United Nations Development Programme
United Nations Department of Economic and Social Affairs
World Energy Council

World Energy Assessment

overview

2004 Update

World Energy Assessment: Overview 2004 Update

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The analysis and conclusions of the World Energy Assessment: Overview 2004 Update do not necessarily reflect the views of the United Nations Development Programme, its Executive Board, the United Nations Department of Economic and Social Affairs, the Member States of the United Nations, or the Member Committees of the World Energy Council.

This publication is an update of the Overview to *Energy and the Challenge of Sustainability,* the World Energy Assessment published in 2000. Although new data are referenced in this volume, citations on data and findings previously referenced in the Assessment are not duplicated here. Readers are invited to turn to the full World Energy Assessment. For information on obtaining the Assessment, please see www.undp.org/energy

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In 2002 government leaders, heads of industry, civil society and representatives of United Nations organisations met in Johannesburg at the World Summit for Sustainable Development (WSSD). Held ten years after the United Nations Conference on Environment and Development, WSSD brought discussions on energy to the center of global debate. The resulting Johannesburg Plan of Implementation stresses that access to reliable and affordable energy services facilitates the eradication of poverty. The importance of producing, distributing and consuming energy services in ways that support sustainable development is also emphasised in relation to changing patterns of production and consumption as well as protecting and managing the natural resource base. Energy is, for the first time in an intergovernmental process, directly linked to the achievement of the Millennium Development Goals, an ambitious set of quantified development targets agreed by the international community during the Millennium Assembly in 2000.

We the three sponsoring organizations of the "World Energy Assessment: Energy and the Challenge of Sustainability", the United Nations Development Programme, the United Nations Department for Economic and Social Affairs, and the World Energy Council are very pleased that energy gained such prominence in these important international discussions. The regional and global discussions leading up to WSSD built heavily on the outcome of the ninth session of the Commission on Sustainable Development (CSD-9) held in April 2001. Providing objective, scientific and technological information on energy trends and issues to inform and support these discussions was the reason that our organisations began collaboration on the World Energy Assessment which was released in 2000 under the Chairmanship of Dr. José Goldemberg.

This publication, which is an update of the Overview of the original World Energy Assessment, has been assembled to reflect current information on energy production and consumption patterns, technology trends and to summarise the important decisions and recommendations concerning energy reflected in CSD-9, WSSD and other international fora. This is particularly important given that the 2006/2007 cycle of the Commission on Sustainable Development will consider energy for sustainable development as well as air pollution/atmosphere, climate change and industrial development.

This will be a key opportunity to focus attention on some of the concrete policy, financing, capacity development, technology and knowledge management approaches that are supporting changes in energy production and use in line with sustainable development goals. It will provide further opportunities to examine distinct regional challenges linked to energy and to address how key energy issues are directly impacting the achievement of development objectives outside the energy sector including, for example, managing and protecting the natural resource base, gender equality, changing unsustainable patterns of consumption and production, and poverty eradication.

More than ever there is urgency to take decisions and implement energy options that accelerate the shift towards sustainable development. Vastly improved access to modern energy services, improved affordability, reliability and greatly enhanced use of technologies that address the challenges of sustainable development are urgently needed.

We believe that energy solutions require joint efforts involving government agencies and policy makers, the private sector and industry, civil society and collaboration within the international development community, including the United Nations system. The challenges of sustainable development are great and the importance of energy in achieving sustainable development goals cannot be overstated. Significant changes in national, regional and global energy systems will be required to meet these challenges. The materials presented represent the views of the contributing authors and have been peer reviewed; they are issued under the supervision of the Editors who are responsible for the content. We remain committed to action on energy for sustainable development and hope you will find this update, prepared under the editorship of Dr. José Goldemberg and Dr. Thomas B. Johansson, helpful in your own considerations on important energy issues. ■

preface

José Goldemberg
Sao Paulo, Brazil

Thomas B. Johansson
Lund, Sweden

May 2004

The World Energy Assessment (WEA) published in the year 2000 – a 500-page document – provides analytical background and scientific information for decision makers at all levels. It describes energy's relationship to sustainable development and analyses how energy can serve as an instrument to reach that goal. The Assessment was based on data and analysis available in 1998.

Since then, important developments have taken place at the inter-governmental, business, and technological levels, the most important of which include:

- The United Nations General Assembly adopted the Millennium Development Goals (MDGs) in 2000. Although no explicit goal on energy was adopted, access to energy services is a prerequisite to achieving all of the MDGs.
- The ninth session of the Commission on Sustainable Development (CSD-9) in 2001 was an important landmark in the process leading to the World Summit on Sustainable Development (WSSD) in reaching a consensus that the current energy situation is not sustainable.
- The WSSD met in September 2002, and its Plan of Implementation made specific recommendations on energy access to facilitate the achievement of the Millennium Development Goals and established a clear link between energy and the eradication of poverty.
- A dramatic increase in interest in the reform and design of energy markets to widen access to energy services and to provide public goods is occurring.
- Electricity crises in California and Brazil increased doubts on the wisdom of liberalisation/privatisation without a greater role for regulation to set objectives, boundaries, and rules for the market.
- The trend towards using natural gas for power generation and road transport has accelerated, and the focus on the availability of natural gas and the infrastructure to transport it has increased as well.

- Some fossil fuel corporations as well as some governments have shown strong interest in exploring the viability of a hydrogen economy and promoting carbon sequestration to reduce greenhouse gas emissions.
- Increasing interest in the expanded use of renewable energy has been demonstrated in a range of settings:
    - The Group of Eight (G8) Renewable Energy Task Force Report issued in 2001 stressed the need to give priority to efforts to renewable energy markets, particularly in the industrialised countries. This would lead to a decrease in costs and thus open the way for use of renewable energy in developing countries.
    - At WSSD, many partnerships between industrialised and developing countries were formed to promote sustainable development with a focus on energy.
    - A number of countries – including Spain, Germany, Brazil, and some states in the United States – have adopted successful laws and regulations designed to increase the use of renewable energy sources.
- In the period 1998-2003, there were increased concerns about energy security (both physical security and security of supply), further emphasised by the September 11, 2001, events in New York and Washington, as well as the war in Iraq.
- Concerns have been raised about the local, regional, and global environmental and social impacts of the use of fossil fuels, as well as of large hydro and mining projects.
- Power failures along the North American eastern seaboard and in England, Sweden, and Italy illustrated the strong dependence of industrialised countries on reliable power networks.
- Progress has occurred in the ratification of the Kyoto Protocol so that it could enter into force upon ratification by Russia. The 2001 Third Assessment by the Intergovernmental Panel on Climate Change (IPCC) concluded that the global mean surface temperature has increased by 0.6 degrees Celsius during the last two centuries "with increasing evidence that most of the warming observed over the last fifty years is attributable to human activities".
- Finally, there is an increasing interest in energy policies and measures that address many, if not all, challenges related to energy simultaneously.

These developments and others led the institutions that established the World Energy Assessment to ask us to update the Overview to that document, taking into account developments since it was finalised in late 1999. The result is the analysis presented here.

The 2004 Overview provides a comprehensive view of energy for sustainable development issues and options. The basic objective of the WEA is maintained, that is, to provide an assessment of issues and options related to energy for sustainable development and to provide information on alternative global experiences. The basic approach developed and presented in the WEA is maintained as well. However, the data and analysis have been updated to reflect new information available through early 2003. ■

sponsoring institutions

The United Nations Development Programme (UNDP) is the UN's global development network, advocating for change and connecting countries to knowledge, experience and resources to help people build a better life. UNDP is on the ground in 166 countries, working with them on their own solutions to global and national development challenges. World leaders have pledged to achieve the Millennium Development Goals, including the overarching goal of cutting poverty in half by 2015. UNDP's network links and coordinates global and national efforts to reach these Goals. UNDP's focus is on helping countries build and share solutions in five major areas including democratic governance, poverty reduction, energy and environment, crisis prevention and recovery, and HIV/AIDS.

The United Nations Department of Economic and Social Affairs (UNDESA) facilitates intergovernmental processes and, through its Division for Sustainable Development, services such bodies as the U.N. Commission on Sustainable Development and U.N. Committee on Energy and Natural Resources for Development. UNDESA also undertakes, among other things, statistical and analytical work to monitor the environment and sustainable development, provides policy and technical advisory services, and implements technical cooperation projects at the request of developing countries in the followup to the 1992 Earth Summit.

The World Energy Council (WEC) is a multi-energy, nongovernmental, global organisation founded in 1923. In recent years, WEC has built a reputation in the energy field through its studies, technical services, and regional programmes. Its work covers long-term energy scenarios, developing country and transitional economy energy issues, energy financing, energy efficiency and liberalisation policies, and environmental concerns. Through its member committees in close to one hundred countries, it has encouraged the participation of private industry throughout the editorial and consultative process of the World Energy Assessment.

For more information on the activities and publications of the three establishing organisations, please visit the following websites – UNDP: www.undp.org/energy; UNDESA: www.un.org/esa/desa.htm; WEC: www.worldenergy.org. ■

acknowledgements

The publication of this World Energy Assessment Overview: 2004 Update would not have been possible without the dedicated efforts of many people, starting with the contributors as well as those who represented the sponsoring institutions. UNDP, UNDESA and the WEC greatly appreciate their efforts.

The editorial process was skillfully guided by José Goldemberg of Brazil and Thomas B. Johansson from Sweden. Their extensive experience in energy, policy issues, and international relations has been invaluable. Their consistent personal and professional commitment to advancing the global agenda on energy for sustainable development, including the completion of this publication, has provided great leadership in the international community. We are also deeply grateful to the contributors for their dedicated efforts in preparing and reviewing this publication under a tight schedule. The contributors are: Dennis Anderson, Suani T. Coelho, Gerald Doucet, Irene Freudenschuss-Reichl, Michael Jefferson, Eberhard Jochem, Stephen Karekezi, Hisham Khatib, Susan McDade, Alan McDonald, José Roberto Moreira, Nebojša Nakićenović, Amulya K.N. Reddy, Hans-Holger Rogner, Kirk R. Smith, Wim C. Turkenburg, Gill Wilkins, Robert H. Williams as well as both José Goldemberg and Thomas B. Johansson.

Project coordination for this publication was provided by Susan McDade and Khalid Husain of UNDP's Sustainable Energy Programme with the continuous support of Maria Castillo and Martha Barrientos.

We appreciate the professional efforts of the entire World Energy Assessment team, particularly Rosemarie Philips, text editor, and Vilma Bortoleto for secretarial support in São Paulo. Special thanks to Julia Dudnik-Ptasznik for the layout and production of this publication. The editors also gratefully acknowledge the comments from Kathleen Abdalla, François Ailleret, S.C. Bhattacharya, Adrian Bradbrook, Bill Chandler, Martha Duenas, J. Gururaja, Günther Hanreich, Ines Havet, Frank von Hippel, Arun Kashyap, Gerald Leach, Amory B. Lovins, Kui-Nang Mak, Eric Martinot, Lars Nilsson, Sara Nordstroem, Cynthia Page, Joel Posters, Antonio del Rosario, Jamal Saghir, Minoru Takada, Sergio Trindade and Raymond Wright. ■

executive summary

The World Energy Assessment provides analytical background and scientific information for decision makers, in language relevant to all stakeholders. It describes energy's fundamental relationship to sustainable development and analyses how energy can serve as an instrument to reach that goal. It was prepared in order to provide scientifically based input to the intergovernmental processes that led up to the treatment of energy in the context of the World Summit for Sustainable Development (WSSD) in Johannesburg in September 2002.

Energy was indeed one of the most intensely debated issues at the WSSD. In the end, agreement was reached to significantly advance the attention given to energy in the context of sustainable development. These developments followed years of efforts to focus on energy as an instrument for sustainable development that intensified after the United Nations Conference on Environment and Development (UNCED) in 1992.

The decision of the institutions that established the World Energy Assessment to update the Overview of the report *World Energy Assessment: Energy and the Challenge of Sustainability* is testament to the Assessment's relevance.

Energy and Major Global Issues

The analysis presented here starts with the linkages between energy and the economy, social and health issues, including poverty alleviation and improvement of the situation of women, environmental protection, and security, and indicates and describes aspects of energy production and use that are incompatible with the goal of sustainable development:

- Access to affordable energy services is fundamental to human activities, development, and economic growth. It is access to energy services, not energy supply *per se* that matters.
- More than two billion people cannot access affordable energy services based on efficient use of electricity and gaseous and liquid fuels. Without access to energy, their opportunities for economic development and

improved living standards are constrained. Women and children, relatively more dependent on traditional fuels, suffer disproportionately.

- Wide disparities in access to affordable commercial energy and energy services in both urban centres and rural areas are inequitable, run counter to the concept of human development, and threaten social stability. Access to decentralised small-scale energy technologies is an important element of successful poverty alleviation.
- The environmental impacts of a host of energy-linked emissions – including suspended fine particles and precursors of acid deposition – contribute to local and regional air pollution and ecosystem degradation. Human health is threatened by high levels of air pollution resulting from particular types of energy use at the household, community, and regional levels.
- Emissions of anthropogenic greenhouse gases, mostly from the production and use of energy, are altering the atmosphere. There is new and stronger evidence that most of the warming observed over the last fifty years is attributable to human activities and that significant climate change would result if twenty-first century energy needs were met without a major reduction in the carbon emissions of the global energy system.
- Dependence on imported fuels leaves many countries vulnerable to disruption in supply, which might pose physical hardships and economic burdens; the weight of fossil fuel imports on the balance of payments is unbearable for many poorer countries. The current energy system of industrialised countries is heavily dependent on fossil fuels, which are geographically concentrated in a few regions of the world.[1]

Finding ways to expand the quality and quantity of energy services while simultaneously addressing the environmental impacts associated with energy use represents a critical challenge to humanity. Major changes are required in energy system development world-wide.

Energy Resources and Technological Options

Physical resources and adequate technologies are available to meet the challenges of sustainable development. Without policy changes, cost differentials will favour conventional fuels for decades to come. Options for using energy in ways that support sustainable development, which requires a consistent focus on social, economic, and environmental processes, include:

- More efficient use of energy, especially at the point of end use in buildings, transportation, and production processes.
- Increased reliance on renewable energy sources.
- Accelerated development and deployment of new energy technologies – particularly next-generation fossil fuel technologies that produce near-zero harmful emissions, but also nuclear technologies if the issues surrounding their use can be resolved.

All three options have considerable potential; however, realising this potential will require removing obstacles to their wider diffusion – including developing market signals that reflect environmental and other costs to society not already internalised in market prices – and encouraging technological innovation.

The relative importance of these options depends on the availability of natural resources. Irrespective of that, a more efficient use of energy is always essential, even in developing countries where increased access to modern energy carriers is top priority.

Are Sustainable Futures Possible?

Analysis using energy scenarios indicates that it is possible to address simultaneously the various sustainable development objectives, using available resources and technical options. The scenarios and subsequent analysis suggest that:

- Continuing along the current path of energy system development is not compatible with sustainable development objectives.
- Realising sustainable futures will require much greater reliance on some combination of higher energy efficiencies, renewable resources, and advanced energy technologies.
- A prerequisite for achieving an energy future compatible with sustainable development objectives is finding ways to accelerate progress for new technologies along the energy innovation chain, from research and development to demonstration, deployment, and diffusion.

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[1] In this report, the term industrialised countries refers primarily to high-income countries that belong to the Organisation for Economic Co-operation and Development (OECD). Developing countries generally refers to lower income countries that are members of the G-77 and China. Although many transition economies also have a high degree of industrialisation, they are often considered and discussed separately because of their specific development requirements.

- Providing access to affordable energy services to people in rural areas poses particular challenges. But it also offers considerable opportunity for improving the lives of billions of people within a relatively short period. Promising approaches include decentralised solutions, appropriate technologies, innovative credit arrangements, and local involvement in decision-making, and especially new mechanisms at the local level that have lower transaction costs.
- Transportation is a key area with its rapid growth and high dependence on fossil fuels. By combining new fuels, both fossil and renewable, with near-zero greenhouse gas emissions and a better mix of improved modes of transportation and vehicle performance, it appears possible to meet sustainability criteria.
- Extending access to electricity to ten million new customers per year is estimated to require investments on the order of $10 billion per year. This offers considerable opportunity for improving the lives of billions of people within a relatively short period.[2]

Any conceivable energy system that would address all sustainable development objectives simultaneously will not be realised without changes in the current policy environment. Creating such an energy system will require policy action at national, regional, and global levels.

Policies and Actions to Promote Energy for Sustainable Development

The analysis presented here identifies key strategies and policies for globally achieving both economic growth and sustainable development. The actions needed include:

- Encouraging greater international co-operation in areas such as technology procurement, harmonisation of environmental taxes and emissions trading, and energy efficiency standards for equipment and products.
- Adopting policies and mechanisms to increase access to energy services through modern fuels and electricity for the two billion people without such access.
- Building capacity among all stakeholders, especially in the public sector, to address issues related to energy for sustainable development.
- Advancing innovation, with balanced emphasis on all steps of the innovation chain.
- Creating market framework conditions (including continued market reform, consistent regulatory measures, and targeted policies) to encourage competitiveness in energy markets, to reduce total cost of energy services to end-users, and to protect important public benefits.
  - Cost-based prices, including phasing out all forms of permanent subsidies for fossil fuels and nuclear power and internalising external environmental and health costs and benefits.
  - Removing obstacles and providing incentives, as needed, with "sunset" clauses, to encourage greater energy efficiency and the development and/or diffusion to wider markets of new technologies for energy for sustainable development.
  - Reversing the trend of declining official development assistance and foreign direct investments, especially as related to energy for sustainable development.

■ ■ ■

The challenges of sustainability are major ones. At the same time, there are hopeful signs. Clearly, energy can serve as a powerful tool for sustainable development. The World Energy Assessment shows that there are indeed combinations of resources and technologies that are capable of meeting most, if not all, of the sustainability changes simultaneously. The finding that measures related to energy can help address several major issues at the same time is highly significant, as it should add support for those measures from different groups in society. The decisive issues are not technology or natural resource scarcity, but the institutions, rules, financing mechanisms, and regulations needed to make markets work in support of energy for sustainable development.

Some governments and corporations have already demonstrated that policies and measures to promote energy solutions conducive to sustainable development work. The renewed focus and broad agreements on energy in the WSSD Plan of Implementation and at the eighteenth World Energy Congress are promising. The formation of many partnerships on energy between and among stakeholders at WSSD is another encouraging sign. A sustainable future in which energy plays a major positive role in supporting human well being is possible! ■

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[2] A billion equals a thousand million.

introduction

The World Energy Assessment provides analytical background and scientific information for decision makers at all levels. It describes energy's fundamental relationship to sustainable development and analyses how energy can serve as an instrument to reach that goal. This overview synthesises the key findings of the report, which is divided into six parts.

Part I outlines the institutional framework, particularly at the United Nations level at which sustainable energy development is discussed, updating previous information to include the important decisions taken in Johannesburg in 2002 at the World Summit on Sustainable Development.

Part II provides the basic facts concerning production of energy carriers and distribution and use of energy, taking 2001 as the reference year. The facts illustrate the heterogeneity among regions in resources availability and energy use.

Part III considers the linkages between the current energy system and major global issues, including poverty alleviation, health, environmental protection, energy security, and the improvement of women's and children's lives. To meet objectives in these areas, major changes in local, regional, and global energy systems are needed.

Part IV examines the energy resources and technological options available to meet the challenges identified. It concludes that physical resources are plentiful enough to supply the world's energy needs through the twenty-first century and beyond, but that their use may be constrained by environmental and other concerns. Options to address these concerns through greater energy efficiency, use of renewable energy sources, and next-generation technologies – are then analysed. The analysis indicates that the technical and economic potential of energy efficiency measures is under-realised, and that a larger contribution by renewables to world energy use is already economically viable. Over the longer term, a variety of new renewable and advanced energy technologies may be able to provide substantial amounts of energy safely, at affordable costs, and with near-zero emissions.

Part V synthesises and integrates the material presented in the earlier parts by considering whether sustainable futures – which address the issues discussed in part III using the options identified in part IV – are possible. The analysis shows that development based on current trends does not meet several criteria of sustainability. However, combinations of resources and technologies exist that would be economically feasible and meet most, if not all, sustainability challenges at the same time. Special attention is given to the challenge of bringing affordable energy to the rural areas of developing countries. It presents approaches to widening access to liquid and gaseous fuels for cooking and heating and to electricity for meeting basic needs and stimulating income-generating activities. Finally, the special challenges in the transportation sector are analysed.

Part VI analyses policy issues and options that could shift current unsustainable practices in the direction of sustainable development, using energy as an instrument to reach that goal. Creating energy systems that support sustainable development will require policies that take advantage of the market to promote greater energy efficiency, increased use of renewables, and the development and diffusion of cleaner, next-generation energy technologies. Given proper signals, market actors could deliver much of what is needed. However, market forces alone are unlikely to meet the energy needs of poor people, or to protect adequately the environment. Sustainable development demands frameworks (including consistent policy measures and transparent regulatory regimes) to address these issues.

part I

Energy at the World Summit for Sustainable Development

Energy was one of the most intensely debated issues at the World Summit for Sustainable Development (WSSD) in Johannesburg in September 2002. In the end, agreement was reached that significantly advances the attention given to energy in the context of sustainable development. These developments followed years of efforts to focus on energy as an instrument for sustainable development after the United Nations Conference on Environment and Development in 1992 and are briefly reviewed here.

The United Nations Conference on Environment and Development

The United Nations Conference on Environment and Development (UNCED) held in 1992, in Rio de Janeiro, Brazil brought to the fore global attention on environment and development issues, but did not explicitly address energy issues in their entirety. Agenda 21, one of the principal non-binding intergovernmental outcomes of UNCED, provides a blue print for sustainable development. Agenda 21 does not, however, contain a specific chapter on energy; but aspects of energy in relation to environment and development have been addressed in Chapter 9 of Agenda 21, in the section entitled "Protection of the Atmosphere". The main emphasis of energy within Agenda 21 was,

> *"…to reduce adverse effects on the atmosphere from the energy sector by promoting policies and programmes as appropriate, to increase the contribution of environmentally sound and cost-effective energy systems, particularly new and renewable ones, through less polluting and more efficient energy production, transmission, distribution and use."*[3]

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[3] United Nations, "Agenda 21", 1992. Chapter 9, paragraph 9.11. Available on the internet at http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm

Intergovernmental considerations at UNCED reflected the pressing concerns linked to the emerging issue of global climate. Although, the need for equity as well as the need for increasing energy consumption in developing countries was reflected in Agenda 21, the issue of universal access to energy services for almost one-third of the global population was not paid adequate attention.

While the role of energy in sustainable development is addressed in several Agenda 21 chapters dealing with human health, protection of atmosphere, transport, industry, agriculture and technology, energy issues and strategies were not comprehensively dealt with within Agenda 21.

Other significant outcomes of UNCED in addition to Agenda 21 are, the United Nations Framework Convention on Climate Change and the establishment of the United Nations Commission on Sustainable Development (CSD) with a mandate for effective follow up to UNCED.

UNCED was followed by a series of major international and UN conferences that considered energy in relation to many aspects of development. Relevant global forums focusing on energy related issues in the 1990s include the following: UN International Conference on Population and Development (1994), Global Conference on Sustainable Development of Small Island States (1994), World Summit on Social Development (1995), the Fourth World Conference on Women (1995), the UN Conference on Human Settlements (1996), World Solar Summit (1996) and the World Food Summit (1996).[4]

The United Nations General Assembly Special Session

A review of the five-year progress of implementation of Agenda 21 by the United Nations General Assembly at its nineteenth special session (UNGASS-19) focused intergovernmental attention on energy for sustainable development for the first time. UNGASS-19 recognized the "need for a movement towards sustainable patterns of production, distribution, and use of energy and, emphasizing the overarching significance of energy for sustainable development" decided that energy and transport issues should be addressed at the ninth session of the CSD.[5] UNGASS-19 also agreed that preparations for CSD-9 should utilize an "Ad Hoc Open-Ended Intergovernmental Group of Experts on Energy and Sustainable Development". In order to provide relevant analytical input to the preparatory process for CSD-9, UNDP, UNDESA and WEC jointly published a report entitled, "World Energy Assessment: Energy and the Challenge of Sustainability."[6] The report had the benefit of inputs from a number of international experts in energy as well as recommendations from a number of regional outreach meetings.

The Millennium Assembly

At the Millennium Summit held in 2000 at the United Nations General Assembly, world leaders agreed to a number of fundamental development goals and associated targets (Annex 1). The Millennium Development Goals (MDGs) are to:

- eradicate extreme poverty and hunger,
- achieve universal primary education,
- promote gender equality and empower women,
- reduce child mortality,
- improve maternal health,
- combat HIV/AIDS, malaria and other diseases,
- ensure environmental sustainability, and
- develop a global partnership for development.

Notably there is no MDG on increased access to energy services, though energy-related indicators are used to measure progress made on environmental sustainability. None of the MDGs can be achieved without much greater access to improved quality and an increased quantity of energy services. Recognition of the importance of energy in achieving sustainable development led many governments to focus on achieving agreement on a clear energy goal that could be agreed upon at the WSSD in Johannesburg.

The Group of Eight (G8) Renewable Energy Task Force

The Renewable Energy Task Force was established in response to an appeal by the Group of Eight (G8) industrialised countries at their meeting in Okinawa in 2000. Stakeholders were invited to join in a Task Force to prepare concrete recommendations to better encourage

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4. A summary of the outcomes of some of these conferences with regards to energy is contained in a UNDP Report, see A.K.N. Reddy, R.H. Williams, and T.B. Johansson, "Energy After Rio: Prospects and Challenges". (New York: UNDP) 1997.
5. UNGASS, "Programme for the Further Implementation of Agenda 21", (A/RES/s-192), 1997: paragraph 45.
6. UNDP, UNDESA, WEC, "World Energy Assessment: Energy and the Challenge of Sustainability". (New York: UNDP) 2000.

the use of renewables in developing countries.

The main recommendation made by the Task Force in 2001 was to reduce costs by expanding markets. As far as wind and photovoltaics are concerned, most current markets are in developed countries; expanding the market for these technologies will help to bring costs down, which is a prerequisite for their use in developing countries. The policies and actions that could bring this about include support for research and development and the use of portfolio standards and tariffs to enhance the market penetration of renewable energy technologies.

As far as biomass is concerned, most of the resources and markets are in developing countries. However, the available technologies are frequently inefficient. Thus the Task Force recommended that multinational development banks use innovative approaches to investments in R&D and market-based financing mechanisms.

Commission on Sustainable Development

At the intergovernmental level, the ninth meeting of the Commission on Sustainable Development (CSD-9) held in 2001 succeeded in reaching consensus on key energy issues and actions needed to address them at national, regional and global levels. CSD-9 also contributed to a shared understanding of the challenges ahead and the significance of energy in terms of its central role in achieving the goals of sustainable development, recognizing the synergies created by the simultaneous pursuit of poverty eradication and mitigation of environmental impacts of energy.

The agreement reached at CSD-9 on energy for sustainable development recognizes for the first time that energy is central to achieving the goals of sustainable development and takes into consideration the fact that:

- nearly one third of the global population of six billion people, mostly living in developing countries, continue to lack access to energy services;
- wide disparities in the levels of energy consumption within and between developed and developing countries exist;
- current patterns of energy production, distribution and utilization are unsustainable.

Access to affordable energy services is fundamental to human activities, development, and economic growth.

Furthermore it was recognized that ensuring access to modern energy carriers for the two billion people without access is one of the prerequisites for meeting poverty reduction goals.

Energy issues and options agreed upon at CSD-9 emphasized *inter alia*, the need for:

- increasing energy efficiency in all economic sectors;
- increased use of renewable energy;
- greater reliance on advanced energy technologies, including advanced fossil fuel technologies, and the sustainable use of traditional energy resources;
- developing appropriate energy services particularly in rural areas;
- integrating energy considerations in socio-economic programmes, especially in policy making of major energy consuming sectors, such as the public sector, transport, industry, agriculture, urban planning and construction;
- enhanced regional and international cooperation on energy for sustainable development;
- integrating energy considerations into bilateral and multilateral development cooperation and into lending policies of development banks;
- continuation of international dialogue on energy for sustainable development in the context of preparations for the World Summit on Sustainable Development.

On the issue of nuclear energy, it was agreed that the choice of nuclear energy rests with individual countries. While some countries considered nuclear power as a sustainable energy source with both economical and environmental advantages, other countries do not consider nuclear energy as compatible with the objective of sustainable development, and that risks related to safety, waste management and transport and stranded costs remain unresolved. For those countries that choose nuclear energy, the challenge lies in ensuring environmentally sound, socially acceptable, and cost-effective solutions and in addressing nuclear safety and spent fuel and waste management as well as public concerns on these issues.

Although CSD-9 recommendations are quite clear on actions needed at various levels- national, regional and global, not specifically provided for in those recommendations were mechanisms and means of implementation. Nevertheless, CSD-9 provided a solid basis for addressing energy for sustainable development and to build further international endeavours based on what was achieved at CSD-9.

Put people's needs and sustainable development at the centre of market reform, regulation and technology diffusion.

The Eighteenth World Energy Congress

Economic growth, social progress, and environmental protection are the three inter-linked pillars of sustainable development. It is important to put people's needs and sustainable development at the centre of market reform, regulation, and technology diffusion.

The eighteenth World Energy Congress in Buenos Aires in October 2001 strongly reaffirmed the goals of energy accessibility, energy availability, and social and environmental acceptability that were established in the World Energy Council (WEC) Millennium Statement, *"Energy for Tomorrow's World—Acting Now!"* (WEC, 2000). Because the achievement of these goals is essential to sustainable development, WEC decided at the eighteenth Congress to focus its 2002-2004 work programme on the following objectives:

- achieving access to commercial energy for the two billion people in the world who do not now have it;
- developing stable regional trade policies, clear legal frameworks, and sensible regulations for energy development;
- keeping all energy options open, including the safe use of nuclear power and the promotion of renewables;
- increasing efficiency through competition and technology diffusion;
- implementing advanced, cleaner technologies to reduce the impact of human-induced emissions on the quality of human life and the natural world around us.

These goals are closely related. Trade and technology access and development drive economic growth that, among other factors, is the prerequisite for addressing poverty and expanding energy access. This in turn is closely linked to availability of energy services and energy acceptability.

More often than not, the financial requirements of energy projects are a bigger challenge than accessing the technology and know-how. Governments, regulators, and energy companies have made progress in these areas, but much more work is needed to address poverty, to improve skills and working conditions, and to reduce/control pollution. It is essential for all stakeholders to continue to work together on realistic market-driven solutions to specific problems. There is a crucial role for the creation of a mechanism that reduces transaction costs between low-income consumers and suppliers of energy services.

Progress in Implementing the United Nations Framework Convention on Climate Change

One of the most serious threats to the environment is climate change. The international response was the adoption of the United Nations Framework Convention on Climate Change in 1992. The objective of the convention is to "stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". Since some two thirds of all greenhouse gases originate in the production and use of energy carriers, mostly from fossil fuels, there is a strong link between climate change mitigation and the global energy system.

The highest decision-making body under the UNFCCC is the "Conference of the Parties" (COP) that meets annually. In 1997, at COP-3 in Kyoto, the Parties agreed to the Kyoto Protocol, which sets legally binding greenhouse gas emissions reduction targets for industrialised countries (called the Annex I Parties). The emission reduction levels are significant as a first step. Several mechanisms are included to help the Parties achieve their commitments, including emissions trading, joint implementation, and the Clean Development Mechanism (CDM). The CDM also has the objective of helping developing countries (non-Annex I Parties) achieve sustainable development. In 2001, at COP-7, the Parties agreed to the Marrakech Accords, which set out details for the implementation of the Kyoto Protocol. Since then, the ratification process has been under way. A large number of countries have ratified the Kyoto Protocol and whether it enters into force depends on whether and when the Russian Federation ratifies. The United States has declared that it will not ratify.

The Intergovernmental Panel on Climate Change (IPCC) provides the UNFCCC processes with scientific information on climate change impact, and adaptation and mitigation. Its Third Assessment Report, released in 2001, concluded, *"there is new and stronger evidence that most of the warming observed over the last fifty years is attributable to human activities"* (IPCC, 2001, p. 10).

COP-8 was held in New Delhi in 2002, and was characterised by discussions over broader commitments, increasing focus on adaptation, the meaning of sustainable development and its relation to climate change, and the possible existence of a dichotomy between development and environment. No agreement was reached on formally negotiating broader and more ambitious commitments.

The World Summit on Sustainable Development

The process leading up to the WSSD in Johannesburg in August/September 2002 consisted of a series of intergovernmental preparatory committee meetings, or "Prep Coms". To provide greater clarity on important issues identified during the preparatory process. U.N. Secretary General Kofi Annan, in a key statement on 14 May, introduced the idea of a framework involving a select few key topics that would guide the Summit discussions. Calling it the "WEHAB Framework", the Secretary General proposed highlighting the topics of Water, Energy, Health, Agriculture, and Biodiversity (WEHAB) for emphasis at the conference.

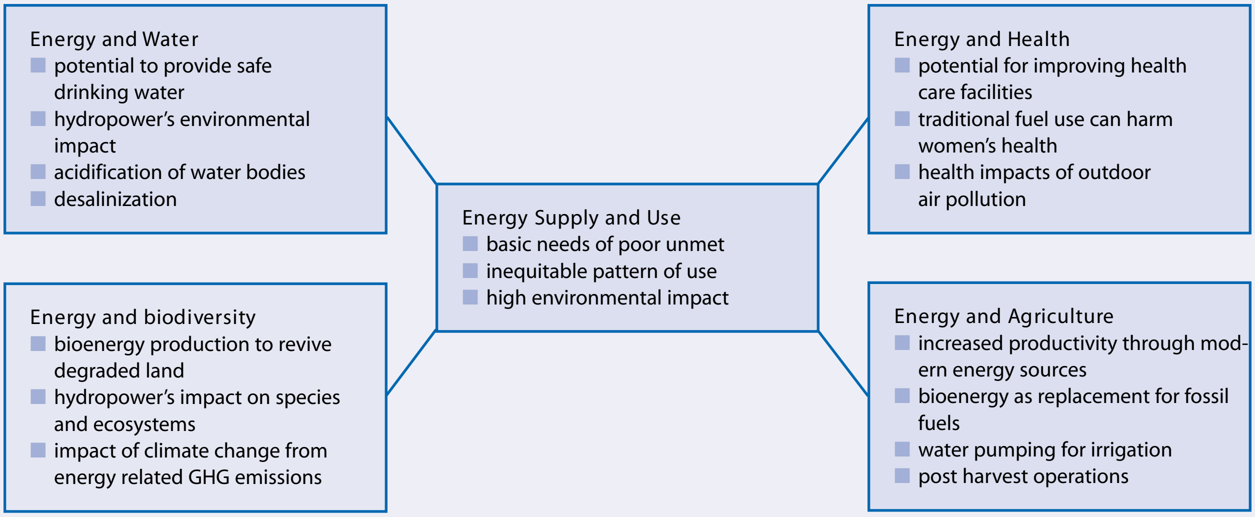
The WEHAB energy framework highlighted the linkages between energy and goals related to water, health, agriculture, and biodiversity, emphasising the interdependence among sustainable development issues (Figure 1). Development goals in the areas of water, health, agriculture, and biodiversity often cannot be met without energy inputs, and the policies adopted in these sectors similarly impact the availability and reliability of energy services.

The energy framework drew international attention to the fact that "there is currently no international nor intergovernmental process to host or facilitate dialogue on priority energy issues". It recommended that concerted action and an energy dialogue at the international level are needed to support energy systems development consistent with sustainable development and to track progress on energy issues in relation to globally agreed development goals (WEHAB, 2002).

Energy was an intensely debated issue at WSSD and agreement on energy was not reached until the final day of the Summit. As such, it is an important element in, the final Plan of Implementation, the central outcome of the meeting. Compared to UNCED in 1992, energy, particularly the issue of access to energy services, moved from the periphery to centre stage. With an overall focus on poverty alleviation at WSSD, many of the non-environmentally derived issues linked to energy systems and services took on greater importance.

There was a strong effort to reach agreement on a global target on renewable energy, with some proposing that 10 percent of total energy supply should come from renewable sources by 2010. This ran into stringent opposition and deliberations were complicated by the

FIGURE 1. EXAMPLES OF THE CRITICAL ROLE OF ENERGY IN WEHAB* PRIORITY AREAS



* WEHAB (water, energy, health, agriculture, biodiversity) is a framework prepared by the Secretariat of the World Summit for Sustainable Development.

Source: Modified from WEHAB, 2002.

Concerted action and an energy dialogue at the international level are needed to support energy systems development consistent with sustainable development.

fact that no clear definition of renewable energy was put forward, especially concerning the role of large hydro and biomass as sources of energy. Many countries voiced concerns that a target specifying energy supply sources was irrelevant or secondary to a supply or access target. There was no agreement on a target specifying increased access to energy services and no agreement on potential financing sources to support this.

The final texts on energy within the Plan of Implementation are found in paragraphs 9, 20, and 38 in the respective chapters dealing with poverty eradication (II), changing unsustainable patterns of consumption and production (III), and protecting and managing the natural resource base of economic and social development (IV) (United Nations, 2002). The introductory section of paragraph 9 urges the international community to:

> *"take joint actions and improve efforts to work together at all levels to improve access to reliable and affordable energy services for sustainable development sufficient to facilitate the achievement of the millennium development goals, including the goal of halving the proportion of people in poverty by 2015, and as a means to generate other important services that mitigate poverty, bearing in mind that access to energy facilitates the eradication of poverty".*

Subsequent items deal with access to modernised biomass, cleaner liquid and gaseous fossil fuels, enhanced energy efficiency, expanded use of renewable energy, and new and advanced energy technologies, including cleaner fossil fuel technology. Paragraph 9 calls for a greater focus on rural electrification as a means to address poverty and underscores the crucial role of policy and regulatory frameworks to achieve this. The overall focus is on increasing access to energy services. Paragraph 9 is particularly important to developing countries, where the majority of poor people live.

Paragraph 20 largely reiterates the conclusions of CSD-9 and calls for greater international financial co-operation to shift towards more sustainable patterns of consumption and production. This paragraph is relevant to all countries, most significantly the industrialised countries, where current patterns of energy production, distribution, and consumption are highly unsustainable. It emphasises diversifying the energy supply mix, increasing the use of renewable energy and low-emissions technology, and enhanced international co-operation. Paragraph 20 calls on the international community to:

> *"diversify energy supply by developing advanced, cleaner, more efficient, affordable and cost-effective energy technologies, including fossil fuel technologies and renewable energy technologies, hydro included, and their transfer to developing countries on concessional terms as mutually agreed. With a sense of urgency, substantially increase the global share of renewable energy sources with the objective of increasing its contribution to total energy supply, recognising the role of national and voluntary regional targets as well as initiatives, where they exist, and ensuring that energy policies are supportive to developing countries' efforts to eradicate poverty, and regularly evaluate available data to review progress to this end".*

Paragraph 38 deals extensively with climate-related issues and reaffirms the UNFCC as the key instrument for addressing climate change, with the ultimate objective of stabilisation of greenhouse gas concentrations in the atmosphere. Further, the agreed text notes that,

> *"States that have ratified the Kyoto Protocol strongly urge States that have not already done so to ratify the Kyoto Protocol in a timely manner".*

Attention is given to energy and transport issues in paragraph 21, with emphasis on an integrated policy approach, energy efficiency and public mass transportation as well as affordability as means to support sustainable development.

Overall the agreement on energy detailed in the Plan of Implementation point to key areas for national, regional, and international co-operation on energy issues. Energy as a means to support the attainment of overall sustainable development objectives beyond the energy sector is clearly recognised, and the important role of the public sector in establishing supportive policy environments to facilitate this is a common thread throughout the Plan.

While the focus of the Johannesburg Plan of Implementation is on implementation, there are no provisions for new international financial agreements or commitments such as those agreed at UNCED. Instead, decisions taken at the summit-level International Conference on Financing for Development held earlier in 2002 (the "Monterrey Summit") were viewed as complementing WSSD decisions. The Monterrey Summit did not address the issue of energy but made general recommendations on mobilising international resources for foreign investment and other private flows.

In relation to energy, a total of 39 partnerships to promote sustainable energy programs in developing countries were presented to the United Nations Secretariat for WSSD, 23 with energy as a central focus and 16 with a considerable impact on energy. These partnerships included most prominently: the UNDESA/UNEP/US EPA-led Clean Fuels and Transport Initiative; the UNDP/World Bank-led Global Village Energy Partnership (GVEP); the LPG (Liquefied Petroleum Gas) Challenge led by UNDP and the World LPG Association; the Alliance for Rural Africa (AREA) led by Electricité de France (EdF); the Johannesburg Renewable Energy Coalition (JREC); the European Union Partnership on Energy for Poverty Eradication and Sustainable Development; and the UNEP-led Global Network on Energy for Sustainable Development (GNESD).

One of the main topics of discussion at the Commission for Sustainable Development in 2003 was the need to establish means of tracking, monitoring, and reporting on progress made in the implementation of these partnership initiatives. Since they are voluntary partnerships, they do not involve binding intergovernmental commitments to support or fund them through new or additional resources. Described as “coalitions among the willing”, these partnerships do form an important new means of engagement between the private sector, civil society, and the development assistance community. They could have a significant impact in some areas of the world.

At its meeting in spring 2003, the Commission on Sustainable Development also adopted a multi-year work program for itself and decided to change its working methods. According to the new way of operation, themes will be taken up in two-year action-oriented "implementation cycles", consisting of a review and a policy session. In its review session, CSD will evaluate progress in implementing Agenda 21, the Programme for the Further Implementation of Agenda 21, and the Johannesburg Plan of Implementation. CSD will also focus on identifying constraints and obstacles in the process of implementation with regard to the thematic clusters. According to the multi-year program, CSD will again take up energy issues in its 2006/07 cycle. ■

part II

Basic Energy Facts

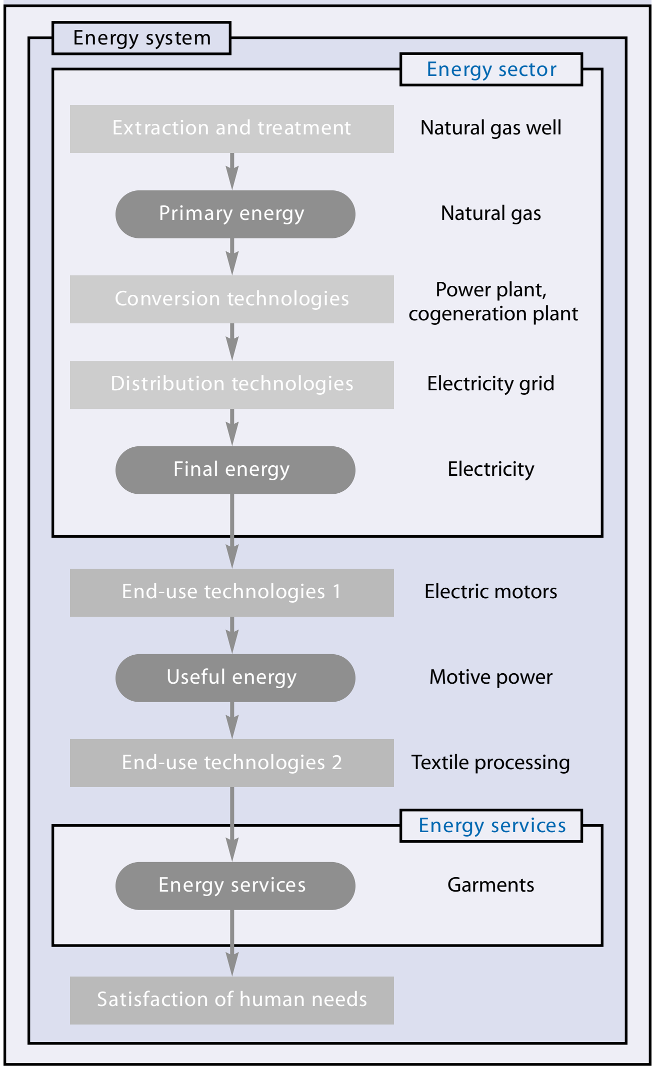
An energy system is made up of an energy supply sector and energy end-use technologies. The objective of an energy system is to deliver to consumers the benefits that energy use offers. The term energy services is used to describe these benefits, which for households include illumination, cooked food, comfortable indoor temperatures, refrigeration, telecommunications, education, and transportation. Energy services are also required for virtually every commercial and industrial activity. For instance, heating and cooling are needed for many industrial processes, motive power is needed for agriculture and industry, and electricity is needed for telecommunications and electronics. It is the availability of and access to energy services, not merely energy supply, that is crucial.

The energy chain that delivers these services begins with the collection or extraction of primary energy that, in one or several steps, may be converted into energy carriers, or final energy such as electricity or diesel oil that are suitable for end uses. Energy end-use equipment – stoves, light bulbs, vehicles, machinery, etc. – converts the final energy into useful energy, which (with the help of additional technologies) provides the desired benefits: the energy services. An example of an energy chain – beginning with natural gas extracted from a well (primary energy) and ending with produced garments as an energy service – is shown in Figure 2.

Energy services result from a combination of various technologies, infrastructure (capital), labour (know how), materials, and primary energy. Each of these inputs carries a price tag, and they are partly substitutable for one another. From the consumer's perspective, the important issues are the economic value or utility derived from the services. Consumers are often unaware of the upstream activities required to produce energy services.

One way to capture the importance of energy services (not merely energy use or supply as an end in itself) is to show its impact on the human development index (HDI), a composite indicator developed by UNDP to show countries' relative well being in social as well as economic terms. Figure 3 displays the correlation between a country's human development index ranking and per capita energy use, with commercial energy used as a proxy for energy services. Because the efficiency of energy use in countries with the lowest per capita energy use is much lower than in countries with higher per capita energy use, the relative level of energy services is even lower in the low per capita energy use countries. Thus Figure 3 shows that an HDI of 0.8 or higher currently requires a minimum energy use of about 1 tonne of oil-equivalent per year per capita (or 42 GJ per capita). It is noteworthy that a higher than ten-fold increase in consumption of energy does not increase the HDI significantly.

FIGURE 2. AN EXAMPLE OF THE ENERGY CHAIN FROM EXTRACTION TO SATISFACTION OF NEEDS



In most low-income developing countries, a small, affluent minority uses various forms of commercial energy in much the same way as most people in the industrialised world do. However, most people in low-income developing countries rely on traditional, non-commercial sources of energy using inefficient technologies such as unventilated stoves or open fires. Traditional energy sources are generally not reflected in energy statistics. Analysis based on "per capita" consumption of commercially distributed energy resources is common because the data are much easier to collect. The resulting analysis, however, does not accurately reflect the world's energy situation. Though less well-documented, non-commercial energy is very significant globally, and is used far more widely than commercial energy in rural areas of many developing countries, particularly the least developed countries.

Per capita use of primary energy in North America was 280 gigajoules in 2000, more than eleven times as much as used by an average sub-Saharan African (who used 25 gigajoules that year when both commercial and non-commercial energy are included).[7] In OECD Europe and OECD Pacific – developed countries in those regions – per capita energy use was about 142 and 180 GJ, respectively. Figure 4 shows per capita commercial and non-commercial energy use in various regions.

Table 1 and Figure 5 show 2001 global primary energy use, including both commercial and non-commercial sources of energy. Fossil fuels (oil, natural gas, and coal) represent nearly 80 percent of the total. Nuclear power contributes approximately 7 percent; however, because nuclear power plants have only one third of thermal efficiency, the final electricity generated for consumption is basically the same as that generated by large hydropower. Large hydropower and "new" renewables (which includes modern uses of biomass and small hydropower, geothermal, wind, solar, and marine energy) each contribute slightly more than 2 percent; the percentage contribution of "new renewable energy sources" has changed little in recent years.

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[7] In this report, the term commercial energy refers to fossil fuels (oil, coal, and natural gas), nuclear energy, and large-scale hydropower. The term traditional energy is used to denote locally collected and often unprocessed biomass-based fuels, such as crop residues, wood, and animal dung. Most traditional energy is used non-commercially (i.e., non-commercial energy). Although traditional energy sources can be used renewably, the term new renewables refers to modern biofuels, wind, solar, small-scale hydropower, marine, and geothermal energy.

FIGURE 3. **RELATIONSHIP BETWEEN HDI AND PER CAPITA ENERGY USE, 1999/2000**

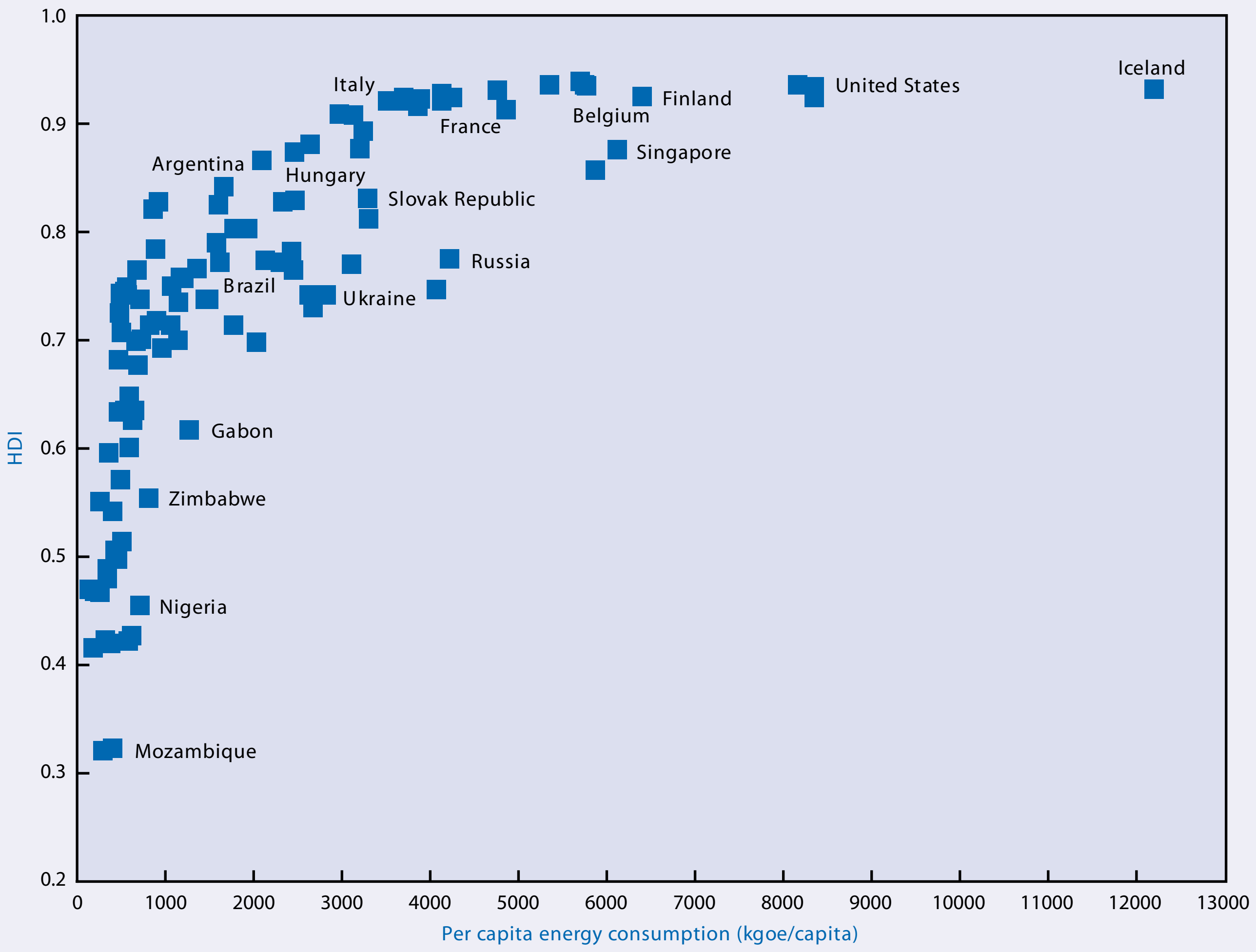
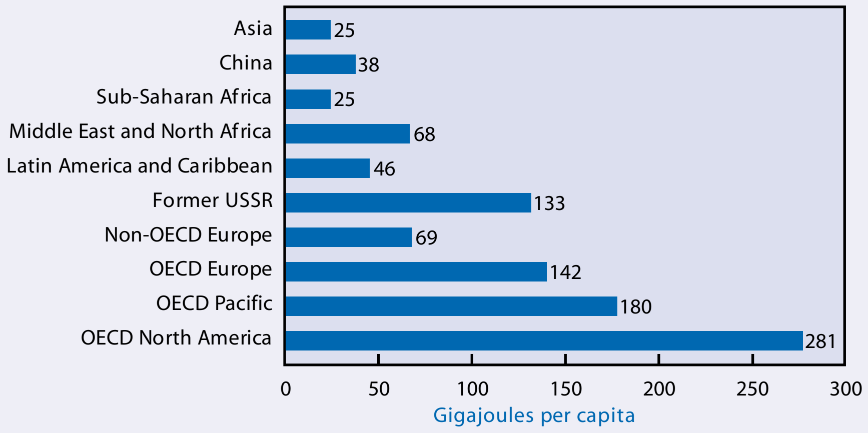


FIGURE 4. **PER CAPITA ENERGY USE (COMMERCIAL AND NON-COMMERCIAL), BY REGION, 2000**



Notes: Asia excludes Middle East, China, and OECD countries; Middle East and North Africa comprises Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates and Yemen; Latin America and Caribbean excludes Mexico; OECD Pacific comprises Australia, Japan, Korea, and New Zealand; Former USSR comprises Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan; Non-OECD Europe consists of Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Gibraltar, Macedonia, Malta, Romania, and Slovenia; OECD North America includes Mexico.

Sources: IEA, 2002a and 2002b.

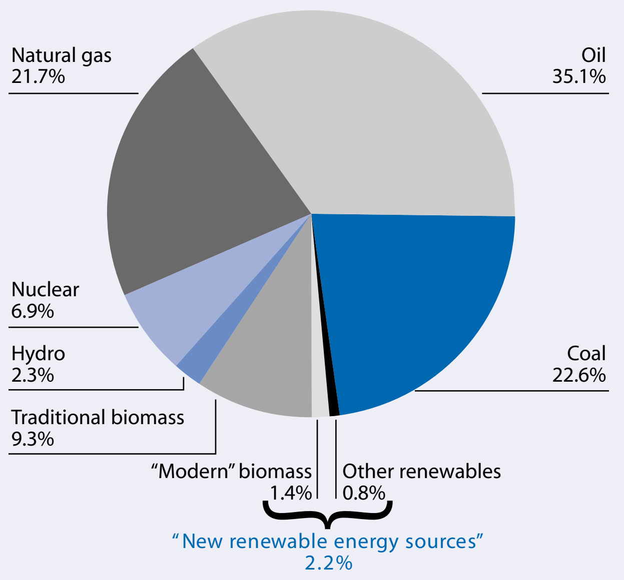
TABLE 1. WORLD PRIMARY ENERGY USE AND RESERVES, 2001

Source	Primary energy (exajoules, EJ)	Primary energy (10^9 tonnes of oil equivalent, Gtoe*)	Percentage of total (%)	Proved reserves (10^9 tonnes of oil equivalent, Gtoe*)	Static reserve-production ratio (years)[a]	Static resource base–production ratio (years)[b]	Dynamic resource base–production ratio (years)[c]
Fossil fuels	332	7.93	79.4	778			
Oil	147	3.51	35.1	143	41	~ 200	125
Natural gas	91	2.16	21.7	138	64	~ 400	210
Coal	94	2.26	22.6	566	251	~ 700	360
Renewables	57	1.37	13.7				
Large hydro	9	0.23	2.3		Renewable		
Traditional biomass	39	0.93	9.3		Renewable		
'New' renewables[d]	9	0.21	2.2		Renewable		
Nuclear	29	0.69	6.9	55			
Nuclear[e]	29	0.69	6.9	55	82[f]	~300 to >10,000[f]	
Total[f]	418	9.99	100.0				

* 1 toe = 42GJ. a. Based on constant production and static reserves. b. Includes both conventional and unconventional reserves and resources. c. Data refer to the energy use of a business-as-usual scenario—that is, production is dynamic and a function of demand. Thus these ratios are subject to change under different scenarios. Dynamic resource base – production was calculated based on a 2 percent growth rate per year from 2000 to peak production (oil 6.1 Gtoe, gas 6.3 Gtoe, and coal 8.9 Gtoe), followed by a 2 percent decline per year until the resource base is exhausted. d. Includes modern biomass, small hydropower, geothermal energy, wind energy, solar energy, and marine energy. Modern biomass accounts for 6.0 exajoules; 2.9 exajoules comes from all other renewables. "Modern biomass" refers to biomass produced in a sustainable way and used for electricity generation, heat production, and transportation (liquid fuels). It includes wood/forest residues from reforestation and/or sustainable management, rural (animal and agricultural) and urban residues (including solid waste and liquid effluents); it does not include traditional uses of fuelwood in inefficient and pollutant conversion systems. e. Converted from electricity produced to fuels consumed assuming a 33 percent thermal efficiency of power plants. f. Based on once-through uranium fuel cycles excluding thorium and low-concentration uranium from seawater. The uranium resource base is theoretically 60 times larger if fast breeder reactors are used.

Source: Updated from WEA, 2000, and Table 7.

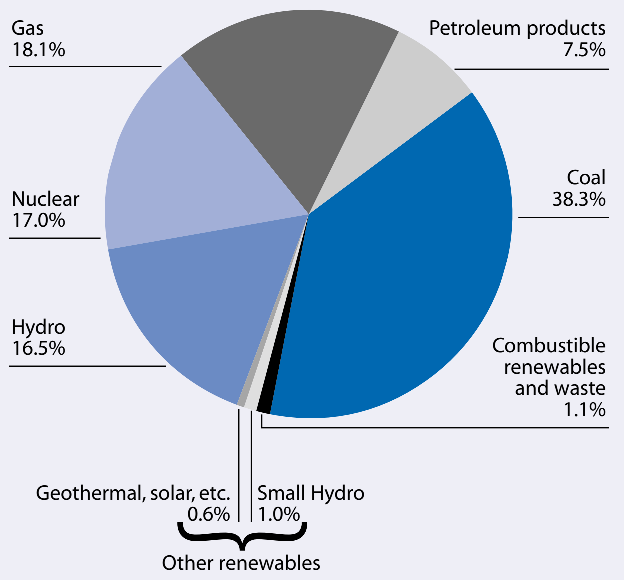
FIGURE 5. WORLD PRIMARY ENERGY USE, BY ENERGY SOURCE, 2001 (SHARES OF 10.2 GTOE)



Population: 6.102 billion
Total energy use: 10.2 Gtoe
Per capita energy consumption: 1.67 toe

Source: Tables 1 and 6.

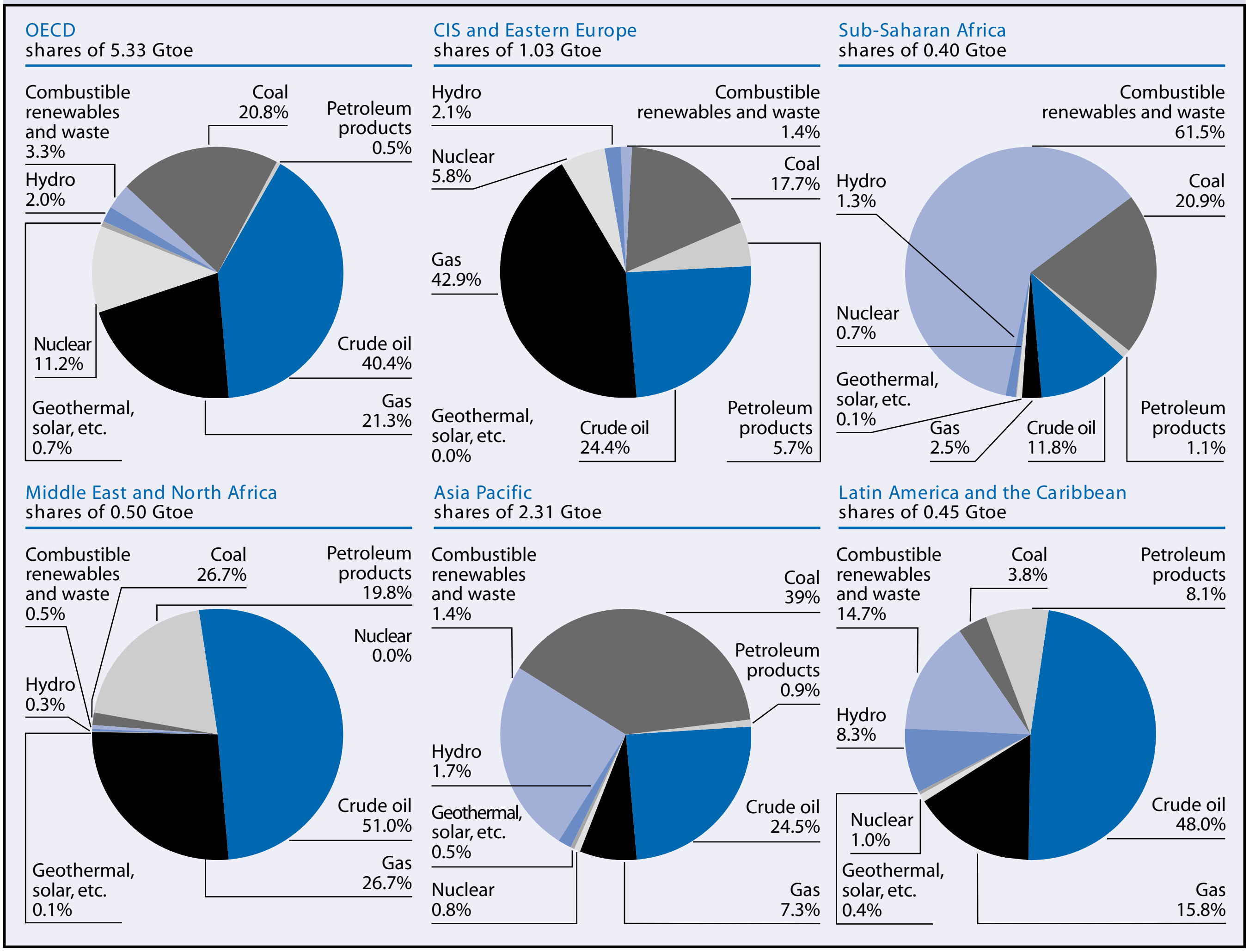
FIGURE 6. WORLD ELECTRICITY PRODUCTION, BY ENERGY SOURCE, 2001 (SHARES OF 15,476 TWH)



Note: Global electricity by source (calculated on the basis of TWh generated, not primary energy).

Sources: IEA, 2003c. Small hydro data from International Association for Small Hydro (IASH), www.iash.info/worldpotential.htm.

FIGURE 7. PRIMARY ENERGY USE IN VARIOUS REGIONS, BY ENERGY SOURCE, 2001



Source: IEA, 2003c.

Figure 6 shows global electricity production, numbers obtained in terawatt hours, i.e., final outputs that reflect the net energy service provided by all sources.

Total sales of energy carriers world-wide in 2001 amounted to on the order of US$2 trillion, about 6 percent of the world's gross domestic product.[8] Small shares of these amounts could make an enormous difference in terms of sustainable development if directed to cleaner energy forms. However, this is still not the case: at present, subsidies to conventional energy are on the order of $250 billion per year, while sales of "new" renewables are on the order of $20 billion per year.

There are great disparities in the way energy is consumed. Average "per capita" primary energy use in the world has reached 1.65 toe per year, which is approximately twenty times greater than minimum human energy requirements for survival, i.e., the daily energy use of primitive man (2000 kcal).

Figure 7 gives a breakdown of primary energy use for various regions (OECD, Commonwealth of Independent States and Eastern Europe, Sub-Saharan Africa, Middle East and North Africa, Asia-Pacific, Latin America and the Caribbean). The regions show large differences in their primary energy mix, reflecting both the availability of primary energy sources and consumption patterns.[9] Figure 8 shows electricity production for the

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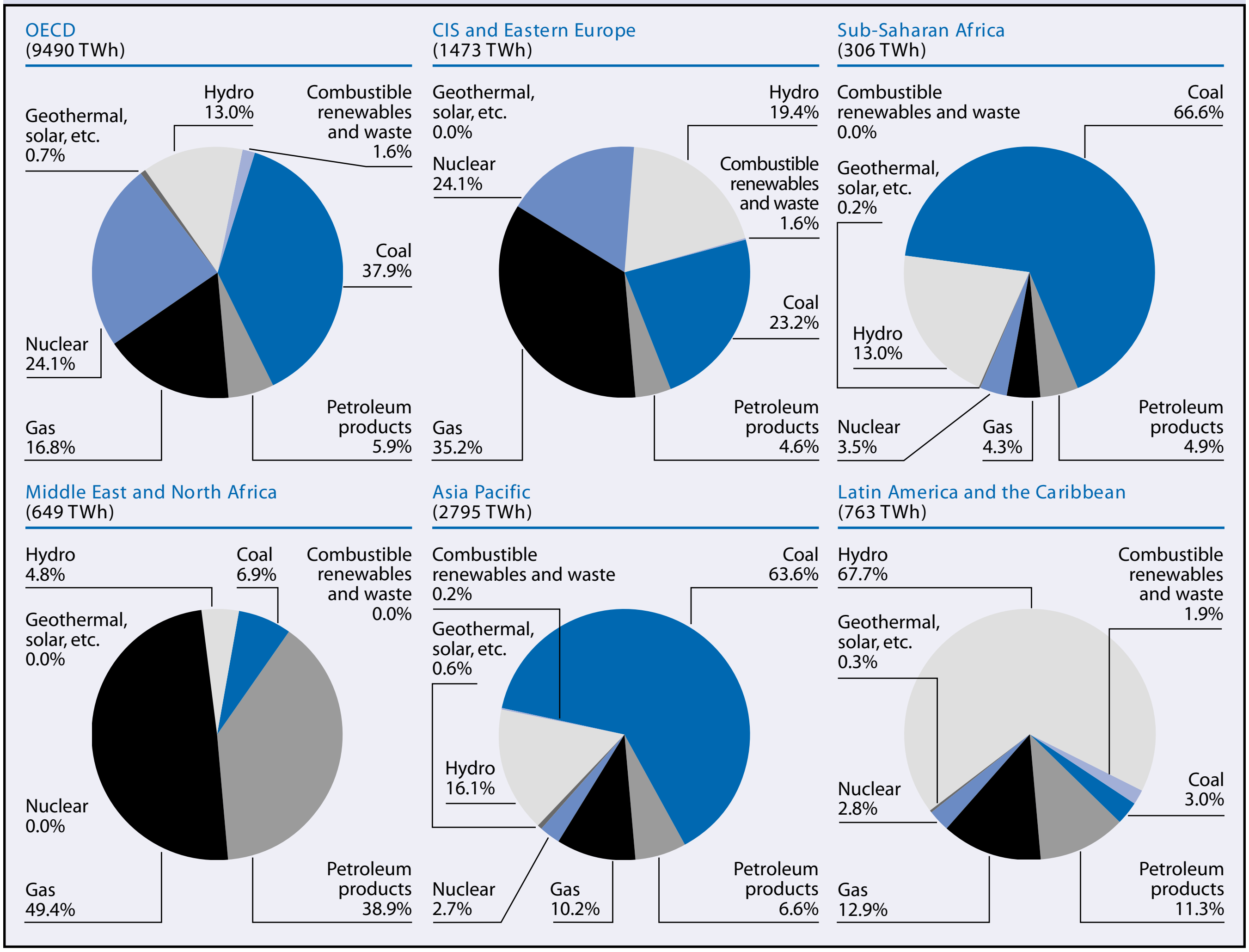
[8] As estimated by converting 10 Gtoe to barrels of oil at a value of US$30 per barrel.

[9] According to the International Energy Agency (2003, p. I.9), "Combustible renewables and waste comprises solid biomass, liquid biomass, biogas, industrial waste and municipal waste. Biomass is defined as any plant matter used directly as fuel or converted into fuels (e.g., charcoal) or electricity and/or heat. Included here are wood, vegetal waste (including wood waste and crops used for energy production), ethanol, animal materials/wastes and sulphite lyes (...) also known as "black liquor (...). Municipal wastes comprises wastes produced by residential, commercial and public service sectors that are collected by local authorities for disposal in a central location for the production of heat and/or power. Hospital waste is included in this category". The Agency also

FIGURE 8. SHARES OF ELECTRICITY PRODUCTION IN VARIOUS REGIONS, BY ENERGY SOURCE, 2001



Source: IEA, 2003c.

same regions, again with large variations.

Fossil fuels use accounts for 83 percent of the energy consumed in industrialised countries, 89 percent in transition-economy countries, and appreciably less in some other regions. In contrast, traditional and modern biomass account for 16 percent of the energy consumed in the developing countries of the Latin America and Caribbean, for 25 percent in developing Asia, and almost 60 percent in Sub-Saharan Africa. Yet it represents only 3 percent of primary energy used in industrialised countries, and is negligible in the transition economy countries of Eastern Europe and the former Soviet Union. Nuclear energy is also significant in industrialised countries (where it is the source of 11 percent of primary energy) and transition economy countries (7 percent); however, it makes only a minor contribution in developing countries (0.4 percent, or even less). Hydropower is unevenly used, providing 72 percent of electricity in Latin America and the Caribbean, and 9 percent in Middle East and North Africa, regions with scarce resources. Non-hydro renewable energy in electricity production is low in all regions.

World-wide, traditional energy accounts for nearly 10 percent of total primary energy used (Figure 5). However, the distribution is uneven: traditional energy accounts for less than 3.4 percent of energy use in industrialised countries but an average of 17.9 percent in developing countries In some low-income developing

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recognises that "Data under this heading are often based on small sample surveys or other incomplete information". The available statistics, do not separate unsustainable sources of biomass (e.g., fuelwood from deforestation) from the sustainable (e.g., biodiesel). Until more comprehensive data are published for all countries, it could be assumed that all Combustible Renewables and Waste (CRW) from developed countries are renewable; for developing countries, at least, the CRW applied into electricity production (thus a modern process) can also be considered renewable.

TABLE 2. PRIMARY ENERGY USE, BY REGION, 2001

Region	TPES* (Gtoe)	Population (billions)	toe/capita	Growth rate 1990-2001 %/year
1. OECD (all industrialised countries)	5.33	1.14	4.68	1.52%
2. Commonwealth of Independent States and Eastern Europe	1.03	0.35	2.98	-3.26%
3. Sub-Saharan Africa	0.40	0.67	0.60	2.23%
4. Middle East and North Africa	0.50	0.31	1.62	4.65%
5. Asia Pacific (non-OECD) with China	2.31	3.21	0.72	3.18%
6. Latin America and the Caribbean (without Mexico)	0.45	0.42	1.07	2.64%
World	10.03	6.10	1.64	1.41%
Developing countries (3+4+5+6)	3.66	4.62	0.79	3.19%

* TPES (total primary energy supply) is the indigenous production of energy, plus imports and positive stock changes, minus exports and international marine bunkers.

Source: IEA, 2003c.

countries, traditional biomass accounts for 80 percent or more of total energy use.

There are significant inequities in annual per capita energy use among groups of countries. In 2001, industrialised countries used 4.7 tonnes of oil equivalent (toe) per capita, in contrast to developing countries, which used only 0.8 toe per capita; the world average was 1.7 toe per capita. The per capita energy use in the sub-Saharan region was only 0.6 toe. The rate of growth in energy use also varies across country groups. Between 1990 and 2001, the average annual growth rate in primary energy use in industrialised countries was 1.5 percent; in developing countries, it was more than twice that amount (3.2 percent, with important variations among different regions of developing countries). Population growth and rising levels of economic activity drive this rapid increase (Table 2).

From this overview, it is clear that the availability and use of energy around the world is extremely heterogeneous. The varying growth rates in energy use have helped to reduce the gap in energy services between industrialised and developing countries and are the result of energy efficiency measures in OECD countries, the export of energy-intensive activities to developing countries, and increased access to energy services throughout the world. Nevertheless, the situation remains far from equitable. ■

part III

Energy and Major Global Issues

Part III analyses the linkages between energy and the economy, social and health issues, environmental protection, and security, and describes aspects of energy use that are incompatible with the goal of sustainable development. It shows that:

- Access to affordable energy services is fundamental to human activities, development, and economic growth. It is access to energy services, not energy supply *per se,* that matters.
- More than two billion people cannot access affordable energy services based on efficient use of gaseous and liquid fuels, and electricity. Without access to energy, their opportunities for economic development and improved living standards are constrained. Women and children, relatively more dependent on traditional fuels, suffer disproportionately.
- Wide disparities in access to affordable commercial energy and energy services in both urban centres and rural areas are inequitable, run counter to the concept of human development, and threaten social stability. Access to decentralised small-scale energy technologies is an important element of successful poverty alleviation.
- The environmental impacts of a host of energy-linked emissions – including suspended fine particles and precursors of acid deposition – contribute to local and regional air pollution and ecosystem degradation. Human health is threatened by high levels of pollution resulting from particular types of energy use at the household, community, and regional levels.
- Emissions of anthropogenic greenhouse gases, mostly from the production and use of energy, are altering the atmosphere in ways that are expected to affect the climate. There is new and stronger evidence that most of the warming observed over the last fifty years

is attributable to human activities. Within a few years, it will be too late to avoid doubling the concentration of carbon dioxide in the atmosphere.

- **Dependence on imported fuels leaves many countries vulnerable to disruption in supply, which might pose physical hardships and economic burdens; the weight of fossil fuels imports on the balance of payments is unbearable for many poorer countries. The existing energy system is heavily dependent on fossil fuels, which are geographically concentrated in a few regions of the world.**

Finding ways to expand energy services while simultaneously addressing the environmental impacts associated with energy use represents a critical challenge to humanity. Major changes are required in energy system development world-wide. The resources and technology options available to meet these challenges – energy efficiency, renewable energy sources, and advanced energy technologies – are analysed later in this volume.

Energy and Social Issues

The relationship between energy and social issues is two-way. The ability to pay for energy services and knowledge of what is available and how best to apply it will affect the level of demand and type of energy services used. Conversely, the quality (cleanliness, reliability, and convenience) and level of access (availability, affordability, and variety) of energy services have an effect on social issues. Lack of access to energy services is closely linked to a range of social concerns, including poverty, lack of opportunities, urbanisation, poor health, and a lack of education for women in particular.

BOX 1. ENERGY AND THE MILLENNIUM DEVELOPMENT GOALS

Energy services can play a variety of direct and indirect roles in helping to achieve several MDGs:

To halve extreme poverty. Access to energy services facilitates economic development – micro-enterprise, livelihood activities beyond daylight hours, locally owned businesses that create employment – and assists in bridging the "digital divide".

To reduce hunger and improve access to safe drinking water. Energy services can improve access to pumped drinking water and provide fuel for cooking the 95 percent of staple foods that need cooking before they can be eaten.

To reduce child and maternal mortality, and to reduce diseases. Energy is a key component of a functioning health system, contributing, for example, to lighting operating theatres, refrigerating vaccines and other medicines, sterilising equipment, and providing transport to health clinics.

To achieve universal primary education, and to promote gender equality and empowerment of women. Energy services reduce the time spent by women and children (especially girls) on basic survival activities (gathering firewood, fetching water, cooking, etc.); lighting permits home study, increases security, and enables the use of educational media and communications in schools, including information and communication technologies (ICTs).

To ensure environmental sustainability. Improved energy efficiency and use of cleaner alternatives can help to achieve sustainable use of natural resources, as well as reduce emissions, which protects the local and global environment.

Source: DFID, 2002.

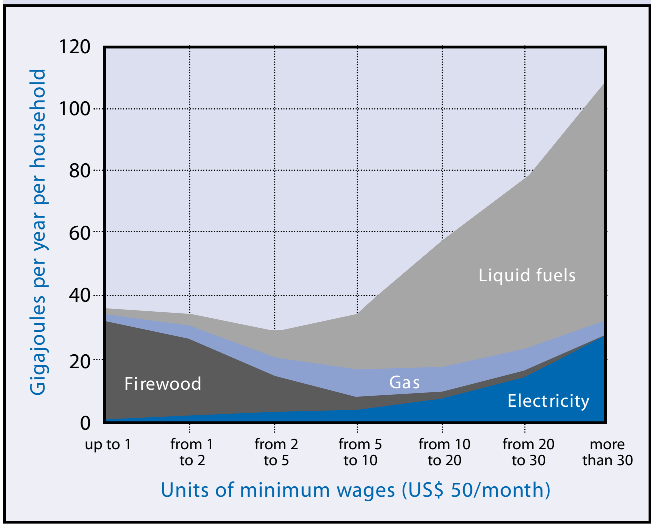
As mentioned in Part I, the WSSD Plan of Implementation recognises the importance of improved access to reliable and affordable energy services to facilitate the achievement of the Millennium Development Goals and the link between access to energy services and poverty reduction. Box 1 shows some ways that energy can help achieve the MDGs. (For more examples of the direct and indirect relationships between energy and the MDGs, see Annex I.)

Poverty is the overriding social consideration for developing countries. Some 1.3 billion people in the developing world live on less than $1 per day. Income measurement alone, however, does not fully capture the misery and the absence of choice that poverty represents. The energy available to poor people – especially their reliance on traditional fuels in rural areas – is not supportive of the development and income generation needed to alleviate poverty.

World-wide, two billion people rely on traditional biomass fuels for cooking and/or have no access to modern energy services. For these people, cooking indoors with poorly vented stoves has significant health impacts. Hundreds of millions of people – mainly women and children – spend several hours per day in the drudgery of gathering firewood and water, often from considerable distances, for household needs. Because of these demands on their time and physical energy, women and children often have no opportunities for education and other productive activities, while their health suffers.

The two billion people lacking access to electricity have inadequate lighting and few labour-saving devices, as well as limited telecommunications and possibilities for commercial enterprise. Greater access to electricity, modern fuels, and clean, efficient technologies such as improved stoves for cooking can enable people to benefit from both short- and long-term advances in their quality of life. Table 3 summarises some of the specific improvements that may result from increased access.

FIGURE 9. AVERAGE ENERGY DEMAND BY INCOME SEGMENT IN BRAZIL, 1998



Source: E. Almeida and A. De Oliveira. "Brazilian Life Style and Energy Consumption," in Energy Demand, Life Style Changes and Technology Development *(London: World Energy Council, 1995).*

Low-income households in developing countries typically use traditional fuels and inefficient technologies. Figure 9 shows the average primary energy demand for various fuels as a function of income levels in Brazil, indicating that higher income segments of the population increasingly rely on modern fuels as income grows.

For low-income households, firewood is the dominant fuel. At higher incomes, commercial fuels and electricity replace wood, offering greater convenience, energy efficiency, and cleanliness. Because convenient, affordable energy can contribute to a household's productivity and income-generating potential, its availability can help families and communities break out of the cycle of poverty.

It is widely understood that population growth has a direct impact on energy by increasing demand. It is less widely understood that access to adequate energy services is associated with increased life expectancy and reduced child mortality and can shift the relative benefits and costs of fertility towards a lower number of desired births in a family. However, this lower number of desired births can only be realised if effective fertility reduction techniques are available. An acceleration of the demographic transition to low mortality and low fertility (as has occurred in industrialised countries) depends on crucial developmental tasks, including improving the environment, educating women, and ameliorating the extreme poverty that may make child labour a necessity. All these tasks have links to the availability of affordable clean energy services.

TABLE 3. ENERGY-RELATED OPTIONS TO ADDRESS SOCIAL ISSUES

Social Challenge	Energy Linkages and Interventions
Alleviating poverty in developing countries	▪ Improve health and increase productivity by providing universal access to adequate energy services – particularly for cooking, lighting, and transport – through affordable, high-quality, safe, and environmentally acceptable energy carriers and end-use devices. ▪ Make commercial energy available to increase income-generating opportunities.
Increasing opportunities for women	▪ Encourage the use of improved stoves and liquid or gaseous fuels to reduce indoor air pollution and improve women's health. ▪ Support the use of affordable commercial energy to minimise arduous and time-consuming physical labour at home and at work. ▪ Use women's managerial and entrepreneurial skills to develop, run, and profit from decentralised energy systems.
Speeding the demographic transition (to low mortality and low fertility)	▪ Reduce child mortality by introducing cleaner fuels and cooking devices and providing safe, potable water. ▪ Use energy initiatives to shift the relative benefits and costs of fertility – for example, adequate energy services can reduce the need for children's physical labour for households chores. ▪ Influence attitudes about family size and opportunities for women through communications made accessible by modern energy carriers.
Mitigating the problems associated with rapid urbanisation	▪ Reduce the "push" factor in rural-urban migration by improving energy services in rural areas. ▪ Exploit the advantages, and moderate the disadvantages, of high-density settlements through land-use planning. ▪ Provide universal access to affordable multi-modal transport services and public transportation. ▪ Take advantage of new technologies to avoid energy-intensive, environmentally unsound development paths.

Energy technology choices in developing countries have important equity implications. Investments in centralised, capital-intensive conventional energy enterprises such as coal-fired power-generation and large dams largely benefit high- and middle-income urban communities, commercial establishments, and industries through electricity distributed through power grids. Poor, dispersed rural communities that are often far from the grid rarely benefit from such investments. Even in urban areas, low-income neighbourhoods and shantytowns are often not connected to the grid. A growing number of studies find that renewable and other decentralised small-scale energy technologies (such as diesel motors and hybrids) are important options for poverty alleviation, particularly technologies that are locally made and that operate using locally available fuels (e.g., hydro power, wind power, solar power, and modern biomass resources). These decentralised energy technologies can be a source of jobs, employment, and enterprise creation for both the rural and urban poor in developing countries, and can be competitive and affordable in isolated areas or other niche markets.

More than two billion people cannot access affordable energy services. Women and children suffer disproportionately.

The increasing concentration of people in urban centres is another key development issue linked to energy. Although the general trend towards urbanisation has many components and may be inevitable, providing more options to rural residents through energy interventions could potentially slow migration and reduce pressure on rapidly growing cities. Energy inputs can improve agricultural productivity, generating better rural incomes and higher value added in this sector. Productive uses of energy provide employment opportunities and reduce the necessity to migrate to urban areas for employment. Productive uses allow income-generating opportunities that can help pay for the energy services, thus making them more affordable and sustainable. There is a clear need for mechanisms to cut the transaction costs between a large number of invisible potential consumers and a discrete number of suppliers of energy services, thereby promoting investment in local productive chains.

In developing countries, addressing the energy needs of the poor, who represent a large majority, will require major structural changes. In industrialised countries, on the other hand, adequate access to affordable energy is problematic only for a minority, and thus is more amenable to social policy solutions. Throughout the world, however, poor households pay a larger fraction of their incomes for energy than do the rich, and so are vulnerable to the effects of rapid increases in the price of energy. Increases in the price of oil in the winter of 1999/2000, for example, posed a hardship for many people, including some in industrialised countries. In addition to paying a larger fraction of their income on energy services, poor households often pay more per unit of energy than rich households do. They have few energy services available to them and have little choice but to use inefficient fuels and technologies. The role of energy efficiency in improving this situation should not be overlooked.

A full menu of energy options needs to be considered in order to achieve the MDGs and lift the poor out of poverty. Renewable energy resources have an important role to play, but traditional biomass resources and fossil fuels coupled with improved, efficient, cleaner technologies will play a major role in providing energy services to the poor for decades to come. Poor people need to be empowered and included in the decision making process, so they can influence the selection of affordable, reliable, and clean energy services that can most appropriately meet their needs. Participatory approaches and managing the expectations of communities are important if the energy services are to be accepted by those communities and maintained well enough to provide sustainable energy services for the future.

Eradicating poverty is a long-term goal of development. But long before that goal is achieved, convenient and affordable energy services could dramatically improve living standards and offer more opportunities to people. Today's inequity is unsustainable. Satisfying the energy service needs of the poor with modern technologies has the potential to improve standards of living and health, and to create new jobs and business opportunities. Allowing one third of the world's population to continue to endure the constraints associated with traditional energy is unacceptable from a humanitarian and a moral standpoint.

Energy and Economic Issues

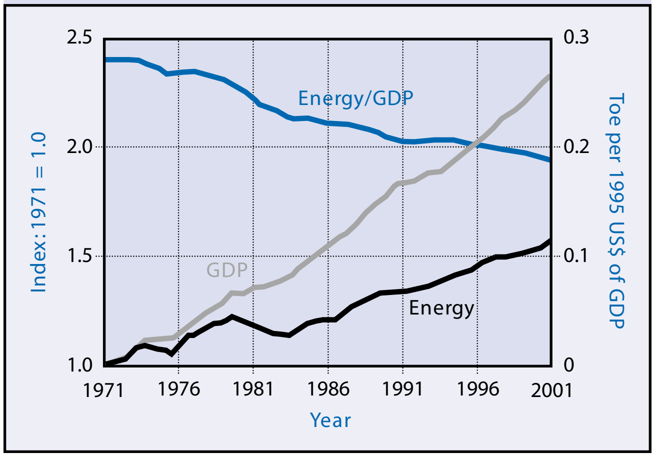
If the global growth rate of about 1.5 percent per year in primary energy use continues (Table 2), total energy use will double between 2000 and 2040, and triple by 2060. In the past thirty years, developing countries' commercial energy use has increased three and a half times as fast as that of OECD countries; energy use has increased even faster in China. This is partly the result of lifestyle changes made possible by rising personal incomes, coupled with higher population growth rates and a shift from traditional to commercial energy in developing countries. It is also partly the result of a shift towards less energy-intensive production and consumption patterns in the OECD countries. On a per capita basis, however, the increase in total primary energy use has not resulted in notably more equitable access to energy services between industrialised and developing countries. Clearly, more energy will be needed to fuel global economic growth and to help deliver opportunities to the billions of people in developing countries who do not have access to adequate energy services and who live on less than $2 a day. The wide gap in per capita consumption of energy services between industrialised and developing countries will not last indefinitely, and there will be considerable pressure on the available physical and human energy resources.

However, the amount of additional energy required to provide the energy services needed in the future will depend on the efficiency with which the energy is produced, delivered, and used. Energy efficiency improvements could help reduce financial investments in new energy supply systems, as they have over the past two hundred years. The degree of interdependence between economic activity and energy use is neither static nor uniform across regions. Energy intensity (the ratio of energy use to GDP) often depends on a country's stage of development. In OECD countries, which enjoy abundant energy services, growth in energy demand is less tightly linked to economic production than it was in the past (Figure 10).

A detailed, long-term analysis of energy intensity for a number of countries reveals a common pattern of energy use driven by the following factors:

- The shift from traditional to commercial forms of energy, industrialisation, and motorisation initially increases the commercial energy/GDP ratio.
- As industrialisation proceeds and incomes rise, saturation effects, as well as an expansion of the service sector (which is less energy intensive), decrease the ratio of commercial energy to GDP after it reaches a peak. Many countries have passed this point of maximum energy intensity, but low-income developing countries have not.
- Given world-wide technology transfer and diffusion, energy efficiency improvements can be the main limiting factor in the growth of energy demand arising from increasing populations and growing production and incomes.
- The more efficient use of materials in better-quality, well-designed, miniaturised products, the recycling of energy-intensive materials, and the saturation of bulk markets for basic materials in industrialised countries contribute to additional decreases in energy intensity.
- In developing countries, technological leapfrogging (i.e., bypassing some of the steps followed in the past in industrialised countries and jumping directly to modern technologies) to the use of highly efficient appliances, machinery, processes, vehicles and transportation systems, and other energy technologies, offers considerable potential for energy efficiency improvements.

FIGURE 10. GDP AND PRIMARY ENERGY USE IN OECD COUNTRIES, 1971-2001



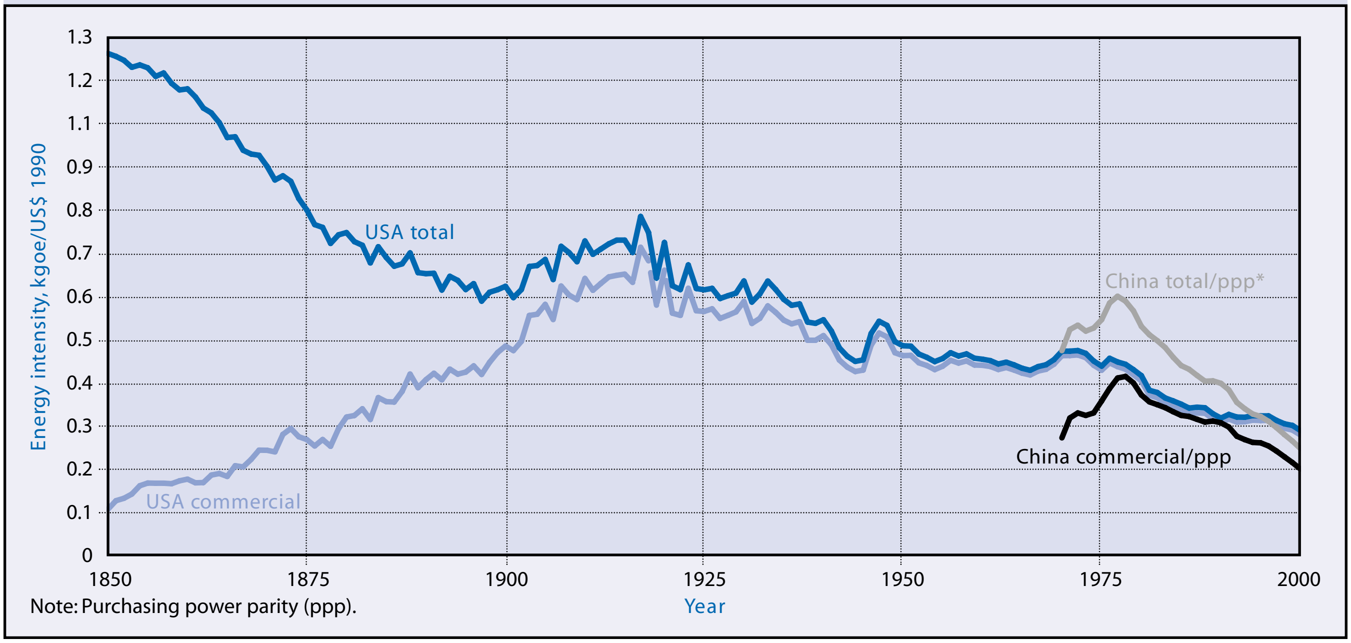
Sources: IEA, 2002a and 2002b.

- In transition economy countries, the decoupling of energy costs and prices, the promotion of energy rather than energy services, and the fact that energy use was often not even metered (and thus not paid for in relation to consumption levels) resulted in low energy efficiency and high energy intensity for the level of GDP.

These drivers are leading to a common pattern of energy use per unit of GDP in industrialised and developing countries; the U.S. experience illustrates this pattern (Figure 11). While initial costs for more energy efficient technologies are often higher than for less energy efficient ones, a life-cycle cost analysis, incorporating the savings from using less energy, shows lower costs. Therefore, in many countries, there are good reasons to adopt – early in the process of development – highly efficient appliances, machinery, industrial processes, vehicles, and transportation systems, thus "leapfrogging" some stages in the development process. China, for example, is following this route; energy intensity (measured in terms of energy use per unit of currency in purchasing power parity) has been falling rapidly since 1975.

Energy prices influence consumer choices and behaviour and can affect economic development and growth. High energy-import prices can lead to increasing import bills, with adverse consequences for business,

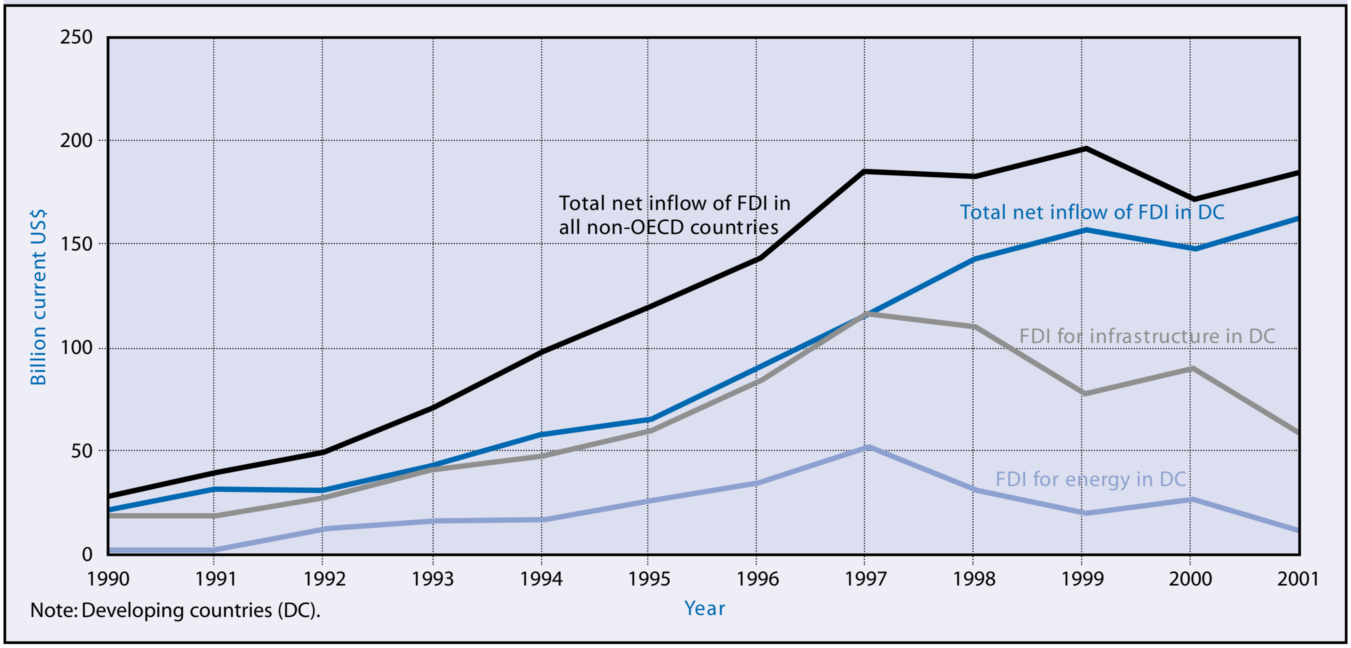
FIGURE 11. ENERGY INTENSITY IN THE UNITED STATES (1850-2000) AND CHINA (1970-2000)



Note: Purchasing power parity (ppp).

Source: N. Nakićenović and E. Slentoe (private communication).

FIGURE 12. NET INFLOW OF FOREIGN DIRECT INVESTMENT, 1990-2001



Note: Developing countries (DC).

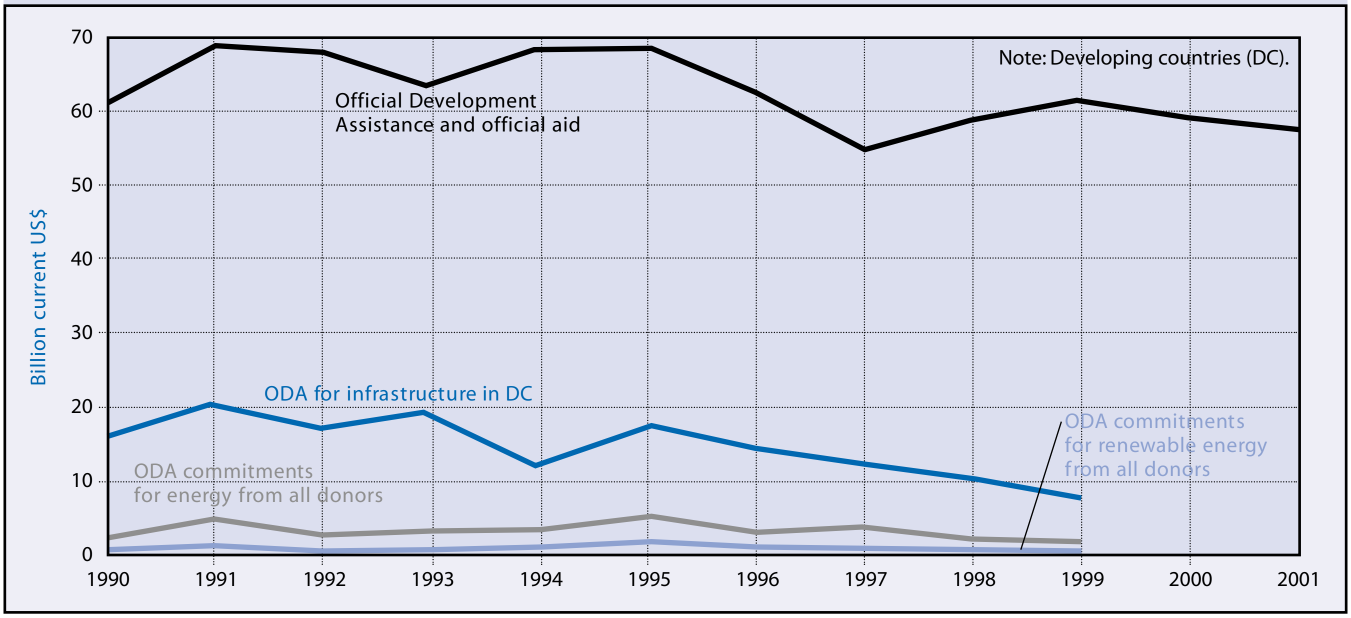
Source: World Bank, 2002, 2003; World Bank, Private Participation in Infrastructure (PPI) Project Database, http://rru.worldbank.org/ppi.

employment, and social welfare. High energy prices could also stimulate exploration and development of additional resources, create a pull for innovation, and provide incentives for efficiency improvements.

Although some impacts of energy prices are fairly steady, others are more transient. For example, different absolute price levels appear to have had little effect on economic development in European countries or Japan relative to the much lower energy prices in the United States and some developing countries. What affected economic growth in all energy-importing countries were the price hikes of the 1970s.

Capital investment is a prerequisite for energy development. Energy system development and structural

FIGURE 13. OFFICIAL DEVELOPMENT ASSISTANCE PROVIDED TO RECIPIENT COUNTRIES, 1990-2001



Source: World Bank, 2002, 2003; World Bank, Private Participation in Infrastructure (PPI) Project Database, http://rru.worldbank.org/ppi.

change are the results of investment in plants, equipment, and energy system infrastructure. Difficulties in attracting capital for energy investment may impede economic development, especially in the least developed countries. Scarce public funds, especially in developing countries, are needed for projects ranging from rural development, education, and health care to energy supplies. Because energy supply is often seen as more capable of generating early revenues than other alternatives, energy investments are increasingly viewed as a private sector matter. Yet private funds are not flowing into many developing countries for a variety of reasons, especially because investors perceive the risks as too high and traditional financing approaches are concerned about capital return and less sensitive to developing-country needs. Time frames for evaluating returns on large infrastructure investments are often too long to attract investment capital seeking short-tem financial returns.

World foreign direct investment (FDI) net inflows to all sectors approached $1,162 billion in 2000 – up from $200 billion in 1990. Foreign direct investment net inflows to developing countries grew from $25 billion to $171 billion in the same period, and increased again to $184 billion in 2001 (Figure 12). Foreign direct investment is generally commercially motivated, and investors not only expect to recover the initial capital but also count on competitive returns. These outcomes may be viewed as too risky in developing countries with potentially fragile governments or without free markets. In fact, very little foreign direct investment reaches the least developed countries. The bulk of foreign direct investment flows are concentrated in a discrete number of developing countries such as China and Brazil.

Unlike foreign direct investment, official development assistance (ODA) declined slightly relative to gross world product in the period 1997-2001 (Figure 13). In 2001, official development assistance from donor countries totalled $57 billion or 0.26 percent of their combined GDP. These numbers are down from over 0.3 percent of GDP in the 1980s, although industrialised countries have in principle agreed to a target of providing 0.7 percent of GDP as ODA.

Against this backdrop, financing is inadequate for energy projects in developing countries. Until the economic risks to foreign investors can be managed (for example, through clear and stable rules for energy and financial markets, steady revenue generation through bill collection, and profit transfers), most developing countries may have to continue to finance their energy development from domestic savings. In countries without such investment, energy will become a constraint on economic growth, particularly if they are oil and gas importers. In many developing countries, energy imports represent more than half of all imports, imposing a heavy burden on foreign exchange and contributing to indebtedness.

Although energy investment as a share of total investment varies greatly among countries, and at

Conventional energy production and consumption are closely linked to environmental degradation that threatens human health.

different stages of economic development within a country, on average, countries invest 1.0-1.5 percent of GDP in the energy sector. This ratio is expected to remain relatively stable. Based on this assumption, current world-wide investment in the energy supply sector (including equipment and infrastructure) amounts to somewhere between \$300 and \$400 billion per year.

Energy, the Environment, and Health

The environmental impacts of energy use are not new. For centuries, wood burning has contributed to the deforestation of many areas. Even in the early stages of industrialisation, local air, water, and land pollution reached high levels. What is relatively new is acknowledgement of energy linkages to regional and global environmental problems and the implications of those linkages. Although energy's potential for enhancing human well being is unquestionable, conventional energy production and consumption are closely linked to environmental degradation that threatens human health and quality of life and affects ecological balances and biological diversity.

The environment-energy linkage is illustrated in Table 4, which shows the share of toxic emissions and other pollutants attributable to human energy supply systems. The human disruption index is the ratio of the human-generated flow of a given pollutant (such as sulphur dioxide) to the natural, or baseline, flow. Thus, in the case of sulphur, for example, the index is 2.7, which means that human-generated emissions of 84 million tonnes per year are 2.7 times the natural baseline flow of 31 million tonnes per year. The table indicates that, together with other human activities, energy systems significantly affect the global cycling of important chemicals. Although the index by itself does not demonstrate that these emissions translate into negative impacts, their magnitude provides warning that such impacts could be considerable. Some impacts are already significant.

Just in the last century, during which the world's population more than tripled, human environmental insults grew from local perturbations to global disruptions. The human disruptions of the twentieth century – driven by a more than twenty-fold growth in the use of fossil fuels augmented by a tripling in the use of traditional energy forms such as biomass – have amounted to the emergence of civilisation as an ecological and geo-chemical force of global proportions.

In other words, the accelerating impact of human life is altering the world at the global level.[10] At every level (local, regional, global), the environmental consequences of current patterns of energy generation and use make up a significant fraction of human impacts on the environment.

Poor air quality resulting from solid fuel use for cooking and heating has significant health and environmental impacts at the household, local, regional and global levels. It is associated with increased sickness and premature death. About 1.6 million premature deaths per year – disproportionately women and children – are estimated to occur from exposure to indoor air pollution caused by burning solid fuels in poorly ventilated spaces. Particulate matter (which is both emitted directly and formed in the air as the result of the emissions of gaseous precursors in the form of oxides of sulphur and nitrogen) and hydrocarbons are growing concerns world-wide. They are especially troublesome in many parts of the developing world, where dirtier fuels predominate with little emissions abatement. No safe threshold level for exposure to small particulate matter has been established. The combustion conditions in small cooking fires and stoves are such that a significant amount of unburned hydrocarbon, including some methane, is emitted to the atmosphere. These greenhouse gases are estimated to amount to several percent of the world's total greenhouse gas emissions. Technologies for mitigation/abatement of these pollutants exist, although at a cost.

Fossil fuel combustion is problematic on several levels (although natural gas produces significantly fewer harmful emissions than do oil or coal). The main pollutants emitted in the combustion of fossil fuels are sulphur and nitrogen oxides, carbon monoxide, and suspended particulate matter. Ozone is formed in the troposphere from interactions among hydrocarbons, nitrogen oxides, and sunlight. Energy-related emissions from fossil fuel combustion, including in the transport sector, are major contributors to urban air pollution, which is thought to be responsible for about 800,000

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[10] In this report, the word insult is used to describe a physical stressor produced by the energy system, such as air pollution. The word impact is used to describe the resulting outcome, such as respiratory disease or forest degradation.

TABLE 4. ENVIRONMENTAL INSULTS DUE TO HUMAN ACTIVITIES, BY SECTOR

Insult	Natural baseline	Human disruption index[a]	Share of human disruption caused by			
			Commercial energy supply	Traditional energy supply	Agriculture	Manufacturing, other
Lead emissions to atmosphere[b]	12,000 t/yr	18	41% (fossil fuel burning, including additives)	Negligible	Negligible	59% (metals processing, manufacturing, refuse burning)
Oil added to oceans	200,000 t/yr	10	44% (petroleum, harvesting, processing, transport)	Negligible	Negligible	56% (disposal of oil wastes, including motor oil changes)
Cadmium emissions to atmosphere	1,400 t/yr	5.4	13% (fossil fuel burning)	5% (burning traditional fuels)	12% (agricultural burning)	70% (metals processing, manufacturing, refuse burning)
Sulfur emissions to atmosphere	31 million t-S/yr	2.7	85% (fossil fuel burning)	0.5% (burning traditional fuels)	1% (agricultural burning)	13% (smelting, refuse burning)
Methane flow to atmosphere	160 million t/yr	3.75[c]	18% (fossil fuel harvesting and processing)	5% (burning traditional fuels)	65% (rice pad-dies, domestic animals, land clearing)	12% (landfills)
Nitrogen fixation (as NO, NH_4)[d]	140 million t-N/yr	1.5	30% (fossil fuel burning)	2% (burning traditional fuels)	67% (fertiliser, agricultural burning)	1% (refuse burning)
Mercury emissions to atmosphere	2,500 t/yr	1.4	20% (fossil fuel burning)	1% (burning traditional fuels)	2% (agricultural burning)	77% (metals processing, manufacturing, refuse burning)
Nitrous oxide flows to atmosphere	33 million t/yr	0.49[c]	12% (fossil fuel burning)	8% (burning traditional fuels)	80% (fertiliser, land clearing aquifer disruption)	Negligible
Particulate emissions to atmosphere	3,100[e] million t/yr	0.12	35% (fossil fuel burning)	10% (burning traditional fuels)	40% (agricultural burning)	15% (smelting, non-agricultural land clearing, refuse)
Non-methane hydrocarbon emissions to atmosphere	1,000 million t/yr	0.12	35% (fossil fuel processing and burning)	5% (burning traditional fuels)	40% (agricultural burning)	20% (non-agricultural land clearing, refuse burning)
Carbon dioxide flows to atmosphere	150 billion t-C/yr	0.05[f,g]	75% (fossil fuel burning)	3% (net deforestation for fuelwood)	15% (net deforestation for land clearing)	7% (net deforestation for lumber, cement manufacturing)

a. The human disruption index is defined as the ratio of human-generated flow to the natural (baseline) flow. b. Automotive portion of anthropogenic emissions assumed to be 50 percent of global 1993 automotive emissions. c. From IPCC, 2001. d. Calculated from total nitrogen fixation minus that from nitrous oxide. e. Dry mass. f. Although seemingly small, because of the long atmospheric lifetime and other characteristics of carbon dioxide, this slight imbalance in natural flows is causing a 0.4 percent increase per year in the global atmospheric concentration. g. From EIA, 2000.

Source: Updated from J.P. Holdren, "The Transition to Costlier Energy", in L. Schipper and S. Myers, eds., Energy Efficiency and Human Activity: Past Trends, Future Prospects *(Cambridge: Cambridge University Press, 1992).*

deaths annually around the world. Precursors of acid deposition from fuel combustion can be precipitated thousands of kilometres from their point of origin – often crossing national boundaries. The resulting acidification is causing significant damage to natural systems, crops, and human-made structures, and can, over time, alter the composition and function of entire ecosystems. In many regions, acidification has diminished the productivity of forests, fisheries, and farmlands.

Acid deposition is a problem because it causes damage to natural and human-made surfaces with which it comes into contact. If soils contain insufficient alkali to neutralise the acid, damage can be caused to vegetation, particularly sensitive tree species and agricultural crops. Lakes can become acidified, leading to the demise of fish populations. Over time the entire natural structure and function of ecosystems can change. Manufactured materials can be attacked: metal surfaces rust and alkaline materials such as concrete, limestone, and marble erode. In Europe, forest damage has long been attributed to acid deposition; despite emission reductions, the health of European forests continues to deteriorate. However, Asia is the region of greatest concern. Acid deposition is being reported throughout Asia, with many areas receiving levels that exceed the carrying capacity of their soils.

Major changes are required in energy systems development world-wide to meet sustainable development challenges.

Desertification in the Sahel and elsewhere in sub-Saharan Africa has links to fuel demand. But it has been difficult to separate out the influence of all the relevant factors, including climate change, intensification of grazing, land-use shifts, and fuel harvesting. Nevertheless, as with deforestation, there are some poor areas where harvesting of wood and brush plays an important role.

Fossil fuel combustion produces more carbon dioxide (CO_2) than any other human activity. This is the biggest source of the anthropogenic greenhouse gas emissions that are changing the composition of the atmosphere and could alter the global climate system, including the amount and pattern of rainfall. Stabilising CO_2 at close to the present concentration would require reducing emissions to half of current levels within the next few decades. Instead, CO_2 emissions continue to increase. Current CO_2 emission trends, if not controlled, will lead to more than a doubling of atmospheric concentrations before 2070, relative to pre-industrial levels. Changes have been observed in climate patterns that correspond to scientific projections based on increasing concentrations of greenhouse gases. With increasing evidence that most of the warming observed over the last fifty years is attributable to human activities, concern is growing especially about greenhouse gas emissions. IPCC concludes in its Third Assessment Report that global mean surface temperature has increased by 0.6 degrees Celsius during the last two centuries due to human activities (IPCC, 2001).

By definition, sustainable energy systems must support both human and ecosystem health over the long term. Thus goals on tolerable emissions should be long term and take into account the public's tendency to demand more health and environmental protection as prosperity increases.

Other forms of conventional energy pose problems as well. Large hydropower projects often present environmental problems related to the flooding of large areas; and there is widespread concern about a range of issues associated with nuclear power, particularly its links to nuclear weapons and the sequestering of radioactive waste. Although the scope of environmental problems related to energy systems may seem overwhelming, numerous strategies could simultaneously benefit the environment (at several levels), the economy, and human well being. For example, replacing solid fuels for cooking with gaseous or liquid fuels could have significant environmental benefits at the local, community, regional, and global scales, with attendant benefits for health and productivity.

Energy Security

Energy security is a term that applies to the availability of energy at all times in various forms, in sufficient quantities, and at affordable prices, without unacceptable or irreversible impact on the environment. These conditions must prevail over the long term if energy is to contribute to sustainable development. Energy security has both a producer and a consumer side to it. In terms of energy resources world-wide to meet energy demand for the foreseeable future there is no energy security problem. However, whether these resources will be available in the marketplace at affordable prices depends on how markets perform, on government taxation and regulation, and on the role of policies such as electrification or subsidies.

Security of supply has taken a higher place on the global agenda recently for a number of reasons: the shift in oil and gas prices from very low levels in the 1990s to higher, more sustained levels today, changes in contracts and other aspects of market reform, deregulation and the establishment of new forms of regulation, protocols to reduce greenhouse gas emissions, and political instability in some main supplier countries (Box 2).

The potential for conflict, sabotage, disruption of production and trade, and reduction in strategic reserves cannot be dismissed. These potential threats lead to sudden transient price increases (price spikes) that cause economic disruptions in many countries and disrupt global economic growth. An increase of $10 per barrel of oil (above relevant average price) can slow the global economy by 0.5 percent annually – a significant amount that points to the need to strengthen global as well as regional and national energy security.

A range of actions can be taken to improve energy security. One important measure is to avoid excessive

BOX 2. SECURITY OF OIL AND GAS SUPPLY

Oil

Dramatic losses of Middle East oil supplies and attendant oil price hikes did not materialise either during or after the Iraq war in 2003. Supply turmoil outside the region in Venezuela, and uncertainty as to Nigeria's capability to keep its oil flowing, increased oil prices in the period leading up to the war and raised concerns about what would happen to the global oil market in the event of war. However, actions by the Organisation of Petroleum Exporting Countries (OPEC) during the pre-war period reassured international markets that there would be no physical shortage. OPEC members, especially Saudi Arabia and Kuwait, committed to using their spare production capacity rather than force consuming countries to tap strategic oil reserves. Moreover, the fact that cumulative OPEC production has been well in excess of the prevailing production quotas also had a calming effect on prices. Drawing on lessons learned in the first Gulf war in 1991, major oil market stakeholders in both the private sector and government knew the importance of early information and transparent information flow to avoid panic buying and logistical disruption.

In essence, markets worked and oil supplies remained secure throughout the Iraq war. For the time being, a system of spare production capacity maintained by core producers paired with the potential for strategic oil stock releases appears to be a most effective remedy in the event of a physical oil supply shortage. While this certainly is reassuring for those concerned about oil and energy security, there is no room for complacency. The war's impacts on oil infrastructures were largely confined to Iraq and did not spread into the rest of the Middle East producing region. The positive experience gained in two wars must not eclipse the fact that sizeable energy import dependence from a single region or oligopolistic supplier will always remain a fundamental supply security risk. As fewer countries continue to have the capacity to export conventional oil, and as long as global demand for oil continues to rise, the scope for chronic conventional oil supply disruption will grow.

Natural Gas

Gas is generally the most expensive fuel on a delivered kWh basis; as a result, growth in gas consumption will be primarily for mid/peak load use. Given this gas use at the margin, spot price signals are of fundamental importance.

In North America, domestic gas supply is declining, creating a growing need for liquid natural gas (LNG) imports. In Western Europe, domestic gas supply is nearly at its peak, and imports by pipeline are not going to grow much since fields in the Siberian region are all in decline and production in other areas of the former Soviet Union are problematic. Long-term commitments by buyers are needed to finance new infrastructure. All these factors suggest that LNG prices will increase in the future. Due to growing markets in North America and Western Europe, the developing countries face penalties if they do not secure enough supply for the needs of their internal markets. High import dependency will continue to be a concern for many countries.

dependence on fossil fuel imports. This involves diversifying supply – both geographically and among various primary energy sources – as well as increasing end-use efficiency and encouraging greater reliance on local, including renewable, resources. Promoting renewable energy will have other positive externalities such as job creation and pollution reduction, provided that these do not have disproportionate costs or waste scarce resources.

Another important measure is fostering greater political stability through international co-operation and long-term agreements among energy-importing countries and between importing and exporting countries. Examples might include wider adoption – and more effective implementation – of the Energy Charter Treaty[11] as well as increased sharing of infrastructure for transporting natural gas. The geopolitical problems involved in building such projects, particularly in Central Asia, should not be overlooked.

Additional measures to enhance energy security include: a) encouraging technology transfers to developing countries (e.g., through joint ventures and public-private partnerships) so they can develop local resources and improve energy production and efficiencies; b) increasing national and regional strategic reserves of crude oil and oil products through increased investment and advanced exploration technologies; and c) promoting sustainable international markets for biofuels (e.g., ethanol) and international trade between producers and consumers of such fuels.

Nuclear power contributes both to the diversity of supply and to supply security since its fuel requirements are small. However, public concern about economic cost, reactor safety, radioactive waste transport and disposal, and nuclear weapons proliferation raises important political issues and has curbed the growth of nuclear energy in many countries. A nuclear accident anywhere in the world or a proliferation incident linked to nuclear power would further reduce support for nuclear power programmes. However, if these concerns can be dealt with in ways that are widely accepted, nuclear energy could contribute significantly to electricity generation in many parts of the world.

One feature enhancing energy security is the growing interdependence between industrialised countries and oil exporters. Oil producers recognise that oil is a traded commodity; they are as anxious about security of demand as oil importers are about security of supply. There is a possibility, however remote, that large military action or a terrorist attack could cause a serious interruption in the flow of oil or natural gas/liquid natural gas (by disrupting sea-lanes, for instance). Building emergency oil stocks can marginally deal with such prospects, but

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[11] The Energy Charter Treaty, together with a protocol on energy efficiency and related environmental aspects, entered into force in 1998. About fifty countries, including the members of the European Union and the Commonwealth of Independent States, Australia, and Japan, have signed it.

such arrangements are expensive, particularly for developing countries. The new International Energy Forum based in Riyadh is an attempt to enhance the producer-consumer dialogue on oil and natural gas.

There is an absolute link between meeting the needs of economic growth, creating the conditions for an acceptable quality of life, and ensuring sustainable development while protecting the environment. Energy security is a delicate balance among these diverse requirements and there is no question that a least-cost mix of efficient use with more diverse, dispersed resources can make the energy system more resilient and sustainable. ■

part IV

Energy Resources and Technological Options

Physical resources and adequate technologies for their deployment are available – or could become available – to meet the challenge of sustainable development. But without policy changes, cost differentials may favour conventional fuels for years to come. Options for using energy in ways that support sustainable development, which requires addressing social, economic, and environmental concerns, include:

- **More efficient use of energy, especially at the point of end use in buildings, transportation, and production processes.**
- **Increased reliance on renewable energy sources.**
- **Accelerated development and deployment of new energy technologies – particularly next-generation fossil fuel technologies that produce near-zero harmful emissions, but also nuclear technologies if the issues surrounding their use can be resolved.**

All three options have considerable potential, but realising this potential will require removing obstacles to wider diffusion, developing market signals that reflect social and environmental costs, and encouraging technological innovation.

Energy Resources

Careful analysis of the long-term availability of energy resources, starting with conventional and unconventional oil and gas, indicates that these resources could last another 50 to 100 years – and possibly much longer – with known exploration and extraction technologies and anticipated technical progress in upstream operations. Coal and unconventional oil resources, and nuclear materials, are so abundant that they could, respectively, last for centuries or millennia (Table 1). Moreover, although fossil fuel prices may rise slowly over time, the large, scarcity-driven increases in energy prices projected in the 1970s and 1980s are not expected to occur in the foreseeable future.

As evidenced periodically, however, prices are subject to volatility. This may occur, for example, if cartels set prices independent of production costs or as a result of geopolitical tension. Some fluctuations in prices can also be expected, especially during the transition to large-scale use of unconventional oil and gas resources, because the timing of investments in upstream production capacities may not correspond with demand or with the objectives of maximising shareholder value. Other cost-pushing factors could arise from the technologically and environmentally more challenging extraction of unconventional oil resources.

Renewable resources are more evenly distributed than fossil and nuclear resources, and energy flows from renewable resources are several thousand times higher than current total global energy use. However, the economic potential of renewables is affected by many constraints –including competing land uses, the amount and timing of solar irradiation and wind patterns, and a variety of environmental concerns.

Although there are no real limits on future energy availability from a resource point of view, the existence of resources is only relevant in the context of how the resources can contribute to the supply of (downstream) energy services. The key issues are:

- Whether technologies to extract, harvest, and convert the vast energy stocks and flows can be developed in time to meet growing demand for energy and reduce production from conventional reserves, particularly of oil and gas.
- Whether the technologies have adverse implications.
- Whether the energy services generated from these resources will be affordable.

Historical evidence suggests that these concerns may be at least partly offset by technological progress, but that such progress needs to be encouraged – by regulations to improve market performance, temporary subsidies, tax incentives, or other mechanisms – if it is to occur in a timely fashion.

There will not be a resource-constraint driven change in the global energy system for a very long time to come.

There will not be a resource-constraint driven change in the global energy system for a very long time to come. The commonly expressed concern of thirty or even ten years ago was for when the world "runs out of oil reserves". However, the World Energy Assessment makes clear that the challenge today is not a lack of resources but how to create a seamless transition to other resources than those currently used, especially from coal and oil.

Energy End-Use Efficiency

The quadrupling of oil prices in the 1970s, the growing awareness of energy-related pollution, and the possibility of climate change have all contributed to a re-evaluation of energy use. The result has been an improvement in the efficiency with which energy is used in industry and power generation as well as in lighting, household appliances, transportation, and heating and cooling of buildings. This more efficient use of energy is a major factor contributing to the improvements in energy intensity that have occurred in the last three decades in almost all industrialised countries, and more recently in many transition economies, as well as in some fast-growing developing countries such as China and Brazil.

The amount of additional energy required to provide the desired energy services depends on the efficiency with which the energy is produced, delivered, and used. Energy efficiency improvements would help reduce financial investments in new energy supply systems and reduce the amount of primary energy needed for a certain level of economic activity, and thereby also the corresponding impact. A major challenge will be to find ways of meeting the growing demand for energy services in developing countries to support desired economic growth without incurring the adverse consequences associated with current patterns of energy use. To accomplish this, significant investment is needed to supply the two-to-four fold increase in primary energy required over the next century, according to World Energy Assessment projections.

Industrialised countries are already characterised by a weaker link between economic growth and energy use than in their early development. In developing countries, consumption will grow regardless, but there is no reason why efficient technologies and processes cannot be adopted at early stages of development. Technological leapfrogging to the use of highly efficient appliances, machinery, processes, vehicles, and transportation systems offers considerable potential for energy efficiency improvements.

Today, the global energy efficiency of converting primary energy to useful energy is about one third. In other words, two thirds of primary energy is dissipated in the conversion process, mostly as low-temperature heat. Further significant losses occur when the useful energy delivers the energy service. Numerous and varied economic opportunities exist for energy efficiency improvements, particularly in the final step of converting useful energy to energy services. Taking advantage of these opportunities, which have received relatively little attention, has the largest potential for further cost-effective efficiency improvements. It would mean less costly energy services and lower energy-related pollution and emissions.

Over the next twenty years the amount of primary energy required for a given level of energy services could be cost-effectively reduced by 25 to 35 percent in industrialised countries (the higher figure being achievable by more effective policies). These reduction opportunities exist in all steps of the energy chain. Reductions are particularly important in the conversion of useful energy to energy services in residential, industrial, transportation, public, and commercial sectors, as they reduce final and primary energy demand along the energy chain. Reductions of more than 40 percent are cost-effectively achievable in transitional economies within the next two decades. And in most developing countries – which tend to have high economic growth and old capital and vehicle stocks – the cost-effective improvement potential ranges from 30 to more than 45 percent, relative to energy efficiencies achieved with existing capital stock.

The implied improvements of about 2 percent per year could be enhanced by structural changes in industrialised and transition countries, by shifts to services and less energy-intensive industrial production, and by saturation effect in the residential and transportation sectors (i.e., there is a limit to the number of cars, refrigerators, television sets, etc., that a society can absorb). Structural changes can come from increased recycling and substitution of energy-intensive materials, improved material efficiency, and intensified use of durable and investment goods. The combined result of structural changes and efficiency improvements could accelerate the annual decline in energy intensity to perhaps 2.5 percent. How much of this potential will be realised depends on the effectiveness of policy frameworks and measures, changes in attitude and behaviour, and the level of entrepreneurial activity in energy conservation and material efficiency.

With effective policies, behaviours, and successful entrepreneurship, the coming decades will likely see new processes, motor systems, materials, vehicles, and buildings designed to substantially reduce useful energy demand. Because the demand for cars is expected to grow rapidly in the developing world, gaining greater efficiencies in this area will be very important. In addition, rapidly industrialising countries could benefit from the introduction of new and more efficient technologies in their energy-intensive basic materials processing. Because these countries are still building their physical infrastructure, they have a growing demand for basic materials. This opens a window of opportunity to innovate and to improve efficiencies of production, particularly in countries undergoing market reform. Investment in new technologies often provides better opportunities than does retrofitting.

Over the long-term, additional and dramatic gains in efficiency are possible at all stages of energy conversion, particularly from "useful energy" to "energy services". Analysis shows that most current technologies are not close to reaching theoretical limits for energy efficiency, and that very significant improvements for the whole energy system may eventually be achieved by replacing traditional technologies.[12]

For a number of reasons the technical and economic potential of energy efficiency, as well as its positive impact on sustainable development, have traditionally been under-realised. Achieving higher end-use efficiency involves a great variety of technical options and players. Because it is a decentralised, dispersed activity, energy efficiency is a difficult issue around which to organise support. It has little visibility and is not generally a popular cause for politicians, the media, or individuals looking for recognition and acknowledgement. In

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[12] Conventionally, energy efficiency has been defined on the basis of the first law of thermodynamics. The second law of thermodynamics recognises that different forms of energy have different potential to carry out specific tasks. For example, a natural gas boiler for space heating may operate at close to 100 percent efficiency (in terms based on the first law of thermodynamics). This seems to suggest that limited additional efficiency improvements are possible. However, by extracting heat from the ground or other sources, a gas-driven heat pump could generate considerably more low-temperature heat with the same natural gas input. The second example illustrates the potential for energy efficiency improvements according to the second law of thermodynamics.

TABLE 5. SELECTED ENERGY-EFFICIENT TECHNOLOGIES AND PRACTICES FOR BUILDINGS

Building Envelope	■ Energy-efficient windows ■ Insulation (walls, roof, floor) ■ Reduced air infiltration
Space Conditioning	■ Air conditioner efficiency measures (e.g., thermal insulation, improved heat exchangers, advanced refrigerants, more efficient motors) ■ Centrifugal compressors, efficient fans and pumps, and variable air volume systems for large commercial buildings
Appliances	■ Advanced compressors, evacuated panel insulation (refrigerators) ■ Higher spin speeds in washing machines/dryers
Cooking	■ Improved efficiency biomass stoves ■ Efficient gas stoves (ignition, burners)
Lighting	■ Compact fluorescent lamps ■ Improved phosphors ■ Solid-state electronic ballast technology ■ Advanced lighting control systems (including day-lighting and occupancy sensors) ■ Task lighting
Motors	■ Variable speed drives ■ Size optimisation ■ Improvement of power quality
Other	■ Building energy management systems ■ Passive solar use (building design) ■ Solar water heaters

addition, significant barriers – primarily market imperfections that could be overcome by targeted policy instruments – prevent the realisation of greater end-use efficiencies.

Energy efficiency policies that use direct or indirect price mechanisms (such as the removal of subsidies and the incorporation of externalities) are effective in lowering consumption trends in price-sensitive sectors and applications. But even without changing the overall price environment, energy efficiency policies should be pursued to address market failures. For example, efficiency standards, appliance and product labelling, voluntary agreements, and professional training or contracting, can increase GDP growth by improving environmental and economic performance, using a given quantity of energy. Examples of energy-efficiency-enhancing technologies and practices for buildings are given in Table 5.

Legal standards (e.g., building codes; well-informed consumers, planners, and decision makers; motivated operators; market-based incentives such as certificate markets; and an adequate payments system[13] for energy) are central to the successful implementation of energy efficiency improvements.

Renewable Energy Technologies

If applied in a modern way, renewable energy sources (including biomass, hydropower, solar, wind, geothermal, and marine) may be highly responsive to environmental, social and economic goals. Their many advantages include:

- diversifying energy carriers, technologies, and infrastructure for the production of heat, fuels, and electricity,
- improving access to clean energy sources,
- balancing the use of fossil fuels and thus saving them for other applications and for future use,
- increasing the flexibility of power systems as electricity demand changes,
- reducing pollution and emissions from conventional energy systems,
- reducing dependency, and minimising spending, on imported fuels, and
- job creation.

Another advantage for many renewable energy technologies is that they are well suited to small off-grid applications, and thus good for remote rural areas.

The natural energy flows through the earth's ecosystem are immense, and the geographical and technical potential of what they can produce for human needs exceeds current energy use by many times. Currently, renewable energy sources supply about 14 percent of the world's primary energy use, predominantly biomass used for cooking and heating, especially in rural areas of developing countries. Large-scale hydropower supplies about 16 percent of global electricity. Its scope for expansion is limited in the industrialised world, where it has nearly reached its economic capacity. In the developing world, considerable potential still exists, but large hydropower projects often face financial, environmental, and social constraints. The World Commission on Dams has done substantial work on this issue and suggested guidelines for reconciling conflicting demands surrounding large dams (WCD, 2000).

It is estimated that together *new renewables* (modern biomass energy, geothermal heat and electricity, small hydropower, low-temperature solar heat, wind electricity,

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[13] An adequate payments system means using metres and payment collection to ensure that all energy services have a price that is paid by all users on a regular basis.

Dramatic gains in efficiency are possible at all stages of energy conversion from useful energy to energy services.

solar electricity, and marine energy) contributed about 9 exajoules (EJ) in 2001, or slightly more than 2 percent of the world's energy use. The amount supplied by the various renewable energy sources is shown in Table 6.

Electricity production from solar photovoltaic systems as well as grid-connected wind turbines has been growing at an impressive rate of about 30 percent per year. Even so, it will likely be decades before new renewables add up to a major fraction of total global energy use, because they currently represent only a small percentage of total energy use. Nevertheless, a few countries have adopted ambitious targets; Germany, for example, has a target of 50 percent renewables by 2050. Impressive growth rates have been achieved in recent years for geothermal and solar thermal heat production, each about 10 percent per year over the last five years (Table 7).

Substantial cost reductions in the past few decades have made a number of renewable energy technologies competitive with fossil fuel technologies in certain applications. Modern, distributed forms of biomass, in particular, have the potential to provide rural areas with clean forms of energy based on the use of biomass resources that have traditionally been used in inefficient, polluting ways. Biomass can be economically produced with minimal or even positive environmental impacts through perennial crops. Its production and use currently is helping to create international bio-energy markets, stimulated by policies to reduce carbon dioxide emissions. Wind power in coastal and other windy regions is promising in the short term as well. Other potentially attractive options include geothermal heat and electricity production, small hydropower, low-temperature solar heat production, and solar electricity production in remote applications.

Table 7 shows that substantial cost reductions can be achieved for most renewable energy technologies. Making these renewable energy sources competitive will require further technology development and market deployments and an increase in production capacities to mass-production levels.

Unlike hydropower and geothermal power sources, wind and solar thermal or electric sources are intermittent, and not fully predictable. Nevertheless, they can be important in rural areas where grid extension is expensive. They can also contribute to grid-connected electricity supplies in appropriate hybrid configurations.

Intermittent renewables can reliably provide 10 to 30 percent of total electricity supplies in the area covered by a sufficiently strong transmission grid if operated in conjunction with hydropower or fuel-based power generation. Emerging storage possibilities (like compressed air energy storage) and new strategies for operating grids offer promise that the role of intermittent technologies can be extended much further. Alternatively, hydrogen may become the medium for storing intermittently available energy production.

Significant barriers will continue to prevent accelerated development of renewable energy technologies, unless deliberate action is taken by governments, the private sector, and individual energy consumers to overcome them. These barriers include high capital costs, economic risks, regulatory obstacles, limited availability of products, lack of public acceptance, information and technology gaps, lack of infrastructure, and lack of incentives. The financial challenge of overcoming high initial costs is particularly great, even though these cost have come down significantly over the past several years. Most barriers can be overcome with appropriate institutional arrangements. Renewable energy plants are often small in size and therefore have small unit costs. This is a

TABLE 6. NEW RENEWABLES, BY SOURCE, 2001 (EXAJOULES AND PERCENT)

Source/ Technology	Contribution	
	EJ	%
Modern biomass energy	6.000	68.00
Geothermal energy	2.100	23.80
Small hydropower	0.360	4.10
Low-temperature solar heat	0.200	2.30
Wind electricity	0.160	1.70
Solar photovoltaic electricity	0.004	0.04
Solar thermal electricity	0.003	0.04
Marine energy	0.002	0.03
	8.900	100.00

Note: Assumed average conversion efficiency: for biomass heat, 85 percent; biomass electricity, 22 percent; biomass combined heat and power (CHP), 80 percent; geothermal electricity, 10 percent; all others 100 percent.

Source: W.C. Turkenburg, Utrecht University, The Netherlands, March 2003. Reprinted with permission.

TABLE 7. STATUS OF RENEWABLE ENERGY TECHNOLOGIES, END 2001

Technology	Increase in energy production, 1997–2001 (percent per year)	Operating capacity, end 2001	Capacity factor (percent)	Energy production, 2001	Turnkey investment costs (2001 US$ per kilowatt)	Current energy cost	Potential future energy cost
Biomass energy							
Electricity	~ 2.5	~ 40 GWe	25–80	~ 170 TWh (e)	500–6000	3–12 ¢/kWh	4–10 ¢/kWh
Heat[a]	~ 2	~ 210 GWth	25–80	~ 730 TWh (th)	170–1000	1–6 ¢/kWh	1–5 ¢/kWh
Ethanol	~ 2	~ 18 bln litres		~ 450 PJ		(8–25 $/GJ	(6–10 $/GJ
Bio-diesel	~ 1	~ 1.2 bln litres		~ 45 PJ		15-25 $/GJ)	10-15 $/GJ)
Wind electricity	~ 30	23 GWe	20–40	43 TWh (e)	850–1700	4–8 ¢/kWh	3–10 ¢/kWh
Solar photovoltaic electricity	~ 30	1.1 GWe	6–20	1 TWh (e)	5000–18000	25–160 ¢/kWh	5 or 6–25 ¢/kWh
Solar thermal electricity	~ 2	0.4 GWe	20 – 35	0.9 TWh (e)	2500–6000	12–34 ¢/kWh	4–20 ¢/kWh
Low-temperature solar heat	~ 10	57 GWth (95 million m^2)	8–20	57 TWh (th)	300–1700	2–25 ¢/kWh	2–10 ¢/kWh
Hydro energy							
Large	~ 2	690 GWe	35–60	2600 TWh (e)	1000–3500	2–10 ¢/kWh	2–10 ¢/kWh
Small	~ 3	25 GWe	20–90	100 TWh (e)	700–8000	2–12 ¢/kWh	2–10 ¢/kWh
Geothermal energy							
Electricity	~ 3	8 GWe	45–90	53 TWh (e)	800–3000	2–10 ¢/kWh	1 or 2–8 ¢/kWh
Heat	~ 10	11 GWth	20–70	55 TWh (th)	200–2000	0.5–5 ¢/kWh	0.5–5 ¢/kWh
Marine energy							
Tidal	0	0.3 GWe	20–30	0.6 TWh (e)	1700–2500	8–15 ¢/kWh	8–15 ¢/kWh
Wave	–	exp. phase	20–35	0	2000–5000	10–30 ¢/kWh	5–10 ¢/kWh
Tidal stream/Current	–	exp. phase	25–40	0	2000–5000	10–25 ¢/kWh	4–10 ¢/kWh
OTEC	–	exp. phase	70–80	0	8000–20000	15–40 ¢/kWh	7–20 ¢/kWh

[a] Heat embodied in steam (or hot water in district heating), often produced by combined heat and power systems using forest residues, black liquor, or bagasse.

Source: W.C. Turkenburg, Utrecht University, Netherlands (March 2003), with contributions from André Faaij (Netherlands), Peter Fraenkel (United Kingdom), Ingvar Fridleifsson (Iceland), Carlo Hamelinck (Netherlands), Geyer (Germany), David Mills (Australia), Jose Roberto Moreira (Brazil), Wim Sinke (Netherlands), Bart van der Ree (Netherlands).

mixed blessing. On the one hand, there is no need to seek large capital investments; on the other hand, transaction costs weigh more heavily, unless many small projects are bundled into larger initiatives.

Because they are small in scale and modular, many renewable technologies are good candidates for continued cost cutting. The cost reductions of manufactured goods, which are typically rapid at first and then taper off as the industry matures, are called experience curves. These curves resulted in industry-wide cost declines of 10 to 20 percent for each cumulative doubling of production for solar photovoltaics, wind generators, gas turbines, and other technologies – due to learning effects, technology improvements, and economies of scale (Figure 14). Similar declines are expected for several other small-scale renewable energy technologies.

At the World Summit on Sustainable Development in September 2002, it was agreed that the contribution of renewables to world energy use should be substantially increased “with a sense of urgency”. Increased use of renewables, it was agreed, should be achieved by “joint actions and improved efforts to work together at all levels”, by “public-private partnerships”, and by “intensifying regional and international co-operation in support of national efforts”. A broad coalition of countries, including Brazil, Canada, New Zealand, Iceland, Norway, and the European Union and its member states, have indicated a willingness to go one step further by committing themselves to targets and timetables.

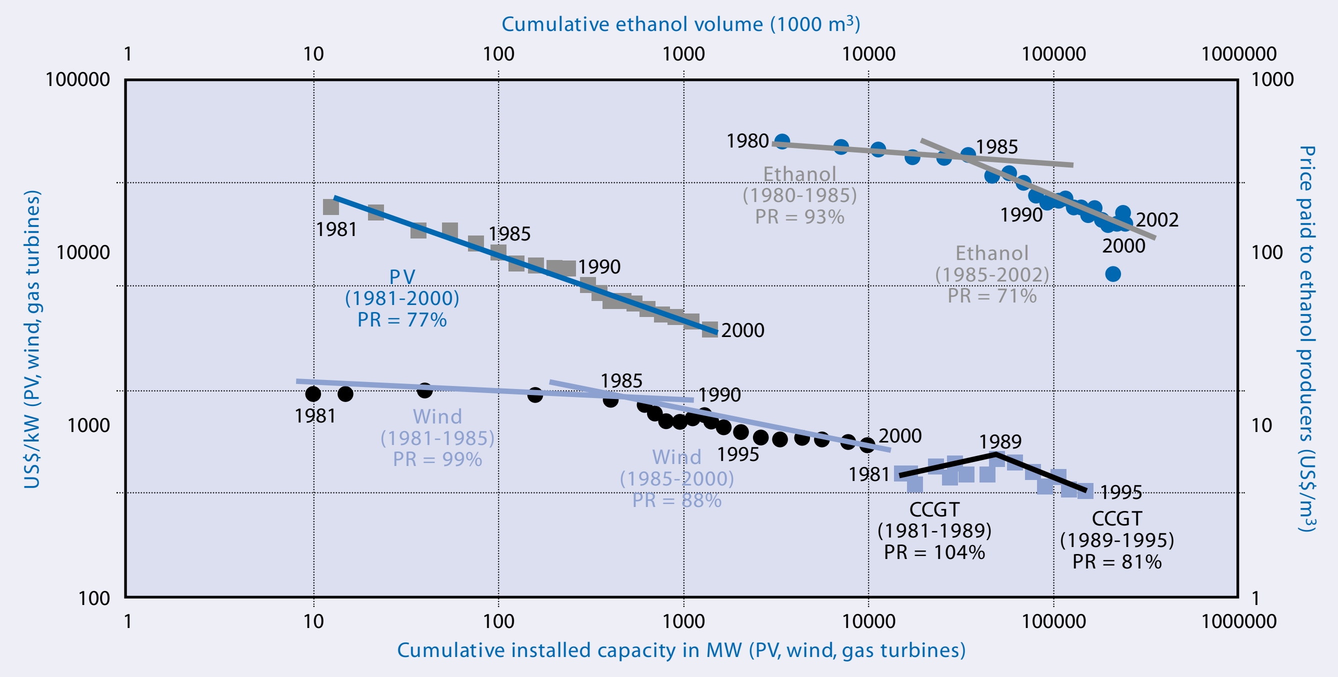
Rapid expansion of a renewable-based energy system will require actions to stimulate the market. This expansion can be achieved by finding ways to drive down the relative cost of renewables in their early stages of development and commercialisation, while still taking advantage of market place economic efficiencies. Pricing based on the full costs of conventional energy sources (including phasing out subsidies and internalising externalities) will make renewable energy more competitive. "Green" pricing of electricity and heat (which lets consumers choose to pay more for environmentally benign energy supplies) is another option some industrialised countries use to stimulate investment in renewables. Other successful incentives include: the use of ambitious but realistic targets and timetables; green certificates that can be traded at a national or international market combined with agreements to reduce emissions (e.g., carbon dioxide); favourable uptake prices for renewable electricity delivered to the grid; tax credits for investments in renewables; subsidies with "sunset" clauses; and concessions for the development of renewable energy resources.

Fossil Energy Technologies

Fossil energy technologies must evolve toward the long-term goal of near-zero air pollutant and greenhouse gas emissions without complicated end-of-pipe control technologies if sustainability goals are to be met. Near-term technologies and strategies should be supportive of this long-term goal.

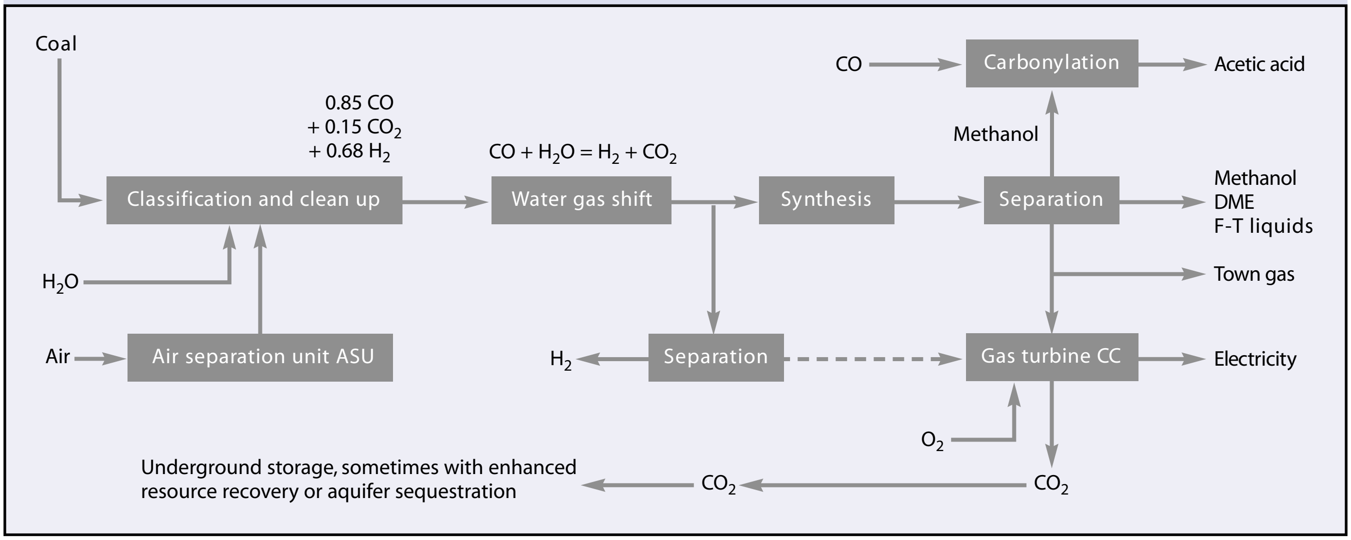
The technological revolution currently underway in power generation, where advanced systems are replacing steam turbine technologies, is a step in the right direction. Several examples can be cited. Natural-gas-fired combined cycle plants offer low cost, high efficiency, and low environmental impact; they are being chosen wherever natural gas is readily available – in some countries even taking the place of new large-hydropower projects. Co-generation (i.e., the combined delivery of heat and power or CHP) based on gas turbines and combined cycles is more cost effective and can play much larger roles in the energy economy than co-generation with steam turbines. Reciprocating engines and emerging micro-turbine and fuel cell technologies are also strong candidate technologies for co-generation at smaller scales, including commercial and apartment buildings. Coal gasification by partial oxidation with oxygen to make "syngas" (mainly carbon oxide and hydrogen) makes it possible to provide electricity via integrated gasifier combined cycle (IGCC) plants at high efficiencies and with air

FIGURE 14. EXPERIENCE CURVES FOR PHOTOVOLTAICS, WINDMILLS, GAS TURBINES, AND ETHANOL PRODUCTION



Sources: For wind turbines, L. Neij., P. Dannemand Andersen., M. Durstewitz, P. Helby, M. Hoppe-Kilpper, and P.E. Morthorst, Experience Curves: A Tool for Energy Policy Assessment *(March 2003); for gas turbines, U. Claeson Colpier and D. Cornland, "The Economics of the Combined Cycle Gas Turbine: An Experience Curve Analysis",* Energy Policy *30, no. 4 (2002), pp 209-216; for photovoltaics, V. Parente, R. Zilles, and J. Goldemberg, "Comments on Experience Curves for PV Modules",* Progress in Photovoltaics: Research and Applications, *John Wiley & Sons, Ltd (2002); for ethanol, J. Goldemberg, S.T. Coelho, P. M. Nastari, and O. Lucon, "Ethanol Learning Curve: The Brazilian Experience",* Biomass and Energy *(in publication).*

FIGURE 15. COAL POLY-GENERATION



pollutant emissions nearly as low as for natural gas combined cycles. Today power from IGCC co-generation plants would often be competitive with power from coal/steam electric plants in either co-generation or power-only configurations.

Very clean syngas, derived synthetic fuels such as synthetic middle distillates and dimethyl ether, can soon play significant roles supplementing conventional liquid fuels (for transportation, cooking, peak power generation, etc.) both to alleviate oil supply security concerns and to facilitate implementation of toughening air pollution regulations. Such fuels can often be produced for global markets at competitive cost from huge low-cost natural gas supplies that would otherwise be stranded assets at remote sites. In natural-gas-poor, coal-rich regions, a promising strategy for producing such fuels is via coal gasification and "poly-generation" – the co-production of various combinations of clean fuels, chemicals, and electricity (Figure 15).

Such systems might include production of extra syngas for distribution by pipelines to small-scale co-generation systems in factories and buildings, thereby making possible clean and efficient use of coal on small as well as large scales. Rapidly growing poly-generation activity is already underway in several countries based on gasification of low-quality petroleum feedstocks – activity that is helping to pave the way for coal-based systems.

Barriers to widespread deployment of advanced co-generation/poly-generation systems are mainly institutional. Most systems will produce far more electricity than can be consumed onsite, so that achieving favourable economics depends on being able to sell co-product electricity to electric grids at competitive prices. Under competitive market conditions, co-generation/poly-generation systems will often be the system of choice (although utility policies have sometimes made selling the excess electricity difficult).

If carbon-based fuels were replaced by hydrogen (H_2), greenhouse gas emissions from combustion would be zero and the only pollutant emissions would be oxides of nitrogen, which can be readily controlled to low levels. If H_2 were used in fuel cells, emissions of oxides of nitrogen would also be reduced to zero.

Near-term pursuit of a syngas-based energy strategy could pave the way for widespread use of H_2 as an energy carrier, because for decades the cheapest way to make H_2 will be from fossil-fuel-derived syngas. Concerns about climate change, urban air pollution, and oil supply insecurity have catalysed world-wide interest in hydrogen, especially as a transport fuel. Fuel cells are getting intense attention, because they offer high efficiency and near-zero air pollutant emissions. Successful development of fuel cells would, in turn, facilitate introduction of H_2, the preferred energy carrier for fuel cells. Automobile manufacturers are racing to develop fuel cell cars, with market entry targeted for 2010-2015 and small demonstration fleets planned as early as 2004. (Small demonstration fleets have been on the U.S. market since December 2002.) The fuel cell car will compete for the role of "car of the future" with the internal combustion engine/hybrid-electric car that is already being introduced into the market.

The use of oxygen rather than air for gasification allows, after the water-shift reaction and the separation of hydrogen by means of membrane technologies, a nearly pure flow of CO_2. Syngas-based energy production strategies thus facilitate capture and storage of carbon dioxide from fossil-fuel energy systems. For hydrogen and/or electricity production, CO_2 capture and storage can lead to near-zero CO_2 emissions with only modest energy penalties. For the production of hydrogen or hydrogen-rich fuels such as dimethyl ether from coal (Figure 15), the cost of capturing the CO_2 co-product would also be low. Thus if hydrogen can be established in the market as a major energy carrier, it can be provided from coal with near-zero total-fuel-cycle emissions of both greenhouse gases and air pollutants for the low incremental cost for capturing and storing CO_2 underground. Syngas can also be produced from biomass sources such as crop residues, and thus provides another route for hydrogen production in the future.

Substantial cost reductions in the past few decades have made a number of renewable energy technologies competitive.

Recent research suggests that the global capacity for secure disposal of CO_2 in geological reservoirs might be adequate to dispose of CO_2 from fossil fuel use for hundreds of years. However, more research and large-scale demonstration projects are needed to verify CO_2 storage as a viable strategy for widespread applications.

Other advanced technologies (for example, ultra-supercritical steam plants, pressurised fluidised bed combustion, and coal IGCC based on partial oxidation in air for power generation; and direct coal liquefaction for synthetic fuels production) offer some benefits relative to conventional technologies. But unlike syngas-based technologies, these near-term options do not offer clear paths to the long-term goal of near-zero emissions without significantly increasing energy costs.

Nuclear Energy

World-wide, nuclear energy accounts for 7 percent of energy use and 17 percent of electricity production. Although it dominates electricity generation in some

BOX 3. CARBON DIOXIDE CAPTURE AND STORAGE

In order achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, the Intergovernmental Panel on Climate Change (IPCC) has indicated that deep reductions in greenhouse gas emissions will be needed in his century. One option is to capture and store carbon dioxide from fossil fuel conversion processes.

In the short term, carbon dioxide can already be removed (i.e., captured, compressed, transported, and stored) from industrial facilities producing concentrated CO_2 streams that are vented to the atmosphere, such as natural gas treatment facilities, refineries, and ammonia plants. CO_2 can also be removed from power plants. One route is to capture CO_2 from the flue gases, using chemical adsorption techniques. Another route is fossil fuel combustion in an O_2/CO_2 atmosphere producing a flue gas mainly consisting of CO_2 that can be stored. Yet another option is the conversion of fossil fuels into CO_2 and hydrogen using steam reforming or a partial oxidation technique followed by a water-gas shift reaction. The CO_2 can be separated from the hydrogen using, for example, membranes or a physical absorption technique. The hydrogen can be combusted in a power plant or further purified to fuel cars or to supply energy to the domestic sector.

Carbon Dioxide Removal (CDR) has an energy and cost penalty. In the case of a power plant, CDR can reduce CO_2 emissions by 90 to 100 percent. However, it will increase the primary energy consumption of electricity production by 15 to 40 percent and electricity production costs by 30 to100 percent, depending on the type, scale, and status of the technologies involved. Capture, compression, transport, and storage of CO_2 is already used for many related applications.

CO_2 can be stored in depleted oil and natural gas reservoirs, deep saline aquifers, and unmineable coal seams. The capacity of safe CO_2 storage in the underground is estimated at one or many thousands Gt of CO_2. In addition, it may be possible to store CO_2 in deep oceans, if the associated environmental concerns can be addressed in an acceptable manner. Early opportunities for CO_2 storage, providing not only costs but also direct economic benefits (fuel), are Enhanced Oil Recovery (EOR) and Enhanced Coal Bed Methane production (ECBM) using CO_2.

RD&D is needed to reduce costs and to improve confidence in the ability of CDR to deliver emission reduction safely and securely. Nearly all investigations in the CDR field started after 1988. Currently most attention is given to the potential, costs, impacts, reliability, and acceptance of underground CO_2 storage. In the United States, there are some seventy CO_2 EOR operations underway which, in total, inject some 33 Mt of CO_2 annually, most of which comes from natural CO_2 accumulations. Other CO_2 EOR projects are planned or underway in Argentina, Trinidad, Turkey, Canada and the North Sea.

In Canada, there are some 31 acid gas injection projects in operation. The acid gas streams consist mainly of hydrogen sulphide (H_2S) and carbon dioxide. In 2001, approximately 1 Mt CO_2 was injected into geological reservoirs including disused oil and gas fields and deep saline reservoirs.

In Western Europe, there is currently one commercial CO_2 injection project, operated by Statoil (Norway). The CO_2 comes from treatment of the natural gas that is extracted from the Sleipner West field. It is injected into a deep saline aquifer that lies at a depth of 800 to 1,500 metres below the floor of the North Sea. To date, over 5 Mt CO_2 have been injected at a rate of 1 Mt per year. A research team is monitoring the fate of the injected CO_2. Several related projects are planned in Algeria, the Barents Sea, Western Australia, and off-shore Netherlands.

A pilot project involving the injection of CO_2 into coal seams is underway in the San Juan Basin of the United States, and additional projects are planned in China, Canada, and Poland. The Intergovernmental Panel on Climate Change is preparing a Special Report on Carbon Dioxide Capture and Storage, scheduled for publication in the first half of 2005.

Source: Wim C. Turkenburg, Utrecht University, The Netherlands, with input from John Gale (IEA GHG Programme, United Kingdom).

Very clean syngas, derived synthetic fuels such as dimethyl ether, can soon play significant roles in supplementing conventional liquid fuels.

countries, its initial promise has not been widely realised. Current projections of nuclear's contribution to global energy are that it will not grow, will grow only slowly, or may even decline during the initial decades of the twenty-first century. Nuclear power is more costly than originally projected, competition from alternative technologies is increasing, and there has been a loss of public confidence because of concerns relating to safety, radioactive waste management, and potential nuclear weapons proliferation. However, because nuclear power can provide energy without emissions of conventional air pollutants and greenhouse gases, it is worth exploring whether advanced technologies could simultaneously offer lower costs, build broad public confidence in the safety of nuclear reactors, ensure that nuclear programs are used for peaceful rather than military purposes, and demonstrate effective nuclear waste management practices. Unlike the Chernobyl-type reactors, the light water reactors (LWRs) that dominate nuclear power globally have had a good safety record, although this record has been achieved at considerable cost in order to minimise accident risk.

The potential linkage between peaceful and military uses of nuclear energy was recognised at the dawn of the nuclear age. Steps taken to create a "non-proliferation regime" through the Nuclear Non-Proliferation Treaty and a series of regional treaties, controls on commerce in nuclear materials and goods and services that might be used to further military ambitions, and safeguards applied on nuclear materials in peaceful nuclear applications, have been successful, by and large, in keeping peaceful and military uses separate. If nuclear power is to contribute more than it currently does, strengthened institutional measures will be needed to maintain this separation, complemented by technological advances aimed at limiting opportunities to acquire nuclear weapons under the guise of peaceful nuclear energy applications and to steal weapons-usable nuclear materials.

Near-term improvements in nuclear reactors can be achieved both through continued evolution in LWRs and through development of new reactor concepts. Already available are LWRs with improved safety features and standardised designs for which there can be a high degree of confidence that performance and cost targets will be met. LWRs can also be modified to make them more proliferation-resistant via a denatured uranium/thorium fuel cycle. Another concept being revisited, the pebble-bed modular reactor (PBMR) – a gas-cooled, helium reactor – claims to have the potential for a high degree of inherent safety without the need for complicated and capital-intensive safety controls; it could also be operated on a proliferation-resistant denatured uranium/thorium fuel cycle.

A lack of low-cost uranium supplies might ultimately constrain nuclear power development based on LWRs. The plutonium breeder reactor, which requires reprocessing spent fuel to recover plutonium for recycling in fresh fuel, was once thought to be a major option for addressing this challenge. But electricity costs for breeders would probably be higher than for LWRs. In addition, preventing proliferation is much more challenging with reprocessing and plutonium recycle than for LWRs operated on once-through fuel cycles.

Alternative long-term options for addressing inadequate uranium supplies include alternative breeder concepts, including particle accelerator-driven reactors, thorium based reactors, uranium from seawater, and thermo-nuclear fusion. Alternative breeder concepts would take decades to develop with no certainty about prospective costs, safety, and proliferation-resistance features. Uranium exists in seawater at low concentrations but in vast quantities; recent research suggests it might be feasible to extract it at relatively low cost. If this technology could be deployed at globally significant scales, it might be feasible to avoid making major new commitments to nuclear fuel reprocessing and plutonium recycling. Although thermo-nuclear fusion could provide a virtually inexhaustible energy supply, it will not be commercially available before mid-century.

Radioactive waste by-products of nuclear energy must be isolated so that they can never return to the human environment in concentrations that could cause significant harm. Although the safety of long-term waste disposal has not been proven, the technical community is confident that this objective can be realised – in large part because of the small volumes of wastes involved. However, in most countries there is no social consensus about the goals and standards for radioactive waste disposal and about strategies (both interim and long-term) for moving forward to implement them. The issues involved are only partly technical. The current social stalemate regarding waste disposal not only clouds the prospects for nuclear expansion but also has made spent-fuel reprocessing a *de facto* interim "nuclear waste management strategy" in some countries. However, fuel reprocessing does not offer economic gains and does not "solve" the waste disposal problem – it merely "buys time" and, unless it is blended as mixed oxide fuel (MOX) for use in LWRs, will create large inventories of plutonium that must be safeguarded.

No long-term disposal facility exists yet for waste from civilian nuclear power plants, and most nuclear power countries have made little or no progress in that direction. Even in Finland, Sweden, and the United States, which have advanced furthest, operating depositories remain more than a decade away. As national waste strategies continue to evolve, it may be of benefit to consider multinational approaches to the management and disposal of spent fuels and other radioactive waste. Considerable economic, safety, security, and non-proliferation advantages may accrue from programmes to collaborate on the construction and operation of international waste repositories. ■

part V

Are Sustainable Futures Possible?

Part V brings together the analysis of challenges presented in Parts I, II and III and the analysis of resources and technology options in Part IV by considering whether sustainable futures are possible. Can combinations of resource and technology utilisation be envisioned that meet all of the sustainability challenges? The analysis presented is at three levels: the overall global system using a range of alternative energy scenarios, plus analysis of two critically important areas: rural energy in developing countries and transportation. A final section looks at the relationship between energy and more widespread economic prosperity.

The analysis indicates that it is possible simultaneously to address the range of sustainable development objectives.

- Continuing along the current path of energy system development is not compatible with sustainable development objectives.
- Realising sustainable futures will require much greater reliance on some combination of higher energy efficiencies, renewable resources, and advanced energy technologies.
- A prerequisite for achieving an energy future compatible with sustainable development objectives is finding ways to accelerate progress for new technologies along the energy innovation chain, from research and development to demonstration, deployment, and diffusion.
- Providing access to affordable energy services to people in rural areas poses particular challenges. But it also offers considerable opportunity for improving the lives of billions of people within a relatively short period. Promising approaches include decentralised solutions, appropriate technologies, innovative credit arrangements, and local involvement in decision-making, and especially new mechanisms at the local level that have lower transaction costs.

- **Transportation is a key area with its rapid growth and high dependence on fossil fuels. By combining new fuels, both fossil and renewable, with near-zero greenhouse gas emissions and a better mix of improved modes of transportation and vehicle performance, it appears possible to meet sustainability criteria.**

Any conceivable energy system that would address all sustainable development objectives simultaneously will not be realised without changes in the current policy environment. Creating such an energy system will require policy action at national, regional, and global levels.

Addressing the Sustainability Challenge: Alternative Scenarios

The construction and analysis of scenarios provides a method for exploring future energy systems and their implications. Scenario construction is not a method for predicting the future; however, by combining plausible and/or interesting assumptions the analysis provides insights as to possible positive and negative characteristics of alternative futures. In constructing energy scenarios, the first questions are: Can combinations of resources and technologies be envisioned that meet *all* sustainability challenges *simultaneously?* Or are there unavoidable trade-offs, e.g., must a choice be made between economic growth and environmental protection? Having identified some "desirable" futures, characterised by meeting all sustainability criteria, the next question is: What would it take to bring about such energy futures in terms of incentives, institutions, rules, and regulations?

Scenario construction involves applying various combinations of assumptions about what world events and trends will affect the energy sector. The issues to be addressed include population growth and age distribution, economic activity and its composition, consumption and production patterns, and limitations in terms of environmental degradation, availability of land and other resources, as well as technologies for energy supply and demand that exist or may be envisioned. The resulting scenarios can then be evaluated in terms of sustainability characteristics.

The World Energy Assessment undertook such a study of how the future could unfold in terms of economic growth, population trends, and energy use (Nakićenović, Grübler, and McDonald, 1998).[14] It started from the premise that, by 2100, 6 to 8 billion additional people – more than doubling today's world population – will need access to affordable, reliable, flexible, secure, and convenient energy services. It assumed that gross world product would grow by a factor of 10 to 15 during the century. It then constructed three sets of energy scenarios (some with multiple variants) by combining assumptions about resources and technologies in a variety of ways. The scenarios were evaluated in terms of compatibility with indicators of sustainability. The WEA concluded that there are indeed a large number of combinations of energy efficiency improvements, renewable energy utilisation, and extensive use of advanced technologies that would have the potential to meet sustainable development criteria.

The WEA scenarios were based on mid-1990s technology, and incorporated only limited improvements in energy efficiency. Utilising advanced fossil fuel technologies discussed in Part IV of this volume would increase the potential for sustainability even more than the WEA scenarios express (see Box 4 for an example). Since the WEA scenarios were presented, there has been no comprehensive energy modelling linking scenarios to the full set of sustainability challenges.

BOX 4. TOWARDS A 2000 WATT PER CAPITA SOCIETY

The Board of the Swiss Federal Institutes of Technology has developed the vision of a "2000 Watt per capita society by the middle of the 21st century". A 2000 Watt per capita energy demand corresponds to 65 GJ per capita per year, which is one third of today's per capita primary energy use in Europe, and slightly below the global average. Assuming a doubling of GDP (gross domestic production) per capita within the next fifty years, the 2000 Watt society implies a four-to-five fold reduction in primary energy use, allowing for some influence of structural change on less energy-intensive industries and consumption patterns.

This vision challenges R&D to improve energy and material efficiency. The findings suggest that new technologies and supporting organisational and entrepreneurial innovations are needed to meet this goal. Some of those technologies and commercial services are available today, but are scarcely applied due to obstacles and unfavourable conditions.

These early findings need further in-depth analysis, but they indicate that the vision of a 2000 Watt per capita society is likely to be technically (and eventually economically) feasible and that its implementation strongly depends on policy priorities in the future.

Sources: Jochem, E., et al., Steps Towards a 2000 Watt Society: Developing a White Paper on Research & Development of Energy-Efficient Technologies, Final Report *(Zürich: Centre for Energy Policy and Economics, 2002); Goldemberg, J., et al., "Basic Needs and Much More with One Kilowatt per Capita",* Ambio *14, no. 4-5 (1985), pp. 190-200.*

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[14] These scenarios are summarised in the World Energy Assessment. The texts are available in United Nations languages at http://www.undp.org/seed/eap/activities/wea/, and thus not repeated here.

Continuing along the current path of energy system development is not compatible with sustainable development objectives.

A large number of scenarios have been constructed, however, aiming at understating the climate change situation.[15]

All of the WEA scenarios supply the desired level of energy services within the constraints of energy resource availability, and lead to a substantial decrease in emissions of air pollutants; however, only some are consistent with the UNFCCC objective of stabilising atmospheric concentrations of carbon dioxide and other greenhouse gases. Two scenarios lead to concentrations of less than 450 parts per million (ppm) by 2100, stabilising some half a century later. This is a considerable achievement, as it represents only a gradual increase from current concentrations of about 370 ppm. It has not been established at what level stabilisation would be needed to achieve the objective of the UNFCCC to "prevent dangerous anthropogenic interference with the climate system".

The considerable differences in expected total energy use among the scenarios reflect different approaches to addressing the needs for energy services in the future, and they demonstrate clearly that policy matters. Achieving the sustainable development scenarios will require a substantial increase in private and public research, development, and deployment efforts to support new energy technologies. Otherwise, most clean fossil and renewable technologies, as well as many energy-efficient end-use technologies, may not reach competitiveness. (The mix of needed efforts may vary depending on the maturity of the specific technology.) Significant technological advances will be required, as will incremental improvements in conventional energy technologies.

In terms of their expected high growth in energy demand, developing countries are well positioned to take advantage of innovations in energy technologies and policies that support them. In general, sustainable scenarios require significant policy and behavioural changes within the next several decades to be achieved. The window of opportunity for making such changes is at most a decade or two. The decisions made during this time will largely determine whether the energy system continues to evolve along current lines or whether it achieves the transition towards more sustainable development paths.

Once basic infrastructures and energy-intensive industrial capacity are in place, investment largely shifts from new capacity to replacement. New technologies can be introduced in this phase, but they take much longer to affect average system performance, as they occur at the much slower rate of replacement investments. If advanced systems and technologies are not selected in decisions about new investment during the next few decades, nations, corporations, and the world will be locked into older, less sustainable options, and sustainability might not be achievable for a long time, if at all. Thus the achievement of sustainable development demands a global perspective, a very long time horizon, and the timely introduction of policy measures to reduce barriers and create incentives for advanced technologies and systems.

Because of the long lifetimes of power plants, refineries, steel plants, buildings, and other energy-related investments such as transportation infrastructures, there is not a sufficient turnover of such facilities to reveal large differences among the alternative scenarios before 2020, especially in the industrialised countries. But the seeds of the post-2020 world will have been sown by then. Thus choices about the world's future energy systems are relatively wide open now. This window of opportunity is particularly significant where infrastructure has yet to be installed, offering the possibility of a rapid introduction of new, environmentally sound technologies.

Clearly, the insight that there are desirable energy futures that meet a whole set of sustainability criteria is very positive. However, these energy futures are unlikely to happen in the current context of market conditions, incentives, and institutional and regulatory structures at the national, regional, and global levels. Options that can be implemented to change the current context are discussed in Part VI.

The Rural Development Challenge

Between 1970 and 1990, rural electrification programmes reached about 800 million additional people. Some 500 million saw their lives improve substantially through the use of better methods for cooking and other rural energy tasks. Despite these enormous efforts to improve energy services to rural populations in the past thirty to forty years, the unserved population has not

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[15] These are reviewed by the Intergovernmental Panel on Climate Change. 2000. Special Report on Emission Scenarios (available at www.ipcc.ch).

decreased significantly in absolute numbers – it remains about two billion people.

Although the unavailability of adequate energy services in rural areas is probably the most serious energy problem confronting humanity in the near future, rural energy remains low on the list of priorities of most governments and corporate planners. Moreover, the increased demands of the more influential (and rapidly growing) urban population will make it more difficult to keep rural development on the agenda.

Addressing the energy needs of rural populations requires a four-pronged strategy.

- First, provide rural income-generating activities with minimally adequate amounts of improved energy services, eventually culminating in the provision of electricity services. Special emphasis needs to be placed on micro (often operated at the household level), small, and medium scale rural enterprises.
- Second, extend electricity services to dispensaries, hospitals, schools, and other rural institutions that provide critical social services, which play a key role in improving the living conditions of the rural population.
- Third, encourage households to move away from inefficient use of unprocessed solid fuels (biomass and coal) to more efficient use, with the eventual aim of shifting to modern energy forms that may potentially be derived either from renewable energy sources (biomass and solar) or from liquid and gaseous fossil fuels.
- Fourth, promote the organisation of local private sector entities into an energy market management organisation that surveys the market for local productive chains, assesses energy resources, and bridges the gap between a large number of isolated consumers and the discrete number of energy service providers and potential investors who will add value to local production. This approach of connecting demand and discrete supply reduces the transaction costs and helps develop the financial engineering required for rural consumers to generate local income.

An effective concept for thinking about the energy needs of rural populations is the "energy ladder", in which consumers "climb" from simple biomass fuels (dung, crop residues, firewood) to the most convenient, efficient form of energy appropriate to the task at hand (usually liquid or gaseous fuels for cooking and heating and electricity for most other uses). "Climbing the energy ladder" involves not only a shift to modern fuels but often also the synergistic use of modern, more efficient end-use devices such as improved cooking stoves. The process does not necessarily mean replicating the past or climbing all the rungs previously climbed by others. In the case of cooking, for example, users do not have to go from fuelwood to kerosene to liquefied petroleum gas (LPG) or electricity. The aim should be – whenever possible – for users to leapfrog directly from fuelwood to the most efficient end-use technologies and the least polluting and affordable energy forms available (including new renewables). Because of the emergence of new technologies, it is also possible to introduce new rungs on the energy ladder, and gain even greater efficiencies and environmental soundness.

Unavailability of adequate energy services in rural areas is the most serious energy problem confronting humanity in the near future.

The energy-related sustainable development goals for rural areas can be derived from the Millennium Development Goals – halving extreme poverty; reducing hunger and improving access to safe drinking water; reducing child and maternal mortality and diseases; achieving universal primary education; promoting gender equality and empowerment of women; and achieving environmental sustainability. The associated energy goals are:

- Satisfying basic human needs by providing all households with minimally adequate amounts of electricity for uses such as lighting and thermal comfort (for example, through fans), in addition to cleaner cooking conditions involving better fuels and cooking devices. Specifically, all households should move away from traditional solid fuels (biomass and coal) for cooking and heating to modern energy carriers, which may potentially be derived from renewable sources (biomass and solar) or fossil fuels.
- Providing affordable electricity to support industrial activity in rural areas and thus provide employment and help curb urban migration. Both centralised (grid extension) and decentralised (stand-alone generators) rural electrification options should be evaluated.

TABLE 8. ENERGY SOURCES AND DEVICES FOR THE NEAR, MEDIUM, AND LONG TERM

Sources and tasks	Present	Near term	Medium term	Long term
Source Electricity	Grid or no electricity	Biomass-based generation Internal combustion engines coupled to generators Wind Geothermal Small hydro PV	Biomass-based generation through micro-turbines and integrated gasifier combined cycle (IGCC) turbines	Fuel cells for baseload power Solar thermal electricity
Fuels	Wood/charcoal/ dung/crop residues	Biofuels Natural gas/LPG/producer gas/biogas Vegetables oils	Biofuels Liquid petroleum gas (LPG) Synthetic gas (syngas) Dimethyl ether (DME)	Biofuels
Co-generation (combined heat and power or CHP)	Diesel engines	Internal combustion engines Turbines	Micro-turbines and IGCC turbines	
Task Cooking	Woodstoves	Improved woodstoves LPG stoves	LPG/biogas/producer gas/ natural gas/DME stoves	Fuel cells
Safe Water	Surface/ tubewell water	Filtered/treated water/ ultraviolet filtration	Safe piped/ treated water (De)centralised water treatment	Gaseous bio-fuelled stoves/ electric stoves/catalytic burners
Lighting	Oil/kerosene lamps	Electric lights	Fluorescent/compact fluorescent lamps	Ultra-safe piped/treated water
Motive Power	Human/animal powered devices	Internal combustion engines/ electric motors	Biofueled prime movers Improved motors	Fluorescent/compact fluorescent lamps
Appliances	—	Electric appliances	Efficient appliances	Biofueled prime movers Improved motors Fuel cells
Process heat	Wood/biomass	Biomass-based generation Electric furnaces Co-generation Producer gas/natural gas-fuelled/solar thermal furnaces	Induction furnaces Biofuels Solar thermal furnaces	Super-efficient appliances Biofuels Solar thermal furnaces
Transport	Animal-drawn vehicles/human-powered bicycles	Petroleum/natural gas-fuelled vehicles Compressed natural gas (CNG) and LPG	Biomass-fuelled vehicles	Fuel-cell powered vehicles

In general, the rural poor are willing and able to pay for energy services if they have appropriate financing options and they are able to meet the first costs of access and/or appliances. The economics of providing basic electricity to rural households should be evaluated according to the costs of supplying comparable energy services through less efficient carriers. In some cases, home solar photovoltaic systems can provide energy services at a lower cost than the kerosene and batteries they replace and can be an economically viable source of rural household power, even at relatively low levels of service provision.

The availability of affordable and adequate energy services in rural areas could lead to major improvements in living conditions and to the fulfilment of basic human needs in a relatively short period of time. The corresponding amount of energy needed to provide such services in rural areas is relatively small. Modern ways of using biomass more efficiently could go a long way towards achieving this objective. Experience has shown that to find the most viable and appropriate solutions to rural energy, the active participation of the people who will use it is a must.

Identifying technological options for energy sources and services depends very much on the time horizon. Starting from the existing technology, three types of technology are needed for each energy-utilising task. A near-term technology should lead to immediate improvement in the present situation. A medium-term technology to achieve a dramatic advance should be available in five to ten years. And a long-term technology should prevail after twenty to thirty years and provide an ideal sustainable solution. The technologies for the near, medium, and long terms should be forward compatible so that the technology at any one stage can be upgraded to the better version. In planning efforts, it is wise to have a balanced portfolio with a combination of near-, medium-, and long-term technologies (Table 8).

The Transportation Challenge

Oil accounts for 97 percent of transportation energy in the industrialised countries, with natural gas (2 percent) and electricity (1 percent) accounting for the rest. The transport sector is growing faster than any other end-use sector in these countries, whose dependence on oil is one of the most daunting problems of the next decades. Growing dependence on oil is even more serious in the developing countries, where energy demand is growing three times faster than in OECD countries. In 2001, transportation accounted for 57 percent of primary oil demand in OECD countries and 39.5 percent in non-OECD countries (IEA, 2003c).

The seriousness of the problem derives from the unique characteristics of individual transportation by automobile, one of the basic characteristics of the industrialised countries, where there are 500 automobiles per 1,000 inhabitants (in the United States, it is 750 automobiles per 1,000 people). In the rest of the world, there are only 50 automobiles per 1,000 people. If industrialised-country levels of automobile ownership prevailed everywhere, the world would have 5 billion cars compared to the current 500 million cars. The consequence would be increased competition for dwindling conventional oil resources, considerably aggravated local environmental pollution, and significantly higher greenhouse gas emissions and congestion.

Attempts to face these problems have been tried along four distinct lines:

Shifting the structure of road transportation (passengers and freight) to less energy intensive transport modes, particularly public transport. In urban areas, this includes greater reliance on public transportation options, particularly bus rapid transit (BRT) and non-motorised transport (NMT). These options have the additional benefit of also being particularly advantageous forms of transport for the urban poor. The need for more urban transport interventions that directly assist the poor is demonstrated by a study in Cairo, Egypt, which found that the 10 percent of the population in the highest income group uses 54 percent of the physical space (roads and highways) dedicated to transport. In Bogota, before the BRT system was introduced, it was estimated that about 71 percent of the motorised trips were made by bus, but private cars that transport only 19 percent of the population – primarily middle- and high-income people – used 95 percent of the road space. Investments in primary roads and high-cost mass transit systems can have the perverse effect of driving out poor people as a result of escalating land and property values.

Reducing the energy intensity of various forms of travel, by improving vehicle efficiency (using less fuel per kilometre), improving utilisation (carrying more passengers or tonnes of freight per vehicle-kilometre), or improving traffic conditions so that vehicles perform better. Engine efficiency is the product of two factors: *thermal efficiency,* expressing how much of the fuel energy is converted into work to drive the engine and vehicle, and *mechanical efficiency,* the fraction of that work which is delivered by the engine to the vehicle. From a technical perspective, gains of 15 to 40 percent are possible in some of these areas.

Promoting more widespread development and use of alternative fuels to gasoline and diesel oil (in Europe, diesel is used by a third of all cars). Currently the primary fuels in use are gasoline for Otto-cycle automobiles and diesel for Diesel-cycle trucks. The primary alternatives on the horizon are:

- **Liquefied petroleum gas and compressed natural gas (CNG),** which have a higher hydrogen-to-carbon ratio than gasoline. They have a higher octane number than gasoline, permitting use of higher compression ratio engines. No major infrastructure changes are required for LPG or CNG use.
- **Biofuels,** produced from biomass, are very close to being competitive with gasoline. They come in several forms. *Biodiesel* is produced from vegetable oils and is used in France and Germany added to diesel oil. *Ethanol* is produced from sugars (particularly sugar cane) and starch by fermentation with yeasts and can be used pure or as a gasoline extender. In Brazil, where ethanol is used both as a blend of 25 percent ethanol and 75 percent gasoline and as neat ethanol (96 percent volume ethanol and

water) in spark-ignition engines, it has replaced more than one half of the gasoline that would otherwise be used. The other large-scale ethanol user is the United States, where ethanol has been used to increase the octane rating of gasoline, to decrease carbon monoxide emissions, and more recently to replace MTBE (methyl ter-butyl ether) in reformulated gasoline. Ethanol fuel programs also exist in Kenya, Malawi, and Zimbabwe. Countries in the early stages of blending ethanol into gasoline are Australia, Canada, China, Colombia, Japan, and Thailand. In the European Union, ethanol is consumed in France, Spain, and Sweden, especially after conversion to ETBE (ethyl ter-butyl ether). Both in the United States and the European Union, the introduction of renewable fuels standards is likely to increase considerably the consumption of bio-ethanol and biodiesel. Lignocelluloses from agricultural and forest industry residues and/or the carbohydrate fraction of municipal solid waste (MSW) are a further source of biomass liquids. Although land devoted to fuel could reduce land available for food production, this is at present not a serious problem. In the longer term, lignocelluloses are likely to become the primary source of biofuels.

- **Electric vehicles using batteries** are of great interest, especially as "urban vehicles", but will probably remain as a niche market for at least a decade. If the electricity that fuels them comes from a non-fossil source, they can yield a significant reduction in greenhouse gas emission. The key barrier to their implementation is the current state of battery technology, resulting in high costs, heavy automobiles, and limited range. Large-scale introduction of electric vehicles could require major infrastructure changes, not only in the energy distribution system and the automobile itself but also in the power generation industry. However, hybrid power trains that combine an electric motor with a spark-ignition engine are already penetrating the market and provide for a suitable transition to more sustainable power trains in the long run.
- **Hydrogen** can fuel ultra-low-emission vehicles. Storage is a problem due to its low energy density. Compressed hydrogen storage is the most probable scheme, although liquid hydrogen or metal hydride storage is also possible. Today, the most probable source of large quantities of hydrogen is natural gas. In the future, hydrogen could be produced from coal or biomass, or from electricity plants using electrolysis techniques. Fuel cells offer another attractive solution because they can produce hydrogen fuel on-board the automobile by reforming methanol, ethanol, natural gas, or even gasoline, thereby avoiding the hydrogen storage problem.

The transport sector is growing faster than any other end-use sector and dependence on oil is one of the most daunting problems.

Improving conversion technologies such as fuel cells or hybrids

- **Fuel cells** produce power electrochemically, rather than through the combustion processes used in conventional engines, and can potentially reach two or three times higher conversion efficiencies than today's internal combustion engine. Fuel cells come in several varieties but the proton-exchange-membrane (also called solid polymer) fuel cell is the leading candidate for automobiles because of its cost, size, simple design, and low operating temperature (< 120° C). The technology was originally used in the U.S. space program. Fuel cell vehicles are still in the development and demonstration stage and unlikely to be introduced commercially before 2010; costs for such vehicles and infrastructure are expected to be very high at least until then.
- **Hybrids** refer to vehicles having an internal combustion engine (powered by gasoline, diesel, or an alternative fuel) and an electric motor. Hybrids made their initial commercial appearance in the late 1990s, first in Japan, later in the United States, and more recently in Europe. Compared with today's conventional vehicles, hybrids are up to 80 percent more efficient.

Policies to reduce the growth of automobile use and freight transportation by road have been rather unsuccessful so far for a number of reasons, including lack of public support, the inelastic response of the transport sector to energy price increases (i.e., drivers do not drive less even with higher fuel prices), and the very slow turnover of transportation infrastructure.

Taking energy into consideration in land-use planning, and in designing physical infrastructure, construction standards, and transportation systems, can reduce some

A low-carbon future is fully consistent with rising living standards in the industrial countries and with economic prosperity in developing countries.

of the growth in energy demand that accompanies rapid urbanisation. Transportation systems may be especially important, given the rapid growth in the number of motor vehicles world-wide. At current rates of growth more than one billion cars are likely to be on the road by 2020. Most of the additional cars will be driven in the cities of the developing world, where they will create more congestion, aggravate urban pollution, and undermine human health – even with optimistic projections about efficiency improvements and alternative fuels. Eventually they are likely to spread out, much as has been occurring in many industrialised countries, to swamp rural areas with road infrastructure and loss of countryside.

Only long-term changes in habits and consumer preferences – reflecting demographic changes, environmental awareness, changes in lifestyles, and higher energy prices – could alter this projection. Government policies can play a crucial role in facilitating such a transition by creating incentives or taxes that reflect the full cycle cost, including externalities of the various alternatives. Successful measures adopted in the central part of London – which basically charges automobile drivers for the use of streets – reduced congestion and almost doubled average speed. Along the same lines are proposals to improve traffic conditions during peak traffic times by promoting carpooling or co-ordinating traffic lights to create “green waves” of easily moving traffic.

Energy and Economic Prosperity

In the industrialised and transitional economies, demand for the services provided by energy – heat, light, motive power, transport, and so forth – continues to grow. However, improvements in the efficiency of energy conversion and use are likely to result in a levelling off – and, over the long term, in a decline – in these countries’ demand for primary energy. In developing countries, in contrast, primary energy demands are expected to grow at about 2.5 percent per year for several decades, as productivity and living standards improve and as more people have access to modern energy for the first time. Developing countries’ current per capita consumption of commercial energy is less than one fifth that of the industrialised countries, and their populations will be nearly ten times larger than industrialised countries in two generations. In any scenario of economic success, world energy demands are thus set to rise significantly in the coming decades, even allowing for improvements in energy efficiency. In the middle of the next decade, energy use in industrialised countries will be surpassed by consumption in the developing countries, exacerbating competition for fossil fuels.

Meeting the energy demands of developing countries will be essential if they are to achieve economic prosperity, and will require considerable investment. It is estimated that annual investments on the order of 2 to 2.5 percent of GDP, presently corresponding to $150 to $200 billion per year, will take place in the developing countries over the next two decades alone. This level of investment is close to historical norms and, with good financial and economic policies, should be affordable.

In the past, investments in the energy sector in developing countries rested heavily – and unnecessarily – on government subsidy, and too little on the financial resources that would be generated by regulatory policies to encourage managerial efficiency and prices that reflect actual costs. However, there is no reason why the energy sector should not be financially self-sufficient. Regulatory policies to encourage cost-reflecting prices would raise sufficient revenues to cover operating costs and generate good returns to investment, and thus attract private finance and investment on a large scale. One of the primary aims of market liberalisation and the new forms of regulation introduced in many countries in the 1990s was precisely this: to reduce the need for government subvention and to attract private capital and investment into the industry. The other aims were to encourage innovation and managerial efficiency.

The regulatory framework also needs to give priority to the task of extending energy services to unserved populations in rural and urban areas. If development succeeds and universal energy service is provided, an additional five to six billion energy consumers will be added over the next fifty years. This is in principle achievable, as demonstrated by the 800 million people to whom electricity service was extended in the period 1970-1990. In fact, under more favourable new regulatory frameworks, more rather than fewer financial resources should become available, motivated by the prospects of higher returns on investment.

However, a disturbing trend of the privatisation programmes of the 1990s is that in many countries the goal of service extension has receded from the regulators' responsibilities. There is a danger that, unless service extension receives priority, privatisation programmes, for all their merits, will come under attack and be delayed so much that what they promise to accomplish will not be done. Service extension does not mean necessarily an extension of electricity grids; in many cases, local solutions such as wind and solar energy can provide the services needed.

Inaccessibility of commercial energy cannot be fully eliminated over the foreseeable time horizon, but it can be significantly reduced. Accessibility needs to be continually improved each year, in percentage terms and in absolute numbers. The two billion people currently without access to commercial energy are increasing at the rate of almost 30 million per year. Correspondingly, service expansion has to surpass this figure by a reasonable margin; each year at least 40 million new people need to be supplied with energy services if the number of people without service is to be reduced. This means providing electricity plus fuels such as liquefied petroleum gas for cooking to at least six million new homes annually. The investment required to achieve this will be around $10 billion per year. This is a small amount that does not exceed 5 percent of global annual energy investment; it is less than 20 percent of global official development assistance. However, it is still beyond the capability of most low-income developing countries.

Although total energy resources are available to meet the expected expansion of demands, the much-discussed environmental problems arising from energy production and use must also be addressed. One urgent issue is local pollution, currently increasing in developing countries in direct proportion to increased energy use. The same thing happened historically in the industrial countries until roughly the last third of the twentieth century, when new low-polluting technologies were developed and brought into use under the stimulus of environmental regulation, enabling local pollution to be greatly reduced even as energy demands continued to rise. Developing countries have the opportunity to adapt and incorporate these technological advances at an earlier stage of development than the industrialised countries. All the evidence shows that the costs of abating local pollution are far outweighed by the benefits.

By addressing the negative externalities of energy generation and use early on, developing countries would find the overall economic well being and prospects of their people improved, not diminished. Rational energy pricing is part of what is needed, but so is a willingness to prompt markets to adopt available technologies and practices to reduce the serious costs of local pollution. There is now a wealth of information and experience to draw on to define an appropriate regulatory framework for the production and use of energy in environmentally more satisfactory ways.

Another urgent issue is climate change. Three insights have emerged from the numerous studies of technology responses to climate change over the past decade.[16]

- Technologies are emerging to support a low carbon energy future, particularly in the fields of efficiency improvements, renewable energy, hydrogen production from fossil fuels and non-carbon sources, and carbon sequestration. It can now be said with reasonable confidence that a low carbon future is technologically feasible, although the transition to such a future will take some time.
- There is immense scope for innovation; costs of new technologies for efficiency and renewables are declining and are unlikely to be much higher than fossil fuel costs, and in some cases lower.
- The transition to a low-carbon economy would have little or no adverse impact on the economic prospects of either the developing or the industrialised countries. In fact, a low-carbon future is fully consistent with rising living standards in the industrial countries and with the goal of developing countries to achieve economic prosperity (Box 5).

What is now needed is a set of policies to stimulate the development and use of low-carbon technologies and practices. Such policies are being put in place at the national level in a number of industrialised and developing countries, e.g., in the form of support programmes for renewable energy, energy efficiency, hydrogen-linked technologies such as fuel cells, and carbon dioxide capture and storage. Most, however, are still tentative and in their early phases (barely a decade old); a number of countries are currently reworking their approaches based on this early experience and the new evidence on climate change put out by the IPCC.

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[16] Major studies include reports by the IPCC, international agencies such as the Global Environment Facility, several industry studies, and the report of the G8 Task Force on Renewable Energy; they are winning acceptance, most recently during the World Summit on Sustainable Development in Johannesburg.

BOX 5. CAN THE WORLD AFFORD TO MOVE TO A LOW-CARBON ENERGY ECONOMY?

The annual expenditures of meeting the world's current primary energy requirements are enormous – around $1 trillion per year, plus perhaps a further $2 trillion per year to provide the supporting infrastructure and services (for example, electricity generation, transmission, and distribution networks; coal mining and distribution networks; gas grids; and oil refining and marketing infrastructure). Such infrastructure investments have made the achievement of economic prosperity possible in the rich countries, and hold the same promise for the developing countries. Is it, therefore, too risky, from an economic viewpoint, to seek to reduce the energy system's dependence on fossil fuels over the long-term in the interests of addressing environmental problems and achieving sustainable development?

Available studies show that the costs of investment in alternatives will not be prohibitive – and indeed may be negative, that is, economies will be better off making these investments, not worse, in the long-term. The reasons:

- Alternatives to fossil fuels are available and abundant, sufficient to meet human energy needs in perpetuity.
- Their costs are not far removed from those of fossil fuels, and in some cases are lower.
- Costs are declining over time with innovation and investment.
- Improvements in the efficiency with which energy is converted and used are leading to cost savings and reduced waste, and are often more than sufficient to offset the extra costs of non-carbon supplies.

Economic studies have consistently put the added costs in the range of minus 1 to plus 2 percent of gross world product over a fifty-year period, during which time world product should rise by 300 to 500 percent in any scenario of economic success. In other words, at worst, investing in non-carbon sources of energy may shave a few months' growth of output off during the fifty-year period, but may even add to output.

Even this conclusion is too pessimistic:

- Such calculations ignore the environmental benefits, both local and global, that numerous studies have concluded can considerably outweigh the costs of pollution abatement by turning to "clean" technologies.
- The scope for reducing economic losses ("deadweight losses") through price reforms and liberalising energy markets is enormous.

Taking these factors into account, the evidence is compelling that both the developing and the rich countries will be economically better off with a transition to energy-efficient, low-carbon economies.

Source: M. Grubb, R. Koehler, and D. Anderson, The Annual Review of Energy and Environment *27, pp. 271–308 (2002).*

It will be important, at the international level, for countries to share experiences in their efforts to define ways forward.

Also needed is additional support to foster innovation and co-operation in the development and use of non-carbon technologies. The Global Environment Facility has helped set the scene by providing finance for proven non-carbon technologies and practices, and has a successful portfolio of projects in over seventy countries; it is also doing much to foster policies that would support market development. Ideally, the Facility needs to be complemented by a parallel initiative to foster international co-operation, innovation, and the commercialisation of advanced non-carbon energy technologies.

Since most of the growth in energy demand will be in developing countries, joint mobilisation of official development assistance from developed countries and international institutions is a must if the aim is a global sustainable future. By adopting the Equator Principles, the private financial community has taken steps to ensure that projects financed by banks are consistent with the environmental and social screening criteria and safeguard policies of the International Finance Corporation and with World Bank guidelines (e.g., on coal mining and production, wind energy conversion systems, and the environment in general).

The banks agree not to provide loans directly to projects in which the borrower is unable to comply with their environmental and social policies and processes. They furthermore agree to require an environmental assessment that includes information on baseline environmental and social conditions, protection of human health, cultural heritage, biodiversity including protection of species and sensitive ecosystems, sustainable development, and use of renewable natural resources.

The Equator Principles apply only to projects costing US$50 million or more, on the grounds that projects below US$50 million only account for 3 percent of the project financing loans market. Many critics argue that the exclusion of lower-cost projects is a major shortcoming of the Equator Principles. They argue that the framework fails to address precisely the projects that can most help the poor in many developing countries, and that participating banks should be encouraged to lower the cut-off point for applying the Principles and to finance more low-cost schemes.

part VI

Policies and Actions to Promote Energy for Sustainable Development

Part VI identifies key strategies and policies for globally achieving both economic growth and sustainable development. The needed actions include:

- Encouraging greater international co-operation in areas such as technology procurement, harmonisation of environmental taxes and emissions trading, and energy efficiency standards for equipment and products.
- Adopting policies and mechanisms to increase access to energy services through modern fuels and electricity for the two billion people without such access.
- Building capacity among all stakeholders, especially in the public sector, to address issues related to energy for sustainable development.
- Removing obstacles and providing incentives to encourage greater energy efficiency and the development and/or diffusion of new technologies – steps which can increase energy services more economically than improvements in generation or distribution.
- Advancing innovation, with balanced emphasis on all steps of the innovation chain.
- Creating market framework conditions (including continued market reform, consistent regulatory measures, and targeted policies) to encourage competitiveness in energy markets, to reduce total cost of energy services to end-users, and to protect important public benefits.
    - Cost-based prices, including phasing out all forms of permanent subsidies for fossil fuels and nuclear power and internalising external

environmental and health costs and benefits.

- **Removing obstacles and providing incentives, as needed, with "sunset" clauses, to encourage greater energy efficiency and the development and/or diffusion to wider markets of new technologies for energy for sustainable development.**
- **Reversing the trend of declining official development assistance and foreign direct investments, especially as related to energy for sustainable development.**

The challenge of energy for sustainable development will require a concerted effort on the part of international organisations, national governments, the energy community, civil society, the private sector, and individuals. Whatever difficulties are associated with taking appropriate action, they are small compared to what is at stake. Because humankind is in a dynamic and critical period of economic, technological, demographic, and structural transition, and because energy systems take decades to change, the time to act is now.

The Context for Sustainable Energy

Energy developments will affect and be affected by major global transformations occurring at the beginning of this new millennium. For instance, though world population continues to grow rapidly, for the first time in history, the number of people being added each year is less than the year before, and more people are living in urban than rural settings. Other major trends that set the stage for sustainable energy policies include:

Increasing Globalisation. Trade barriers have been reduced in recent years and world trade is growing rapidly. The global economy is steadily becoming more integrated through mergers, acquisitions, joint ventures, and the expansion of multinational companies. Multinational companies are playing an increasing role in fossil fuel production and distribution, gas and electric systems, and manufacturing of energy end-use technologies. As companies and markets become more international, policy interventions will require co-ordinated action and harmonisation in order to be more effective.

Shifting Governmental Responsibilities. The fact that market forces extend beyond national borders has made it more difficult for governments to raise taxes and still stay competitive globally. Government activities are increasingly moving toward regulation and oversight to ensure that markets work efficiently and advance social benefits.

Restructuring and Liberalising Energy Markets. All over the world, the allocation of materials and human and financial resources, as well as the selection of products and technologies, are increasingly done by private actors and, at least partially, as a function of market conditions. Many nations are corporatising or privatising formerly government-owned utilities and petroleum and natural gas companies, and introducing competition and new regulatory frameworks, in part to increase efficiency and attract private capital to the energy sector. Government oversight is essential to protect public benefits in a market-driven energy sector.

The Emerging Information Technology Revolution. The microelectronics revolution and its various ramifications are well known. The economic and structural transformations from the information age are likely to have far-reaching and difficult-to-predict structural consequences. The Internet and related information technologies also offer tremendous potential in terms of technology transfer, capacity building, and awareness raising.

Increased Public Participation in Decision Making. The freer flow of information and increasing globalisation has been accompanied by a wave of democratisation. Throughout the world, large numbers of people without economic power are gaining political power. Local groups are becoming more involved in the decision-making process and affecting public policy formulation. Women are becoming more active in the political process.

These trends are likely to provide a growing impetus to keep sustainable development high on the political agenda and energy as an important ingredient to that goal.

A Policy Framework to Promote Energy for Sustainable Development[17]

The WEA scenarios exercise shows that, although energy *can* contribute to sustainable development, *whether and how well* it does depends on a range of factors. These include access to information and technologies, the availability of finance and supporting institutions, attitudes and behaviours, and – in particular – policies and policy frameworks that encourage change in the desired direction. Current approaches to energy development,

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[17] This section draws on Johansson and Goldemberg (2002).

and the current rate of change, are not compatible with key elements of sustainable development. The following are some general principles for decision makers and programme designers to use as a framework when formulating strategies and policies for energy for sustainable development.

Encourage Greater Co-operation at the International Level. The ongoing process of globalisation means that ideas, finances, and energy are freer to flow from one country to another. Productive ways of moving forward might include combining national efforts, for example, in the procurement of renewable energy technologies. Other options include international harmonisation of environmental taxes and emissions trading, particularly among developed countries, and energy efficiency standards of equipment and products.

Concerted action is needed in the energy field to implement the various international agreements that have been reached in recent years. These include major international conventions that emerged from UNCED (particularly the United Nations Framework Convention on Climate Change), the major United Nations conferences of the 1990s, and the World Summit on Sustainable Development.

Important developments in setting goals and quantitative targets for renewable energy have occurred at the regional level. Examples of significant efforts include:

- The European Union Member States have agreed on renewable energy targets, increasing the share of renewable primary energy from 6 percent in 1995 to 12 per cent by 2010, and increasing the proportion of electricity generated from renewable sources from 14 percent in 1997 to 22 per cent in 2010.
- The Latin American and Caribbean Initiative, signed in May 2002 in São Paulo, included a target of 10 percent renewable energy by 2010. As a whole, this region had 24.4 percent of energy use as renewables in 2002, but that includes 15.6 percent in the form of combustible renewables and waste, which in most countries is not renewable (see footnote 5). Most of the Caribbean countries and a few in Latin America were below the 10 percent mark in 2002.

The Carbon Sequestration Leadership Forum is a co-operative effort by governments and the private sector to address the issue of carbon capture and storage (Box 6).

Make Modern Energy Carriers Affordable for Rural Consumers. Rural areas need affordable energy to meet basic needs. This affordability may, at least initially, require subsidies to be reduced over time. One option is to target the subsidies to the neediest consumers. Another option is to introduce market efficiencies and extend the smallest subsidy needed to achieve social objectives. Indeed, the subsidy may be provided as an integral part of a new social contract: energy providers meet rural energy needs by providing low-cost services while highly competitive conditions are simultaneously created in the energy sector (a key element of energy reforms).

BOX 6. THE CARBON SEQUESTRATION LEADERSHIP FORUM

The Carbon Sequestration Leadership Forum (CSLF) is a co-operative effort of several countries and large companies organised in 2003 to stimulate work on carbon sequestration, that is, the capture and storage of carbon emitted in the form of CO_2 from large power plants and other installations burning fossil fuels. The basic premises of its work are the following:

- Sequestration complements energy efficiency and other forms of carbon-free energy, as part of a portfolio response to managing greenhouse gas emission.
- Industry supports a globally co-ordinated sequestration program through the CSLF and notes the following key requirements needed to ensure success: build substantial trust with the public, expand the CSLF's country membership, and facilitate opportunities for collaboration among industry, government, academia, and other important stakeholders.
- Sequestration is critical to the production of hydrogen from fossil fuels without CO_2 emissions, possibly paving the way to a hydrogen-based economy.

To that effect, the Forum supports:

- Moving large-scale sequestration demonstration projects forward as rapidly as possible to provide society with technically, economically, and socially viable options for carbon-neutral energy.
- Developing a flexible portfolio of sequestration techniques that focuses on geological sequestration, yet includes other approaches such as terrestrial sequestration, including re-injection in coal mines, oil fields, and the oceans.

Countries are pursuing sequestration in various ways. The European Union, for example, has set the following targets for its work on sequestration: reducing the cost of CO_2 capture from 50-60 Euros to 20-30 Euros per tonne of CO_2 captured; achieving capture rates above 90 percent; and assessing the reliability and long-term stability of sequestration.

One way to finance the needed subsidies would be to complement the creation of competitive markets with the establishment of a public benefits fund generated by wire and pipe charges on electricity and gas providers that cannot be passed on to consumers. Such funds have been adopted or are under consideration in several countries as a means of protecting public benefits under competitive market conditions. Other options include carefully designed economic incentives, perhaps using tax regimes.

Specifically, some of these revenues could be used to subsidise the poorest households until they are able to work themselves out of poverty. This strategy could

The most critical targets for capacity development in the energy sector world-wide are macro-planners, energy policymakers, and new regulatory agencies.

be made entirely consistent with a shift to greater reliance on market forces to efficiently allocate resources. For example, a rural energy concession could be created to bring adequate energy services at a set price to a particular rural area. If the concession were awarded competitively, market forces would find the least costly mix of energy technologies with the least amount of subsidy to satisfy the concessionaire's obligation to provide affordable energy services to all. The task of supplying energy to the large, currently unserved rural population is one of the most daunting problems faced today in many developing countries and the sample solutions cited here do not exhaust the measures being developed world-wide.

Develop Capacity. Capacity development can be understood as the process of creating, mobilising, and converting skills/ expertise, institutions, and contexts to achieve specific desired socio-economic outcomes, such as using energy as an instrument for sustainable development. Capacity development is a long-term process that must be achieved through activities at the individual, institutional, and systemic level. The public sector, both at national and local levels, is the key target and recipient of capacity development.

All of the policy actions proposed here depend on human skills and knowledge, as well as institutional and government support. The most critical targets for capacity development in the energy sector are macro-planners, energy policymakers, and new regulatory agencies. The ongoing process of energy sector reform, utility restructuring, corporatisation, and re-regulation demands regulators who can keep up with quickly changing conditions – and this applies equally to industrialised and developing countries. The objectives of market reform, in terms of economic optimisation and social improvement, cannot be reached unless effective regulatory capacities exist to direct the functioning of the market. Capacity development should be a priority in new policy frameworks, and funding for capacity improvements should be part of domestic energy planning and development co-operation. Thus attention to capacity should be considered a crucial and crosscutting element of all development co-operation and energy sector programmes. Special attention needs to be given to the multi-sectoral capacity needs of rural areas.

Improve End-Use Energy Efficiency. Enhancement of end-use equipment can generally provide energy services more economically than improvements in generation or distribution. In addition to reducing externalities associated with energy use, improvements in energy efficiency can stimulate new industries in energy-saving goods and services.

For a number of reasons, the technical and economic potential of energy efficiency improvements has been under-realised. Numerous technical options and players could be involved in achieving higher end-use efficiency. Improving the energy efficiency of an economy is a decentralised, dispersed activity, with limited visibility, making it a less attractive cause for politicians, the media, or individuals looking for recognition and acknowledgement. In addition, significant barriers – primarily market imperfections that could be overcome by targeted policy instruments – prevent the realisation of greater end-use efficiencies. The barriers include:

- lack of adequate information, technical knowledge, and training;
- uncertainties about the performance of investments in new and energy-efficient technologies;
- lack of adequate capital or financing possibilities;
- high initial and perceived costs of more efficient technologies;
- high transaction costs (for searching and assessing information and for training);
- lack of incentives for careful maintenance;
- the differential benefits to the user relative to the investor (for example, when energy bills are paid by the renter, the property owner may have no incentive to invest in technology);
- external costs of energy use not included in energy prices;
- patterns and habits of consumers, operators, and decision makers, which may be influenced by many factors, including ideas of social prestige and professional norms;
- lack of attention to R&D investments in energy efficiency improvements.

Realising cost-effective energy efficiency potentials will be beneficial not only for the individual energy consumer but also for the economy as a whole.

Pricing energy correctly is important, but by itself is not sufficient to overcome the significant barriers to efficiency improvements. Energy efficiency policies that use direct or indirect price mechanisms (such as the removal of subsidies and the incorporation of externalities) are effective in lowering consumption trends in price-sensitive sectors and applications. But even without changing the overall price environment, energy efficiency policies should be pursued to address market failures. For example, energy service companies, which typically contract for a given level of energy services, can overcome some of these barriers because they have the incentive and expertise to find the least costly, most energy-efficient mix of options. Public sector procurement policies can be helpful for similar reasons.

Specific policy instruments can target different players – from consumers and builders to car manufacturers, urban planners, and industrial designers and engineers. Some of the approaches that have been effective in various contexts include energy efficiency standards and labelling, low-interest loans to cover investments in energy improvements, large-scale procurement that incorporates energy-efficiency requirements in the bidding process, educational campaigns, tradable certificates for energy efficiency improvements, tax incentives, and voluntary agreements. For larger public entities or private enterprises, integrated resource planning can be used to identify the least-cost options of meeting the need for energy services, looking at both supply and demand issues.

Encourage Energy Innovations. Energy innovations face barriers all along the energy innovation chain (from research and development, to demonstration projects, to cost buy-down, to widespread diffusion). Some of these barriers reflect market imperfections; some reflect inadequacies in the public sector domain; and some reflect differences of view about needs, corporate priorities, relevant time horizons, and reasonable costs. The amount of public support needed to overcome such barriers will vary from one technology to the next, depending on its maturity and market potential. Obstacles to technology diffusion, for example, may need to be given higher priority than barriers to innovation. Direct government support is more likely to be needed for radically new technologies than for incremental advances where the private sector functions relatively effectively.

Interventions should aim at helping the most promising energy innovations surmount bottlenecks wherever they occur in the innovation chain – a complex, interactive system requiring networks of innovation, knowledge sharing, and demand "pull" as well as supply "push". Over the past two decades, countries

TABLE 9. **THE ENERGY INNOVATION CHAIN: BARRIERS AND POLICY OPTIONS**

	Research and Development (laboratory)	Demonstration (pilot projects)	Diffusion	
			Early deployment (technology cost buy-down)	Widespread dissemination (overcoming institutional barriers and increasing investment)
Key barriers	■ Governments consider R&D funding problematic ■ Private firms cannot appropriate full benefits of their R&D investments	■ Governments consider allocating funds for demonstration projects difficult ■ Difficult for private sector to capture benefits ■ Technological risks ■ High capital costs	■ Financing for incremental cost reduction (which can be substantial) ■ Uncertainties relating to potential for cost reduction ■ Environmental and other social costs not fully internalised	■ Weaknesses in investment, savings, and legal institutions and processes ■ Subsidies to conventional technologies and lack of competition ■ Prices for competing technologies exclude externalities ■ Weaknesses in retail supply, financing, and service ■ Lack of information for consumers and inertia ■ Environmental and other social costs not fully internalised
Policy options to address barriers	■ Formulating research priorities ■ Direct public funding ■ Tax incentives ■ Technology forcing standards ■ Stimulating networks and collaborative R&D partnerships	■ Direct support for demonstration projects ■ Tax incentives ■ Low-cost or guaranteed loans ■ Temporary price guarantees for energy products of demonstration projects	■ Temporary subsidies ■ Tax incentives ■ Government procurement ■ Voluntary agreements ■ Favourable pay-back tariffs ■ Competitive market transformation initiatives	■ Phasing out subsidies to established energy technologies ■ Measures to promote competition ■ Full costing of externalities in energy prices ■ "Green" labelling and marketing ■ Concessions and other market-aggregating mechanism ■ Innovative retail financing and consumer credit schemes ■ Clean Development Mechanism

Source: Adapted from President's Council of Advisors on Science and Technology (PCAST), Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation *(Washington, DC: PCAST, 1999).*

TABLE 10. REPORTED* INDUSTRIAL-COUNTRY PUBLIC SECTOR SPENDING ON ENERGY RD&D

	1975	1980	1985	1990	1995	1998
Energy conservation	321	974	747	534	1,069	1,134
Fossil fuels	603	2,570	1,461	1,776	902	565
Oil and gas	143	552	442	345	406	282
Coal	460	2,018	1,018	1,431	496	283
Renewable energy	206	1,941	845	564	681	652
Solar PV	24	391	242	192	236	237
Other solar options	49	669	158	96	98	62
Wind	7	185	144	92	112	95
Biomass	6	142	163	82	139	173
Geothermal	116	430	125	89	79	65
Others	4	124	13	13	17	20
Nuclear energy	5,434	7,839	7,798	4,905	4,052	3,590
Nuclear fission	4,823	6,635	6,363	3,864	3,091	2,838
Nuclear fusion	611	1,204	1,435	1,041	961	752
Power and storage technologies	140	432	269	250	317	360
Other technologies/ other energy research	836	1,192	809	957	1,126	1,112
Total	7,540	14,949	11,927	8,986	8,146	7,413

* IEA total reported countries, in US$ millions (2002 prices and exchange rates)

Source: IEA, 2003; see http://library.iea.org/rdd/eng/TableViewer/wdsdim/dimensionp.asp

have experimented with a growing number of policy instruments – from target setting and procurement policies to green labelling and fiscal incentives. Table 9 summarises some of the barriers to, and policy options for, energy innovation.

After a steep increase in the 1970s related to the oil crises in these years, public expenditure for energy research, development, and demonstration (RD&D) has been falling steadily in industrial countries, from US$15 billion in 1980 to about US$7 billion in 2000. Of this amount, in 2000, about 8 percent was on renewables, 6 percent on fossil fuels, 18 percent on energy efficiency, 47 percent on nuclear energy, and 20 percent on other items (Table 10). About two third of the decline occurred in the United States. Major declines also happened in Germany, the United Kingdom, and Italy. Public spending on energy RD&D remained stable or increased in Japan, Switzerland, Denmark, and Finland.

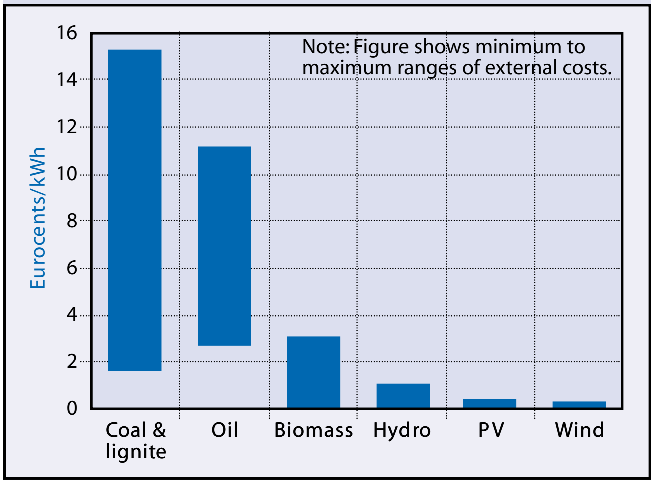
Making Markets Work Better. Throughout the world, markets are playing a larger role in energy investment decision making and in the determination of energy prices. When they are functioning well, markets sustain the pressure on competing producers to find productivity gains, which creates a continuous force for technological change that improves the efficiency with which resources are converted into valued goods and services. However, market-based approaches are no panacea – especially in the energy sector, where significant market imperfections require attention and oversight. In many countries, markets barely function. Huge populations of both city dwellers and rural families are excluded from markets by extreme poverty. The following policies can improve the functioning of energy markets.

Price energy correctly. Prices should cover all costs and needed investments, and thus ensure adequate revenue for the company or agency providing the energy. Earned revenues should cover operating and capital costs, including investment in system expansion where warranted (this may be difficult to achieve in many developing countries). Rates should also take account of differences between the marginal and the average costs of providing goods and services. However, while pricing reform can lead to economic efficiency, it is important not to pursue such reforms without regard to other sustainability objectives. Changes in tariff design can lead to substantial shifts in the revenue requirements from different consumer groups, so these distributional effects may need to be offset with some form of compensation or softened by a lengthy transition period.

Where well-functioning markets do exist, policies should attempt to ensure that competitors are playing on a level field. Two measures are particularly critical in this regard: removing subsidies and accounting for social costs or externalities.

Restructure subsidies to support sustainable development. Global subsidies to conventional energy amount to about US$250 billion per year. They represent a substantial market distortion, discourage new entrants into the market, and undermine the pursuit of energy efficiency (Box 7). Although subsidies may have a role to play in providing the poorest of the poor access to modern energy, few of the subsidies now in place serve this purpose. There are some notable exceptions; for example, South Africa used cross-subsidies to double the proportion of its population with access to electricity in the 1990s. Similarly, temporary subsidies can help to reduce the cost of new entrants into the market such as

FIGURE 16. EXTERNAL COSTS FOR ELECTRICITY PRODUCTION IN THE EUROPEAN UNION, BY SOURCE



Source: Data from the European Commission – ExternE Programme (European Union 5th Research and Technological Development Framework Programme).

BOX 7. COST OF ENERGY SUBSIDIES

Subsidies comprise all measures that keep prices for consumers below market level or keep prices for producers above market level or that reduce costs for consumers and producers by giving direct or indirect support. Energy subsides comprise a wide variety of public interventions:

- direct grants to cover losses of coal mines or domestic purchase obligations for coal
- support to low-income households to purchase fuels for heating and cooling
- all sorts of tax breaks for energy users, including lower value added tax (VAT) rates low-interest loans, and allowing public energy companies to earn a lower-than-market rate of return
- R&D support for nuclear fusion programs
- deficit payments to miner pension funds to compensate for the costs of Black Lung Disease and early retirement
- end-user energy prices at rates below market level
- a recent phenomenon, the non-payment of tax bills and bail out operations of public companies.

Much of this energy support is not directly visible but is hidden in public and economic structures. In total, energy subsidies currently amount to over $US240 billion per year. Nearly two thirds of all subsidies flow to fossil fuels (coal, oil, and gas). In fact, since power generation usually involves burning fossil fuels, adding subsidies for electricity further raises the share to over 80 per cent.

COST OF ENERGY SUBSIDIES, BY SOURCE, 1995-98 (US$ BILLION/YR)

	OECD Countries	Non-OECD Countries	Total
Coal	30	23	53
Oil	19	33	52
Gas	8	38	46
All fossil fuels	***57***	***94***	***151***
Electricity	[a]	48	48
Nuclear	16	nil	16
Renewable and end-use	9	nil	9
Non-payments and bailout[b]	0	20	20
Total	82	162	244
Per capita ($US)	88	35	44

a) Subsidies for electricity in OECD countries are included in fossil fuel subsidies, by energy source.
b) Subsidies from non-payments and bail out operations are not included in data by energy source.

Sources: André de Moor, "Towards a Grand Deal on Subsidies and Climate Change", Natural Resources Forum *25, no. 2 (May 2001); Cees van Beers and André de Moor,* Public Subsidies and Policies Failures: How Subsidies Distort the Natural Environment Equity and Trade and How to Reform Them *(Cheltenham, UK: Edward Elgar Publishers, 2001).*

wind, photovoltaics, etc. Figure 14 shows declining costs as cumulative investments in new energy sources grow.

Modest, time-limited subsidies – sometimes in the form of small amounts of electricity to satisfy households' needs – may be justified for social and environmental objectives. However, substantial subsidies are both unsustainable financially and harmful to economic growth because resources are not used efficiently. Moreover, they often do not go to the people whom they are ostensibly designed to help. Generally, subsidies to cover capital improvements rather than operating costs are most effective. Subsidies may also be used to promote technological advances and organisational learning. However, they are unlikely to lead to sustainable markets unless they create conditions whereby they are no longer needed.

Address externalities. In the absence of intervention, markets fail to address the substantial negative side effects of conventional energy use. External costs can be as large as or larger than the market. Figure 16 shows the external costs associated with various kinds of electricity production; for coal, for example, the external costs range from 2-15 eurocents per kWh; market costs for power generation are typically 3-10 eurocents per kWh. In some cases, such as certain effects of unmitigated climate change, it has been argued that the external costs are essentially "infinite", much larger than the costs of mitigation. If such costs are not reflected in the market conditions seen by investors, optimal decisions will not be made in the marketplace.

As more attention has focused on external social and environmental costs, a variety of instruments and approaches have been devised to improve the functioning of markets, either through restrictions or through prices. A general term for the analysis behind such policies is social costs, which is defined as the combination of private financial costs (those capital and operating costs normally seen in the market) with uncompensated negative externality costs.

One way to improve market functioning is through information, labelling, and pricing policies to change

BOX 8. THE TEXAS RENEWABLES PORTFOLIO STANDARD

Under the Renewables Portfolio Standard (RPS) in Texas, retail electricity suppliers are required to include a specified percentage of renewables in their generation portfolio. Annual renewable-energy generation targets back the policy. Texas state authorities have set targets to increase the amount of energy generated by renewables to 2,880 MW by 2009, including 2,000 MW from "new renewables" (i.e., modern biofuels, wind, solar, small-scale hydropower, marine, and geothermal energy). Wind energy currently dominates the installed capacity of renewables, with supply costs of around 4.7 cents/kWh (of which 1.7 cent/kWh is covered by a federal production tax credit).

Projections show that the first-year target of 400 MW of new capacity to be installed by 2003 will be exceeded significantly. Several factors are contributing to the policy's success: clear renewable energy targets, clear eligibility of what qualifies as a renewable resource project, stringent non-compliance penalties, a Tradable Renewable Energy Certificate system that encourages flexibility and minimises costs, and a dedicated regulatory commission that fully involved numerous stakeholders during the detailed design of the policy. A major lesson from Texas is that, although new and relatively untested as a policy tool, the RPS, in combination with tax credits, has the potential to cost-effectively support the establishment of a robust renewable energy market.

Source: G8 Task Force on Renewable Energy, Final Report, June 2001.

consumer behaviour to favour "greener" products. Governments may take a more dominant role by, for example, specifying emission levels or efficiency standards. A number of emerging hybrid policies, such as renewable portfolio standards and certificate markets, so-called cap and trade policies, combine the efficacy of regulatory approaches with the flexibility and cost-effectiveness associated with market-oriented pricing policies. One example of green certificate markets, or renewable portfolio standards, is shown in Box 8. Another example of the power of incentives and predictable market conditions is the approach taken by the German Renewable Energy Law (Box 9).

BOX 9. GERMAN RENEWABLE ENERGY SOURCES ACT

Germany's Renewable Energy Sources Act was passed in 2000 to establish a framework for doubling the market share of renewable energy sources by 2010. The mechanism of a set feed-in price for electricity delivered to the power grid was adopted to promote technological progress and achieve decreasing cost of the electricity-producing technologies; this decreasing adaptation was not part of the preceding Electricity Feed-In Act of 1991. Spain adopted a similar law in 1998.

The German law sets specific maximum prices paid by the distribution companies. The increased cost is passed on to all electricity consumers for each individual renewable energy technology, based on its annually decreasing real cost. The aim of the tariffs is to initiate a self-sustaining market for renewables and to create a critical mass through a large-scale market introduction programme. The incentives, in the form of a guaranteed market and higher set tariffs, thus create an artificial competition between emerging renewable technologies and conventional ones. These incentives are revised downwards periodically, decreasing 55 percent between 1991 and 2003 from 18.4 cents/kWh to 8.33 cents/kWh. As a result of this law, Germany today has the largest installed wind capacity in the world (mid-2003: around 12.5 GW).

In 2002, Brazil adopted a law to promote adoption of wind energy, photovoltaics, small hydro, and biomass. The law was designed to protect the national interest where the market alone cannot; its goal is to have renewable forms of energy providing 3000 MW, approximately 5 percent of all electricity consumption, by 2006.

A key lesson learned is that such laws lead to reductions in cost as production increases, as indicated in Figure 14. As cumulative investment in new capacity grows, the cost per unit comes down.

Re-Regulate Liberalised Electricity Markets. When markets work well, competition can drive down costs and open up opportunities for new players. Liberalisation by itself, however, will not protect or enhance public benefits. Moreover, oligopolies may replace monopolies, with limited benefits to consumers. Thus regulation is even more critical in a liberalised energy sector, and a regulatory framework should be established before energy corporations are privatised. Someone must have responsibility for ensuring system adequacy and reliability. The California and Brazil experiences, as well as the recent blackouts in London and along the North American eastern seaboard, provide examples of the seriousness of adopting wrong policies in a liberalised setting (Box 10). Clearly a strong leadership role for public policy and institutions is essential.

* * *

A sustainable future in which energy plays a major positive role in supporting human well being is possible!

The challenges of sustainability are major ones. At the same time, there are hopeful signs. Clearly, energy can serve as a powerful tool for sustainable development. The Assessment shows that there are indeed combinations of resources and technologies that are capable of meeting most, if not all, of the sustainability changes simultaneously. The finding that there are measures related to energy that help address several major issues at the same time is highly significant, as it should add support for those measures from different groups in society. The decisive issues are not technology or resource scarcity, but the institutions, rules, and regulations needed to make markets work in support of energy for sustainable development.

Some governments and corporations have already demonstrated that policies and measures to promote energy solutions conducive to sustainable development work. The renewed focus and broad agreements on energy in the Johannesburg Plan of Implementation and at the eighteenth World Energy Congress are promising. The formation of many partnerships on energy between stakeholders at WSSD is another encouraging sign. A sustainable future in which energy plays a major positive role in supporting human well being is possible!

BOX 10. ELECTRICITY CRISIS IN CALIFORNIA AND BRAZIL

Beginning in the summer of 2000, California suffered an electricity crisis that has caused many to doubt the wisdom of efforts to introduce customer choice into electric power markets or even of major restructuring of electricity systems. Other countries such as Brazil have also experienced problems of supply availability, and of extreme price volatility in electric power markets, as a result of efforts to privatise state-owned enterprises. In both countries, the crisis consisted of frequent blackouts and/or blackout warnings, and extraordinary volatility in wholesale prices.

From the standpoint of sustainability, the California crisis teaches a number of important lessons. First, California adopted a market design that did not value efficiency and load management appropriately. The dismantling of the regulated monopoly structure in California in the 1990s was accompanied by a significant drop in spending on energy efficiency, which cost California an estimated 1,100 MW in energy savings by 2000. This drop occurred because utilities, with state approval, reduced spending on energy efficiency in anticipation of retail competition, thereby departing from the historic California policy of taking into account both the market barriers to and the societal benefits from energy efficiency.

Second, the restructured California market did not permit energy efficiency and load management to participate on equal terms with new supplies. This flawed market design left the California Independent System Operator paying ten times more to buy power than customers would have been charged to save the same amount. The market mechanisms and metering devices necessary to allow the demand side of the market to respond to price signals are still being implemented.

Third, in anticipation of lowered prices from conventional sources in the new "market", California utilities in 1995 persuaded the Federal Energy Regulatory Commission to override a state requirement that they purchase 1,400 MW from renewable sources over the next few years. These renewable resources, together with improved energy efficiency, would have substantially mitigated the crisis.

Fourth, California citizens responded dramatically and successfully to the crisis by reducing their consumption by some 6 percent in the first half of 2001, showing the contribution that energy conservation can make in a crisis even when few advance planning and price incentives have been developed. The measures taken included intensive public information, rate incentives, and incentives for more efficient appliances, as well as an extensive conservation program by the state government itself. By underestimating the extent of the efficiency response and signing long-term contracts to ward off an extended crisis, California is now committed to paying apparently excessive prices for power that customers turn out not really to need, at least at the price they must pay for it.

Fifth, California has learned the need for continued state involvement in power supply management in order to assure that values the short-term market tends to ignore – such as reliability, price predictability, environmental impact, and the furtherance of renewable energy – are reflected in power procurement decisions.

More than 90 percent of Brazil's electricity comes from hydroelectricity. From 1995 on, as a result of increasing international interest rates and the declining investment capacity of the state, the Brazilian government initiated a process of privatising and liberalising the electricity market. Despite high expectations, investments in new electricity generation did not follow increased consumption. A modest rate of precipitation in the first months of 2001 caused a serious electricity shortage; in response, the government imposed a compulsory 20 percent cut for almost all electricity consumption that lasted almost a full year, to April 2002.

Source: P. Bradford in Goldemberg and Johansson, 2002, pp. 92–94

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annexes

Annex I. Matrix of Energy and the Millennium Development Goals

Goal	IMPORTANCE OF ENERGY TO ACHIEVING THE GOALS Some Direct and Indirect Contributions
1) Extreme poverty and hunger ■ To halve, between 1990 and 2015, the proportion of the world's people whose income is less than one dollar per day. ■ To halve, between 1990 and 2015, the proportion of people who suffer from hunger.	■ Access to affordable energy services from gaseous and liquid fuels and electricity enables enterprise development. ■ Lighting permits income generation beyond daylight hours. ■ Machinery increases productivity. ■ Local energy supplies can often be provided by small scale, locally owned businesses creating employment in local energy service provision and maintenance, fuel crops, etc. ■ Privatisation of energy services can help free up government funds for social welfare investment. ■ Clean, efficient fuels reduce the large share of household income spent on cooking, lighting, and keeping warm (equity issue – poor people pay proportionately more for basic services). ■ The majority (95 percent) of staple foods need cooking before they can be eaten and need water for cooking. ■ Post-harvest losses are reduced through better preservation (for example, drying and smoking) and chilling/freezing ■ Energy for irrigation helps increase food production and access to nutrition.
2) Universal primary education ■ To ensure that, by 2015, children everywhere will be able to complete a full course of primary schooling.	■ Energy can help create a more child friendly environment (access to clean water, sanitation, lighting, and space heating/cooling), thus improving attendance at school and reducing drop out rates. ■ Lighting in schools helps retain teachers, especially if their accommodation has electricity ■ Electricity enables access to educational media and communications in schools and at home that increase education opportunities and allow distance learning ■ Access to energy provides the opportunity to use equipment for teaching (overhead projector, computer, printer, photocopier, science equipment). ■ Modern energy systems and efficient building design reduces heating/ cooling costs and thus school fees, enabling poorer families greater access to education.
3) Gender equality and women's empowerment ■ Ensuring that girls and boys have equal access to primary and secondary education, preferably by 2005, and to all levels of education no later than 2015.	■ Availability of modern energy services frees girls' and young women's time from survival activities (gathering firewood, fetching water, cooking inefficiently, crop processing by hand, manual farming work). ■ Clean cooking fuels and equipment reduces exposure to indoor air pollution and improves health. ■ Good quality lighting permits home study and allows evening classes. ■ Street lighting improves women's safety. ■ Affordable and reliable energy services offer scope for women's enterprises.
4) Child mortality ■ To reduce by two thirds, between 1990 and 2015, the death rate for children under the age of five years.	■ Indoor air pollution contributes to respiratory infections that account for up to 20 percent of the 11 million deaths in children each year (WHO 2000, based on 1999 data). ■ Gathering and preparing traditional fuels exposes young children to health risks and reduces time spent on child care. ■ Provision of nutritious cooked food, space heating, and boiled water contributes towards better health. ■ Electricity enables pumped clean water and purification.
5) Maternal health ■ To reduce by three quarters, between 1990 and 2015, the rate of maternal mortality.	■ Energy services are needed to provide access to better medical facilities for maternal care, including medicine refrigeration, equipment sterilisation, and operating theatres. ■ Excessive workload and heavy manual labour (carrying heavy loads of fuelwood and water) may affect a pregnant woman's general health and well being.
6) HIV/AIDS, malaria and other major diseases. By 2015, to have halted and begun to reverse: ■ the spread of HIV/AIDS ■ the scourge of malaria ■ the scourge of other major diseases that afflict humanity.	■ Electricity in health centres enables night availability, helps retain qualified staff, and allows equipment use (for example, sterilisation, medicine refrigeration). ■ Energy for refrigeration allows vaccination and medicine storage for the prevention and treatment of diseases and infections. ■ Safe disposal of used hypodermic syringes by incineration prevents re-use and the potential further spread of HIV/AIDS. ■ Energy is needed to develop, manufacture, and distribute drugs, medicines, and vaccinations. ■ Electricity enables access to health education media through information and communications technologies (ICT).
7) Environmental sustainability ■ To stop the unsustainable exploitation of natural resources; and ■ To halve, between 1990 and 2015, the proportion of people who are unable to reach or to afford safe drinking water.	■ Increased agricultural productivity is enabled through the use of machinery and irrigation, which in turn reduces the need to expand quantity of land under cultivation, reducing pressure on ecosystem conversion. ■ Traditional fuel use contributes to erosion, reduced soil fertility, and desertification. Fuel substitution, improved efficiency, and energy crops can make exploitation of natural resources more sustainable. ■ Using cleaner, more efficient fuels will reduce greenhouse gas emissions, which are a major contributor to climate change. ■ Clean energy production can encourage better natural resource management, including improved water quality. ■ Energy can be used to purify water or pump clean ground water locally, reducing time spent collecting it and reducing drudgery.

Source: DFID, 2002.

Annex II. Energy Units, Conversion Factors, and Abbreviations

TABLE A1. ENERGY CONVERSIONS*

To:	Terajoule (TJ)	Gigacalorie (Gcal)	Megatonne oil (equiv) (Mtoe)	Million British thermal units (Mbtu)	Gigawatt-hour (GWh)
From:	Multiply by:				
Terajoule (TJ)	1	238.8	2.388×10^{-5}	947.8	0.2778
Megatonne oil (equiv) (Mtoe)	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11,630
Million British thermal units (Mbtu)	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
Gigawatt-hour (GWh)	3.6	860	8.6×10^{-5}	3,412	1

* IEA figures. Additional conversion figures available at http://www.iea.org/stat.htm

TABLE A2. UNIT PREFIXES

k	kilo (10^{3})
M	mega (10^{6})
G	giga (10^{9})
T	tera (10^{12})
P	peta (10^{15})
E	exa (10^{18})

TABLE A3. ASSUMED EFFICIENCY IN ELECTRICITY GENERATION (FOR CALCULATING PRIMARY ENERGY)

Type of power	Assumed efficiency
Nuclear power	.33
Hydroelectric	1.00
Wind and solar	1.00
Geothermal	.10

TABLE A4. ABBREVIATIONS

CO_2	Carbon dioxide
H_2	Hydrogen
GWe	Gigawatt electricity
GWth	Gigawatt thermal
MWe	Megawatt electricity
TWh	Terawatt - hour
GJ	Gigajoule
PJ	Petajoule
EJ	Exajoule
Gtoe	Gigatonnes oil equivalent
ha	hectare
km^2	square kilometre
t	tonne

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World Energy Assessment:
Overview 2004 Update

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