has played, and continues to play, in most developing countries. In developing countries it still accounts for an estimated one third of primary energy use while in the poorest up to 90% of all energy is supplied by biomass. Over two billion people cook by direct combustion of biomass, and such traditional uses typically involve the inefficient use of biomass fuels, largely from low cost sources such as natural forests, which can further contribute to deforestation and environmental degradation. The direct combustion of biomass fuels, as used in developing countries today for domestic cooking and heating, has been called "the poor man's oil" ranking at the bottom of the ladder of preferred energy carriers where gas and electricity are at the top.

The picture of biomass utilization in developing countries is sharply contrasted by that in industrialized countries. On average, biomass accounts for 3 percent or 4 percent of total energy use in the latter, although where policies supportive of biomass use are in place, e.g. in Austria, Sweden, and Finland, the biomass contribution reaches 12, 18, and 23 percent respectively. Most biomass in industrialized countries is converted into electricity and process heat in cogeneration systems (combined heat and power production) at industrial sites or at municipal district heating facilities. This enables a greater variety of energy services to be derived from biomass which are much cleaner and use the available biomass resources more efficiently than is typical in developing countries.

Biomass energy has the potential to be "modernized" worldwide, that is produced and converted efficiently and cost-competitively into more convenient forms such as gases, liquids, or electricity. A variety of technologies can convert solid biomass into clean, convenient energy carriers over a range of scales from household/village to large industrial. Some of these technologies are commercially available today while others are still in the development and demonstration stages. If widely implemented, such technologies could enable biomass energy to play a much more significant role in the future than it does today, especially in developing countries.

2.2 The Future Role of Biomass

Modernized biomass energy is projected to play a major role in the future global energy supply. This is being driven not so much by the depletion of fossil fuels, which has ceased to be a defining issue with the discovery of new oil and gas reserves and the large existing coal resources, but rather by the recognized threat of global climate change, caused largely by the burning of fossil fuels. Its carbon neutrality (when produced sustainably) and its relatively even geographical distribution coupled with the expected growth in energy demand in developing countries, where affordable alternatives are not often available, make it a promising energy source in many regions of the world for the twenty-first century.

Most households in developing countries that use biomass fuels today do so either because it is available at low (or zero) financial cost or because they lack access to or cannot afford higher quality fuels. As incomes rise, preferences tend to shift away from biomass. For example, in the case of cooking, consumer preferences shift with increasing income from dung to crop residues, fuelwood, coal, charcoal, kerosene, liquified petroleum gas, natural gas, and electricity (the well-known household energy ladder). This shift away from biomass energy as incomes rise is associated with the quality of the energy carrier used rather than with the primary energy source itself. If biomass energy is instead modernized, then wider use is conceivable along with benefits such as reduced indoor air pollution. For example, in household cooking gaseous or liquid cooking fuels can be used far more efficiently and conveniently, reaching many more families and emitting far fewer toxic pollutants, than solid fuels.

Estimates of the technical potential of biomass energy are much larger than the present world energy consumption. If agriculture is modernized up to reasonable standards in various regions of the world, several billions of hectares may be available for biomass energy production well into this century. This land would comprise degraded and unproductive lands or excess cropland, and preserve the world's nature areas and quality cropland. Table 1 gives a summary of the potential contribution of biomass to the worlds energy supply according to a number of studies and influential organizations. Although the percentile contribution of biomass varies considerably, depending on the expected future energy demand, the absolute potential contributions of biomass in the long term is high, from about 100 to 300 EJ per year.

Source	Time frame (year)	Total projected global energy demand (EJ)	Contribution of biomass to energy demand (EJ/yr), and % of total	Remarks
Shell (1996)	2060	940 1500	207 (22%) 221 (14%)	- Sustained growth * - Dematerialization+
IPCC (1996)	2050 2100	560 710	180 (32%) 325 (46%)	Biomass intensive energy system development
Greenpeace (1993)	2050 2100	610 986	114 (19%) 181 (18%)	Fossil fuels are phased out during the 21st century
Johansson et al. (1993)	2025 2050	395 561	145 (37%) 206 (37%)	RIGES model calculation
WEC (1993)	2050 2100	671 895–1880	94 (14%) 132–215 (15–11%)	Outcome of 1 scenario

Table 1: Role of biomass in future global energy use according to five different studies *(Source: Hall, 1998; WEA, 2000)*

An Intergovernmental Panel on Climate Change (IPCC) study has explored five energy supply scenarios for satisfying the world's growing demand for energy services in the twenty-first century while limiting cumulative CO_2 emissions between 1990 and 2100 to fewer than 500 gigatons of carbon. In all scenarios, a substantial contribution from carbon-neutral biomass energy as a fossil fuel substitute is included to help meet the CO_2 emissions targets. When biomass is grown at the same average rate as it is harvested for energy, it is approximately carbon-neutral: carbon dioxide extracted from the atmosphere during growth is released back to the atmosphere during conversion to energy. Figure 2 shows the results for the IPCC's most biomass-intensive scenario where biomass energy contributes 180 EJ/year to global energy supply by 2050—satisfying about one-third of the total global energy demand, and about half of total energy demand in developing countries. Roughly two-thirds of the global biomass supply in 2050 is assumed to be produced on high-yield energy plantations covering nearly 400 million hectares, or an area equivalent to one-quarter of present planted agricultural area. The other one-third comes from residues produced by agricultural and industrial activities.

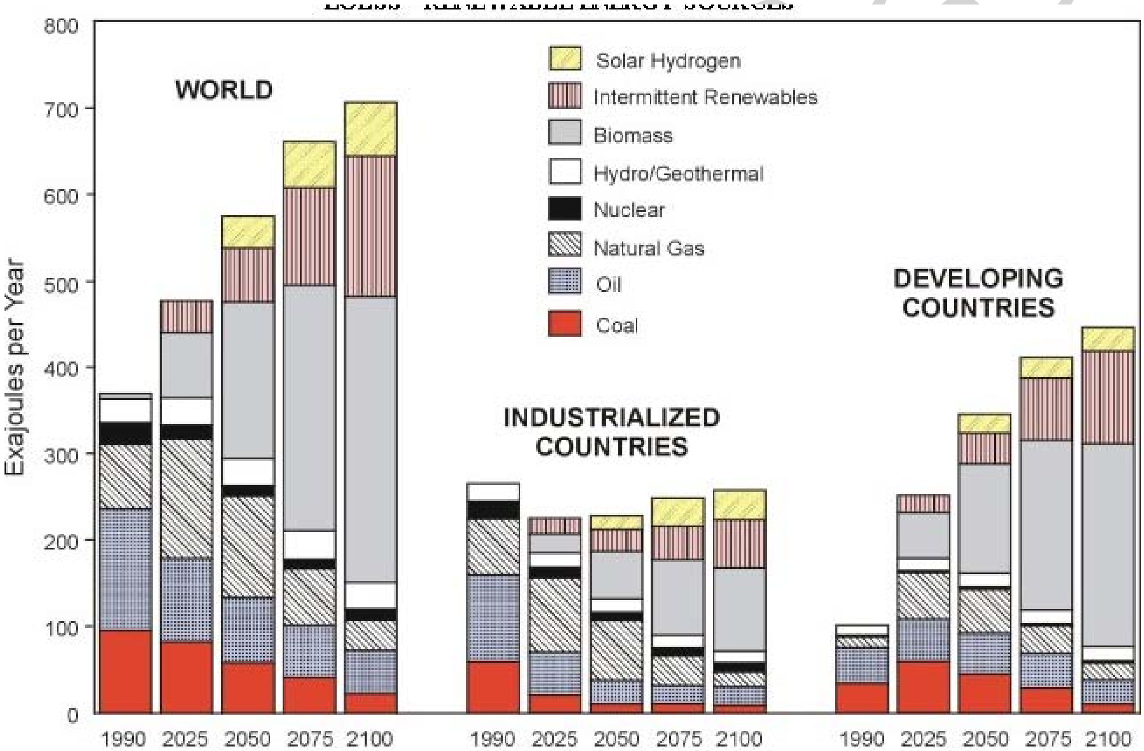

Figure 2: Primary commercial energy use by source for the biomass-intensive variant of the IPCC model (IPCC, 1996), shown for the world, for industrialized countries, and for developing countries
(Source: Sivan, 2000)

Such large contributions of biomass to the energy supply might help address the global environmental threat of climate change, but it also raises concerns about local and regional environmental and socio-economic impacts. Such issues (discussed in more detail below) include the: depletion of soil nutrients from crop land due to the removal of agricultural residues; leaching of chemicals applied to intensively-cultivated biomass energy crops; loss of biodiversity associated with land conversion to energy crops; diversion to energy uses of biomass resources traditionally used for non-energy purposes, or conversion of land from food to energy production. Bioenergy systems, more so than most other types of energy systems, are inextricably linked to their local environmental and socio-economic contexts.

On the other hand, the large role biomass is expected to play in future energy supplies can be explained by several considerations. Firstly, biomass fuels can substitute more-or-less directly for fossil fuels in the existing energy supply infrastructure. Intermittent renewables such as wind and solar energy are more challenging to the ways we distribute and consume energy. Secondly, the potential resource is large. Thirdly, in developing countries demand for energy is rising rapidly due to population increases, urbanization, and rising living standards. While some fuel switching occurs in the process, the total demand for biomass will also tend to increase, as is currently seen for charcoal. Consequently, there is a growing consensus that energy policies will need to be concerned about the supply and use of biofuels while supporting ways to use these fuels more efficiently and sustainably.

2.3 Biomass Energy Conversion Technologies and Applications

There are a variety of technologies for generating modern energy carriers - electricity, gas, and liquid fuels - from biomass, which can be used at the household (~10 kW), community (~100 kW), or industrial (~ MW) scale. The different technologies tend to be classed in terms of either the conversion process they use or the end product produced.

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Biographical Sketches

Antonia V. Herzog is a Postdoctoral Fellow, in the Energy and Resources Group, Renewable and Appropriate Energy Laboratory, University of California, Berkeley. She holds the following degrees: BA Physics, Vassar College, 1987; BE Engineering, Dartmouth College, Thayer School of Engineering, 1988; MS Applied Physics, Columbia University, School of Engineering and Applied Science, 1989; Ph.D. Physics, University of California, San Diego, 1996. She received her Ph.D. for research on the low-temperature quantum mechanical behavior of one- and two-dimensional superconducting, metallic, and insulating nano-wires. She was then awarded a Sloan Post-doctoral Fellowship in Neurobiology by the Salk Institute for Biological Studies in La Jolla, California where she worked in the Systems Neurobiology Laboratory for a year studying the functional connectivity of cortical neurons in the visual cortex using intracellular electrophysiological recordings in brain tissue. Becoming increasingly interested in the interface between science and public policy she made a break from basic research and moved to Washington, DC where she initially worked at the American Association for the Advancement of Science (AAAS) as a consultant exploring various issues related to the ethical, legal and social implications of science and technology before being awarded the 1998-1999American Physical Society Congressional Science Fellowship. As a Congressional Science Fellow Dr. Herzog spent a year working in Senator John D. Rockefeller IV's (Democrat-West Virginia) personal office as a Legislative Assistant covering science and technology and energy and environmental issues. Her work included legislation to promote alternative fuel vehicles, increase non-defense research and development funding, and facilitate technology transfer from the federal labs to the private sector. A growing concern with sustainable and environmentally sound international development and aid particularly in the energy sector prompted Dr. Herzog to join Dr. Daniel Kammen's Renewable and Appropriate Energy Laboratory (RAEL) in the Energy and Resources Group at the University of California, Berkeley beginning in January of 2000. She has received the prestigious University of California President's Postdoctoral Fellowship for a renewable energy power generation development project based in Zimbabwe, Africa. Generally her interests include the dissemination of renewable and appropriate energy systems in the developing countries, the potential socioeconomic and environmental impacts of renewable energy technologies and resource management systems locally and globally, and the impacts of climate change policy in the developing countries particularly the potential of the Clean Development Mechanism to foster sustainable development.

Timothy E. Lipman is a Postdoctoral Fellow, Energy and Resources Group, Renewable and Appropriate Energy Laboratory, University of California, Berkeley. He holds the following degrees: BA Anthropology, Stanford University, 1990; MS Transportation Technology and Policy, University of California, Davis, 1998; Ph.D. Environmental Policy Analysis, University of California, Davis, 1999. He completed his Ph.D. with the Graduate Group in Ecology at the University of California at Davis, then serving as Associate Director of the Fuel Cell Vehicle Center at the Institute of Transportation Studies at UC Davis, and is now a Post-doctoral Fellow with the Energy and Resources Group at the University of California at Berkeley. In March 1998, Dr. Lipman received an M.S. degree in the technology track of the new UC Davis Graduate Group in Transportation Technology and Policy. While enrolled at UC Davis, Dr. Lipman worked as a researcher ITS-Davis on a CALSTART neighborhood electric vehicle project and on a California Air Resources Board electric vehicle cost and performance study, as well as participating in various smaller projects. He has authored or co-authored several journal articles and ITS-Davis research reports on policies to encourage the production and use of neighborhood electric vehicles, on the potential use of hydrogen as a transportation fuel, on the manufacturing costs of electric vehicle technologies, and on greenhouse gas emissions from transportation fuel cycles. He has authored papers for annual meetings of the Transportation Research Board, the Electric Vehicle Symposium, and the National Association of Environmental Professionals. Dr. Lipman has received several fellowships and awards, including the 1999 Council of University Transportation Centers "Charlie Wootan dissertation award, a 1998 IGERT teaching fellowship, a 1997 University of California Transportation Center Dissertation Grant, a 1996 ENO Foundation Fellowship, a 1995 University of California Transportation Center Dissertation Grant, and a 1994 Chevron Foundation Fellowship. Dr. Lipman is also a graduate of Stanford University, where in 1990 he completed a self-designed B.A. in Anthropology, focusing on environmental and technology transfer issues in the developing world. He has previously worked as an environmental analyst and technical writer under a Boeing Aerospace, Inc. contract with the NASA-Ames Research Center in Mountain View, California, and as a policy intern at the Bank Information Center in Washington, D.C.

Daniel M. Kammen is Associate Professor of Energy and Society in the *Energy and Resources Group*, University of California, Berkeley, U.S.A..He is Director of the Renewable and Appropriate Energy Laboratory. He hold the following degrees: BA Physics, Cornell University, 1984; MA Physics, Harvard University, 1986; Ph.D. Physics, Harvard University, 1988. He received his doctorate in physics for work on theoretical solid state physics and computational biophysics. He was then the Wezmann and

Bantrell Postdoctoral Fellow at the California Institute of Technology in the Divisions of Engineering, Biology, and the Humanities (1988 - 1991). At Caltech and then as a Lecturer in Physics and in the Kennedy School of Government at Harvard University, Kammen developed a number of projects focused on renewable energy technologies and environmental resource management. At Harvard he also worked on risk analysis as applied to global warming and methodological studies of forecasting and hazard assessment. Kammen received the 1993 21st Century Earth Award, recognizing contributions to rural development and environmental conservation from the Global Industrial and Policy Research Institute and *Nihon Keizai Shimbun* in Japan. From 1993 - 1998 Kammen was an Assistant Professor of Public and International Affairs in the Woodrow Wilson School of Public and International Affairs at Princeton University. Dr Kammen played a key role in developing the interdisciplinary Science, Technology, and Environmental Policy (STEP) Program at Princeton, which awards undergraduate and masters certificates and a doctoral degree. He has been Chair of STEP for the past four years and co-chair before that. In July of 1998 Kammen joined the interdisciplinary Energy and Resources Group (ERG) at Berkeley as an Associate Professor of Energy and Society. Dr Kammen is also the founding director of a new Renewable and Appropriate Energy Laboratory (RAEL) that is based in the Department of Nuclear Engineering at Berkeley. He has been a Visiting Lecturer at the University of Nairobi, and is a Permanent Fellow of the African Academy of Sciences where he directs a field research and training program on energy and sustainable development in Africa. His research interests include: the science, engineering, management, and dissemination of renewable energy systems; health and environmental impacts of energy generation and use; rural resource management, including issues of gender and ethnicity; international R&D policy, climate change; and energy forecasting and risk analysis. He is the author of over 110 journal publications, several edited volumes, a book on environmental, technological, and health risks (*Should We Risk It?*, Princeton University Press, 1989) and numerous reports on renewable energy and development. He has been featured on radio, network and public broadcasting television and in print as an analyst of energy, environmental, and risk policy issues and current events. Kammen advises the U. S. and Swedish Agencies for International Development, the World Bank, and the Presidents Committee on Science and Technology (PCAST). Further information on his research, publications, teaching and policy work is available at: URL: http://socrates.berkeley.edu/~dkammen.