Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential

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ROBERT H. WILLIAMS

The Energy Technology Options *Conference opened with a presentation from Professor Thomas Johansson on the prospects for renewable energy in a global context. It was based upon a study commissioned by the United Nations Solar Energy Group for Environment and Development, which he chairs. This study has since been published in a large book entitled* Renewable Energy: Sources for Fuels and Electricity; *it contains reports by specialists on a long list of renewable technologies (see Table of Contents at the end of this paper). The present paper consists of excerpts from Chapter 1 of that book, reprinted here with permission of the publishers. (The book may be obtained from Island Press, Box 7, Dept. UN, Covelo, California, USA 95428, or by telephone: In the US 1-800-828-1302; From outside the US 707 983 6432; FAX 707 983 6414. ISBN 1-55963-139-2 (hardcover, US$85), ISBN 1-55963-138-4 (paperback, US$45).)*

La conférence sur les options technologiques en matière d'énergie s'est ouverte par un exposé du Professeur Thomas Johansson sur les perspectives d'utilisation d'énergies renouvelables dans un contexte mondial. Elle se fonde sur une étude commandée par l'organisation United Nations Solar Energy Group for Environment and Development, dont il est le président. Cette étude a été publiée depuis, dans un volume important intitulé Renewable Energy: Sources for Fuel and Electricity; *il contient des rapports de spécialistes relatifs à une longue liste de technologies renouvelables (voir la table des matières à la fin de l'article). Le présent article est composé d'extraits du chapitre 1 de ce livre, que nous reproduisons ici avec la permission de l'éditeur. On peut se procurer ce livre auprès de Island Press, Box 7, Dept. UN, Covelo, California, USA 95428, ou par téléphone: USA 1-800-828-1302; en dehors des USA 707 983 6432; Facsimile 707 983 6414. ISBN 1-55963-139-2 (relié, US$85) ISBN 1-55963-138-4 (livre de poche, US$45).*

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Major Findings

If the world economy expands to meet the aspirations of countries around the globe, energy demand is likely to increase even if strenuous efforts are made to increase the efficiency of energy use. Given adequate support, renewable energy technologies can meet much of the growing demand at prices lower than those usually forecast for conventional energy. By the middle of the 21st century, renewable sources of energy could account for three-fifths of the world's electricity market (see Figure 1) and two-fifths of the market for fuels used directly (see Figure 2). Moreover, making a transition to a renewables-intensive energy economy would provide environmental and other benefits not measured in standard economic accounts (see Box A). For example, by 2050 global carbon dioxide (CO_2) emissions would be reduced to 75% of their 1985 levels provided that energy efficiency and renewables are both pursued aggressively (see Figures 3a and 3b). And because renewable energy is expected to be

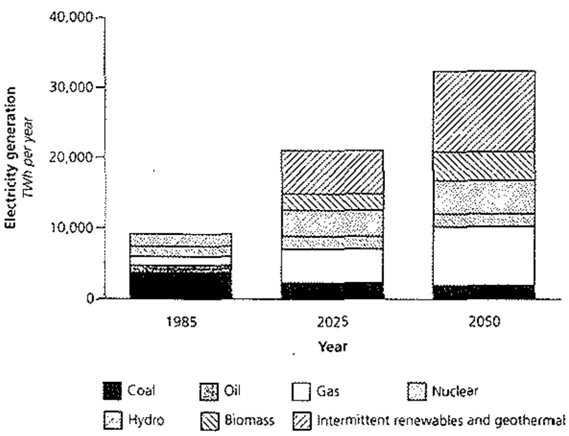

Figure 1: Electricity Generation for the Renewables-Intensive Global Energy Scenario

Renewables can play major roles in the global energy economy in the decades ahead. In the global energy demand scenario adopted for this study, global electricity production would more than double by 2025, and more than triple by 2050. The share of renewable energy generation would increase from 20% in 1985 (mostly hydroelectric power) to about 60% in 2025, with roughly comparable contributions from hydropower, intermittent renewables (wind and direct solar power), and biomass. The contribution of intermittent renewables could be as high as 30% by the middle of the next century.

A high rate of penetration by intermittent renewables without electrical storage would be facilitated by emphasis on advanced natural gas-fired gas turbine power generating systems. Such power generating systems — characterized by low capital cost, high thermodynamic efficiency, and the flexibility to vary electrical output quickly in response to changes in the output of intermittent power-generating systems — would make it possible to "back up" the intermittent renewables at low cost, with little, if any, need for electrical storage. For the scenario developed here, the share of natural gas in power generation nearly doubles by 2025, from its 12% share in 1985.

competitive with conventional energy, such benefits could be achieved at no additional cost.

This auspicious outlook for renewables reflects impressive technical gains made during the past decade. Renewable energy sys-

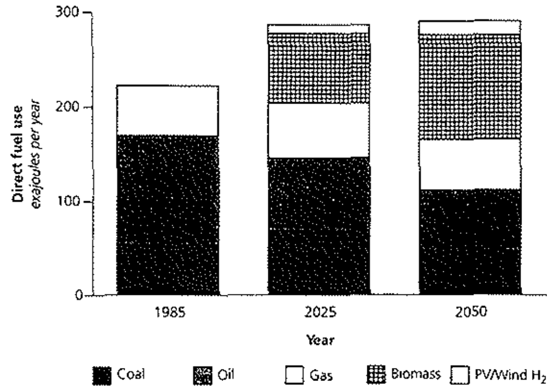

Figure 2: Direct Fuel-Use for the Renewables-Intensive Global Energy Scenario

In the global energy demand scenario adopted for this study, the use of fuels for purposes other than electricity generation will grow by less than one-third, much less than the generation of electricity (compare this figure with figure 1). The renewables contribution to fuels used directly could reach nearly one-fourth by 2025 and two-fifths by 2050, with most of the contribution coming from biomass-derived fuels — methanol, ethanol, hydrogen, and biogas. Methanol and hydrogen may well prove to be the biofuels of choice, because they are the energy carriers most easily used in the fuel cells that would be used for transportation.

tems have benefited from developments in electronics, biotechnology, materials sciences, and in other energy areas. For example, advances in jet engines for military and civilian aircraft applications, and in coal gasification for reducing air pollution from coal combustion, have made it possible to produce electricity competitively using gas turbines derived from jet engines and fired with gasified biomass.[1] And fuel cells developed originally for the space program have opened the door to the use of hydrogen as a non-polluting fuel for

1/ In this study, the term "biomass" refers to any plant matter used directly as fuel or converted into fluid fuels or electricity. Sources of biomass are diverse and include the wastes of agricultural and forest-product operations as well as wood, sugarcane, and other plants grown specifically as energy crops.

Box A: Benefits of Renewable Energy not Captured in Standard Economic Accounts

Social and economic development: Production of renewable energy, particularly biomass, can provide economic development and employment opportunities, especially in rural areas, that otherwise have limited opportunities for economic growth. Renewable energy can thus help reduce poverty in rural areas and reduce pressures for urban migration.

Land restoration: Growing biomass for energy on degraded lands can provide the incentives and financing needed to restore lands rendered nearly useless by previous agricultural or forestry practices. Although lands farmed for energy would not be restored to their original condition, the recovery of these lands for biomass plantations would support rural development, prevent erosion, and provide a better habitat for wildlife than at present.

Reduced air pollution: Renewable energy technologies, such as methanol or hydrogen for fuel-cell vehicles, produce virtually none of the emissions associated with urban air pollution and acid deposition, without the need for costly additional controls.

Abatement of global warming: Renewable energy use does not produce carbon dioxide and other greenhouse emissions that contribute to global warming. Even the use of biomass fuels will not contribute to global warming: the carbon dioxide released when biomass is burned equals the amount absorbed from the atmosphere by plants as they are grown for biomass fuel.

Fuel supply diversity: There would be substantial interregional energy trade in a renewables-intensive energy future, involving a diversity of energy carriers and suppliers. Energy importers would be able to choose from among more producers and fuel types than they do today and thus would be less vulnerable to monopoly price manipulation or unexpected disruptions of supplies. Such competition would make wide swings in energy prices less likely, leading eventually to stabilization of the world oil price. The growth in world energy trade would also provide new opportunities for energy suppliers. Especially promising are the prospects for trade in alcohol fuels such as methanol derived from biomass, natural gas (not a renewable fuel but an important complement to renewables), and, later, hydrogen.

Reducing the risks of nuclear weapons proliferation: Competitive renewable resources could reduce incentives to build a large world infrastructure in support of nuclear energy, thus avoiding major increases in the production, transportation, and storage of plutonium and other nuclear materials that could be diverted to nuclear weapons production.

transportation. Indeed, many of the most promising options described in our book are the result of advances made in areas not directly related to renewable energy, and were scarcely considered a decade ago.

Moreover, because the size of most renewable energy equipment is small, renewable energy technologies can advance at a faster pace than conventional technologies. While large energy facilities require extensive construction in the field, where labor is costly and productivity gains difficult to achieve, most renewable energy equipment can be constructed in factories, where it is easier to apply modern manufacturing techniques that facilitate cost reduction. The small scale of the equipment also makes the time required from initial design to operation short, so that needed improvements can be identified by field testing and quickly incorporated into modified designs. In this way, many generations of technology can be introduced in short periods.

Key Elements of a Renewables-Intensive Energy Future

An energy future making intensive use of renewable resources is likely to have the following key characteristics:

- There would be a diversity of energy sources,

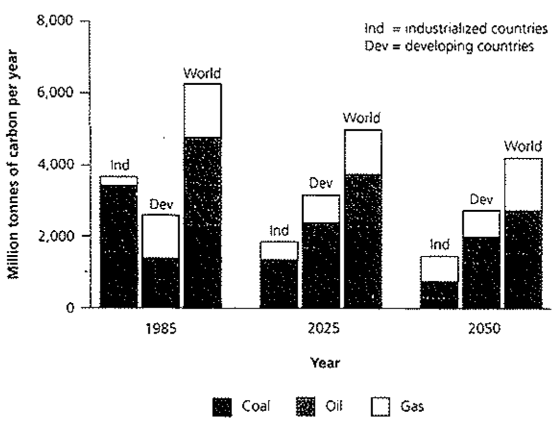

Figure 3a: Emissions of CO_2 for the Renewables-Intensive Global Energy Scenario, by World Region

Global CO_2 emissions from the burning of fossil fuels associated with the renewables-intensive global energy scenario would be reduced 12% by 2025 and 26% by 2050.

During this period, the CO_2 emissions from the industrialized countries (including former centrally planned Europe) would be reduced nearly in half by 2025 and nearly two-thirds by 2050. The industrialized country share of total worldwide emissions would decline from about three-fourths in 1985 to about two-fifths in 2025 to about one-third in 2050.

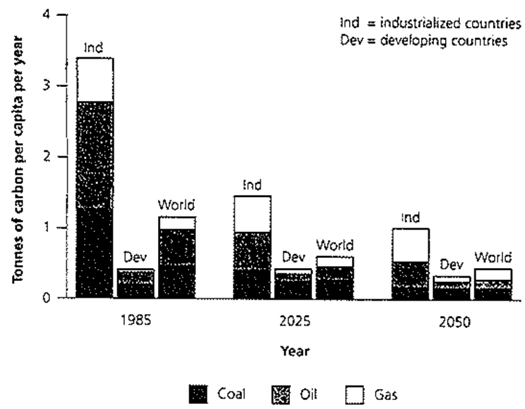

Figure 3b: Per Capita Emissions of CO_2 for the Renewables-Intensive Global Energy Scenario, by World Region

Global CO_2 emissions per capita associated with the renewables-intensive global energy scenario would be reduced nearly in half by 2025 and by more than three-fifths by 2050.

Despite the rising relative contribution of developing countries to total global CO_2 emissions (see figure 3a), per capita emissions of developing countries in 2050 would still be only one-third of those for industrialized countries.

the relative abundance of which would vary from region to region. Electricity could be provided by various combinations of hydroelectric power, intermittent renewable power sources (wind, solar-thermal electric, and photovoltaic power), biomass power, and geothermal power. Fuels could be provided by methanol, ethanol, hydrogen, and methane (biogas) derived from biomass, supplemented by hydrogen derived electrolytically from intermittent renewables.

Emphasis would be given to the efficient use of both renewable and conventional energy supplies, in all sectors. Emphasis on efficient energy use facilitates the introduction of energy carriers such as methanol and hydrogen. It also makes it possible to extract more useful energy from such renewable resources as hydropower and biomass, which are limited by environmental or land use constraints.

- Biomass would be widely used. Biomass would be grown sustainably and converted efficiently to electricity and liquid and gaseous fuels using modern technology, in contrast to the present situation, where biomass is used inefficiently and sometimes contributes to deforestation.
- Intermittent renewables would provide as much as one-third of total electricity requirements cost-effectively in most regions, without the need for new electrical storage technologies.
- Natural gas would play a major role in supporting the growth of a renewable energy industry. Natural gas-fired turbines, which have low capital costs and can quickly adjust

their electrical output, can provide excellent back-up for intermittent renewables on electric power grids. Natural gas would also help launch a biomass-based methanol industry; methanol might well be introduced using natural gas feedstocks before the shift to methanol derived from biomass occurs.

- A renewables-intensive energy future would introduce new choices and competition in energy markets. Growing trade in renewable fuels and natural gas would diversify the mix of suppliers and the products traded (see Figure 4), which would increase competition and reduce the likelihood of rapid price fluctuations and supply disruptions. It could also lead eventually to a stabilization of world energy prices. In addition, new opportunities for energy suppliers would be created. Especially promising are prospects for trade in alcohol fuels, such as methanol derived from biomass. Land-rich countries in sub-Saharan Africa and Latin America could become major alcohol fuel exporters.
- Most electricity produced from renewable sources would be fed into large electrical grids and marketed by electric utilities.
- Liquid and gaseous fuels would be marketed much as oil and natural gas are today. Large oil companies could become the principal marketers; some might also become producers, perhaps in joint ventures with agricultural or forest-product industry firms.
- The levels of renewable energy development indicated by this scenario represent a tiny fraction of the technical potential for renewable energy. Higher levels might be pursued, for example, if society should seek greater reductions in CO_2 emissions.

Constructing a Renewables-Intensive Global Energy Scenario

Our findings are based on a renewables-intensive global energy scenario which we developed in order to identify the potential markets for renewable technologies in the years 2025 and 2050, assuming that market barriers to these technologies are removed by comprehensive national policies.[2] Some global features of the scenario are presented in Figures 1 to 4. Separate detailed scenarios were constructed for 11 world regions (see Johansson *et al*, 1993, Appendix).[3]

In constructing the scenario it was assumed that renewable energy technologies will capture markets whenever (1) a plausible case can be made that renewable energy is no more expensive on a life-cycle cost basis than conventional alternatives,[4] and (2) the use of renewable technologies at the levels indicated will not create significant environmental, land use, or other problems. The economic analysis did not take into account any credits for the external benefits of renewables listed in Box A.

Energy Demand

The market for renewable energy depends in part on the future demand for energy services: heating and cooling, lighting, transportation, and so on. This demand, in turn, depends on economic and population growth and on the efficiency of energy use. Future energy supply requirements can be estimated by taking such considerations into account. For the construction of the renewables-intensive energy scenario, future levels of demand for electricity and for solid, liquid, and gaseous fuels were assumed to be the same as those projected in a scenario by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change.

The Working Group developed several projections of energy demand. The one

2/ See "An Agenda for Action" in Chapter 1 of Johansson *et al* (1992) pp. 43-63.

3/ The regions are Africa, Latin America, South and East Asia, Centrally Planned Asia, Japan, Australia/New Zealand, United States, Canada, OECD Europe, former Centrally Planned Europe, and the Middle East.

4/ Assumptions about the cost and performance of future renewable energy equipment are based on detailed analyses of technologies in Chapters 2-22 of Johansson *et al*. For a list of these chapters, see the Table of Contents reprinted at the end of this paper.

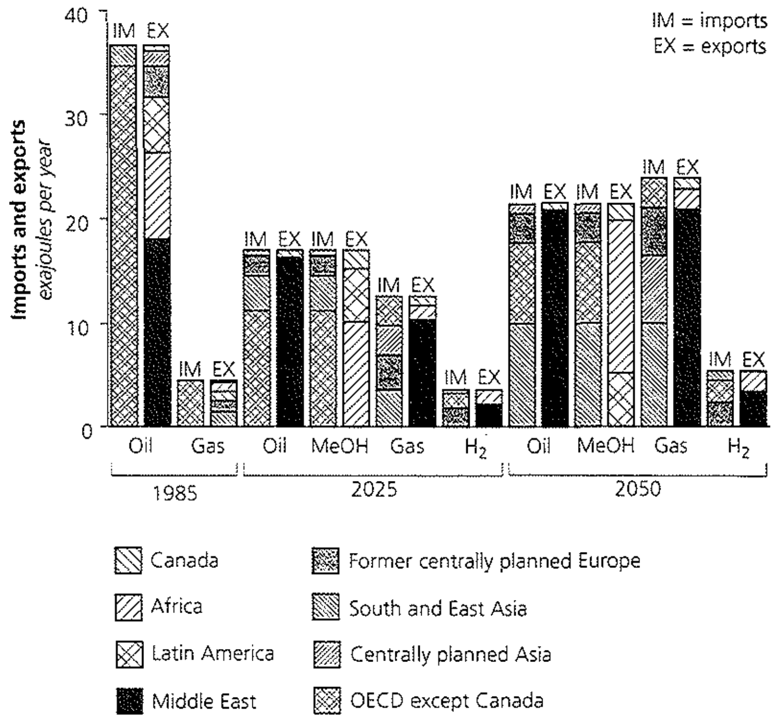

Figure 4: Interregional Flows of Fuels for the Renewables-Intensive Global Energy Scenario

The importance of world energy commerce for the renewables-intensive global energy scenario is illustrated here. This figure shows that in the second quarter of the next century there would be comparable interregional flows of oil, natural gas, and methanol, and that hydrogen derived from renewable energy sources begins to play a role in energy commerce. This diversified supply mix is in sharp contrast to the situation today, where oil dominates international commerce in liquid and gaseous fuels.

Most methanol exports would originate in sub-Saharan Africa and in Latin America, where there are vast degraded areas suitable for revegetation that will not be needed for cropland. Growing biomass on such lands for methanol or hydrogen production would provide a powerful economic driver for restoring these lands. Solar-electric hydrogen exports would come from regions in North Africa and the Middle East that have good insolation.

adopted for the renewables-intensive scenario is characterized by "high economic growth" and "accelerated policies" (see Figure 5). The accelerated policies case was designed to demonstrate the effect of policies that would stimulate the adoption of energy-efficient technologies, without restricting economic growth. Because renewable technologies are unlikely to succeed unless they are part of a program designed to minimize the overall cost of providing energy services, the energy-efficiency assumptions underlying the accelerated policies scenario are consistent with the objectives of the renewables-intensive scenario.

The high economic growth, accelerated-policies scenario projects a doubling of world population and an eight-fold increase in gross world economic product between 1985 and 2050. Economic growth rates are assumed to be higher for developing countries than for those already industrialized. Energy demand grows more slowly than economic output, because of the accelerated adoption of energy-efficient technologies, but demand growth outpaces

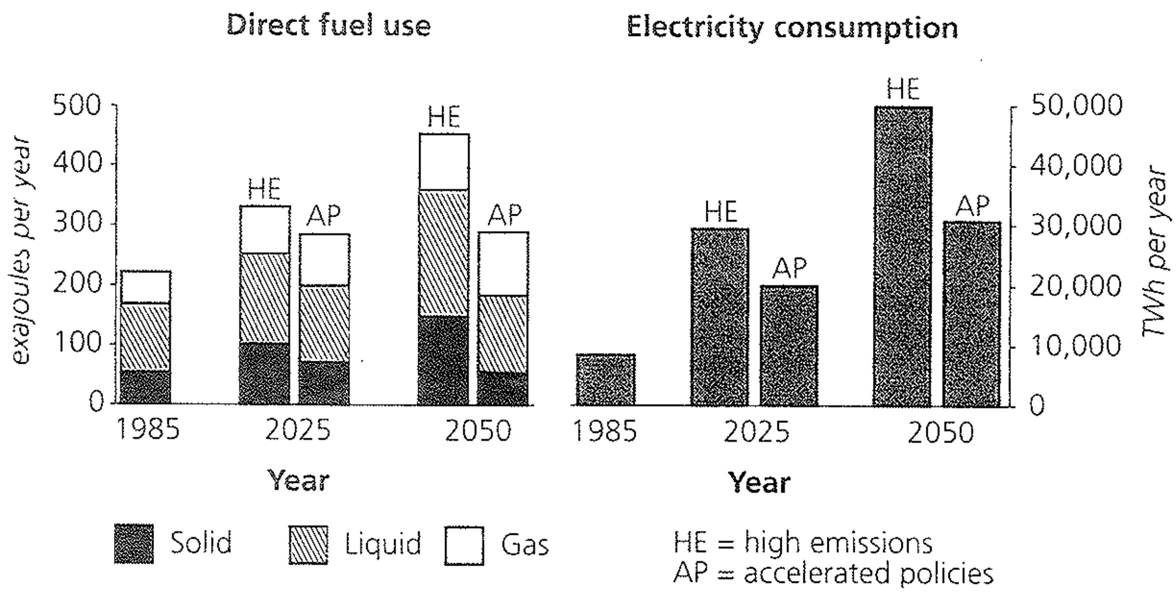

Figure 5: Alternative Global Energy Scenarios Developed by the Intergovernmental Panel on Climate Change

The two alternative scenarios for the direct use of fuels (left) and electricity consumption (right) shown here were developed by the Response Strategies Working Group (RSWG) of the Intergovernmental Panel on Climate Change (IPCC), as a contribution to that group's assessment of strategies for responding to the prospect of climatic change arising from the buildup of greenhouse gases in the atmosphere. Both scenarios are characterized by high economic growth. The lower energy demand scenario provides the basis for developing the renewables-intensive global energy supply scenario in the present study. For details see the appendix to chapter 1 in Johansson et al, 1993.

efficiency improvements — especially in rapidly growing developing countries. World demand for fuel (excluding fuel for generating electricity) is projected to increase 30% between 1985 and 2050 and demand for electricity 265% (see figure 5).

The Working Group's assumptions about energy efficiency gains are ambitious; nonetheless cost-effective efficiency improvements greater than those in the scenario are technically feasible, and new policies can help speed their adoption. Structural shifts to less energy-intensive economic activities may also reduce the energy needs of modern economies below those projected.[5]

Energy Resources

Construction of a global energy supply scenario must be consistent with energy resource endowments and various practical constraints on the recovery of these resources.

5/ For example, per capita energy use in OECD Europe is presently about 20% less than in Eastern Europe and the former Soviet Union. In the accelerated-policies scenario, per capita energy demand declines in OECD Europe and increases 60% by 2050 in Eastern Europe and the former Soviet Union. In light of the rapid economic and political changes now under way, it is doubtful that these two regions will take such divergent paths.

In the renewables-intensive energy scenario, global consumption of renewable resources reaches a level equivalent to 318 exajoules per year of fossil fuels by 2050 — a rate comparable to total present world energy consumption. Though large, this rate of production involves using less than 0.01% of the 3.8 million exajoules of solar energy reaching the earth's surface each year. The total electric energy produced from intermittent renewable sources (some 34 exajoules per year (EJ/yr)) would be less than 0.003% of the sunlight that falls on land and less than 0.1% of the energy available in the winds. Moreover, the electric energy that would be recovered from hydropower resources, some 17 EJ/yr by 2050, is small relative to the 130 to 160 EJ/yr that are theoretically recoverable (Chapter 2).[6] The amount of energy targeted for recovery from biomass, 206 exajoules per year by 2050, is also small compared with the rate (3,800 EJ/yr) at which plants convert solar energy to biomass (Chapter 14).

The production levels considered are therefore not likely to be constrained by resource availability. A number of other practical considerations, however, do limit the renewable resources that can be used. The scenario was constructed subject to the following restrictions:

- Biomass must be produced sustainably,[7] with none harvested from virgin forests. Some 62% of the biomass supply would come from plantations established on degraded lands or, in industrialized countries, on excess agricultural lands. Another 32% would come from residues of agricultural or forestry operations. Some residues must be left behind to maintain soil quality or for economic reasons; three-fourths of the energy in urban refuse and lumber and pulpwood residues, one-half of residues from ongoing logging operations, one-fourth of the dung produced by livestock, one-fourth of the residues from cereals, and about two-thirds of the residues from sugar cane are recovered in the scenario. The remaining 6% of the biomass supply would come from forests that are now routinely harvested for lumber, paper, or fuel wood. Production from these forests can be made fully sustainable — although some of these forests are not well managed today.
- Although wind resources are enormous, the use of wind equipment will be substantially constrained in some regions by land-use restrictions — particularly where population densities are high. In the scenario, substantial development of wind power takes place in the Great Plains of the United States (where most of the country's wind resources are found), while in Europe the level of development is limited because of "severe land-use constraints" (Chapter 4).
- The amounts of wind, solar-thermal, and photovoltaic power that can be economically integrated into electric generating systems are very sensitive to patterns of electricity demand as well as weather conditions. The marginal value of these so-called intermittent electricity sources typically declines as their share of the total electric market increases. Analysis of these interactions suggests that intermittent electric generators can provide 25 to 35% of the total electricity supply in most parts of the world (Chapter 23). Some regions would emphasize wind, while others would find photovoltaic or solar-thermal electric systems more attractive. On average, Europe is a comparatively poor location for intermittent power generation, so that the penetration of intermittent renewables there is limited to 14% in 2025 and 18% in 2050.
- Although the exploitable hydroelectric potential is large, especially in developing countries (Chapter 2), and hydropower is an excellent complement to intermittent electric sources, the development of hydropower will be constrained by environmental and social concerns — particularly for projects that would flood large areas. Because of these

6/ Chapter references refer to Johansson *et al* (1993). See the Table of Contents at the end of this paper.

7/ See Johansson *et al* (1993), p. 13 and Chapter 14.

constraints, it is assumed that only a fraction of potential sites would be exploited, with most growth occurring in developing countries. Worldwide, only one-fourth of the technical potential, as estimated by the World Energy Conference, would be exploited in the scenario by 2050. Total hydroelectric production in the United States, Canada, and OECD Europe would increase by only one-third between 1985 and 2050, and some of the increase would result from efficiency gains achieved by retrofitting existing installations.

CONVENTIONAL FUELS

By making efficient use of energy and expanding the use of renewable technologies, the world can expect to have adequate supplies of fossil fuels well into the 21st century. However, in some instances regional declines in fossil fuel production can be expected because of resource constraints.

Oil production outside the Middle East would decline slowly under the renewables-intensive scenario, so that one-third of the estimated ultimately recoverable conventional resources will remain in the ground in 2050. As a result, non-Middle Eastern oil production would drop from 103 EJ/yr in 1985 to 31 EJ/yr in 2050. To meet the demand for liquid fuels that cannot be met by renewables, oil production is assumed to increase in the Middle East, from 24 EJ/yr in 1985 to 34 EJ/yr in 2050. Total world conventional oil resources would decline from about 9,900 EJ in 1988 to 4,300 EJ in 2050.

Although remaining conventional natural gas resources are comparable to those for conventional oil, gas is presently produced globally at just half the rate for oil. With adequate investment in pipelines and other infrastructure components, gas could be a major energy source for many years. In the decades ahead, substantial increases in gas production are feasible for all regions of the world except for the United States and OECD Europe. For the United States and OECD Europe, where resources are more limited, production would decline slowly, so that one-third of these regions' gas resources will remain in 2050. In aggregate, gas production outside the Middle East would increase slowly, from 62 EJ/yr in 1985 to 75 EJ in 2050. But in the Middle East, where gas resources are enormous and largely unexploited, production would expand more than 12-fold, to 33 EJ/yr in 2050. Globally, about half the conventional gas resources would remain in 2050.

The renewables-intensive scenario was developed for future fuel prices that are significantly lower than those used in most long-term energy forecasts. It is expected that in the decades ahead the world oil price would rise only modestly and the price of natural gas would approach the oil price (which implies that the gas price paid by electric utilities would roughly double). There are two primary reasons for expecting relatively modest energy price increases: first, overall demand for fuels would grow comparatively slowly between 1985 and 2050 because of assumed increases in the efficiency of energy use; and second, renewable fuels could probably be produced at costs that would make them competitive with petroleum at oil prices not much higher than at present.

Public Policy Issues

A renewables-intensive global energy future is technically feasible, and the prospects are excellent that a wide range of new renewable energy technologies will become fully competitive with conventional sources of energy during the next several decades. Yet the transition to renewables will not occur at the pace envisaged if existing market conditions remain unchanged. Private companies are unlikely to make the investments necessary to develop renewable technologies because the benefits are distant and not easily captured by individual firms. Moreover, private firms will not invest in large volumes of commercially available renewable energy technologies because renewable energy costs will usually not be significantly lower than the costs of conventional energy. And finally, the private sector will not invest in commercially available technologies to the extent justified by the external benefits (e.g., a stabilized world oil price or reduced greenhouse-gas emissions) that would arise from their widespread deployment. If these problems are not addressed, renewable energy will enter the market relatively slowly.

Fortunately, the policies needed to achieve the twin goals of increasing efficiency and expanding markets for renewable energy are fully consistent with programs needed to encourage innovation and productivity growth throughout the economy. Given the right policy environment, energy industries will adopt innovations, driven by the same competitive pressures that have revitalized other major manufacturing businesses around the world. Electric utilities will have to shift from being protected monopolies enjoying economies-of-scale in large generating plants to being competitive managers of investment portfolios that combine a diverse set of technologies, ranging from advanced generation, transmission, distribution, and storage equipment to efficient energy-using devices on customers' premises. Automobile and truck manufacturers, and the businesses that supply fuels for these vehicles, will need to develop entirely new products. A range of new fuel and vehicle types, including fuel-cell vehicles powered by alcohol or hydrogen, are likely to play major roles in transportation in the next century.

Capturing the potential for renewables requires new policy initiatives. The following policy initiatives are proposed to encourage innovation and investment in renewable technologies:

- Subsidies that artificially reduce the price of fuels that compete with renewables should be removed; if existing subsidies cannot be removed for political reasons, renewable energy technologies should be given equivalent incentives.
- Taxes, regulations, and other policy instruments should ensure that consumer decisions are based on the full cost of energy, including environmental and other external costs not reflected in market prices.
- Government support for research on and development and demonstration of renewable energy technologies should be increased to reflect the critical roles renewable energy technologies can play in meeting energy, developmental, and environmental objectives. This should be carried out in close cooperation with the private sector.
- Government regulations of electric utilities should be carefully reviewed to ensure that investments in new generating equipment are consistent with a renewables-intensive future and that utilities are involved in programs to demonstrate new renewable energy technologies in their service territories.
- Policies designed to encourage the development of a biofuels industry must be closely coordinated with both national agricultural development programs and efforts to restore degraded lands.
- National institutions should be created or strengthened to implement renewable energy programs.
- International development funds available for the energy sector should be directed increasingly to renewables.
- A strong international institution should be created to assist and coordinate national and regional programs for increased use of renewables, to support the assessment of energy options, and to support centers of excellence in specialized areas of renewable energy research.

There are many ways such policies could be implemented. The preferred policy instruments will vary with the level of the initiative (local, national, or international) and with the region. On a regional level, the preferred options will reflect differences in endowments of renewable resources, stages of economic development, and cultural characteristics.

The integrating theme for all such initiatives, however, should be an energy policy aimed at promoting sustainable development. It will not be possible to provide the energy needed to bring a decent standard of living to the world's poor or to sustain the economic well-being of the industrialized countries in environmentally acceptable ways, if the present energy course continues. The path to a sustainable society requires more efficient energy use and a shift to a variety of renewable energy sources.

While not all renewables are inherently clean, there is such a diversity of choices that a shift to renewables carried out in the context of sustainable development could provide a far cleaner energy system than would be feasible by tightening controls on conventional energy.

The central challenge to policymakers in the decades ahead is to frame economic policies that simultaneously satisfy both socio-economic developmental and environmental challenges. The analysis in our book demonstrates the enormous contribution that renewable energy can make in addressing this challenge. It provides a strong case that carefully crafted policies can provide a powerful impetus to the development and widespread use of renewable energy technologies and can lead ultimately to a world that meets critical socio-economic, developmental and environmental objectives.

References

Johansson, Thomas B., Henry Kelly, Amulya K.N. Reddy & Robert H. Williams (Editors) (1993) *Renewable Energy: Sources for Fuels and Electricity* (Washington, DC & Covelo, California: Island Press) pp. 1160.

As a service to readers interested in the details of renewable technologies, the Table of Contents of the above book is reproduced below.

Renewable Energy Sources for Fuels and Electricity
