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Transitioning to a Renewable Energy Future

White Paper

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Contents

Executive Summary

This White Paper provides a rationale for effective governmental renewable energy policies worldwide, as well as sufficient information to accelerate effective governmental policies. It is the thesis of this White Paper that a worldwide effort to generate the renewable energy transition must emerge at the top of national and international political agendas, starting now.

In the history of human energy use, the White Paper records that sustainable resources were the sole world supply, even in nascent industrial development well into the 1800s, and that the world will necessarily again have to turn to sustainable resources before the present century is over. The fossil fuel period is therefore an "era", not an age, and highly limited in time in comparison with the evolution, past and future, of civilizations and societies. Accordingly, it is critical for governments to view what remains of the fossil fuel era as a transition.

The White Paper reveals that policies now in existence, and economic experience gained by many countries to date, should be sufficient stimulation for governments to adopt aggressive long-term actions that can accelerate the widespread applications of renewable energy, and to get on a firm path toward a worldwide "renewable energy transition", so that 20 % of world electric energy production can come from renewable energy sources by 2020, and 50 % of world primary energy production by 2050. There can be no guarantee this will happen, but the White Paper presents compelling arguments that show it is possible, desirable, and even mandatory.

The window of time during which convenient and affordable fossil energy resources are available to build the new technologies and devices and to power a sustained and orderly final great world energy transition is short – an economic timeline that is far shorter than the time of physical availability of the "conventional" energy resources. The White Paper argues that the attractive economic, environmental, security and reliability benefits of the accelerated use of renewable energy resources should be sufficient to warrant policies that "pull" the changes necessary, avoiding the "push" of the otherwise negative consequences of governmental inaction. There is still time left for this.

The White Paper presents three major conditions that are driving public policy toward a renewable energy transition:

1) newly emerging and better understood environmental constraints;
2) the need to reduce the myriads of risks from easy terrorist targets and from breakdowns in technologies on which societies depend; and
3) the attractiveness of the economic and environmental opportunities that will open during the renewable energy transition.

The renewable energy transition will accelerate as governments discover how much better the renewable energy policies and applications are for economies than the present time- and resource-limited policies and outmoded and unreliable centralized systems for power production and distribution.

Today, it is public policy and political leadership, rather than either technology or economics, that are required to move forward with the widespread application of the renewable energy technologies and methodologies. The technologies and economics will all improve with time, but the White Paper shows that they are sufficiently advanced at present to allow for major penetrations of renewable energy into the mainstream energy and societal infrastructures. Firm goals for penetrations of renewable energy into primary energy and electrical energy production can be set by governments with confidence for the next 20 years and beyond, without resource limitations.

Specifically, with regard to the renewable energy technologies, the White Paper shows the following:

- *Bioenergy:* about 11 % of world primary energy use at present is derived from bioenergy, the only carbon-neutral combustible carbon resource, but that is only 18 % of today's estimated bioenergy potential. Estimates for world bioenergy potential in 2050 average about 450 EJ, which is more than the present total world primary energy demand. Fuel "costs" for the conventional resources become instead rural economic benefits with bioenergy, producing hundreds of thousands of new jobs and new industries.

- *Geothermal Energy:* geothermal energy has been used to provide heat for human comfort for thousands of years, and to produce electricity for the past 90 years. While geothermal energy is limited to those areas with access to this resource, the size of the resource is huge. Geothermal energy can be a major renewable energy resource for at least 58 countries: thirty-nine countries could be 100 % geothermal powered, with four more at 50 %, five more at 20 %, and eight more at 10 %. Geothermal energy, along with bioenergy, can serve as stabilizing "baseload" resources in networks with the intermittent renewable energy resources.

- *Wind Power:* global wind power capacity exceeded 32,000 MW by the end of 2002, and has been growing at a 32 % rate per year. Utility-scale wind turbines are now in 45 countries. The price of wind-produced electricity is now competitive with new coal-fired power plants, and should continue to reduce to where it will soon be the least expensive of all of the new electricity-producing resources.
  A goal of 12 % of the world's electricity demand from wind by 2020 appears to be within reach. So is a goal of

20 % of Europe's electricity demand by 2020. This development pace is consistent with the historical pace of development of hydroelectric and nuclear energy. The 20 % penetration goal for the intermittent renewable energy resources is achievable within present utility operations, without requiring energy storage.

- *Solar Energy:* The energy from the sun can be used directly to heat or light buildings, and to heat water, in both developed and developing nations. The sun's radiant energy can also directly provide very hot water or steam for industrial processes, heat fluids through concentration to temperatures sufficient to produce electricity in thermal-electric generators or to run heat engines directly, and produce electricity through the photovoltaic effect. It can be used directly to enhance public safety, to bring light and the refrigeration of food and medicine to the 1.8 billion people of the world without electricity, and to provide communications to all regions of the world. It can be used to produce fresh water from the seas, to pump water and power irrigation systems, and to detoxify contaminated waters, addressing perhaps the world's most critical needs for clean water. It can even be used to cook food with solar box cookers, replacing the constant wood foraging that denudes ecosystems and contaminates the air in the dwellings of the poor.

- *Buildings:* in the industrial nations, from 35 % to 40 % of total national primary use of energy is consumed in buildings, a figure which approaches 50 % when taking into account the energy costs of building materials and the infrastructure to serve buildings. Letting the sun shine into buildings in the winter to heat them, and letting diffused daylight enter the building to displace electric lighting, are both the most efficient and least costly forms of the direct use of solar energy. Data are mounting that demonstrate conclusively enhancements of human performance in daylit buildings, with direct economic and educational benefits that greatly multiply the energy-efficiency "paybacks". The integrated design of "climate-responsive" buildings through "whole building" design methods enables major cost-savings in actual construction, normally yielding 30 % to 50 % improvement in energy efficiency of new buildings at an average of less than 2 % added construction cost, and sometimes at no extra cost.

- *Solar Energy Technologies:* serious long-range goals for the application of solar domestic water and space heating systems need to be established by all governments, totaling several hundred million square meters of new solar water heating systems worldwide by 2010. A worldwide goal of 100,000 MW of installed concentrating solar power (CSP) technology by 2025 is also an achievable goal with potentially great long-term benefits.

  Photovoltaic (PV) solar electric technology is growing worldwide at an amazing pace, more than doubling every two years. The value of sales in 2002 of about US$ 3.5 billion is projected to grow to more than US$ 27.5 billion by 2012. PV in developed and developing nations alike can enhance local employment, strengthen local economies, improve local environments, increase system and infrastructure reliability, and provide for greater security. Building-integrated PV systems (BIPV) with modest amounts of storage can provide for continuity of essential governmental and emergency operations, and can help to maintain the safety and integrity of the urban infrastructure in times of crisis. PV applications should be an element of any security planning for cities and urban centers in the world.

The White Paper stresses the importance of governmental policies that can enhance the overall economic productivity of the expenditures for energy, and the great multiplier in the creation of jobs from expenditures for the renewable energy resources rather than for the conventional energy sources. Utilities are not in the job producing business, but governments are, supporting the need for governments to control energy policies and energy resource decisions.

National policies to accelerate the development of the renewable energy resources are outlined, emphasizing that mutually supporting policies are necessary to generate a long-term balanced portfolio of the renewable energy resources. Beginning with important city examples, the discussion moves to national policies, such as setting renewable energy standards with firm percentage goals to be met by definite dates. The specific example of the successful German "feed-in" laws is used to illustrate many of these points.

Market-based incentives are described in the White Paper, to compare with legislated goals and standards, and discussed in terms of effectiveness. It is shown that various voluntary measures, such as paying surcharges for "green power", can provide important supplements to funding for renewable energy, but that they cannot be sufficient to generate reliable, long-term growth in the renewable energy industries, nor to secure investor confidence. Reliable and consistent governmental policies and support must be the backbone for the accelerated growth of the industries.

It is also shown in this White Paper that the energy market is not "free", that historical incentives for the conventional energy resources continue even today to bias markets by burying many of the real societal costs of their use. It is noted that the very methodologies used for estimating "levelized" costs for energy resources are flawed, and that they are not consistent with the more realistic economic methodologies used by modern industries. Taking into account future fuel supply risk and price volatility in net present valuations of energy resource alternatives paints a very different picture, one in which the renewable energy resources are revealed to be competitive or near-competitive at the present time.

Even though this White Paper emphasizes the readiness of the renewable energy technologies and markets to advance the penetration of these resources to significant levels in the world, an important component of any national renewable energy policy should be support for both fundamental and applied R&D, along with cooperation with other nations in R&D activities to enhance the global efficiency of such research. It is both significant and appropriate that the European Commission has agreed to invest for the next five-year period in sustainable energy research an amount that is 20 times the expenditure for the 1997-2001 five-year period.

Governments need to set, assure and achieve goals to accomplish simultaneously aggressive efficiency and renewable energy objectives. The implementation mechanisms for achieving these goals must be a packaged set of mutually supportive and self-consistent policies. The best policy is a mix of policies, combining long term renewable energy and electricity standards and goals with direct incentive and energy production payments, loan assistance, tax credits, development of tradable market instruments, removal of existing barriers, government leadership by example, and user education.

The White Paper concludes with the presentation of two comprehensive national energy policies to demonstrate the method of integration of various individual strategies and incentives into single, long-range policies with great potential returns.

All of those square meters of collectors and hectares of fields capturing solar energy, blades converting the power of the wind, wells delivering the Earth's thermal energy, and waters delivering the energy of river flows, waves and tides, will displace precious and dwindling fossil fuels and losses of energy from the worldwide phase-out of nuclear power. Sparing the use of fossil fuels for higher economic benefits, or using them in fuel-saving and levelizing "hybrid" relationship with the intermittent renewable energy resources (sun and wind), will contribute to leaner, stronger, safer societies and economies. And, in the process, carbon and other emissions into the atmosphere will be greatly reduced, now as a result of economically attractive new activities, not as expensive environmental penalties.

Summary of Policy Options and Implementation Mechanisms

- National multi-year goals for assured and increasing markets for renewable energy systems, such as "Renewable Energy Standards" (also called, in the U.S., "Renewable Portfolio Standards", or RPS), or the EU Renewables Directive, especially when formulated to support balanced development of a diversity of renewable energy technologies;

- Production incentives, such as "feed-in" laws, production tax credits (PTC), and net metering;

- Financing mechanisms, such as bonds, low-interest loans, tax credits and accelerated depreciation, and green power sales;

- System wide surcharges, or system benefits charges (SBC), to support financial incentive payments and loans, R&D and public interest programs;

- Credit trading mechanisms, such as Renewable Energy Credits (RECs) or carbon reduction credits, to enhance the value of renewable energy, to increase the market access to those energy sources, and to value the environmental benefits of renewables;

- Specific governmental renewable energy "quotas" for city and state renewable energy procurements;

- Removal of procedural, institutional and economic barriers for renewable energy, and facilitation of the integration of renewable energy resources into grids and societal infrastructure;

- Consistent regulatory treatment, uniform codes and standards, and simplified and standardized interconnection agreements;

- Economic balancing mechanisms, such as pollution or carbon taxes (which can then be diverted as "zero sum" incentives to the non-polluting and non-carbon technologies);

- "Leveling the playing field" by redressing the continuing inequities in public subsidies of energy technologies and R&D, in which the fossil fuels and nuclear power continue to receive the largest share of support.

Preface: Solar Energy from Then to Now and Beyond

Solar energy is *not* an “alternative energy”. It is the original and continuing primary energy source. All life and all civilizations have always been powered by solar energy. Expanding the technical applications of solar energy and its other renewable energy cousins to carry civilizations forward is simply a logical extension of its historic role, but also the inescapable key to achieving sustainability for human societies.

The solar energy that is absorbed by the Earth and atmosphere drives the great cycles of weather and ocean currents, distributing the energy over the face of the Earth. Solar energy provides the evaporation engine, lifting moisture to the atmosphere from where it can fall, bringing clean, fresh water to plants and filling the ponds, lakes, aquifers, streams, rivers and oceans, spawning and supporting all forms of life. Solar energy is tapped by plants through photosynthesis to energize the growth, directly and indirectly, of all life on Earth. The solar energy stored in wood and woody crops has been released by lightning in fire to renew wild ecological systems. More recently humans have released that stored solar energy in controlled fires to provide comfort and cooking. And the sun’s direct heat has been adapted into shelters to warm humans in cold climates for time eternal.

As human social groupings evolved into cities, the sun continued to provide support with ever expanding uses of its energy for life and commerce. Rivers filled by sun-provided water became transportation sources and locations for great cities. The solar-driven power of wind was tapped to grind grain in great windmills, and to power the sails across the oceans carrying explorers, settlers, and materials for commerce, and cross-fertilizing civilizations. Water falling over water wheels converted the sun’s energy of evaporation to power for machinery, such as for the early printing presses and cotton gins, and then turned the early (hydroelectric) generators to bring electricity to cities.

The solar energy released in burning wood turned water to steam to greatly advance industry and transportation, and to provide for human thermal comfort in homes and buildings. Although the widespread use of coal developed in the second part of the 1800s, and oil was discovered in the 1800s, wood was still the primary energy used to power industrial civilizations into the early 20th Century.

It was only during this most recent century that human societies transitioned to the fossil fuels for their primary energy needs, forgetting, over time, that the energy in gas, oil and coal is also solar energy that had been stored in living tissue (biomass) that did not get a chance to decay, but rather was stored, compressed, heated, and turned into fossil fuels over the last 500 million years. The cheap access to coal in new coal-mining settlements, and then the convenience of oil and gas, caused the widespread abandonment of passive solar, daylighting, and other environmental design features for buildings. Although solar water heating was commercialized and common in a number of areas at the beginning of the 20th century, it, too, was replaced by the cheap convenience of gas and electricity. The direct use of solar energy has been replaced by the indirect use of stored solar energy. Yet solar energy it still is.

From yielding the energy that powers the chemical, mechanical and electrical functions of all living things, and conditions their supporting environment, the sun’s role in life and ecosystems has always come first, and will continue to do so for as long as life exists on this planet. Societies that accept this principle will flourish, while those that try to evade this truth for their own short-term economic benefit will fail.

So one way or another, civilizations have remained, to this day, powered by solar energy. (Of the two primary non-solar resources, nuclear energy contributed 6.8 %, and geothermal energy 0.112 %, to world primary energy in the year 2000.) Most often, though, we have used profligately and wastefully, and taken for granted, the limited resource of fossil fuels. The fossil fuels are being steadily depleted, and they *cannot* be replaced on any reasonable time scale of human civilizations. While the lifetime of oil and gas may stretch out through the first half of this century, the transition to sustainable alternatives must happen well before the physical or economic depletion of these valuable stored energy resources. *Civilization must begin to take seriously this transition.*

There is a readily available solution – *the renewable energy resources.* They are non-polluting, inexhaustible, operate in stable harmony with the Earth’s physical and ecological systems, create jobs and new industries out of expenditures that previously had gone to purchase fuels, contribute to physical and economic self-sufficiency of nations, are available to both developed and developing nations, and cannot be used to make weapons.

We have turned to "yesterday's sunshine" stored in fossil fuels for about 100 years, after relying on “today’s sunshine” for all of human history before that. Therefore, it is a thesis of this White Paper that the world must emerge from this brief fossil-fueled moment in human history with a renewed dependence on “today’s sunshine” for the entire portion of human history yet to be written.

Framework, Scope and Limitations of this White Paper

Opening with a discussion of the new elements that are today driving public policy toward the renewable energy transition, this White Paper presents information on applications and policies for those renewable energy resources that are in great abundance worldwide, but which have barely begun to be developed to their full potential. The present status and rate of growth of each of the major renewable energy technologies is briefly summarized, to help inform the reader of their technical and market maturity and to demonstrate the potential for renewable energy resource development.

The "baseload" renewable energy resources (bioenergy and geothermal energy) are first presented, because of their widespread historical contributions to meeting the energy needs of the world and their promise for future large-scale expansion. This is followed by the "intermittent" renewable energy resources (wind and direct thermal and electrical applications of radiant solar energy).

The next section delineates the various policies that have been emerging to advance renewable energy technologies and applications worldwide, to outline the portfolio of options available today for governments and nations.

Policies for the development of new large-scale hydroelectric power projects are not presented. Hydroelectric energy has been long commercialized. And an argument can be made that, while hydroelectric energy remains a very important worldwide renewable (and sustainable) energy resource (producing about 2.3 % of world primary energy supply in 2000 and 17 % of global electricity production), few large rivers remain to be tapped, and those that do are revealing ecological benefits from running free that exceed the benefits of being corralled behind dams to impound water and to produce electricity. Small hydroelectric applications ("micro hydro") can still fill important local niches for power.

Existing hydroelectric power has great potential to complement, level, and even store the energy from intermittent renewable energy resources, thereby increasing the value and utility of both. So it will continue to be a valuable resource in the transition and beyond. But on a worldwide scale hydroelectric power is nearing its maximum potential development already.

Nuclear power is also not presented as a realistic policy option in this White Paper. Nuclear energy currently makes a small but significant worldwide contribution (6.8 % of world primary energy – that is, all energy consumed by end users – in 2000, and about 17 % of global electric energy production, both figures still less than those for renewable power and energy production). But it appears that the pace of nuclear plant retirements will exceed the development of the few new plants now being contemplated, so that nuclear power may soon start on a downward trend. It will remain to be seen if it has any place in an affordable future world energy policy. And even if it does, it would be incredibly foolish to place all of the world's hopes on just one resource, for if it fails, what then? As nature strengthens its ecological systems through diversity, so must governments seek policies that support a diversity of energy resources. For developing nations, the energy resources of greatest importance are those that are locally available, and which can be tapped and applied affordably by locally available human resources. Nuclear power fails all of these tests. The renewable energy resources pass them.

The ultimate definition of "sustainability" must accept as primary the maintenance and integrity of the solar-driven ecological and physical systems, or human societies and economies will surely perish.

In keeping with the aim of this White Paper – to accelerate the application of the *presently commercialized* renewable energy resources – future possibly important applications, such as ocean thermal energy conversion (OTEC), wave energy, and tidal power, are also not discussed. But one can expect that these, too, will sometime in the future take their places in the complete portfolios of opportunities to utilize nature's gift of renewable energies.

The following material presents just enough about each of the selected resources to be read by busy decision-makers, to support the types of policies available to them, to support the value of setting aggressive goals which are also realistic, and to suggest the kinds of benefits that will accrue from those policies. This paper focuses on generating and supporting the *process* of the renewable energy transition.

This White Paper owes much to the many informational resources, both people and publications, from which the material for this paper has been drawn. But this is intended to be a policy piece, not a research paper, so, with the exception of the figures, the following material is presented without specific source attributions. The principal resources are acknowledged at the end of this paper.

Definitons, terminology, and conversion factors

An attempt has been made in this White Paper always to put stated numbers in a relative context, to reveal their policy meaning. Nevertheless, it is helpful here to relate energy units from the two major systems presently in use worldwide, or to other convenient measures, to reveal values used throughout this White Paper, as well as to provide definitions applicable to this paper and in common use in reports.

Work performed at the rate of 1 Joule/second is one watt of power. Conversely, the energy produced by 1 watt of power over an hour is one watt-hour. Power usage is normally measured in the more applicable unit of kilowatt hours (kWh, or the energy produced by 1,000 watts of power over a period of one hour).

For societal energy reporting, larger units must be used. The most common for the outputs of power production facilities and societal energy statistics is megawatt hours (MWh, or one million watt-hours), or gigawatt-hours (GWh, which is one billion, or 10^9, watt-hours). For national or world annual energy consumption, the unit of Terawatt-hours is the most convenient (TWh, which is one trillion, or 10^{12}, watt-hours, or one billion kWh).

The most useful unit for cataloging energy use by nations and the world is the Exajoule (EJ), which is a billion billion (10^9 x 10^9, or 10^{18}) joules. Since the energy content of 1,055 joules is equal to the energy content of one Btu (the energy needed to heat one pound of water one degree F), it is apparent that 1.055 EJ is therefore equal to one quadrillion ("Quad", or 10^{15} Btu) of energy. (For confused decision-makers reading this, it is sufficiently accurate to first order to just equate EJ and Quads in one's head while reading, to allow thought in the units to which the reader is most accustomed. A mental error of only 5.5 % is made that way, and it can easily be corrected when thoughts are put to paper or computer.)

A unit in widespread use is million-tonnes-of-oil-equivalent (Mtoe), which is, by definition, 41.868 Petajoules (PJ, or 10^{15} joules). The energy content of a billion tonnes, or Gigatonne, of oil (Gtoe, or 10^9 tonnes) is therefore about 41.9 EJ.

One kWh is also 3.6 million joules (3,414 Btu) of energy, allowing a conversion from customary electrical energy to thermal energy units. In order to keep descriptions of both electrical and thermal energy in a common energy notation, which of those is being discussed is sometimes made explicit by notating kWh_e for kilowatt-hours of electrical energy, or kWh_t for kilowatt-hours of thermal energy.

How much energy is available from the renewable energy resources? The bright overhead sun can deliver energy to a square meter of surface area on Earth directly facing the sun at the rate of about 1,000 watts (1kW – this is the "standard sun" used to evaluate the efficiency of solar energy systems, which are consequently rated in terms of "peak watts" output under a 1kW/m² illumination, or W_p). If the solar collector surface could absorb 100 % of the solar radiation that strikes it and if it could convert that energy with 100 % efficiency then it would produce 1kWh of energy each hour. Of course, it is not perfectly efficient, so the energy delivered by the solar energy system is less – usually in the range of 5 % to 15 %. The power content of an 11 m/sec (25 mph) wind is also about 1 kW/m² perpendicular to the wind direction, but wind turbines cannot extract that with complete efficiency, either – they usually range from 25 % to 35 %. And an Exajoule (EJ) of energy is roughly equivalent to the energy obtainable from the transformation of 52 million tonnes of dry wood biomass.

Introduction – A Global Energy Transition, Steering the Correct Course

During the recent development of human civilizations, societies and industries, experience has shown that it takes about 60 years for the world to transition from primary dependence on one resource of energy to a new resource or set of resources. It took about 60 years for us to transition from our dependence on wood to coal, and by then we were already in the beginning of the 20th century. It took perhaps another 60 years or so (from 1910 to 1970) to transition fully out of dependence on coal to a dominant dependence on oil and natural gas, although coal has continued to be important for electricity production.

Much of the world has seemingly settled into fossil fuels as though they will be forever available, or as though any further energy transitions will be the tasks of future generations, not of the present. And yet environmental limits to the unlimited use of fossil fuels, with potentially hugely negative economic implications for all nations, are now apparently emerging, and these limits are indeed being taken seriously in policy formulations by most of the developed world's governments.

As this White Paper will substantiate, the renewable energy resources had emerged by the year 2000 into sufficient technological and market maturity to begin to affect global primary energy production, even though still very modest in total percentage terms. If this is indeed the tip of the next great energy transition, then our own history suggests that, by 2030, we should be deep into the emergence of the next age of energy resources.

We have stalled the start of that transition for at least the last 30 years. Fossil fuels have continued to dominate a highly distorted and artificial energy market. Today's low fossil fuel prices result in part from the continuing benefits of very large government subsidies, and in part from having no value assigned to the great chemical "feedstock" potential of these rich hydrocarbons in comparison with simply burning them. No economic value is assigned either to future resource availability or to costs assigned to the environmental and human health impacts of their use. The money to be earned by the finders and sellers of fossil fuels, and the political power that has come with that, has further delayed any serious beginnings of the next energy transition.

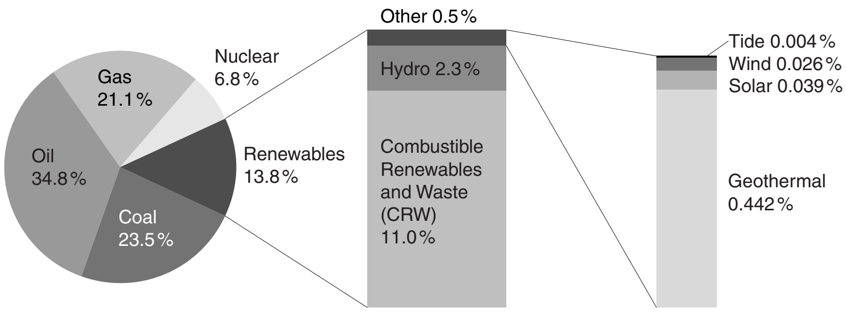


Fig. 1: Fuel Shares of World Total Primary Energy Supply, Year 2000. The growth of wind-electric installations between 2000 and 2002 has increased wind's share of world total primary energy supply to 0.042 %. Wind is 0.7 % of world installed electric power capacity in nameplate rating, but closer to 0.2 % in power produced, because wind operates only about 30 % of the time at its full rating. This demonstrates how far the non-hydro renewables must go in order to assume a larger share of the world's total energy and electricity production.
Source: IEA,"Renewables in Global Energy Supply", an IEA Fact Sheet, November, 2002

The continuing political clout of nuclear power advocates is leading to renewed investments of public funds in some countries (e.g. the United States and France) to support that technology in amounts that greatly exceed investments of public funds in renewable energy resources, possibly delaying the transition to a diversity of stable and reliable energy sources even more. This is a huge gamble by those few governments. The majority of world governments are turning away from this form of energy because it is such a complex technology, expensive, vulnerable to terrorists or to misuse as a source of material for weapons of mass destruction, potentially dangerous in its own right (e.g. Three Mile Island, and Chernobyl), and dependent on waste storage solutions which have yet to be perfected.

Nuclear power will never hold its own in free energy markets, that is, without massive public subsidies in assuming the risks of owner default or accidents with consequences possibly orders of magnitude more expensive than private insurance companies can afford to cover, or be affordable to developing nations. The lifecycle of nuclear power, from plant construction to decommissioning, and including the environmental consequences of the complete fuel cycle, leads to a significant emission of the very greenhouse gases that the use of nuclear power is touted to avoid.

Fuel for nuclear power plants is also an element from the Earth's crust that is in limited abundance. And there are already far less expensive ways to make hydrogen from renewable energy than from nuclear energy, removing yet another presumed economic justification for the construction of new nuclear power plants.

Nuclear energy may therefore be practical only for a time limited by fuel resource availability and technical, security, environmental, economic and ethical considerations. While it may provide some useful energy during the transition, nuclear energy will most certainly not be a long-term survivor *of* the transition. Other resources must be developed and applied on a global scale.

Continual postponement of a serious worldwide initiation of the renewable energy transition is a precarious gamble, potentially jeopardizing our ability to launch it at all as the clock to accomplish it in economically attractive ways winds down. Further stalling the renewable energy transition also gambles the world's security and stability, as present centralized energy systems become vulnerable terrorist targets, and dependence on economically critical resources from politically unstable areas of the world continues to increase.

Stalling a serious, large scale worldwide effort to launch the full-scale renewable energy transition will produce a more dangerous world, gamble away any hope for equity between nations of the world, and also gamble away the future opportunities of our own children and grandchildren. And what are the governments of tomorrow to say to them? We're sorry? It was the past governments that blew it?
Or, even worse, our past governments really didn't care about you, and used economic criteria that discounted your rights while also acting on the assumption that saving the world was uneconomic?

For example, Canada will not be able to provide more exports of natural gas to meet the anticipated natural gas shortfall in the U.S. But since natural gas is the choice for multiple new electric power plants being built or planned in the U.S., suggestions are now surfacing that the U.S. growing need be met by liquefied natural gas imported and stored, which will greatly raise the price of electricity, increase U.S. dependence on foreign sources, increase the deficit in balance of payments, and yield yet a new convenient set of targets for terrorists – LNG tankers and storage facilities

It is the purpose of this White Paper to reveal the enormous momentum now being generated worldwide in renewable energy applications and policies, to underscore that the ingredients are now in place for the renewable energy transition to begin, to reveal the benefits already known to derive from these first steps, and to compare and evaluate the policies that are emerging as the most effective to accelerate the application of renewable energy resources.

The elements of that transition have already appeared, and been tested both for technical feasibility and in world energy markets. Governments don't have to start something new – they only need the political will to expand that which is already developed, studied and tested, and which now stands ready to burgeon into a new life-supporting industry for the world – the renewable energy resources.

It is a thesis of this White Paper that *a worldwide effort to generate the renewable energy transition must emerge at the top of both national and international political agendas, starting now.* It is the expectation that this White Paper can serve as the basis for the adoption with confidence by governments of policies that will launch an orderly worldwide renewable energy transition.

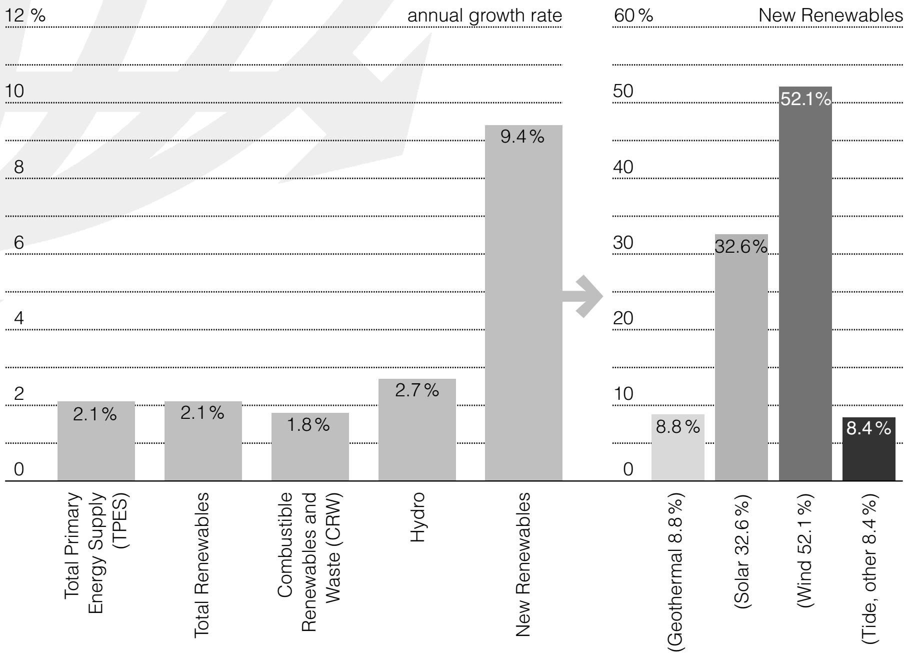


Fig. 2: Annual growth of renewable energy supply from 1971 to 2000. Growth in total renewables kept up, in percentage terms, with growth in Total Primary Energy Supply(TPES) during that almost 30-year period, which means that total installed renewables increased considerably, but renewables installations have not been gaining on total world supply increase. (The very high annual percentage growth rates for the "new renewables" of solar and wind result in part from the very low level of applications at the beginning of this reporting period.)
Source: IEA,"Renewables in Global Energy Supply", an IEA Fact Sheet, November, 2002

New Elements Driving Public Policy toward a Renewable Energy Transition

Environmental warnings

For years scientists, governments, and people have considered the potential of renewable energy resources for providing society with efficient and environmentally responsible energy. In parallel, enormous strides have been made in renewable energy technologies and markets. But until recently most of those have all taken place at a leisurely pace, generally with no particular sense of urgency.

This was not always the case. For example, U.S. President Jimmy Carter was the first world leader to announce, as he did in 1976, that energy policy would be his highest priority. He launched vigorous programs to advance energy efficiency and solar energy, and to lead the United States on an “Energy Independence” path. But his programs soon mired in politics, and he was scorned for his famous televised talk wearing a sweater in front of a fireplace. The U.S. subsequently turned its policy back to the conventional energy resources, and is now the unfortunate world leader in the profligate use of oil in inefficient vehicles and in producing the world’s largest single share of greenhouse gas emissions from all sources. Smaller countries with bigger ambitions have taken over the world leadership in the development and sales of renewable energy technologies, clearly already to their own economic benefit.

The world scene is now dramatically altering from the past. Of particular significance are the impacts of climate change from global warming that are apparently emerging with already perceivable negative economic consequences for most nations, and projections of very serious costs in the future. While present heat spells cannot be scientifically attributed to global warming, the 19,000 deaths in Europe from the August 2003, heat wave reveals ominous potential consequences. The initial cautious pronouncement by the Intergovernmental Panel on Climate Change (IPCC) of a “discernible” evidence of human contributions to global warming was advanced in their 2001 Assessment to “There is new and stronger evidence that *most* of the warming over the last 50 years is attributable to human activities.”

It is not the warming per se that is of such great concern so much as the potential impacts that warming can have on the energy flows on the Earth’s surface, which are expressed in perturbations to the Earth’s climates. A scientific consensus is emerging, as expressed by the Chairman of the IPCC, as he warned in the 2001 Assessment that “The overwhelming majority of scientific experts, whilst recognizing that scientific uncertainties exist, nonetheless believe that human-induced climate change is already occurring and that *future change is inevitable.”*

A UN-sponsored report (by Innovest Strategic Value Advisors) further concluded in October, 2002, that “Worldwide losses from natural disasters appear to be doubling every ten years … the cost of climate change could soar to US$ 150 billion a year within the next ten years.“, and “The increasing frequency of severe climatic events … has the potential to stress insurers and banks to the point of impaired viability or even insolvency.” The projections are far graver and more basic for the low-lying and developing nations, as seas rise and rains dry up, yet they alone cannot control their environmental destinies. They must appeal to the developed nations to alter policies to reduce the risks for all nations.

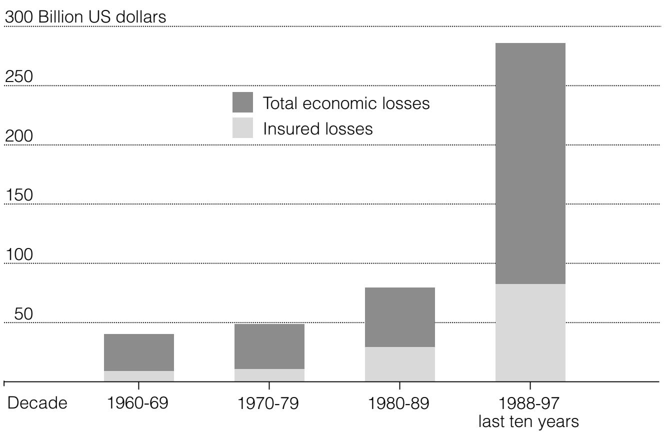


Fig. 3: The increasing impact on the U.S. economy from major weather and flood catastrophes, expressed in constant dollars. Already the share repaid by the insurance companies is excessive, causing a reduction in the scope of storm insurance coverage, and leaving the American public increasingly exposed to the economic consequences of climate change. This is the basis for making the avoidance or mitigation of the impacts of climate change a matter of public policy and governmental action.
Source: Munich RE Group, 1999

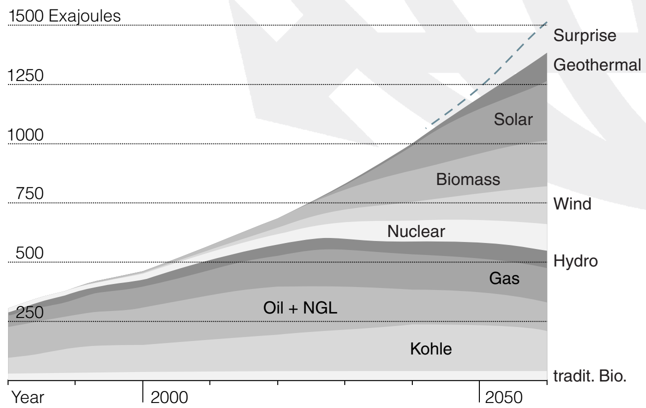


Fig. 4: A very well known scenario for a possible renewable energy transition, prepared by Shell International in 1996. World energy growth would increasingly be met by renewable energy resources, until, by about the middle of this century, more than half of the world’s energy needs would be met by the clean energy resources. This scenario shows that, to accomplish such a transition, contributions by renewable energy sources, even though small, must begin to emerge onto the world scene very early this decade.
Source: Shell International Limited

Avoiding risks

It is risk, and risk avoidance, that is the dramatic new driver of public policy emerging into public discourse today. Climate change is perceived as a serious future ecological and economic risk. So is terrorism. Power plants, transmission lines and substations, and gas and oil pipelines, are all attractive and accessible centralized targets for terrorists who wish to bring the working of a society to a quick and decisive halt. The distributed renewable energy technologies, on the other hand, operate in smaller units, often building-by-building, yielding targets too widespread and small to be of interest to terrorists. Energy security comes from the integration of these many sources of energy into the grid. The destruction of one will have little impact on the others, or on the energy network as a whole. A few bombs could not bring a society based upon distributed energy resources to its economic knees.

Risks to a nation's energy systems also arise from within, from the very design of the systems and the potential unreliability of their components. This was illustrated in remarkable fashion by the enormous blackout in the United States in August of 2003. A sequence of generation plant and transmission line "trips", one leading to another, like falling dominoes, began at 2 in the afternoon on August 14. Within two and one-half hours five major transmission lines, three coal-fired powerplants, nine nuclear powerplants, and an important switching station, had all tripped off.

Before it was over 100 power plants, including 22 nuclear plants in the U.S. and Canada, had gone off line. The power failures spread through eight states and two Canadian provinces, leaving 50 million Americans and Canadians, living in portions of the United States from New York City on the East to Detroit in the Midwest, and Toronto, Canada, to the north, completely in the dark. Economic losses from this two-day event are expected to be about US$ 5-6 billion.

The American President's response was to call for upgrading the nation's aging utility grids, but more enlightened observers recognized this as a sign of the fundamental failure of interconnected, centralized systems, and a call for governments to start diversifying the grid with distributed energy sources. This was echoed just four days later in a front page story, "Energizing Off-Grid Power", in the prestigious American business newspaper The Wall Street Journal. The U.S. Congress has shown its unwillingness to invest anything like US$ 6 billion in the development and deployment of distributed energy systems, yet the failure to do so has been graphically shown to lead to the risk of losses of equivalent amount.

Just one month later it happened again, but this time in Italy! Before this second blackout was over 58 million Italians were without power. Once again, a problem in a central, interconnected grid took down an entire electricity system for an entire country. The case for a distributed system of diversified resources could not have been better emphasized than by these two massive outages.

Which policy is better for the economy? Losses diminish an economy. New technologies strengthen it. Continuing to invest in old ways of producing and distributing energy does not reduce the systemic risks from massive, centralized systems. Investing in new ways of producing and distributing energy in smaller scale, decentralized systems can greatly reduce the large risks, and the possibility of future economic losses from system failures. The safety and reliability attributes of distributed energy resources need to be taken explicitly into account when evaluating relative costs of energy supply systems.

Yet the risk to the very fabric of society extends beyond terrorism and utility network vulnerability. While we don't know exactly when the world demand for oil will exceed daily production, when it does (certainly sometime in the early part of this century) it will forever alter the economics of world energy resources, and promote an intensive international competition for those resources. We have already seen how readily nations are willing to go to war to protect regions rich in oil resources. And the world is experiencing risks to peace and political stability by nations with the potential to utilize nuclear fuel to create weapons of mass destruction. Without the leadership of the developed nations in turning away from these destructive paths, the world will become more dangerous still.

Opportunities for governments

The risks of failing or outmoded national energy policies can do great harm to national economies. Energy costs are embodied in everything – day-to-day costs for the energy essentials to support lives, embodied energy in all that we make, consume, and eat, and embedded energy expenditures in the costs of all goods on the domestic and world markets. Societies that can make and sell products with less invested energy costs will get a very large advantage on the world market – and soon. Those societies that can stabilize their long-term energy costs, and isolate their internal and external market activities from cost increases and supply instabilities of conventional fuels, will have an even larger advantage. And those societies that transform the expenditures for fuels, which must be imported, into support for useful and productive employment for their own people in their own energy efficiency and renewable energy industries, will convert an energy cost to an economic *stimulus.*

When governments consider all of the risks, the potential benefits to be enjoyed by energy-efficient societies that rely increasingly on their own available and inexhaustible environmental energy resources, in locally and regionally distributed applications, become persuasive. Indeed, one can probably say with confidence that it will be those nations that will be the safest, most secure, and economically strongest by the middle of this century. Or, one can state that *the economic and policy risks of inaction in the aggressive adoption of energy efficiency and the renewable energy resources are far greater than any economic risks or impacts of such programs.*

These factors have been a driving force for policy development by the European Union. The EU appears to be doing well in holding firm to greenhouse gas reduction targets, although meeting the emission cuts is proving difficult to some member nations. The EU is already experiencing energy productivity gains, and a steadily increasing share of locally available renewable energy resources in their energy mixes, all in the interest of providing for risk avoidance, price and supply stability, and enhanced job production and other economic benefits throughout Europe. Many members of the EU continue to recognize that, in order to realize these benefits, strong financial incentive policies, coupled with firm national goals, are still needed to pull the renewable energy resources along so they can compete on the (unevenly subsidized) playing field with conventional energy resources.

If the “external” costs of the impacts of developing and using conventional energy resources are taken into account, and if “risk adjusted portfolio management” is adopted for energy resources, whereby the future price uncertainties of conventional energy resources are factored into a net present evaluation of long-term costs, a good argument can be made to governments that several of the renewable energy resources are *already* less costly on a net present value basis, and far more beneficial to societies and economies, than the conventional energy resources. Energy efficiency measures that save enormous amounts of money are still waiting to be adopted world wide, and renewable energy technology applications have scarcely begun to tap into their full potential. Yet both turn costs for fuels into support for new jobs and more robust economies while, at the same time, dramatically reducing the climate risks to all nations *as a bonus, at no extra cost.*

"There is nothing more difficult to plan, no more dangerous to manage, than the creation of a new system. For the creator has the enmity of all who would profit by the preservation of the old system and merely lukewarm defenders in those who gain by the new one." Machiavelli, 1513

The Renewable Energy Resources: Characteristics, Status of Development, and Potential

Bioenergy

Biomass is the result of the photosynthetic conversion of solar energy and carbon dioxide into the chemical and physical components of plant material. These, then, become storage mechanisms, enabling that solar energy to be transferred through plant and animal ecosystems, humans, and industrial systems. The useful work produced by the conversion of biomass is therefore still "solar powered". This is true whether the biomass was produced over a 500 million year period, and heated and compressed by geologic processes to become fossil fuels, or whether newly grown plant material is used to produce "bioenergy". This includes the functioning of human bodies and minds, powered by the stored solar energy released in food consumption. ("Biomass" as used today and in this White Paper does not refer to fossil fuels, but only to material produced by present growth processes on Earth.)

Energy produced in various ways from biomass for societal and industrial use is termed "Bioenergy". Reasonable projections accord the largest share of future renewable energy to bioenergy, justifying its position as the opening renewable energy resource in this White Paper. This is partly because of its great and accessible uses in both developing and industrial nations, and for its multiple values, including direct heating, cooking, and the production of electricity or chemical products. Except for the desert regions of the world (abundantly endowed with direct solar energy) or Arctic and Antarctic regions (abundantly endowed with wind energy), biomass is a resource found worldwide.

While bioenergy has remained critically important to the life support systems of developing nations, and continues in that importance today, in the industrial nations bioenergy as a percentage of national primary energy has actually reduced significantly since the 1800s. For example, 85 % of the primary energy of the United States came from bioenergy in 1860, a figure that had been reduced to 2.5 % by 1973. In 1860 the dominant energy resource for residential use and industrial development of the United States was fuel wood, but by about 1910 it had been supplanted by coal, and later by the addition also of oil and gas. Bioenergy faded from our industrial economies for a time, but it is starting an extremely important resurgence, for a variety of reasons all relevant to the economic development and environmental protection of industrial nations.

Biomass is the only combustible carbon resource that is "carbon neutral". Bioenergy conversion of biomass operates within the Earth's natural carbon cycles, and therefore does not contribute to climate change and greenhouse warming problems. Analysis has shown that the greenhouse warming potential of biomass combustion is lower than that of all of the fossil fuels, including gas, even with carbon sequestering. Analysis has further revealed that, with the sole exception of carbon monoxide, the combustion of biomass produces substantially lower emissions than the combustion of coal.

Energy derived from biomass can offer important benefits for modern industrial societies. For example, the stored solar energy can be released continuously when used as a fuel in vehicles, or for the production of "baseload" electricity. This feature allows bioenergy to serve as an energy "leveler" when used in hybrid systems that also get energy from the intermittent renewable resources – e.g. sun and wind. Ownership of bioenergy plants by operators of the intermittent resources also provides for important economic counterbalances of the revenues from the intermittent resources. It was reported that half of the Germany wind power developers are diversifying into biomass and bioenergy.

Biomass can be mixed with coal to reduce environmental emissions in the production of coal-fired electricity, it can be converted directly to liquid fuels, and it can greatly enhance rural economies

Fig. 5a: Bioenergy from wood refuse and chips
Source: U.S. National Renewable Energy Laboratory (NREL)

Fig. 5b: Community combined heat and power (CHP) plant, fueled by wood chips, for 300 families in Denmark
Photograph by Dr. Donald Aitken

through its production and harvesting. It has been estimated, for example, that tripling U.S. biomass energy use by 2020 could produce US$ 20 billion in new income for farmers and rural areas. And the creation and conversion of biomass to bioenergy, biofuels and bioproducts can be a significant source of new jobs. It has also been estimated that, in the U.S., 66,000 new jobs and US$ 1.8 billion in new income were created from the production of electricity from biomass during the 1980-1990 period, an industry that also attracted US$ 15 billion in new investment capital.

The efficiency of utilization of the bioenergy resource is just as important as the absolute amount of bioenergy that is utilized. Technical efficiency is dramatically enhanced when bioenergy is used in combined heat and power (CHP) applications, whereby the top energy from biomass or biogas combustion is extracted for the production of electricity, and the lower grade heat is used for thermal applications, such as the district heating of buildings. This is also an example of what the Europeans term "cascading" of energy.

The Danish, for example, responded to a new governmental policy to promote CHP at a time in which essentially none of the Danish electricity was produced in CHP systems. In only ten years (by 2000) 40 % of all Danish electricity production had been converted to CHP (along with 18 % more to wind power). Oil burners were bypassed in homes in which the hot water from the new local (and locally owned) district heating plant, using locally-grown feedstocks, such as straw, was piped in.

In 2001 20 % of Finland's energy came from the bioenergy conversion of wood residues and its use in CHP applications. A remarkable example of "cascading" of bioenergy is in Jyväskylä, Finland, where a 165 MW wood-cofired power plant produces about 65 MW of electricity, with the remainder of the thermal energy going first to buildings, and then, at even lower output temperatures, to greenhouses to promote food production in the cold climate at that 61 degree North latitude. Analysis has verified that the natural replenishment of wood in the nearby forests exceeds the extraction rate for the plant.

Economic, environmental and social considerations are leading biopower production into new, more efficient technologies, such as gasification, with the biogas then used in integrated gas combined cycles (IGCC) systems. Finland has produced the world's pioneering biomass gasification plant, which has been operational for over six years. A governmental subsidy program has helped India to install multi-megawatts total of small gasifier internal combustion engines (ICE).

Brazil continues to be the world leader in the production of Ethanol fuel from biomass (sugar cane), but the U.S. ethanol production (from corn), at about 70 % of that of Brazil, may soon catch up as a result of governmental requirements (Clean Air Act) for cleaner-burning (higher oxygen content) fuel mixtures. The European Union, which is promoting the energy efficiency of diesel engines, is the world leader in biodiesel production (from oil seeds), also leading to cleaner burning engines and a reduction of contamination from accidental spills. Expenditures both for fuels and for emission control devices that would otherwise have gone for energy resources imported from outside the region or country are instead diverted to the creation of employment and the enhancement of local and regional economies.

The current bioenergy resource potential is significantly greater than present use, offering an attractive opportunity for new governmental incentives and policy initiatives to increase the economically and environmentally beneficial uses of this resource, without concern that these programs would be resource limited. Aggressive governmental programs to tap into the advantages of bioenergy will also help to set future societal priorities and reduce some technical and social uncertainties, hence assuring that bioenergy can continue to meet its potential for world economies well beyond the renewable energy transition.

(This White Paper will demonstrate that this is true for all of the renewable energy resources.)

With all of this promising economic and environmental potential, where does bioenergy stand at present, and where could it be with more vigorous governmental support? Three recent estimates put the present global primary energy derived from biomass at about 46 Exajoules (EJ), with 85 % of that in "traditional" uses (firewood, dung), and 15 % in more industrial uses, such as fuel, combined heat and power (CHP), and electricity. Put in perspective, the world primary energy use for the year 2000 was about 417 EJ, so 11 % of world primary energy use at present is derived from bioenergy. This is about 18 % of an estimated world bioenergy resource potential of about 250 EJ at present.

To what extent could bioenergy serve as a significant contributor to a renewable energy transition? The sources of biomass material for bioenergy conversion are from wood or forest residues, agricultural crop residues, energy crops from surplus cropland or from degraded land, and waste from animals or humans, including the uniquely human energy resource of municipal solid waste. While the future technical potential of bioenergy resources can be estimated with some degree of confidence, there are a combination of uncertainties in the multiple ways in which bioenergy resources can be gathered or developed, and uncertainties about future societal policies and priorities, that will profoundly affect the actual extent of this renewable energy resource.

For example, the greatest potential for future bioenergy resources is expected to come from production on surplus agricultural land. But whether there is any "surplus" land depends on the way agriculture is conducted in the future (that is, whether it requires high chemical and energy inputs, or progressively e-volves toward more sustainable meth-ods with low environmentally degrading inputs), and on the competition for food. The latter depends both on world popu-lation growth and on world average diet. These variables can lead to a range of projections that vary from significant land available for bioenergy crops to no land at all.

Careful recent analyses have been made to try and determine, under conservative-ly optimistic but also realistic assump-tions, the world bioenergy potential that could be achieved by 2050. An average estimate of about 450 EJ (10.8 Gtoe) is emerging, although, as suggested above, this could go from zero to over twice this amount. *Remarkably, this untapped bioenergy potential is more than present total world primary energy.*

Major worldwide bioenergy goals are being set, and governments are suppor-ting new bioenergy activities. A recent estimate suggests that the biopower generation alone in Europe could grow to 55,000 MW (55GW) by 2020.

And a recently released "Vision for Bio-energy and Bio-based Products in the United States" sets goals for 2020 of 5 % of U.S. electricity and industrial heat demand from bioenergy, 20 % of all transportation fuels from biofuels, and for bio-based products to represent 25 % of U.S. chemical commodities.

New biopower plants in the 30 MW to 40 MW range have been announced for Australia and Thailand. The United Kingdom is examining new biomass crop plantations and forest residue resources for CHP applications. The Finnish government in 2002 raised in-vestment subsidies for bioenergy by 40 %, opening the way for small-scale biofuel-fired CHP plants to be profitable. This has the secondary benefit of en-hancing the profitability of sawmills as their energy costs are stabilized.

For bioenergy – or any of the renewable energy resources, for that matter – to make meaningful contributions to the renewable energy transition, and beyond, requires considerably greater efficiencies in energy end-use utilization than today. A large absolute contribution of bioener-gy to a huge world energy appetite might be relatively small, whereas that same amount could be highly significant to an efficient world. *Government policy toward both bioenergy and energy effi-ciency will be driven by the expected significance and economic and environ-mental benefits of the results.*

The actual percentage of world primary energy demand in 2050 that 450 EJ of bioenergy might meet depends therefore on assumptions for world energy growth over the next 50 years. One scenario would have 450 EJ of bioenergy be 15 % of the requirement in a world in which global primary energy demand over the next 50 years has increased 500 % above today's values. The vision of this White Paper is of a renewable energy transition that leads to over 50 % of world primary energy from renewable energy by 2050, which suggests that, perhaps at a minimum, bioenergy might produce about one-third of that require-ment.

Bioenergy development, as well as all of the other renewable energy resources, will also accelerate when many of the "costs" are recognized to be "economic benefits", contributing to the economy, rather than just taking away. In bioener-gy this is certainly true, for example in the development of new jobs to enhan-ce rural and farming communities. A 1992 analysis showed that already by then 66,000 jobs in the U.S. were being supported by income from the wood and biomass industries, and that the potential could be as high as 284,000 new jobs by 2010 if energy crops and

Fig. 6a: A farmer planting an energy tree plantation.
Source: NREL

Fig. 6b: Community combined heat and power (CHP) plant, fueled by waste straw grown in the near vicinity, for 300 families in Denmark
Photograph by Dr. Donald Aitken

advanced technologies are commercialized in the U.S. Most of these jobs would be in rural areas. They would also provide sufficient extra income to help farmers to keep their lands.

Bioenergy also works within the Earth's carbon balance (e.g. avoiding future carbon taxes), and can contribute to the maintenance of biodiversity by offering near-urban ecosystems suitable for some species of birds and wildlife. When all such advantages are quantified on a regional, state or country level, and when energy "costs" are viewed from the overall balance of governmental priorities and societal benefits, bioenergy and the other renewable energy resources are much more economic than traditional and narrow energy cost analyses still seem to suggest.

Geothermal energy

Humans have always wanted to be comfortable, and have always been clever in their use of natural resources, so it is no surprise that archaeological evidence suggests that for possibly 10,000 years Native Americans enjoyed the benefits of natural hot springs. It is well known that these benefits were also exploited by the Greeks and Romans 2000 years ago. The world's first geothermal district heating system was constructed in Chaudes-Aigues, France in the 14th century, a system that continues to operate today.

Minerals were extracted from geothermal waters starting in 1175, and chemicals from the waters in the early 1900s, both leading to new industries in the area of Larderello, Italy, subsequently shown to be the hottest geothermal spot of the entire European continent. Prince Ginori Conti created the world's first electricity from geothermal steam on July 15, 1904, in Larderello. The world's first geothermal power plant, a 250 kW_e plant, was subsequently built, also in Larderello, in 1913, and by 1914 it was providing electrical power to chemical plants and many villages in the Tuscany region of Italy. Today the Larderello geothermal field produces 400 MW of electrical energy.

Because fossil fuels were already the "new" thing, there was a lull of 45 years before new geothermal power plants were built, first in New Zealand in 1958, then experimentally in Mexico in 1959, followed by the beginning of the development of the geothermal resource in the Geysers area just north of San Francisco, USA, in 1960. While geothermal energy resources are not available to all nations, 67 nations are now using geothermal energy, with geothermal electric power production in 23 nations, so it is at least a pervasive, if not uniformly available, resource. Following bioenergy it is presently the second largest non-hydro renewable energy resource worldwide, so it is being presented as the second resource in this White Paper.

But is it "sustainable"? The Geysers, still the world's largest single geothermal electric power generation site, was

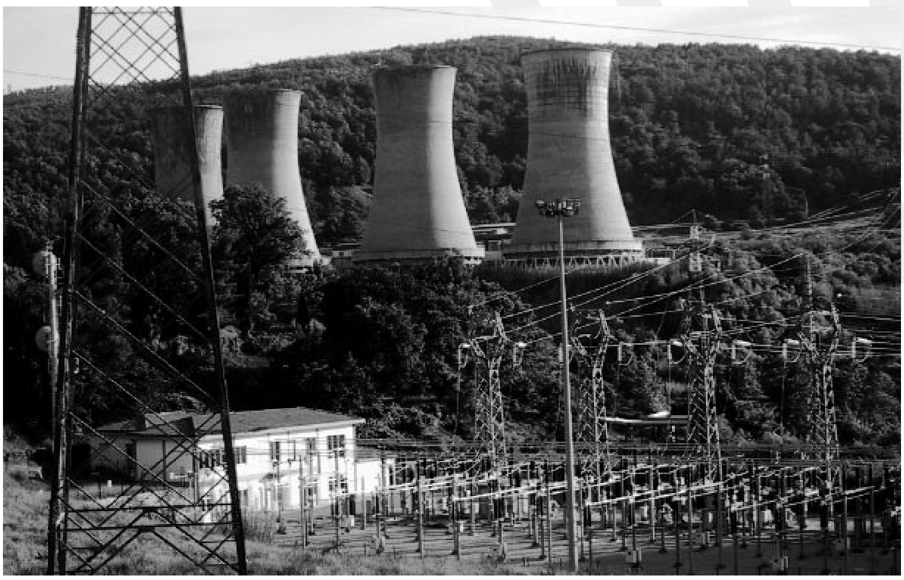


Fig. 7: Where world geothermal power production first started, Larderello, Italy. Site of the first experiment to use geothermal steam to produce electricity, on July 15, 1904, then site of the world's first geothermal powerplant, 250 kW_e, in 1914. Larderello, located on the hottest geothermal spot in all of Europe, today produces about 400 MW net of geothermal electric power.
Photograph by Dr. Donald Aitken

rapidly built up to 2,000 MW of power plants, which subsequently tapped the steam wells at a rate faster than they could be replenished by water flowing to the geothermal heat sources. This forced a reduction of power production to just under 1000MW.

This has, however, also produced a very useful synergy, in which 340 L/s (5,400 gpm) of treated wastewater is soon to be pumped 48 km from the city of Santa Rosa to the geothermal fields and reinjected into the underlying aquifer. The Lake County effluent recycling project is already on line, and adding 70 MW back into the system. The extra energy produced from the additional steam resulting from the water injection is greater than the energy needed to pump the wastewater, so that two benefits are achieved simultaneously: waste water disposal and enhanced geothermal power production. It is a moneymaking opportunity both for the city and for the geothermal developers.

Geothermal energy can provide economically beneficial energy to many countries of the world. It produces little to no pollutants, while contributing to energy self-sufficiency of cities, regions and nations. The 95 % availability factor for geothermal electric power generation can enhance the value of portfolios of several of the intermittent renewable energy resources. Geothermal energy can directly contribute to the creation of new jobs, industries, and enhanced local and regional economic activity. It is incumbent on governments where geothermal resources are available to offer incentives to promote and accelerate the application of geothermal energy.

Nevertheless, the important lesson learned from the experience at the Geysers is that while geothermal energy is renewable, it is only *sustainable* when the extraction of the heat energy is in equilibrium with the rate of replenishment of the resource. It has been shown that for hot water and steam sources this occurs sufficiently rapidly to produce truly sustainable geothermal power opportunities, provided that the resource is *proven* in amount and sustainability *before* development, and then not over extracted. Extraction of geothermal energy from near-surface magma heat, as on the island of Hawaii or in Iceland, is most probably also a *"sustainable"* resource on the time scale of human societies. But for the production of power from the heat energy of hot rocks much farther below the surface the replenishment of the geothermal heat extracted from the rock may occur very slowly, and hence may be *"depletable"* on the time scale of human societies.

So where does geothermal energy stand today, and what is the potential for its expansion in the future that would warrant serious governmental policy and financial support? Geothermal energy is used both *directly,* as a resource of useful heat, and for *electrical power generation.* With regard to the latter, the latest estimate is 8,000 megawatts (MW_e) of geothermal electric power capacity worldwide in 2002, producing 50,000 gigawatt hours (GWh_e) of energy per year, primarily as base-load power, to provide electrical service to 60 million people, mostly living in the developing nations. This saves 12.5 million tonnes of fuel oil per year (Mtoe).

The direct worldwide use of geothermal energy was estimated for 2002 to be 15,200 MW_t, delivering 53,000 GWh_t/yr. This saves an additional 15.5 Mtoe per year. The end-uses for the direct use of geothermal energy are extremely diverse, including space heating, domestic water and pool heating, geothermal heat pumps, greenhouse heating, aquaculture pond and raceway heating, agricultural drying, snow melting, absorption cycle air conditioning, and a number of other smaller uses. The greatest single use is for space heating, which absorbs about 37 % of the direct geothermal energy worldwide.

The greatest share of world geothermal electrical energy generation (GWh_e/yr) is in the Americas (North, Central and South), collectively with 47.4 % or the worldwide total energy production, followed by Asia (including Turkey) at 35.5 %, and Europe at 11.7 %. The largest proportional use of direct geothermal energy is in Asia (including Turkey), at 45.9 % of the world total, followed by Europe at 35.5 % and the Americas at 13.7 %.

The size of the geothermal resource is huge. A U.S. Department of Energy estimate is that the thermal energy in the upper ten kilometers of the Earth's crust is *50,000 times the energy of all known oil and gas resources in the world.* Another estimate has it that the geothermal energy potential for the western United States alone is fourteen times the proven and unproven U.S. coal reserves. Reasonable projections suggest that at least a 10 % per year growth in geothermal energy applications should occur through 2010, which would lead to 20,100 MW_e and 39,250 MW_t of geothermal power worldwide by 2010. Other projections suggest that between 35,000 and 72,000 MW of electrical generation capacity could be installed using today's technology, the higher figure representing over 8 % of total world electricity production.

The Philippines has the largest proportion of geothermal-produced electrical energy in its portfolio at 27 % (2002) of national electrical energy use. It is the ambition of the Philippines to become the number one user of geothermal electrical energy. It has been reported, however, that thirty-nine countries could be 100 % geothermal powered, with four more at 50 %, five more at 20 %, and eight more at 10 %, demonstrating that geothermal energy can be a major resource for at least 58 countries.

It is not necessary to have a geothermal energy potential that could provide a major percentage of overall national energy consumption in order for geothermal energy to be economically beneficial. In Hawaii, the geothermal energy is concentrated on the "Big Island" (Hawaii), while the population center is on the island of Oahu. The production of hydrogen from electricity produced by geothermal energy is about to be undertaken on Hawaii as well as in Iceland, heralding a model in which hydrogen becomes the geothermal energy "carrier" transported from remote source locations to population centers and for multiple fueled end-uses. And geothermal energy where available even in modest amounts, can, along with bioenergy, provide a resource to help "level" a portfolio with large amounts of intermittent resources (sun and wind).

The geothermal industry creates jobs in all aspects of geothermal energy prospecting, development, and application. Geothermal facilities produce lease fees, taxes, and production royalties to local governments. The end uses of geothermal energy produce more jobs, industries, and revenues. The geothermal industry in the U.S., the world's largest, is a US$ 1.5 billion per year industry. Over the next 20 years geothermal energy could become a US$ 20 billion to US$ 40 billion worldwide industry.

Wind power and intermittent renewable energy resources

Energy and power from the wind

Wind Energy is solar energy once removed. The energy to move air masses comes from the unequal solar heating of the atmosphere and the Earth's surface, resulting in unequal air pressure distributions. Nature's attempts to redress these inequalities produces the great flows of air, from local micro levels to massive global levels. Some of the thermal energy of the sun is thereby converted to the kinetic energy of the air. Giant blades turned by the winds spin powerful generators, converting the wind's energy into electricity. The power density of a 40 kmh wind (sweeping through one square meter of intercepted area) is equivalent to the power density of the bright sun (about 1,000 watts/m^2). The total energy carried by the winds on the Earth, therefore, is huge. The energy that can be extracted from winds accessible to human development is also huge.

Over 60,000 utility-scale wind turbines are now operating in 45 countries, as well as in 27 States in the United States, with total installed global wind power capacity exceeding 32,000 MW (32 GW) by the end of 2002. Wind-electric generation by the 12,000 MW of installed wind-electric capacity in world-leading Germany produced about 20 billion kWh (20 TWh) at the end of 2002 to meet 4.7 % of Germany's national electricity needs, while 20 % of Danish electricity now comes from wind-electric generation. The Schleswig-Holstein area of Germany had already surpassed its 2010 target of 25 % of the area's electrical energy needs from wind power by June 2003, with 26 % of the region's electricity now from wind power. This low-cost and readily available renewable energy resource, which is growing at a 32 % annual rate, has led to a rate of installation of new wind projects around the world for both 2001 and 2002 valued at about US$ 7 billion per year, with renewed acceleration of growth expected for 2003. The price of wind-produced electricity is now competitive with new coal-fired power plants, and should continue to drop until it is the least expensive of all of the new electricity-producing resources.

The wind industry is creating significant new economic opportunities. A realistic world target for wind-electric installations in 2007 is 110 GW, representing US$ 100 billion in investments, and equaling the installed capacity of all U.S. nuclear power plants. By 2007 wind-power installations could also represent 24 % of all new world bulk power installations. By one estimate the wind industry could be worth US$ 25 billion a year by 2010, with over US$ 130 billion in cumulative installed system value.

The Danish wind turbine manufacturer Vestas has, since 1979, built over 11,000 wind turbines that are installed in 40 different countries. It is a major source of in-country jobs and export income for the country. It has been estimated that the 12,000 MW of wind energy installed in Germany by the end of 2002 has created 42,000 permanent jobs – one job for every 285 kW of installed capacity. And it has been noted that much of the support for wind development in Spain has come from the "bottom up", supported by regional governments wishing to build new factories and to create new jobs.

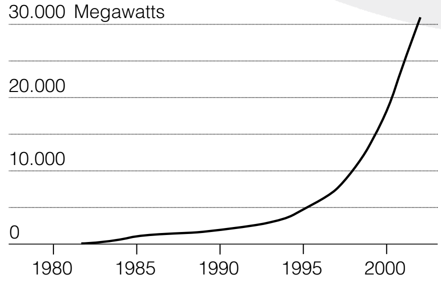


Fig. 8: The dramatic growth in world installed wind capacity, from 1980 through 2002.
The recent growth rate of 32 %/year could lead to an installed capacity of 110,000MW (110GW) at the end of the next five years.
Source: Worldwatch Institute, updated by Earth Policy Institute from BTM Consult, AWEA, EWEA, Wind Power Monthly

The wind turbines that are seen on farms and fields throughout Europe, the U.S., and India are proving to be windfalls for the rural economies. Contrary to the frequent assertion of the coal industry lobby that wind development "takes" massive amounts of land, wind development is fully compatible with farming and ranching activities. Wind turbines placed on a farm or ranch might account for only 1 % of actual land taken out of agricultural production for the turbines, or only 5 % when allowing for access roads. This slight loss of agricultural use is greatly offset, however, by economic benefits accruing to the landowner.

For example, a three-turbine farmer-owned and financed wind development in a good wind regime, with 750 kW turbines, could net the farmer US$ 40,000 per year while simultaneously paying off the construction loan in 10 years, leaving a net income in excess of US$ 100,000 per year after that. Even the revenue from leasing the space for the turbines to developers can double the farmer's or rancher's per-acre income, adding an income source that is oblivious to droughts and fluctuating commodity prices. This income can make the difference between a small farmer having to sell his property or being able to continue farming.

The wind resource is not, and will not be, a limit to the development of wind energy worldwide. Experience has shown that goals for wind-electric installations that have previously seemed to be ambitious are being easily met, and are consequently being revised upwards for future years. Utility experience has demonstrated that major percentage penetrations of wind power systems are practical. Billions of dollars of new industries, and thousands of new jobs, are being created for the benefit of the countries capitalizing on this globally-available resource. Costs for wind-electric power are now in the range for wind energy to be able to compete with fossil fuel-based power production (and certainly below the costs of nuclear power). Nevertheless, governmental policies, firm governmental goals, and governmental incentives are necessary to provide assurance to the financial community so that they will continue to invest in the expansion of the wind industry, and to capture the additional unquantified societal benefits of reliable, sustainable, clean and locally-produced power.

The wind resource and its economic benefits are available regardless of economic status of the country. India is presently 5th in total wind power applications, with 1,702 MW installed by the end of 2002, and might have a total developable resource of 45,000 MW. The Ministry of Non-Conventional Energy Sources (MNES) in India encourages wind as a means to diversify India's energy economy and to begin to wean India from oil, natural gas and coal.

Factories have been constructed in India that enable up to 70 % of the components of the turbines to be made locally, and the entire system assembled and installed, with local labor, producing important new jobs in a job-thirsty country, and routing energy revenue through the local economies. Ownership of locally-placed wind turbines also addresses the poor reliability of India's electrical infrastructure, adding value for factories or businesses, a factor in the development of locally-owned "clusters" of privately owned generators in India, rather than big-business or utility owned wind farms.

Estimates of wind power and energy potential have recently been revised to allow for the new wind turbine technologies that operate more efficiently in lower wind regimes and are placed at greater heights above the ground, to take into account the rapid growth in size of wind turbines (the world average size of new turbines exceeded 1MW in 2002), and to include the most rapidly developing application – off shore installations.

One result of this reassessment is that, far more than just meeting all U.S. electric generation requirements, wind power could provide for *all* U.S. energy needs. Other estimates suggest that wind power could, in the future, meet *all* of the electricity needs of the *world* and perhaps even all *energy* needs of the world.

Even if these estimates prove to be overly optimistic, a goal of 12 % of the world's electricity demand from wind by 2020 (equivalent to 20 % of the world's 2002 use of electricity) appears to be realistically within reach. (This would be about one and one-quarter million MW of installed capacity, producing a little over 3 billion megawatt-hours of energy each year.) The European Union's goal of 20 % of Europe's electricity demand to be met by wind energy in 2020 is also well within reach. This development scenario for wind energy would be consistent with the historical pace of development of hydroelectric and nuclear energy.

It is important to realize, however, that the 32,000 MW of nameplate wind capacity installed worldwide at the end of 2002 was 0.4 % of world electricity supply. If projections suggesting 177,000 MW by 2012 are realized, that might still only be about 2 % of world electricity supply, but the growth is exponential, so that the 2020 targets remain both reasonable and feasible.

Achieving high penetrations of energy from wind and other intermittent renewable energy sources

Experience gained to date in countries and areas with significant shares of wind resources in their energy mix shows that intermittently available energy resources within the present frameworks and operations of existing utility grids can meet at least 20 % of electrical energy requirements. Areas in Denmark, with a countrywide average of 20 % of its electrical energy from wind power, gain at times 100 % of their electric energy from regional networks of wind turbines.
The Schleswig-Holstein area of Germany has achieved an average penetration of 29 % of the area's electrical energy needs from wind power. *The international targets for wind development by 2020 are therefore realistically and economically achievable within the presently installed utility infrastructure.*

Wind and radiant solar energy resources are meteorological phenomena that are fairly well predictable within a 24-hour lead-time, which should normally be sufficient to plan for and facilitate adjustments to the energy flows in the grid. The larger the geographic scale of the renewable energy interconnections through a regional transmission grid, the more likely that a low wind resource in one region will be off-set by wind availability in another, or that low wind resource availability at any one time and place could be offset by a simultaneous high solar resource from a different area (provided that the region or country has exploited the opportunity to develop and interconnect a diversity of complementary renewable energy resources).
Regional and international transmission grids to allow for the import and export of renewable electricity across different climate regions will therefore facilitate greater penetrations of the intermittent environmental energy resources. Such multi-country grids are being seriously considered to support a high renewable energy penetration throughout Europe and Scandinavia.

The ability to increase the penetration of energy from intermittent resources into the utility grids beyond the readily accessible figure of about 20 % will require additional technical and political features. For example, the availability of a stable electrical "backbone", such as Denmark enjoys in that country's transmission line interconnection with Germany, has enabled greater penetration of Danish wind energy resources into the grid, demonstrating that international cooperation across national boundaries can enhance renewable energy development. The reliability of such a "backbone" can also draw to a considerable extent on the "baseload" renewable energy resources, such as hydroelectricity, bioenergy and geothermal, where they are available. Hydroelectric energy, for example, is already widely available and quite conveniently adjustable in output over a short time scale. Converting the hydroelectric resource from baseload to "intermittency-leveling", in systems with high penetrations of wind and solar energy, could enhance both the reliability and renewable resource capacity potential of the total electrical grid.

These stable locally available load-leveling energy resources can sometimes also work in synergy with other national energy efficiency goals, such as the conversion of 40 % of the nation's combustion sources of electrical energy in Denmark during the 1990s to combined heat and power (CHP). Many of these new CHP systems are small, local bioenergy plants using biomass fuel from nearby fields. This not only puts the waste heat to useful work, greatly increasing the overall efficiency of the combusted fuels, but also provides sources of power that could be regulated locally to balance the production characteristics of local wind turbines or solar-electric "farms". The farmers, biomass plant owners and operators,

Fig. 9a, b: Wind energy developments are compatible with ranching, as shown in Denmark, and farming, as shown in the U.S. Income from wind developments on ranch and farmlands are important new sources of rural revenue. *Photographs by Dr. Donald Aitken* and wind turbine or solar system owners and operators, are all paid out of funds that would otherwise have gone to the purchase of electrical energy powered by imported fuels.

Nevertheless, in the future energy storage mechanisms will also have to be developed and adopted. At present serious work is being done on a number of energy storage technologies, such as capacitors, batteries and fuel cells, springs, flywheels, compressed air, or pumped storage of water. For example, a UK "flow battery" has been constructed with a capacity of 120 MWh, and a maximum rated power output of 15 MW. Discharge can be in minutes or hours (limited by the maximum power delivery rate), and can be cycled indefinitely. Advances in all of the other potential storage technologies are also being made.

The synergy between hydrogen development and the application of the renewable energy technologies will be significant. Hydrogen, a clean energy when burned, will be produced by clean energy resources. And the energy from those clean resources will be converted to fuel for on-demand clean energy applications, fully decoupled from renewable energy source fluctuations. The economic and societal values of both the hydrogen and the renewable energy resources will be enhanced by that synergy. The parallel renewable energy and hydrogen transitions will be mutually supportive.

A few notes about the hydrogen transition

The most likely long term candidate for energy storage from the intermittent renewable energy sources will be hydrogen, which can convert electricity derived from renewable energy into a fuel, for its development will also be supported by its potential for transforming transportation and stationary energy systems worldwide. Remote sources of renewable energy in areas of attractive wind, solar or geothermal energy potential can become hydrogen factories. The transportation of that hydrogen for use in local, distributed fuel cells (which are also CHP devices) will then allow the original renewable energy to be delivered as power and heat on demand, and where needed.

The renewable energy transition, however, does not need to wait for further major new developments in other technologies. Widespread and large-scale application of energy storage technologies will not be needed until after 2020, and perhaps not until 2030. The development of hydrogen fuel and applications will proceed independently of the renewable energy transition, pulled by the attractive economic benefits of the hydrogen transition, and pushed by aggressive government programs, so that by then the hydrogen technology and infrastructure can be expected to be sufficiently ready to support higher penetration levels of the intermittent renewable energy resources.

The corollary of this argument, though, is that the environmental success of the hydrogen transition will depend entirely on the utilization of renewable energy resources instead of the conventional energy sources to produce the hydrogen. This was emphasized by Romano Prodi, President of the European Commission, in a speech in June, 2003: "It is our declared goal of achieving a step-by-step shift towards a fully integrated hydrogen economy, based on renewable energy, by the middle of the century." (Source: Renewable Energy World, July/August, 2003.)

Direct use of the sun's energy

Overview

The indirect uses of solar energy, such as hydroelectric, wind power, and bioenergy, together with the non-solar environmental energy resource, geothermal, produce energy that presently dwarfs the combined outputs of all direct applications of radiant solar energy, and will continue to do so for perhaps two more decades. But the value of renewable energy resources in future societal portfolios is not measured just by the kilowatt-hours that are produced. The great economic advantages of many of the uses of solar energy in direct end-use and distributed utility applications, the great security value of many of those applications, the high value-added economic benefits of several of the solar energy technologies and their related new industries, the availability of radiant solar energy resources where the other resources are not also present (e.g. deserts, areas with little wind, etc.), and the importance of developing a diverse "portfolio" of renewable energy resources to provide for system stability and resource reliability, all support the critical importance of direct solar energy applications and governmental policies to accelerate those applications.

The energy from the sun can be used directly to heat or light buildings, to heat pools for the affluent or communities, or to provide domestic hot water to meet basic thermal and hygienic requirements for the rich and poor alike, in both developed and developing nations. The sun's radiant energy can also directly provide very hot water or steam for industrial processes, heat fluids through concentration to temperatures sufficient to produce electricity in thermal-electric generators or to run heat engines directly, and produce electricity through the photovoltaic effect.

The radiant energy from the sun can be used directly to enhance public safety, to bring light and the refrigeration of food and medicine to the 1.8 billion people of the world without electricity, and to provide communications to all regions of the world. It can also be used to produce fresh water from the seas, to pump water and power irrigation systems, and to detoxify contaminated waters, addressing perhaps the world's most critical needs for clean water to drink and to grow food. It can even be used to cook food with solar box cookers, replacing the constant wood foraging that mostly falls on the shoulders of women, and which also denudes ecosystems and contaminates the air in poor shelters.

It is this diversity of opportunities that makes solar energy such an attractive option for so many applications and with critically important potential for all cultures, regions, economies and peoples of the world.

Of course, these applications only produce energy during daylight hours, and work better where there is more solar insolation, both of which are often mentioned as serious limitations to the usefulness of solar energy. But with proper design and choice of materials, solar energy that enters buildings during the day can keep those buildings warm and comfortable through the night, while well insulated water tanks can store solar heated water for use at all times of the day or night. People are most commonly at work during daytime hours when carefully shaded daylighting can replace the electricity demand and heat output of artificial lighting, and daylighting of buildings works well even when it is cloudy. Businesses most commonly need industrial process heat during the daytime, and the major demand for electricity is during daylight hours.

It is today public policy and political leadership, rather than either technology or economics, that are required to move the widespread application of solar energy technologies and methodologies forward. The technologies and economics will all improve with time, but they are sufficiently advanced at present to allow for major penetrations of solar energy into the mainstream energy and societal infrastructures. And significant goals can be now set with confidence for major percentage improvements in energy efficiency and increases in solar and renewable energy applications for the next 50 years, at which time the world should be receiving over 50 % of all energy needs from locally available environmental resources, with most of these being from direct and indirect uses of solar energy. There are no resource limitations to this scenario.

As a result, the *effectiveness* of solar energy production is a matter of its ability to meet the needs of the users, rather than only related to the time of its collection. This is also true with regard to the coincidence of radiant solar energy to the needs of the electrical grids, which tend to peak in the afternoons, especially on hot, sunny days, so the "capacity factor", or output on a 24-hour average, of solar energy systems, has little economic meaning. The *effective capacity factor* of solar electric energy production, that is, the availability of solar electric energy produced when it is needed, can sometimes exceed 80 %, or even 90 %, and is often 3 times the physical "capacity factor", while other solar applications, such as water, pool and space heating, can deliver their value by the heat collected during the day and stored in the water or building, over a 24-hour period.

Human behavior can also influence the *effective capacity factor* of solar energy systems. Washing clothes and bathing in the evening maximizes the benefit of water heated by the sun during the day.

Fig. 10a, b: Solar energy in all of its diversity. The house, located in Boston, Massachusetts (designed by Solar Design Associates) features energy-efficient design, passive solar space heating, daylighting, active solar space heating, solar water heating, and solar electricity, all integrated to produce a "zero net energy" home. But equally important is the use of solar energy to bring the basic essentials, such as fresh water, light, and medicines, to developing nations, represented by the PV-powered fresh water pumping in India shown on the right.
Fig. 10b: Photograph by Dr. Donald Aitken

Similarly, in Denmark it was shown that people with PV systems alter their behavior to maximize the use of PV electricity when it is being produced. In California (USA), time-of-use metering of net-metered PV systems gives economic advantage to just the opposite behavior, in which the sale of PV-electricity back into the grid during peak times is maximized by minimal electricity use in the building during those times, when the return to the producer can be as high as 30 US cents/kWh. Low-cost electricity is then purchased by the customer during the non-daylight hours. Since most of the buildings are residential, they are often unoccupied during the day anyway, when the owners are at work.

The annual solar resource is surprisingly uniform, within a factor of about two, throughout almost all of the populated regions of the world. The lower end of this resource availability would be an economic death knell if solar were only feasible in desert climates, but the extraordinary applications of photovoltaic energy technology in Germany (at latitudes parallel to southern Canada) and Japan, the significant solar water heating applications in Germany and Austria, and passive solar and daylighting applications in Finland and Alaska, demonstrate that economically attractive applications of solar energy are not limited to just the sunniest climates. It is a *sufficient* resource almost worldwide.

Productive R&D programs, supported both by industry and by governments, are continuing to advance the technologies, and address areas, such as energy storage, to further the economic benefits and value of the application of solar energy. But in the meantime, houses and buildings are *now* ready to make use of direct solar energy applications, and, as presented earlier in this White Paper, electricity grids are now well positioned to allow for major penetrations of the intermittent renewable electric energy sources.

Passive solar heating and daylighting of buildings

In general, in the industrial nations, from 35 % to 40 % of total national primary use of energy is consumed in buildings, a figure which approaches 50 % when taking into account the energy costs of building materials and the infrastructure to serve buildings. A recent analysis of energy use in buildings revealed that, when fairly including all energy costs in and related to buildings, the U.S. buildings sector accounts for 48 % of primary energy consumption, 46 % of all CO_2 emissions, and is the fastest growing source of energy consumption and emissions.

In Europe, 30 % of national energy use is for space and water heating alone, representing 75 % of total building energy use. In the United States 37 % of all primary energy is used in buildings, and 2/3 of all of the electricity used *in the country* is used in buildings, with up to half of that directly or indirectly resulting from artificial lighting and the thermal impacts of those fixtures. Buildings can account for one-third of a nation's greenhouse gas emissions, and one-third of a nation's production of waste.

From a thermodynamic standpoint, letting the sun shine into buildings in the winter to heat them, and letting diffused daylight enter the building to displace electric lighting, while providing for careful summer shading and interior glare control, are both the most efficient and least costly forms of the direct use of solar energy. Such simple concepts are rooted in prehistoric structures. Early Native Americans, for example, provided for year-round comfort in harsh environments with natural heating, cooling and ventilation designs.

Early Greek and Roman architects adapted the principles of natural energy design to their homes and cities. Socrates encouraged the use of what today is called "passive solar" design in homes, praising the value of letting the low winter sun penetrate the south side of buildings, and the benefit of being able to shade out the high summer sun.

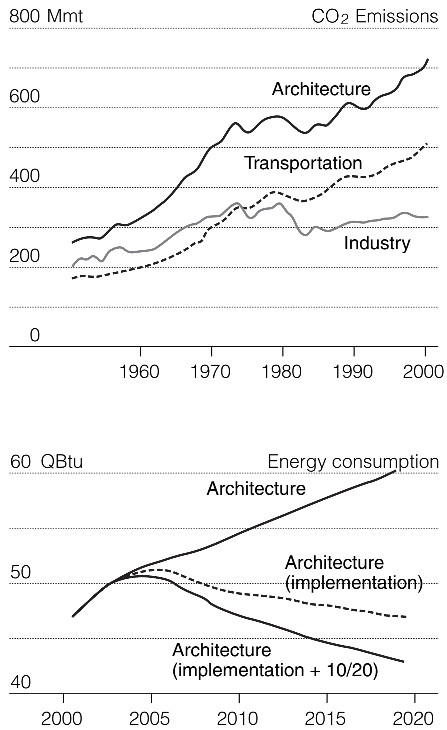


Fig. 11a, b: In the U.S., "architecture", which includes all residential and commercial sectors, along with the portion of the industrial sector containing buildings and building materials, is the largest single energy user (at 48 % of primary energy), as well as the largest, and fastest growing, emitter of CO_2. Aggressive but totally achievable (and affordable) changes in buildings efficiency policy nationwide could lead to a reduction in building energy use, shown as the "implementation" trajectory in the lower graph. If the Union of Concerned Scientist's "Clean Energy Blueprint" is also adopted (10 % of U.S. electricity from renewables by 2015 and 20 % by 2025) the energy impact of buildings in the U.S. could be further reduced as shown in the "implementation + 10/20 portion" of the graph. *Source: Edward Mazria, SOLAR TODAY, May/June, 2003, 48-51*

Vitruvius took these principles further into what is today called “climate responsive” design, noting that different climates require different designs for comfort. The great European cathedrals of the middle of the last Millennium used daylight in spectacular fashion to illuminate the interiors. Office buildings constructed in great cities to almost the end of the 19th century had to rely on careful daylighting design and natural ventilation for illumination and comfort.

These same techniques are available today, with *enormous* worldwide potential to reduce the energy and climate impacts of buildings on a short time scale. This is aided by lessons learned from important programs, like the passive solar and daylighting tasks of the IEA (International Energy Agency), and by important advances in building materials, specularly selective glazings, insulation, and lighting technologies and controls, along with ever more user-friendly computer simulation tools to help designers achieve the best result.

Data are mounting that demonstrate conclusively enhancements of human performance in daylit buildings, with direct economic benefits that greatly multiply the energy-efficiency “paybacks”. Office worker productivity and job satisfaction have been shown to be improved in daylit buildings, resulting in very large “bottom line” benefits for the employers. Increases of up to 15 % in sales in daylit shopping areas and stores are leading to changes in design approaches to these commercial establishments. And up to 25 % improvements in learning rate and test scores of children in daylit classrooms are being recorded in careful statistical research.

All of these measured results demonstrate significant societal values that go well beyond the energy and climate reduction potentials of such “sustainable” building designs. One can argue that expenditures to reap these economic benefits justify the energy-efficient and daylighting designs on their own merits, so that *the reduced energy use and emissions of greenhouse gases from such buildings are “free” benefits.* The integrated design of “climate-responsive” buildings through “whole building” design methods enables major cost-savings in actual construction, normally yielding 30 % to 50 % improvement in energy efficiency of new buildings at an average of less than 2 % added construction cost, and sometimes at no extra cost. Simple cost paybacks are in the range from immediate to a maximum of five years.

> *After efficiency in all areas, the most accessible, least cost, and economically beneficial starting point for any national or local energy policy aimed at reducing the use of conventional energy resources and lowering the production of greenhouse gases is with buildings. This includes upgrading existing buildings, and designing all new residential and commercial buildings for maximum energy efficiency and the optimal use of locally available environmental resources for light and comfort. Billions of US dollar equivalents can be diverted in this way out of unnecessary expenditures for building energy and lighting into productive economic uses, such as creating new jobs, or supporting education and health. And billions more can be earned as a direct result of the improved performance of occupants and users of those same buildings and schools.*

Fig. 12a, b: The Real Goods Solar Living Center, a retail store in Hopland, California, USA (designed by Van der Ryn Architects). A complete “bioclimatic” design, the building features passive solar heating, daylighting, natural ventilation and cooling, PV electricity and native landscaping. Energy savings compared to a conventional design in the Hopland climate are 90 %. In-store sales are 50 % higher than projected because the interior daylighting and comfort are so good.

Photographs by Dr. Donald Aitken

Solar water and space heating

Solar water heating is hardly a new technology, but even with the rapid growth presently being experienced in Europe, Israel and China it still falls short of its potential. Gas-fired and electric water heaters are convenient and technically simple, but by using high grade and high temperature fossil-fueled or electric energy to heat water almost all of the thermodynamic "work" potential of those energy resources is wasted, potential which could be put to much more productive economic use. And for many in developing nations, solar water heating in simple passive tank-type units is the only affordable source of hot water for washing and bathing.

It is to the benefit of all economies to promote and accelerate solar water heating on a large scale. The overall economic benefit to societies of solar water heating justifies serious promotional and incentive programs by governments. Serious long-range goals for the application of solar domestic water and space heating systems need to be established by all governments, totaling worldwide at least several hundred million square meters of new solar water heating systems by 2010. Governments will need to provide supportive political framework conditions for this to be accomplished.

Although hot water in the home does not produce jobs and does not power industries, the fuel now being used to heat that water certainly could. And shortages are already foreseen for gas-fired electrical energy production. When that electricity is used for water heating, it is a particularly wasteful use of natural gas, since it takes twice as much gas for a unit of heat in the water when the gas is burned in a power plant to produce electricity than it does if the gas is burned directly in the water heater. But gas-fired water heating also wastes all of the potential chemical benefits of natural gas, which could otherwise have high value-added applications.

It is a far better investment for society to let the sun provide a major share of the heat for the water, in order to recover the economic benefits of the displaced gas resources. The water is still reliably heated, but with a much lower proportion of conventional energy required. The solar-displaced gas is returned to power other more important elements of the economy. The money that would have been spent for fuels to heat water becomes money spent instead, for example, on jobs to produce, install and maintain the solar water heaters, and those jobs also enhance the strength of local economies. The value to society of solar water heating, therefore, is far greater than simple cost "payback" calculations would suggest. And solar water heating can make a significant contribution to the meeting of targets for the reduction of CO_2 emissions, a social obligation not governed by simple cost payback considerations.

Solar water heating today is a fully mature technology. About 12.3 million m² of solar water heaters had been installed in the EU member countries by the end of 2002, with the annual rate of installation at close to 1.5 million m² per year in 2001, but down to 1.2 million m² in 2002. About 60 % of these, however, are in just three countries – Germany (with over 50 % of the EU sales of solar water heaters), Greece and Austria – which have the best-developed markets. Cyprus, with over 50 % of its Mediterranean hotels and 92 % of all homes having solar water heating, leads the world in terms of square meters of solar water heater installed per capita, at 0.8 m² per person. In continental Europe, Greece leads this measure of public acceptance at 0.26 m² per capita, followed by Austria at 0.20 m² per person, and then, in order, Denmark, Germany and Switzerland. The overall EU average at the end of 2002 was 0.26 m² per person.

The European Union has set a goal of 100 million m² of solar collectors installed by 2010 in Austria, Belgium, Britain, Denmark, France, Germany, Greece, Italy, the Netherlands, and Spain, which would require an annual rate of growth of over 35 % (referenced to the year 2000). The present European growth rate would produce about 80 million m², so the EU goal is for an even more ambitious installation rate. Still, these figures pale in comparison with an estimated EU countrywide potential of 1.4 billion m², which could generate 683 TWh of thermal energy per year.

The increasing popularity of solar water heating for "active" space heating in Germany, Austria and Switzerland, as well as serious considerations being given to solar district heating, as pioneered in Sweden, can help to drive up the sales of this technology. So can City ordinances, such as the one adopted in 1999 and implemented in 2000 in Barcelona that requires solar systems to be used to deliver at least 60 % of the hot water for homes and businesses. Within 18 months the solar thermal collector area in Barcelona increased 750 %, to 14,000 m². This city requirement is being introduced in Madrid and

Fig. 13a: Solar Water Heating in China.
Source: Li Hua, RENEWABLE ENERGY WORLD, July/August, 2002, p. 105

Fig. 13b: Solar water and space heating in Kathmandu, Nepal.
Photograph by Dr. Donald Aitken

Seville and other areas. And in order to revitalize a stagnating solar water heating industry, the German government agreed in February, 2003, to raise the incentives for solar water heating systems from 92 Euros to 125 Euros per square meter of collector surface, which has noticeably improved the 2003 Germany market.

The European figures (and population) pale in comparison with China, which had 26 million m^2 of solar water heaters installed by the end of 2000, and 1,000 manufacturers of solar water heating components and systems by the end of 2001. The Chinese government goal is for 65 million m^2 of solar water heaters by 2005. It has been speculated that, if homebuilding continues according to Chinese government goals, and there is even a modest use of solar water heating in those new homes, China could reach 3 billion m^2 per year by 2010. This is driven by the lack of availability of gas for water heating, so that solar water heating competes with electric water heating, and is the *cheaper alternative.*

Solar thermal electric energy generation

When solar energy is concentrated by reflecting surfaces, the energy density can be dramatically increased. This enables high temperatures to be achieved in fluids in "receivers" that can then be transferred to generate electricity in thermal-electric generators. This technology, generically referred to as "CSP" for "Concentrating Solar Power", falls into three categories: parabolic troughs, power towers, and heat engines.

Parabolic troughs are long parabolic-shaped mirrors mounted in rows to heat the fluid that flows in energy-collecting receiver pipes maintained along their lines of focus by adjustment of the position of either the mirror or the receiver. The hot fluid is then flashed to steam in a conventional (but low-temperature) turbine generator. Power towers represent fields of mirrors ("Heliostats") that focus their energy onto the top of a tower, where it is collected and sent by very high temperature fluid to the thermal power generator.

Heat engines (Stirling engines) direct solar energy with very highly focused heliostats onto a piston, which then drives an engine through air expansion. Each Stirling engine is directly mounted onto its own three-axis tracking heliostat. The technical target for the Stirling engines is to be maintenance-free for 50,000 to 100,000 hours of operation.

Dish-Stirling engine/heliostat combinations have been mounted and tested, with development moving well on the way toward the anticipated 25 kW_e modular units that could be so valuable in the future. (Until recently, a Dish-Stirling engine/heliostat combination held the world record for efficiency in converting solar energy to electricity of about 35 %.) More work remains to be done to assure the targeted long life and reliability of the engines, and to produce low-cost heliostats. The technical barriers appear to be quite within range of economic solutions.

The world's largest set of solar-electric generators, 354 MW of parabolic trough technology in three fields, continues to operate in the United States in southern California. The first units were installed in the early 1980's, and the completed system has been in full operation for the last 17 years. The Harper Lake plant is 160 MW, and the Kramer Junction plant is 150 MW. Much has been learned from these significant projects, and they have proven the practicality and reliability of this solar thermal electric technology. Similarly, the 10 MW power tower,

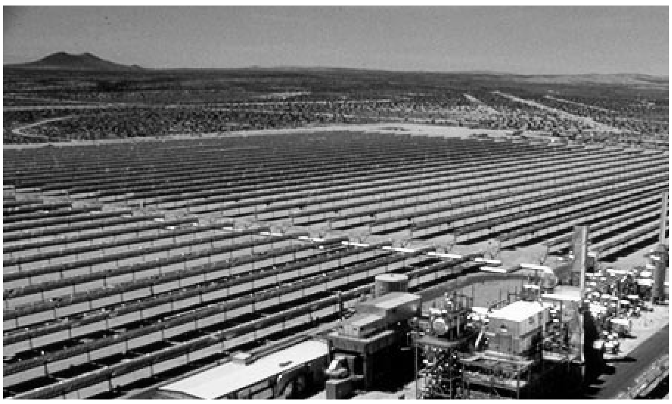


Fig. 14a: A portion of the world's largest solar thermal-electric generator (on the left), part of the 354 MW system in California. Shown also is the embedded gas-fired generator for 25 % "hybrid" operation, to level the output of the solar system, demonstrating a useful synergy between renewable energy and conventional energy production.

Fig. 14b: Solar I, the 10MW "power tower" in southern California.
Source Fig. 14a: NREL
Source Fig. 14b: U.S.D.O.E.

also in southern California, Solar I and II (the second representing a rebuild of Solar I to accommodate the introduction of liquid sodium heat transfer and storage into the project), met all research objectives for performance and reliability.

Even though CSP plants can be built today which produce energy at about half of the present cost for photovoltaic-produced electricity, the CSP technologies in particular have been slow to be extrapolated to larger scale and world markets. The slow acceptance of CSP has been due to various financial and institutional barriers. The primary one is that building a solar plant is like building a fossil fuel plant and paying for 30 years worth of fuel all at the same time. Consequently, the plant must be fully financed up front, with an attractive return to investors. In addition, the physical plant is generally taxed, while fuels for conventional power plants are not. This unfairly penalizes the solar plants for the "free" fuel.

Concentrating Solar Power (CSP) is a valuable component of the renewable energy portfolios of countries with a sufficient solar resource, and warrants inclusion in governmental policies aimed at stimulating and developing balanced resource portfolios of the renewable energy technologies. A worldwide goal of 100,000 MW of installed CSP technology for 2025 is an achievable goal with potentially significant long-term benefits.

These barriers can be addressed by providing subsidized low-cost loans, redressing the tax inequities, providing energy production incentives, and continuing to support R&D that can lead to more efficient reflectors, components and thermal systems. CSP is also extremely sensitive to the solar resource, needing to be built where it is the sunniest and clearest, and most economic when built in systems up to 400 MW in size.

If the barriers are all addressed, and the best physical conditions can be met, projections suggest that, after the installation of a few thousand megawatts of CSP power plants, the costs without subsidies could come down to be competitive with fossil fuels. But in contrast to fossil fuels, CSP plants will provide economic certainty for the 30-year warrantied life of the plant, free of the highly volatile and unpredictable costs and availability of conventional fuels well into the future.

The economics become more attractive and on a shorter time scale when CSP provides solar energy to supplement gas energy in an Integrated Solar Combined Cycle System (ISCCS). The solar energy displaces some of the fuel as well as some of the combustion emissions, improving both the fuel economics and environmental performance, while the marginal cost of the solar components adds proportionately less to the overall cost of the gas-fired system. Smaller and more versatile CSP plant designs are being developed for the 100 kW to 1 MW range, with the application flexibility that this would provide compensating in local benefits for the higher kWh production costs. And storage techniques that are being developed to provide up to the economic optimum of 12 hours of energy storage, which would yield maximum utility for the received solar energy, will also enhance the economics of CSP.

World interest in CSP is picking up, with significant projects planned in many countries, and valuable GEF funding being provided for more. New CSP projects are underway in the U.S. (Nevada) and Spain, and nearly so in Israel and South Africa. GEF funding of US$ 50 million each has been given to Mexico, Egypt, Morocco and India, for CSP projects presently under development. Iran, Algeria and Jordan are considering ISCCS projects. Economic projections suggest the viability of CSP also for Greece, Italy, Portugal, Australia, Brazil, Liberia, Tunisia and China, and a potential for a cumulative world total of over 100,000 MW of CSP electricity generation in place within the next 25 years.

The Nevada 50 MW parabolic trough system is particularly interesting in that it is the direct result of new state governmental policy. The Nevada legislature adopted in 2001 an aggressive renewable portfolio standard (RPS) which will require the State's investor owned utilities to provide 5 % of their energy sales from renewable energy (geothermal, wind, solar and biomass) in 2003, ramping up over the next ten years to 15 % in 2013. In order to promote the development of a "portfolio" of renewable energy resources in a State that already has geothermal power plants and in which wind energy will be competitive, Nevada added an explicit "solar" component to their RPS, in which 5 % of all new renewable energy development must be in the solar energy technologies. This will require about 60 MW of solar-electric generation over the next ten years.

The Nevada utilities elected to build a 50 MW solar thermal parabolic trough power plant, with expansion possibility to 60 MW, as a one-shot response to the solar RPS requirement. The system will be constructed by Duke Power, and is to come online in 2005. The Nevada utilities will buy the power output of the system over a 20-year sales contract period, guaranteeing the income necessary to support the financing of the construction and operation of the system. The system is expected to produce an average of 102.4 thousand MWh each year, enough to meet the 1,000 KWh monthly average needs for 8,400 Nevada homes (large homes in a very hot climate, requiring significant air conditioning).

The experience gained with this new parabolic trough system should help to lead to cost-reducing developments, and the further revival of solar thermal electric systems in the United States, demonstrating the value of government policy in accelerating the development and application of the renewable energy technologies.

Solar photovoltaic electric energy production

The most recognizable solar energy technology today results from the many applications, considerable publicity, and numerous incentive programs in support of solar electricity production by photovoltaic (PV) systems. Even though it is the most expensive of the solar technologies in terms of energy production, it is the most versatile, simplest to install and cheapest to maintain, and provides a highly valued product – electricity – generally at or close to the point of use, avoiding the cost and risk of failure of infrastructure.

PV modules can be used to power telephones or traffic and warning signs, to reduce corrosion in metal bridges, to power water pumps and wells, to provide light and power for remote houses and villages, to refrigerate medicines, to reduce purchased energy in grid-connected homes and commercial establishments, to provide both power and shade in parking lots, to charge electric cars, and for many more applications. A designer can readily specify PV roofing shingles, standing seam roofing with “stick-on” PV, PV shading overhangs, PV curtain wall glazing, and PV skylights. Flat hotel and commercial roofs are being decked over with PV without requiring any roof penetrations and providing for insulation and shading at the same time, producing electricity and reducing the cooling load for the building. The provider of half of the commercial PV rooftop systems in the United States has seen their average system size grow from 94 kW_p in the year 2000 to 260 kW_p in 2002, and to close to 350 kW_p in 2003. This includes several installations of 1 MW or more.

PV systems integrated throughout the grid in a “distributed utility” structure can make it impossible for a terrorist to bring down a city by destroying its energy sources. The convenient and centralized targets of power plants, substations and transmission lines will vanish within cities that produce and distribute their own power on-site. Similarly, a city with distributed energy systems that can be "islanded" from the grid will be shielded from many of the problems caused when a major transmission network collapses, or central power plants suddenly go offline, all of which occurred simultaneously in the Northeastern U.S. in August of 2003 and in Italy in September.

Building-integrated PV systems (BIPV) with modest amounts of storage can provide for continuity of essential governmental and emergency operations, and help to maintain the safety and integrity of the urban infrastructure: street lights and communication links will continue to operate, and essential city and safety services will continue to be available from civic and administration buildings with their own energy systems. *This should be a basic element of security planning for all cities and urban centers in the world.*

PV is an industry that is growing worldwide at an amazing pace. Over 560 MW_p of PV modules were manufactured and sold worldwide in 2002. The average rate of growth of the industry in the beginning of this Millennium has been 36.6 %, representing more than a doubling every two years, and it increased by 44 % in 2002. The value of worldwide PV sales in 2002 of about US$ 3.5 billion is projected to grow to more than US$ 27.5 billion in 2012.

Far from settling down on one major type of technology (like VHS beating out Beta in video recorder standards), the PV industry continues to innovate in many ways. The most popular PV technologies are still monocrystalline and polycrystalline (or multicrystalline) silicon cells (93 % of worldwide PV cell sales in 2002), because they are the most efficient, are proven by years of application and operation, and are very stable. Silicon is the most abundant element on the surface of the Earth, and it is non-toxic.

The ability of thin films to be adapted so easily to building materials, such as glass facades and windows, along with the potential for high volume mass production of films on glass or on flexible substrates, is leading to new PV cell compounds that are also being developed and marketed, such as single- or multi-junction amorphous Silicon or mixed-phase microcrystalline silicon, Copper Indium Diselenide ($CuInSe_2$, or CIS) and Cadmium Telluride (CdT). Still, close to 99 % of worldwide solar cell production in 2002 was silicon-based, which supports an apparent emerging trend away from products requiring scarce or toxic materials.

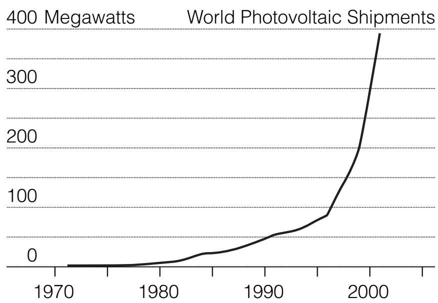


Fig. 15a The dramatic increase in world photovoltaic module shipments. It surpassed 500 MW_p in 2002. *Data source: Paul Maycock.*

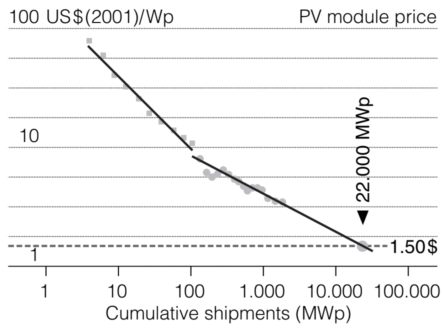


Fig. 15b: PV experience curves for 1976-2001 and projection to a breakeven price of US$ 1.50/W_p, demonstrating the importance of promoting high volume applications.
Slide source: Dr. John Byrne, data by Paul Maycock (2002)

The ability to layer films to capture the full solar spectrum potentially allows thin film solar cells to achieve efficiencies equivalent to the crystalline devices.

And PV is sold by the watt, not by the square meter, so lower-efficiency applications directly applied to convenient building materials with ample surface areas (walls, roofs, glass) can often be the most economic choice. Nevertheless, the reliable and proven crystalline and polycrystalline modules will probably continue to dominate the PV field for the next two decades.

Measuring the value of PV in cost per kWh produced undervalues many of the attributes of this versatile technology. For example, when PV is used to power roadside emergency phones, the cost of the produced energy by the small PV panels on the top of the poles may well be over $ 1/kWh, but the cost of the telephone is US$ 5,000 less than it would be if wires had to be run underground from phone to phone. So the use of PV can often enable a lower overall project cost.

Equally important is the value of PV in meeting some of the most essential needs of humanity. In India, by the end of 2002, 5084 solar PV water pumps had been installed in rural areas, with a total capacity of about 5.55 MW_p. And 2,400 villages and hamlets had been electrified in India with PV. This barely taps into the potential for bringing fresh water and light to the poor and remote populations in India, but it certainly confirms the feasibility and benefits.

Large, ground-mounted central PV powerplants in sunny areas may well become important in the future. Such applications become ever more feasible as the efficiency of PV cells continues to improve. A solar-to-electric energy conversion efficiency of 20 % for large area crystalline silicon cells for module production was reached by a Japanese manufacturer in 2003. A world record efficiency for the conversion of sunlight to electricity of 36.9 % was achieved in 2003 in a compound cell designed to be used in a tracking concentrator. Mirrors are less expensive than solar cells, so such developments should aid in reducing the costs of central-station types of PV powerplants.

The energy potential of such solar applications is huge. In the U.S., for example, a fairly small fraction of the government-owned Nevada Test Site land in Southern Nevada could, in theory, provide enough solar electricity to meet the needs of the entire United States (in quantity – this ignores the difficulty of transporting that energy all the way across the country, but it does illustrate the resource potential).

The most popular application of PV today, however, is on roofs. The world leaders today in rooftop installations are Japan and Germany. In Japan, a generous subsidy from the government since 1994 has promoted this market, while, in Germany, the costs of incentive supports are spread to the whole electrical system customer base through the "feed-in" payments made to the producers of PV electricity. These policies, in turn, enable their own manufacturers to reduce costs by volume sales and to become more competitive in the world market.

The Japan and German policies are also driven by long-range national goals to increase the penetration of renewable energy for its societal and economic benefits. This policy has vaulted Japan into a position as the world's leading manufacturer of PV modules, producing almost half (49.1 %) of the world production in 2002. Just one manufacturer in Japan has outdone all of the other regions of the world in producing 123.07 MW_p of PV in 2002, while a second has announced plans to produce over 100 MW_p annually by 2004. All of Europe produced 135 MW_p (24 %) of the world's PV modules in 2002, while the United States produced 120.6 MW_p (21.5 %), and the rest of the world produced 55 MW_p (9.8 %).

The three most significant national PV programs are the "Residential PV System Dissemination Program" in Japan, the "100,000 Roof Solar Electric Program" in Germany, and the "Million Roofs" solar program in the United States. But while the Japanese and German programs are heavily subsidized by credit or production incentives, to assure that the goals are met, the U.S. program is voluntary. Pledges in the U.S. that exceed one million solar (thermal or electric) systems by 2010 have been announced, but the actual installation of that many is not at all certain. Meanwhile, installations by the

Fig. 16a: A residential solar roof application in Japan. *Source: Photo from Japan Photovoltaic Association*

Fig. 16b: A multifamily building in Freiburg, Germany, using the roof for solar water heating, and the south wall for solar electric energy production.

thousands are continuing in Germany and Japan, as well as in other European countries.

Applications in 2002 for what was to be the final year (2003) of the Japanese program exceeded 32,000 for private housing alone, with a total of 40,000 applications for the year. This brought their "70,000 roofs" program to 117,500! Total Japanese government expenditures on this program over its five fiscal years (1999-2003) have been US$ 739 million. The program is so popular that the government agreed to continue it for 3 more fiscal years (to 2006). This will certainly aid the Japan government's near-term goal of manufacturing 500 MW_p of PV annually, with 250 MW_p for internal consumption and the rest for export. They are also supporting this goal with an FY 2003 investment of US$ 218.6 million for PV R&D and "promotion", which even includes support for "grass roots" activities.

The rate of growth in PV applications in Germany since 1999, driven by the "100,000 roof" program, has been immense. Total installed PV system power in Germany grew from about 68 MW_p in 1999 to 278 MW_p by the end of 2002, producing, in 2002, 190 gigawatt-hours of electricity. By the end of 2002, 55,000 rooftop PV systems had been installed in Germany, with 98 % of those grid-connected. The total power of the accepted applications for PV roofs in 2002 in Germany was over 78 MW_p, up from 60 MW_p just the previous year, and bringing the total installed power just on residential roofs to 200 MW_p. Financial incentives and low-interest loans for FY2003 are expected to continue to support the installation of 95 MW_p more of rooftop systems, but with the support shifting more to production (feed-in) incentives.

The result of these policies is that over 60 % of the PV systems installed in the EU countries were installed in Germany. This is followed by Italy and Switzerland, each with about 10 % or so of Germany's installations. But when taking the population numbers into account, Switzerland actually leads the EU installations at 2.8 W_p per capita, followed by Germany at 2.3, and the Netherlands at 1.1.

It is important to note that the measured average daily energy production from the German rooftop PV systems is about 2.33 kWh/kW_p of installed capacity (averaged over the entire year), scarcely half of the output that can be achieved in the sunnier climates of the world. This demonstrates that the value of aggressive solar energy programs to governments and economies does not require the "best" solar climate but, again, simply a "sufficient" one.

It is appropriate and important for all governments to include firm solar electric energy goals, geared to specific targets for specific years, in their policies. This is more than just encouraging "Renewable Portfolio Standards", for the renewable energy transition will require the development and deployment of the full spectrum of solar energy technologies, not just the least expensive of the renewable energy technologies (e.g. wind). Specific provision to encourage photovoltaic applications and to advance photovoltaic technologies must be part of any renewable energy policy, in order to assure the benefits unique to this technology, and to continue to provide the market pull that will bring the costs down further.

For some time PV has been the low-cost option for many remote and modular applications, needing no further economic justification. But the apparent high cost for urban PV applications has remained a deterrent (again the problem of effectively buying the hardware and the lifetime of energy production all up front). Fortunately, the cost of PV modules and systems continues to reduce dramatically. Factory prices for PV modules are now from US$ 2.00 to US$ 3.00/ watt and complete operational systems can now be installed in the United States for between US$ 5/watt and US$ 7/watt, depending on the size of the systems, without subsidies. Prices for fully installed systems in Japan were at US$ 6.50/W_p in 2002, before the government subsidy, showing a dramatic price decline as a direct result of the government's multi-year buy-down program and the tens of thousands of installed systems that resulted from it.

When subsidies or volume sales and experience, or both, bring the costs to purchasers down to US$ 3.00/watt for fully installed systems, the effective cost of the electricity amortized over 30 years will be from 8 to 12 US cents/kWh, making PV not only fully competitive with utility provided electricity, but probably the cheaper option as future electricity costs from conventional fuels continue to rise. And the cost of that PV-produced electricity will remain fixed for the lifetime of the PV system, yielding at least one cost figure for people and businesses that will not grow in the future. (PV modules are currently warrantied for 20-25 years, but should last for twice that long.)

One forecaster sees these very low cost achievements by the end of this decade, at which point he expects to see the world market reach 10,000 MW_p in annual shipments. An average PV production growth of 25 % from 2000 to 2010 would lead to annual production of 2,500 MW_p by 2010, while an average growth rate of 50 % would lead to annual production of 16,000 MW_p by 2010, so the 10,000 MW_p estimate lies somewhere between these growth rates.

A recently published estimate shows that even if costs are reduced to US$ 1.50 per W_p for the modules and US$ 3.00 per W_p for installed systems by 2010, the PV industry would still need to expend from US$ 25 billion to as high as US$ 114 billion during the 2000-2010 period to support PV factory investment, working capital and end-user financing. Gaining investor confidence to assure these capital investments will therefore be extremely important, potentially greatly aided by long-term government PV-purchase programs along with annually growing and long-term legislated system-wide or country-wide goals for PV applications (e.g. part of a “solar RPS” component). The reward will be enhanced economic activity for the host region or country, more than returning the governmental incentive investments.

For example, a 1992 input-output analysis by the U.S. Department of Energy of the potential economic impact of a new 10 MW_p PV fabrication plant planned for Fairfield, California (near San Francisco) showed that the sum of direct and indirect sales would be about US$ 55 million per year, while adding in the “induced” economic activity related to the location of the plant and its employees and the direct and indirect sales activity could exceed US$ 300 million per year. State and local income taxes could be enhanced by US$ 5 million per year, and local sales tax revenue could be another US$ 3million per year.

Solar photovoltaic technology, in concert with energy efficient and sustainable design of buildings and integrated into the electrical grid, can make a substantial contribution to the energy needs of almost all countries of the world. But the societal value of PV, and hence the worthiness of public support and governmental stimulus, goes well beyond just the kWhs produced by the PV systems. PV in developed and developing nations alike can enhance local employment, strengthen local economies, improve local environments, increase system and infrastructure reliability, and provide for greater security. The PV industry is already a multi-billion dollar new industry, growing worldwide by almost 40 % per year, with opportunities for economic advancement and international marketing competitiveness by those nations, such as Japan and Germany, that make a concerted effort to draw the industry to within their boundaries.

National and Local Factors Supporting the Development and Application of Renewable Energy Technologies

Meeting international greenhouse gas reduction commitments

The major driving force for the expansion of renewable energy applications in countries other than the United States has been national commitments to meet the greenhouse gas reductions adopted in the Kyoto Accord (the Kyoto conference of parties to the Climate Convention in 1997, COP-3). Even without the U.S. participation, the 55 states representing 55 % of the world CO_2 emissions produced by developed nations in 1990, required for formal ratification of the accord, will be reached when Russia signs on.

The European Commission ratified its participation in the Kyoto Accord, and set firm targets, in support of the Accord's objectives, for renewable energy percentages of 12 % EU-wide energy from renewables by 2010, and 22.1 % penetration into the electricity sector by renewables in 2010. This will be policy whether or not the treaty enters into force. Japan has taken the same stand, introducing in 2003 a new "environment tax" to continue to raise the funds necessary to reduce emissions down to their Kyoto Accord levels.

Within this EU-wide goal each EU nation has been assigned a specific carbon-emission reduction target (in percent, compared to 1990 levels), based on their past accomplishments and resource availability as well as their current economic strength. But some EU member states have set longer and more ambitious targets, such as the proposal by the British Prime Minister for a 60 % reduction in UK greenhouse gas emissions by 2050. An 80 % reduction of emissions has been proposed for Germany by 2050, the latter as a consequence of their long-range efficiency and renewable energy policy (more about this below).

Long term carbon reduction goals are powerful long-term drivers for the renewable energy industries, leading to ambitious goals for renewable energy development beyond 2010, such as that of England, for 20 % of its energy from renewable energy by 2020; Scotland, for 40 % of its energy from renewables by 2020; and Germany, for about 40 % of its primary energy and 65 % of its electricity from renewable energy sources by 2050.

The evidence is that, when renewable energy development is accompanied by aggressive energy efficiency goals and programs, the committed reduction of greenhouse gas emissions can be accomplished in the industrial nations at little to no net long-term cost to their economies. On the contrary, a number of studies have shown that short term increases in expenditures will be balanced by long-term energy cost savings, and new efficiency and renewable energy industries and jobs will lead to a flow of new monies throughout society, stimulating all sectors of the economy. Avoidance of greenhouse gas emissions is therefore expected to be a stimulus for net positive economic benefits for countries over the longer term. Renewable energy development and implementation will be a major component of these programs.

Goals are only goals, though, unless *supported by implementing legislation and actions, with sufficient financial backing.* Long-term goals for the reduction of greenhouse gas emissions create a rational framework for governments within which energy supply and efficiency policies and programs may be established and justified, and annual national financial commitments set to implement these goals. *Without these, the goals will not be met.*

Enhancing the productivity of energy expenditures, and the creation of new jobs

The policy rationales for renewable energy applications go well beyond just environmental. The opening language of the "Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001" states:

The Community recognizes the need to promote renewable energy sources as a priority measure given that their exploitation contributes to environmental protection and sustainable development. In addition, this can also create local employment, have a positive impact on social cohesion, contribute to security of supply…

In support of the stimulus of local employment by renewable energy, an analysis by the U.S. Public Interest Research Group calculates that an investment to increase the use of renewable energy in the U.S. to 20 % of the nation's electricity supply would create "three to five times as many jobs as a similar investment in fossil fuel." The U.S. Worldwatch Institute estimated that solar thermal systems would generate from 2 to 2.5 times as many jobs as coal or nuclear. Global employment in the wind industry alone by 1999 was estimated to have contributed directly and indirectly to the creation of 31,000 new jobs, and world applications have doubled since then, creating thousands of additional jobs.

It has been estimated that, over the 12 years (1991-2002) following the Bundestag's 1990 approval of the "Electricity Feed-in Law (EFL)", which gave producers of solar and wind energy in Germany a wholesale price guarantee of 90 % of the retail price of electricity, leading to a 5 % share of German electricity from those technologies in 2002, approximately 40,000 new jobs were created. In contrast, the German nuclear industry, which supplies about

30 % of Germany's energy, employs 38,000 people, suggesting that renewable energy industries are ten times more efficient in producing jobs than the nuclear industry. It has been further estimated that meeting the German target of a 100 % increase in renewable energy (from 6 % to about 12 %) by 2010 could create 25,000 more jobs in all of the renewables.

In the United States, 25,000 new jobs have been created in, by and from the PV industry, which has developed to an annual production and sales in 2002 of 100 MW_p. A U.S. Department of Energy estimate is that this could increase to 68,000 jobs (direct, indirect and induced) by the time the U.S. is producing 480 MW of PV each year. Another recent estimate is for 300,000 jobs in the U.S. PV industry by 2025. These values make the PV industry in the U.S. equivalent at present to major computer industries, such as Dell Computer, or Sun Micro-systems, and it could become as large as General Motors. This is also equivalent to the estimate (284,000 jobs) that would be produced in the biomass power industry in the U.S. when it reaches a level of annual activity of about US$ 6 billion. And it has been estimated that the German long-range energy model presented later in this paper could lead to 250,000 to 350,000 new jobs by 2050.

The economic impacts from the development of new renewable energy sources, and the local application of the technologies, offer important ancillary benefits for societies, not the least of which is enhancement of economic diversity and security, the creation of new jobs, and greater local and national economic productivity of money spent for energy. It is also clear that energy resource policies are appropriate to governments, not the utilities, for the utilities are not in the job-producing business, and governments are.

When new jobs are created, the "economic multiplier" goes into effect, greatly expanding the economic benefits of the direct expenditure on the jobs. For example, a 1992 input-output analysis by the U.S. Department of Energy of the potential economic impact of a new 10 MW_p PV fabrication plant planned for Fairfield, California (near San Francisco) showed that the sum of direct and indirect sales would be about US$ 55million per year. Adding in the "induced" economic activity related to the location of the plant and its employees and the direct and indirect sales activity could exceed US$ 300 million per year, yielding a 500 % multiplier in local and regional economic benefits. State and local income taxes could be enhanced by US$5 million per year, and local sales tax revenue could be another US$ 3 million per year, further increasing the regional benefits.

An input-output analysis by the State Department of Administration in Wisconsin (USA) in 1995 revealed that the impact of the spending of US$ 6 billion by Wisconsin for out-of-state fossil fuel energy resources (coal and oil) was equivalent to sending support for 175,000 jobs out of the State. This represented a significant loss of economic productivity for Wisconsin. That same analysis showed that an alternative scenario for the development of 750 MW of new electric generation capacity within Wisconsin from locally available indigenous resources (mostly biomass), compared to the conventional fossil fuel scenario, would have increased the cost of electricity in the State by about 1 US cent/kWh. This would be more than offset, though, by the benefits to the State economy from the new jobs created by the new local renewable energy industries, which would be equivalent to putting about 2.5 US cents/KWh back into the overall State economy. The higher cost for electricity from the local renewable energy resources would consequently still produce a large *net* benefit for the State's economy. Added up over 30 years of operation, this could yield several *billion* US dollars of *net disposable income* and net gross product to the State.

These kinds of regional economic analyses provide ample justification for the expenditure of State funds, supported by all energy users in the State (through a System Benefits Charge, or SBC – a small surcharge on each kWh sold) to support the higher-cost electricity from locally available resources, because it generates more net money and new jobs for the State. The same arguments hold for the benefits of the feed-in laws of Germany, Spain and Denmark, where the higher costs for electricity created by renewable energy resources is spread over all utility bill payers in the country.

While much of this discussion has centered on the United States and Germany, both wealthy industrial states, the same arguments can be made for the economic efficiency of keeping energy money flowing in the local economy, rather than sent away for imported fuels or electricity, for *all cities, States and countries.* This is of particular meaning for the developing nations, where the creation of jobs is critically important. Every opportunity to convert expenditures for necessities into meaningful employment needs to be exploited. Relying on locally produced energy from local energy resources also contributes greatly to economic security and reliability.

Policies to Accelerate the Application of Renewable Energy Resources

Overview

All of the foregoing considerations provides sufficient justification for serious efforts by governments to provide policy and financial incentives for the accelerated application of the renewable energy resources, and for serious legislated goals for ever-increasing amounts of renewable energy in the primary power and electricity mixes. A myriad of mechanisms and policies to accomplish this have been adopted by different countries, some intended to "push" the applications through laws and binding commitments for percentages of renewable energy in the energy and electricity mixes by certain dates, and some intended to "pull" the technology and applications through funding for R&D and various incentives schemes. These include the following generic policy frameworks and elements:

- National multi-year goals for assured and increasing markets for renewable energy systems, such as Renewable Energy Standards (also called Renewable Portfolio Standards – RPS – in the United States), Renewables Obligation, or the EU Renewables Directive, especially when formulated to support balanced development of a diversity of renewable energy technologies;
- Specific governmental renewable energy "quotas" for city and state renewable energy procurements;
- Production incentives, such as "feed-in" laws, production tax credits (PTC), and net metering;
- System wide surcharges, or system benefits charges (SBC), to support financial incentive payments, R&D and public interest programs;
- Financing mechanisms, such as bonds, low-interest loans, tax credits and accelerated depreciation, and green power sales;
- Credit trading mechanisms, such as Renewable Energy Credits (RECs) or carbon reduction credits, to enhance the value of renewable energy, to increase the market access to those energy sources, and to value the environmental benefits of renewables;
- Removal of procedural, institutional and economic barriers, and facilitation of the integration of renewable energy resources into grids and societal infrastructure;
- Consistent regulatory treatment, uniform codes and standards, and simplified and standardized interconnection agreements;
- Economic balancing mechanisms, such as pollution or carbon taxes;
- "Leveling the playing field" by redressing the continuing inequities in public subsidies of energy technologies and R&D, in which the fossil fuels and nuclear power continue to receive the largest share of support.

Within these generic policies, though, are many sub-options that must be carefully selected to insure the best program for any particular technology appropriate to country and locale.
For example, in the promotion of solar thermal energy in Europe, the following listing of potential funding instruments and incentive systems has recently been put forth:

- Fiscal measures
  - tax relief, exemption, write off
  - low-interest credit
  - energy/CO_2 taxes
  - reduced VAT
  - exceptional write-offs
- Investment support
  - national
  - regional
  - local
  - energy suppliers
  - special foundationseco-bonus for sustainable building
  - support for bottom-up initiatives
- Regulations
  - exceptions from building regulations
  - energy and building standards
  - obligations
- Organizational measures
  - centralized information centers
  - DIY groups
  - free/cheap advice
  - long-term agreements
  - approved financing plans
- Other
  - project financing
  - exceptional financing
  - approved funding policy
  - information/solar campaigns
  - demonstrations projects
  - solar prices

Source: ASTIG 2001, quoted from Marion Schoenherr in REFOCUS, Mar/Apr 2003, p. 33

There have been varying degrees of success by the various policies, and much has been learned. And although some policies (e.g. the "electricity feed-in laws" of Germany, Denmark and Spain) appear to have been much more effective in leading to significant expansion of renewable energy production than others that have been tried and then rejected (e.g. the "quota" policy of the UK), the European Commission is allowing the diversity of mechanisms in member states to advance renewable energy to continue through 2005 before attempting to implement a Community framework.

A recent report by the Lawrence Berkeley National Laboratory (Berkeley, California, USA, as reported in REFOCUS, Jan/Feb. 2003) examined case studies in the United States of the impacts and effectiveness of "clean energy funds" on utility scale projects. The mechanisms examined included up-front grants (actual support for projects), forgivable loans (to support early expenses, and paid back only if the project is completed), production incentives (payments per kWh of actual production), power-purchase agreements, and renewable portfolio standards. They concluded that long-term power purchase agreements (at least ten years) for the outputs of renewable energy systems are critical, but investor confidence to support those agreements comes *first* from stable long term policies, such as renewable energy standards, supplemented, but to a lesser extent, by green power markets.

Working capital requirements for the renewable energy industries must also be met. An analysis of PV financing recently concluded that 80 % to 90 % of the PV market would need to have financial assistance for the end-user. It was also reported that end-user credit with reasonable terms can increase the market demand for PV by *ten times.* Similarly, in developing nations the acquisition of PV systems could increase from a 2 %-5 % level without financing to possibly 50 % with financing. Not to be ignored are also the capital requirements for factories and sales distribution, including inventory and receivables. All of these can be facilitated by governmental buy-downs of interest rates, along with tax and investment incentives, to facilitate the infusion of funds into the renewable energy industries.

City policies can lead the way

Countrywide programs with the support of national governments for the development of renewables will clearly have the greatest impacts. But often creative initiatives can be generated by progressive-minded city governments, leading to major advances in public perception of new technologies. This seems to be particularly true with regard to PV technologies, since so many of the building-integrated grid-connected PV systems can be applied within cities, and the distributed benefits from those PV applications can be especially advantageous for enhancing the reliability and safety of city services and infrastructures.

City governments can take responsibility for the decisions of their utilities in at least two ways. Certainly the simplest is a city-owned utility, or a “municipal” utility, as it is termed in the United States. While the municipal utility is governed by an elected Board of Directors, they are citizens of the city, and the workings of the utility are integrated into the financial and administrative structures of the city. Utility resource decisions that can benefit other city economic sectors, such as the production of new jobs, can be made. But cities that are served by large, investor-owned utilities can also take it upon themselves to finance energy efficiency and renewable energy applications that provide favorable environmental, economic and reliability benefits to the city.

Cities can be major players in stimulating the market and lowering costs for the renewable energy resources for all countries of the world. And because they are cities, where people live and work, public confidence and support for the renewable energy transition can be spurred. City programs can be replicated throughout the world, tailored to local cultures, economies, and renewable resources.

An intermediate framework that is just now raising interest in the United States, because of recent enabling legislation, is "Community Aggregation". This permits all utility customers in a city, or in multiple cooperating cities, to write power purchase agreements as one single customer. The contract can be with an energy service provider (ESP), either for lower cost service, or to meet more stringent requirements set by the city for conservation, efficiency and meeting renewable energy standards greater than those imposed on their previous utility service provider. The first of these was the "Cape Cod Agreement", in which 21 towns on Cape Code, (Massachusetts) aggregated and wrote a new and lower-cost contract for electrical energy.

Rural-electric cooperatives, which can either represent individual cities or small regions, are also governed by elected Boards, and are hence answerable to the people they serve. This gives them some leverage in promoting the local economic welfare when they elect to build and own locally-sited renewable energy resources, or support farmer-developed local renewable electricity sources with long-term power purchase contracts.

In the following, three U.S. (California) examples are offered, all of which are large enough to have some influence on the world PV market. The first two are municipal electric utilities, while the third, San Francisco, is a city which does not own its own utility, but which has nevertheless made a major financial commitment to efficiency and PV applications. All three demonstrate the enthusiasm of city residents to participate in a city’s energy future, and in the renewable energy transition, as well as the power of cities to accelerate that transition.

The Sacramento Municipal Utility District

Perhaps the world’s most consistent, famous and exemplary city renewable energy policy has been the PV programs of the Sacramento, California, Municipal

Utility District (SMUD). The new renewable energy programs were initially stimulated by the city's decision to shut down a very expensive and poorly-operating 800 MW nuclear powerplant. That shutdown forced the city to purchase 25 % of its power from the market, leading to several rate increases. A very progressive new SMUD administrator, David Freeman, vowed that within three years SMUD could make up the power shortfall with energy efficiency, become the nation's leading solar utility, and recover the previous low electricity rates.

That promise was fulfilled. SMUD became the *world's* leading solar-electric utility during the latter half of the 90s. Today, the electricity rates in the city, without the nuclear plant and with increased energy efficiency and the solar and other renewable energy sources, are about the same as they would have been if those changes had never been introduced. The lessons learned by the SMUD experience have been presented and praised worldwide.

The SMUD PV program was based on an early vision by the SMUD program officials of the potential of PV nationwide and worldwide. They could foresee 15,000 MW of PV installed in the U.S., and 70,000 MW installed worldwide, by 2020. Simultaneously, they anticipated that with such aggressive installation rates PV costs could be driven down to US$ 3.00/installed watt (realistic AC output rating), including operations and maintenance (O&M) costs, by 2010, and further lowered to US$ 1.50/installed AC watt output by 2020. SMUD officials then set SMUD's own goals for participation in this overall vision: 10 MW of PV within the city by 2003, and 25,000 installed city systems (about 50 MW) by 2010.

The SMUD District conducted a survey, and discovered that 24 % of their customers would be willing to pay more for PV-produced electricity, representing a city PV market potential of over 200 MW. More particularly (and realistically), they found that 14 % of their customers would be willing to pay 15 % more, and 8 % would be willing to pay 30 % more, still representing over 35 MW of potential PV customer base.

By the year 2000 SMUD had installed 650 systems within the city for about 7 MW of new, distributed PV power, including 550 homes, as well as churches, schools, businesses, and parking lots. Their largest city-owned system was a 500 kW array that also provides shading in their hot climate for cars in the County Fairgrounds parking lot.

As the SMUD District launched their PV Pioneer II program in 1999, another survey showed a market potential of 10,000 to 36,000 new customers who wanted to own their own systems, representing an opportunity for between 30 MW and 100 MW of additional PV. Under the PV Pioneer II program SMUD buys down PV system costs of its customers to US$ 3.00/watt, fully installed, representing about a 50 % contribution from SMUD to the customer. On the basis of long-term (5-year) contracts with their suppliers, the aim was to have the SMUD contribution gradually diminish, and to have the actual installed cost of the later Pioneer II systems be reduced to a total of US$ 3.00/watt AC. When US$ 3.00/watt costs for PV are placed on a 30-year home mortgage, this produces PV electricity for those Sacramento customers at from 9 to 12 US cents/kWh, making it fully economic for the home owning customers to opt for the PV installations.

SMUD justified their own expenditures in the start-up of the program by explicitly quantifying not just the value of the electricity produced by the PV, but also the primary and secondary voltage support benefits of PV introduced into the distribution grids, as well as other tangible and real "distributed utility" benefits from PV. And SMUD adopted a policy framework of the "Sustained Orderly Development" of PV systems over the years, a framework in which guaranteed multi-year bulk PV purchases and numbers of new installations would contribute to a reduction in costs. They held their suppliers to this cost-reduction timetable as a condition of signing multi-year contracts.

SMUD's program has not been without setbacks. For example, their primary contracted supplier failed to meet the SMUD purchase needs, forcing the District to purchase replacement PV modules at higher costs. And a few other obstacles appeared that have slowed, but certainly not stopped, their ambitious programs. Nevertheless, well-earned widespread publicity has been lavished on this program, and worldwide awards bestowed on its creators. It is a courageous effort – one city determined to affect the development of a world market and world PV prices.

Los Angeles and San Francisco

Stimulated by the Sacramento precedent, the Los Angeles, California Department of Water and Power, the world's largest municipal utility, now offers up to US$ 5.50/watt cost buydown incentive for PV systems in its territory. This is increased to a US$ 6.00/watt rebate if the PV is manufactured in a plant located within the city limits (because of the economic "multiplier" benefit from locally produced components). In 2002 2.3 MW_p of PV systems were installed. In 2003 Los Angeles reaffirmed its 10 year, US$150 million incentive program for PV. Incentive programs for energy efficiency and "Green Power for a Green LA" purchasing options complement this program.

In 2001 the voters of San Francisco, California, without a municipal utility and dependent on the regional investor-owned utility for its power, approved a US$ 100 million bond issue to serve as a public loan fund to buy down the costs for new energy efficiency projects and the installation of 50-60 MW of new PV electricity within the City. After being shown that neighborhoods within this city, which is famous for its summer fogs, actually have 85 % of the radiant solar energy potential of Phoenix, Arizona, and with the endorsement of business, labor, public health and environmental groups, the San Francisco voters approved the bond measure by a vote of 73 % in favor.

The San Francisco PV and efficiency bond program combines energy savings with the new solar energy applications, so there will be no net new cost to San Francisco taxpayers. It is expected that this will increase reliability of city services and safety, displace fossil-fueled generation that would otherwise have to be constructed to meet growth within this highly-developed and beautiful city, and create new businesses and jobs for the city. Already the cities of San Diego, Denver and New York have contacted San Francisco to understand how they might accomplish the same objectives in their cities.

Procedural requirements will delay the issuance of those bonds for a year or more. But instead of waiting, the city proceeded to fund and construct its first major project on its own, combining an energy efficiency conversion with a 650 kW rooftop PV array on the City's Moscone Convention Center. This will lower the city's energy bill for their convention center by US$ 200,000 per year. Many more projects are to follow.

This is to be followed by the installation of 100 more rooftop PV systems, in order to develop the infrastructure and simplify the city's procedures in preparation for a massive intrusion of PV once the bonds have been issued. These projects are all being developed in a "revenue neutral" way, which will allow the city to recover its costs for these projects.

National policies to promote new renewable energy development

Renewable electricity standards

The policy of setting renewable electricity standards (often in the literature called-Renewable Portfolio Standards, or RPS) is now expected to be the primary policy that drives the development of renewable energy in the United States, and the concept is emerging as fundamental to the assured development of renewable energy worldwide. Every country that sets firm goals for an incrementally increasing percentage of renewable energy that must be introduced into the country's energy mix by certain dates, with intermediate goals for intermediate dates, has in effect set "A Renewable Energy Portfolio Standard" (or a Renewable Energy Obligation, as it is called in the UK). This is now true for the entire European Union and all of its member states.

An adopted renewable electricity standard gives great flexibility to electricity providers. They can elect the least expensive means to meet the standard's time and percentage requirements by generating the renewable electricity themselves, or by purchasing it from someone else, or through buying credits from other providers. The result is the greatest amount of new renewable energy generation at the least cost, and a continuing incentive by renewable energy providers to drive the costs down still further.

Because there are no firm federal targets for renewable energy development in the United States, 13 states (as of August, 2003) have adopted some form of a renewable electricity standard. State-by-state renewable energy programs are extremely important to generate momentum and confidence in the new renewable energy industries. But individual state programs become poor substitutes for a nationwide policy if an entire country is to make meaningful progress toward the renewable energy transition.

Adopting firm goals for incremental year-by-year renewable energy development provides the framework for confident multi-year investments in new businesses, stimulating the economy while also assuring that the goals will be met. But the renewable electricity standard is also a simple policy to implement, one which uses market forces within the spectrum of renewable energy resources to meet the scheduled applications goals at the lowest renewables market cost. Only those renewable technologies that are market ready and proven can compete.

Developing a balanced renewable energy portfolio

Merely setting goals, or adopting multi-year standards, however, does not assure anything. Government-sponsored implementation programs and further incentives are absolutely necessary to back-up those goals. Germany's feed-in laws, for example (see the next section of this White Paper), are aimed at achieving specific long-range goals for the addition of renewable energy to the country's energy mix. The funding mechanism of the feed-in law appears to be providing sufficient incentive for the market to respond with enough new renewables to meet the German goals. But German government spending programs and loans form the basis for this.

One of the strengths of the renewable energy standard can also be one of its potential weaknesses. The very free market method the adopted standard inures can preclude development of any but the least cost renewable energy options. At current prices, wind is the big winner, while solar, geothermal and bioenergy cannot compete equally.

Yet, ultimately, the final, great, world energy transition will require utility-scale applications of all renewable energy technologies, to promote large-volume production and large-scale applications that can drive prices down, and to enhance system reliability through resource diversity. A multi-year renewable electricity standard works in the best long-term interests of any country, therefore, when it is included within a package of policy instruments intended to support the development of a balanced portfolio of renewable energy technologies tailored to the state of development of each of those technologies.

The renewable energy standard can be "fixed" to accommodate a diversity of renewable energy resources. For example, the standard can be divided into "tiers", such as introduced in both the States of Arizona and Nevada when they specified that a certain percentage of the renewable electricity resources developed to satisfy the state RPS standards must be from the solar energy technologies. This complicates the application of the standard somewhat, but has been shown to be quite feasible.

The standard itself can be somewhat "self-fixing" if a large enough standard is adopted. Analytical appraisals by the Union of Concerned Scientists demonstrated that, with a standard of 10 % or less, a modest amount of geothermal energy and landfill gas will still be able to compete. But if the standard is as high as 20 % by 2020, a considerable amount of new biomass also becomes competitive, and near the end of the forecast period so do the solar technologies. It is important, though, to promote the parallel development of the full spectrum of renewable energy resources early on, rather than waiting for market dynamics to open the competitive door, for governments and utilities will want to know that the technologies are mature and reliable, and markets and electricity customers will be rewarded if prices have already been brought down by vigorous incentive programs.

A "package" of policies can include direct financial incentives for those technologies that cannot yet compete to fulfill the standard's obligations. For example, in the United States, major rebates for installed photovoltaic systems are offered by many states and municipal utilities, even in those states that have adopted aggressive renewable portfolio standards. In California, the state with the largest renewable electricity standard in the U.S. (20 % renewable electricity by 2017), a rebate of US$ 4.00/ watt is provided in 2003 for PV systems of up to 30 kW_p in size. (The incentive amount will gradually be reduced for new systems installed in subsequent years, to track expected reductions in PV system costs.) Larger commercial-sized PV systems received a significant multi-year financial boost when the California Public Utilities Commission authorized US$ 125 million per year for five years (2004-2009) to support incentives of US$ 4.50 per W_p for systems over 30 kW_p in size. And commercial establishments in California can also add federal solar and investment tax credits to the utility credit, allowing them to install PV systems that will deliver electricity for around 9 US cents/kWh, a fully competitive price, and one that won't increase over the years.

The conclusion reached here, and again and again in this White Paper, is that governments need to develop energy efficiency and renewable energy policies that are appropriate to the specific countries, and that maximize the overall economic "value" of balanced and diverse policy portfolios. The largest segment of a renewable electricity standard might well be delivered by the most competitive or least costly form of renewable electricity production, but supplementary incentive programs add diversity to pure market responses, increase the development of new industries and the creation of new jobs, and provide greater assurance of reliability in a future, integrated energy network.

Similarly, Japan's "70,000 (PV) Roofs" program, reliably announced and funded from 1994 to the present (and extended to 2006) led to 424 MW_p of installed systems (117,500 roofs) by the end of 2002, dropping the cost to the consumer by 41 % from 1995 to a 2002 price of US$ 6.50/W_p. As the price dropped, so did the government subsidy, from 50 % in 1994 to 15 % in 2002, but the popularity of the program continued to grow.

The PV electricity cost is still higher than electricity delivered wholesale into grids by wind systems, but the PV output cost is the customer cost, since building-integrated PV systems do not require expenditures for transmission and distribution. The result is that, within a package of governmental incentives, PV electricity can indeed compete with lower-cost but remote resources developed under a national set of renewable electricity standards. In California, as well as in Germany and other European countries, this has led to major new commercial rooftop and parking lot PV systems.

A market-indicator showing the benefit of the California state government PV incentives is that the provider of half of the commercial PV rooftop systems in the United States, including most of those in California, has seen their average size for new installed PV systems grow from 94 kW_p in 2000 to 260 kW_p in 2002, and to nearly 350 kW_p in 2003, with several installations of 1 MW_p each.

Geothermal and biomass-derived energy are also more expensive than wind systems today. But both can be used in combined heat and power applications (CHP), with potential end-use efficiencies for the conversion of energy to useful work of up to 80 %. Twice the usable energy outputs, even at twice the cost of other competing heat-only or electricity-only energy resources, can still be cost-effective. And both geothermal energy and bioenergy can provide stable supply "backbones" with very high capacity values to enhance the useful cost effectiveness of the intermittent renewable energy resources, thereby further increasing the value of the renewable energy network.

In similar fashion, solar thermal-electric energy generation is today also more expensive than the conventional forms of electric energy production. But the often near-coincidence of the electrical output from solar plants with the expensive peaking power periods of local and regional grids can greatly enhance the value of the produced electricity. In California, for example, homes and businesses with time-of-use meters pay about 30 US cents/kWh during the 12:00 - 6:00 PM peak demand times, a period almost completely spanned by the available solar energy resource. All of the renewable electric generation options can beat this price! And even greater economic benefit and reliability can be produced with hybrid solar/gas-fired power plants, assuring that the peak demand schedules will always be met, while (as revealed by the California solar-thermal electric experience) up to 75 % of the energy can be met by solar energy.

One especially successful policy instrument: "feed-in" tariffs

It is illustrative to examine one quite successful policy application in some detail – the "feed-in" laws (a fixed governmental incentive payment for each kWh produced). The Danish feed-in incentive was the driver for the widespread adoption of wind energy in Denmark. Other countries followed suit.

No single renewable energy support or incentive policy will be able to stand alone in assuring the desired acceleration of renewable energy development. It will always be necessary for governments to formulate a package of policies that provide a combination of goals, incentives, removal of barriers, and further enabling actions, to advance the development of the renewable energy resources.

Germany first instituted "feed-in" financial incentives in 1990, which were subsequently improved in the Renewable Energy Law (EEG) that went into effect on April 1, 2000. Under the EEG, solar generated electricity in Germany is subsidized by a payment of up to 45.7 Euro cents/kWh, to a maximum program total of 1,000 MW_p. The tariff continues to be paid for 20 years, but the payment for new systems diminishes by 5 % per year on the assumption that costs will decline over time. In Spain the tariff for PV power production is 40 Euro cents/ kWh for systems smaller than 5 kW, and 20 Euro cents/kWh for systems up to 25 MW in size. France began in 2002 to offer 15 Euro cents/ kWh for electricity produced by PV.

Similar (but, of course, lower) "feed-in" incentives are offered in Germany for wind energy, as well as for other renewable energy resources. The difference in feed-in incentives is designed to balance the differing financial needs of the various renewable energy resources according to their state of market emergence, so that a true "portfolio" of renewable energy resources is developed. This is an excellent policy that is especially important for the solar energy resources, as they presently produce more expensive power than wind energy.

The EEG in Germany remains flexible, subject to change as experience dictates. For example, in order to redress the advantages of wind systems placed in the windiest regions with the relative disadvantages of those placed in regions of lower wind velocities, the German feed-in incentive for wind production is now dependent on the strength of the wind resource at the site of the turbine.

It appears to be no accident that the adoption of the "feed-in" law policy in Germany, Denmark and Spain has placed those three countries in positions of preeminence in wind and solar energy applications. But the very success of such laws can also lead to unacceptable burdens on government finances. The Germans therefore finance the direct production incentives, as well as accumulate the resources for low-interest loans for renewable energy producing facilities, from surcharges placed on the sale of electricity to all customers (this is called a Systems Benefits Charge, or SBC, in the United States). Spread around this way, the surcharge is a very small percentage of the monthly utility bills. This demonstrates the synergy of having multiple policies, including both guaranteed payments to renewable energy producers and the passing of the financial responsibility onto all energy users of the country through a small surcharge.

This does *not* imply that simply adopting feed-in laws will guarantee a rapid escalation of renewable energy applications. Portugal, Greece and Italy, for example, also adopted feed-in laws, but did not support them sufficiently with other implementing legislation, such as simplifying planning permits, providing low-cost loans, or guaranteeing grid access. As a result, they have not been effective.

The developing nations

Although the importance of the renewable energy transition to developing nations was acknowledged at the beginning of this White Paper, it has focused heavily on policies appropriate to the developed nations. The leadership in the development of the renewable energy technologies and in the large-scale applications that will bring prices down for all nations must necessarily fall on the developed nations. The urgency is therefore for those nations to commit to the renewable energy transition as soon as possible. On the other hand, the developing nations have the opportunity to move directly into the renewable energy transition, skipping many of the large-scale centralized power systems that are now becoming obsolete and dangerously unreliable in the developed countries, and maximizing their energy expenditures for the benefit of the creation of new jobs and local industries.

In this paper it was noted, for example, that China is supporting the development of millions of solar water heaters, stimulated by the lack of natural gas infrastructure and the high cost of electricity. The San Francisco-based Energy Foundation has a Bejing Office and is providing technical and policy expertise to the Chinese Government toward the introduction of energy efficiency and the renewable electric energy sources into China's utilities. There are highly qualified engineers and scientists in China, a huge pool of potential labor, and very serious air-pollution and resulting public health problems caused by fossil fuel use, all of which provide the necessary underpinnings for serious Chinese government policy developments in the application of the renewable energy resources.

China is instituting its first large-scale renewable energy application with a US$ 340 million electrification program to bring PV electricity to the 30 million inhabitants still without electrical power, and putting it all on a fast track. The first 20 MW$_p$ of PV, along with small hydro and PV-diesel and PV-wind hybrids, are to produce village power systems in 1061 villages and to be completed in only 20 months, by the end of 2004. This is to be extended to another 20,000 villages during the 2005 - 2010 period. This will make China a major player in the world PV market, with a program sponsored solely by the Chinese government, but relying for technical and training assistance on a number of international institutions, including the U.S. Department of Energy.

India launched a serious wind-electric program in the 1990s, and is now one of the world leaders in the application of that technology. Even though India imports critical components of their wind systems, they are capable of manufacturing up to 70 % of the components in India and, of course, installing and maintaining the systems with local labor. India has also introduced a few thousand solar-electric water pumps.

Although India has sought to bring centrally-produced electricity to all of its communities and, especially, to its farmers, the electric distribution networks are generally inefficient, unreliable and have huge losses (including major power theft). As with China, India has qualified scientists and engineers, a huge pool of potential labor, poor air quality and dirty sources of coal, again setting the stage for an aggressive turn away from the unproductive centralized systems and toward the new renewable and distributed systems. India is just now considering adopting renewable energy development as a major new and permanent energy "core" policy.

The benefits of the renewable energy transition will accrue to all nations of the world. But it is the governments that can afford to take the first steps that must do so. Governments that can afford aid to the developing nations in the form of renewable energy technologies must provide it. The renewable energy transition must take place everywhere.

The most urgent needs in Africa are access to clean water and detoxification of dirty water to promote public health, and at least a little light in each dwelling, office and school to enhance living quality and productivity and to aid in advancing education. The PV technologies, which are admirably suited to meet these needs and to mitigate the problems of the poor centralized energy systems, are now being applied by the thousands, but they are still only a tiny fraction of Africa's gargantuan need. Africa's countries are mostly struggling to meet more basic needs, and relying on outside countries and agencies to bring renewable energy applications to them

Applications of renewable energy resources in the developing nations can help to meet the most basic of human needs and enhance the quality of life for billions of people. From the sheer numbers of potential applications, millions of small renewable energy systems in developing nations can contribute in major ways to the lowering of costs and the expansion of the renewable energy transition around the world. But, with the possible exception of China and, perhaps soon, also of India, firm long-range national standards and governmental policies in the developing nations are generally not yet evident in forms helpful for discussion in this White Paper. Their lack of financial resources and need for technical and economic assistance from outside often outweighs all else.

It is those governments that can afford these first important steps that are the primary audience of this White Paper, explaining the emphasis on policies appropriate to the developed nations.

Market-based Incentives

Overview

One of the strengths of the renewable electricity standard is that it is market-based, but it depends first on governments adopting and implementing the long-term goals, and regulating and enforcing compliance. Investors see it as a beacon of confidence. But others see it as bad policy, requiring what they think is heavy-handed government intervention in what they feel should be a fully free energy market. Various alternative "market-based" incentive schemes have been introduced for the promotion of renewable energy, partly to satisfy a political philosophy by some legislators who would prefer to see market mechanisms determine winners and losers than to rely on government coercion or incentives. These include Quotas, the "Certificates Trading Model (CTM)", "green power" sales, and the international trading of "green certificates". These have been operating with varying degrees of success (and also failure) in several European countries.

Credit-trading mechanisms and exploitation of the green market should supplement, and be implemented in combination with, the more powerful policy instruments, such as renewable electricity standards and feed-in laws. In this circumstance the trading of renewable energy credits and the financial bonus of the green markets could play a major role in developing and supporting renewable energy markets.

The idea of certificate trading is that support for the renewable energy technologies will come from having two markets, one for the power produced and the second for the value of the certificates generated and traded. That value can either be set by the free market, or, better, supported by governmental policies in which firm targets for carbon emission reduction or renewable energy development have been implemented with explicit requirements and penalties for non-compliance. These targets can be met either by acquiring renewable energy directly, or by developing new on-site renewable energy generation, or by the acquisition of equivalent generation through the purchase of green certificates, e.g. one Renewable Energy Credit (REC) for each MWh of renewable energy generated by the seller of the certificates. This enhances the value of the green energy for the producer, potentially making it more profitable to produce and sell the energy and attracting investors at an earlier stage in the renewable energy market development. And it greatly enhances the potential for the successful fulfillment of national RPS goals.

The difficulty with these schemes has been in the loss of certainty for investors, since they cannot predict market demand or price for certificates, so the renewable energy generators can no longer reliably predict revenue. When the Danish government recently switched from the fixed feed-in tariffs to the CTM, their renewable energy industries came virtually to a halt. And Britain's introduction of the "Renewable Obligation Certificate" (ROC) as part of the April 2002, UK "Renewables Obligation Order", has not, in its first year, been very successful. This is due in part from a disparity between too many sellers and too few buyers, but there are other structural issues emerging as well. Monies that might have gone into the construction of new wind systems, for example, have instead been buried in ROC financial transactions. And different market rules in different countries can cloud the operation of an international certificate trading market.

Emissions credit trading is another potentially important market-based policy option, to "internalize" societal costs of emission impacts. Europe will soon begin carbon emissions trading. So most probably will Canada. And, as with renewable energy policy, several U.S. states are developing their own carbon emissions credit-trading program, in the absence of a national U.S. commitment to targeted greenhouse gas reductions. A similar emissions credit trading system is well established in the United States for various environmental pollutants (SO_2, NO_x, and VOCs). But emissions trading is just one option, and cannot be implemented simultaneously with renewable energy credit (REC) trading, or green power sales, to avoid "double counting" of renewables benefits.

Emissions and credit trading policies do not on their own carry the economic power to accelerate and maintain renewable energy markets. Successes, such as in Texas (USA), where wind energy has been installed at a rate well in excess of intermediate goals toward a 2010 RPS, have resulted from the successful combination of certificate trading (RECs) within a policy framed by a significant RPS, and aided by the U.S. Production Tax Credit (PTC – equivalent in concept to the European feed-in incentives).

The REC portion of the Texas policy covers about 10% of the cost of the wind power generation, but that fairly small increment can often be an important contribution toward paying the marginal extra costs of green power production. That also depends on the value of the RECs. In cases, such as the UK, the "ROC" (Renewable Obligation Certificates) has been introduced in such a way as to yield prices of up to US$ 100 per MWh. So the rules by which the RECs (or ROCs) are introduced have a profound affect on their ultimate market value.

"Green" power surcharges and certificate sales can also be very effective in tapping into the interest of those members of the public seeking to participate directly in affecting better energy policies, and hence raising at least some funds for renewable energy from outside the normal governmental revenue stream. The potential total financial resources to be gained by this approach are limited to that segment of customers who are willing to pay more, for social returns (estimated, for example, to be a maximum of 8 % of utility customers in the United States). And high marketing costs for green power products can eat up much of the green premium before it can be invested in new or existing renewable energy production. The result is that economies of scale probably cannot be reached with funds raised from green power surcharges alone, so that this would remain a relatively expensive way to raise support for renewable energy.

The Netherlands green power program, however, offers an example of the kind of framework in which green power marketing can be raised to a level of significance. In that country, 1.3 million customers, or 20 % of the population, had, by the end of 2003, signed up for green power, exceeding the capacity of Netherlands producers to deliver, and hence requiring out-of-country purchases of green power to meet this new market. This success has been driven by the implementation by the Dutch government of a countrywide and almost income-neutral "ecotax", increasing the cost of conventional power by 6 eurocents/kWh, and hence allowing some green power to be offered at a *discount*. The World Wildlife Fund has aided the Netherlands in supporting a major media campaign to stimulate customers to accept these attractive green power contracts.

It is clear, in parallel with the conditions necessary to make RECs into important financial policy instruments, that *with additional supporting governmental policy and public education* the power of a green market can be substantially enhanced. Again, it is the *combination* of policies and financial instruments that produce effective results.

Requirements for introducing fair market incentives for renewable energy

Redressing inequities in market subsidies for the energy sources

The biggest problem of *any* "market based" program is that the present markets for the *conventional* energy resources are highly distorted by continuing governmental subsidies. "Subsidies" of any kind for an energy technology must be created and implemented fairly. Unfortunately, policy makers only look at (and often complain about) new proposed subsidies for new renewable energy resources, forgetting that the conventional energy resources have received, and are continuing to receive, massive subsidies that have produced fully artificial prices for fossil fuels and nuclear power alike. This makes it impossible for the renewable energy resources to compete on the open market, as many policy makers would like to think, since there is no such thing at present as a fair market for the conventional energy resources.

A consistent imbalance of subsidies creates a false message in the marketplace about the viability of renewable energy resources. Equalizing subsidies to all energy sources must include recognition of risks and price volatility factors, and should also include an explicit accounting of social and environmental costs and benefits.

For example, a report by the Renewable Energy Policy Project (REPP) estimated that out of US$ 150 billion spent by the U.S. government on energy subsidies from 1947 to 1999, nuclear power received 96.3 %. Nuclear energy and wind energy in the United States each produced about the same amount of energy in the first 15 years of the application of those technologies, but during that stage in their development the subsidies were US$ 39.4 billion for nuclear and US$ 900 million for wind, a difference of a factor of 40. More telling, the first 15-years of subsidy amounted to US$ 15.30/kWh produced by nuclear power, US$ 7.19/kWh produced by solar energy technologies, and 46 US cents/kWh produced by wind power. Expanding these averages to the first 25 years of commercialization of each of these technologies reveals even longer-term subsidies for nuclear power of 66 US cents/kWh, for solar energy of 51 US cents/kWh, and for wind energy of 4 US cents/kWh.

This inequity was not redressed by 1999, even though support for renewable energy had grown to the US$ 1 billion/year level by then (with 75 % of that in tax subsidies for Ethanol fuels). Fossil fuels received US$ 2.2 billion in subsidies in that same year. Nuclear energy in the U.S. was in its 52nd year in 1999, and it still received US$ 640 million in direct subsidies.

Recent consideration by the U.S. Congress of guaranteed loans for the construction of six to eight new nuclear power plants would represent a public exposure of potentially US$ 13 billion in liability against potential default by the plant owners. And extension of the Price Anderson Act, which limits the liability of insurance carriers in the United States to US$ 9 billion in the event of a nuclear accident, exposes the U.S. public to up to US$ 300 billion in unrecoverable costs in the event of a major nuclear power accident, such as happened in Chernobyl, or almost happened at Three Mile Island in the U.S.

No accident could conceivably happen at a renewable energy power plant that would expose the public to economic liability of these massive proportions. And the impact of shielding the public from these very great financial risks, and using public funds to support that "shield", gives completely false market signals.

Developing a consistent method for estimating energy costs

Another difficulty in market-based schemes for the promotion of renewable energy is the highly distorted method of estimating "levelized" prices for the conventional energy resources, against which the "competitiveness" of the renewable energy resources is determined. It is well known, for example, that the failure to estimate the environmental costs of energy production, and to internalize those in some way to be reflected in the cost of conventional energy production, leaves the consumers paying for energy resources simultaneously out of different pockets – direct purchases, indirect taxes and health costs. If these social costs could be made explicit, or explicitly tied to the decision to buy energy produced by a particular resource, the disparity between the costs of the conventional energy resources and the non-polluting renewable energy resources would be greatly reduced, if not, in many cases, completely eliminated.

Good arguments can be made that if in the U.S., for example, the costs of military measures taken to protect access to foreign sources of oil were factored into the direct cost of oil, the price at the gas pump would probably *double,* bringing the cost of American oil and gas up to the levels now experienced in Europe, and perhaps causing Americans to rethink the benefits of fuel efficient vehicles.

The failure of market analyses to properly evaluate costs and prices for conventional energy resources goes even deeper, though, into the very mathematical frameworks of the analyses. For example, the pioneering works of Dr. Shimon Awerbuch show convincingly that energy security will be more greatly affected by fuel price *volatility* then by fuel supply *disruptions.* His analyses further demonstrate that the volatility of conventional fuel prices adds a "risk" element to an estimation of discount rates that dramatically *raises* the net present value of the costs of conventional fuels, while at the same time *lowering* the net present value of the costs of the renewable energy sources. Related analyses by the Lawrence Berkeley Laboratory (U.S.) quantify this "gas fuel price hedge" from gas price volatility as adding 0.3 to 0.6 US cents/kWh for gas, or reducing the cost for the fuel-free resources by the same amount. Awerbuch concludes that the cost models used by energy planners hearken back to the Model T days, and have been discarded in other industries. Yet they continue to be used for projections of relative costs of energy.

Proper social accounting of costs and benefits of energy sources, econometric analyses that follow the relative economic efficiency of expenditures for energy in terms of larger societal benefits (e.g. new industries and jobs produced), and correctly applied risk-adjusted and volatile-price economic theory, paint a dramatically different picture from conventional economic analyses, one in which the renewable energy sources are quite evidently the safest, securest, and probably even today the cheapest, alternative

The conclusion from risk-based economic analyses is that biomass, hydroelectric energy, wind, and geothermal, all show *lower* net present value costs today than *all* of the conventional fuels, including boiler-burned and IGCC coal, turbine-burned and combined cycle gas, and nuclear energy. Solar thermal and PV also have risk-adjusted costs that are shown to be lower than conventional estimates, but are still higher than the other renewable energy resources.

Furthermore, the entire concept of "levelizing" energy costs over a long period totally ignores the impact that rising energy costs will have on future decision makers. Whereas the cost of gas "levelized" over 30 years may

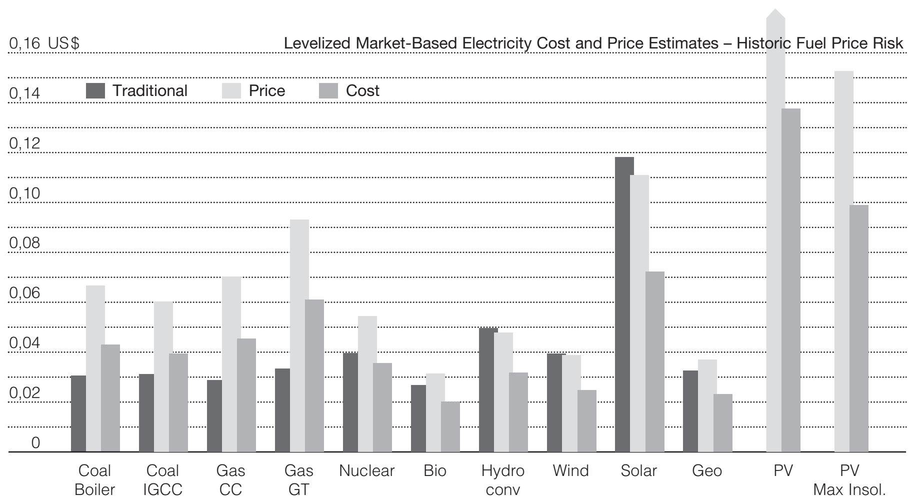
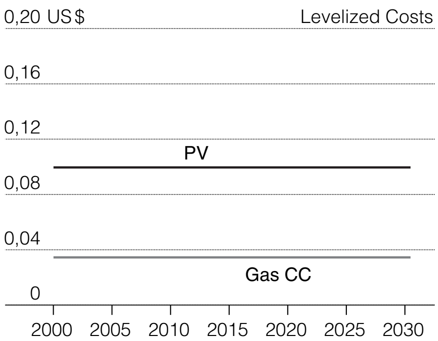


Fig. 17: Risk-Adjusted Cost of Electricity Estimates Based on Historic Fuel Price Risk.
Source: Dr Shimon Awerbuch, RENEWABLE ENERGY WORLD, Mar-April, 2003, p. 58, with PV data added from other Awerbuch work.

appear to be lower today than the cost of geothermal energy, or biomass energy, when the costs for gas begin to escalate (from the squeezing of domestic and world gas markets) while the costs for geothermal and biomass energy continue to be reduced, there will be a time when all of those costs cross over, leaving gas as clearly the more expensive *immediate* resource. Future governments and decision makers will be dismayed to then find that they are trapped into 20-year purchase agreements based upon the unreal "levelizing" of what is really a dynamically changing market. The renewable energy sources will look ever more favorable in future markets and to future governmental decision makers, while the conventional energy resources will become more and more costly.



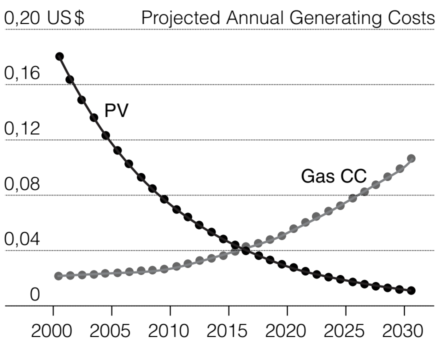


Fig. 18 a, b: Levelized costs mask important intertemporal information. Customers after 2015 may be displeased with the year 2000 choice of gas CC.
Source: Dr. Shimon Awerbuch

The Role of R&D in Supporting the Renewable Energy Transition

Countries with the most advanced R&D programs will become the technology leaders. In the case of renewable energy the technologies are still improving and developing while, at the same time, fully market-ready applications of the technologies are also being continuously improved from experience gained in commercial applications in the field. Continued R&D in solar energy has a very important role to play for years to come.

An important component of any national renewable energy policy should be support for both fundamental and applied R&D, along with cooperation with other nations in R&D activities to enhance the global efficiency of such research. R&D can lead to new industries, and R&D breakthroughs can produce new competitive advantages for nations, while contributing to the advancement of the fields for the benefit of all countries.

For example, in the area of PV it has been noted that much fundamental R&D remains to be done that goes beyond just cell research to include balance of systems components and integrated systems. Fundamental physics remains to be done to increase efficiency and reliability of PV cells or films, but equally important are continual improvements in the integration of PV into building components and systems and into distributed energy supplies. Significant new breakthroughs and new directions are still possible.

There is much R&D still to be done with the solar thermal electric technologies as well, in order to increase efficiencies and reduce costs of mirrors, heliostats, collectors and electric energy generators, and to develop and refine thermal energy storage systems that can give up to the critical 12 hours of thermal storage that will greatly enhancing the economics of solar thermal electric systems. But equally important is research to reduce the cost and increase the reliability of solar water heating components.

Biomass gasification holds much promise for future clean energy production, but needs considerable further development. More work also needs to be done to improve the ability to co-fire biomass with coal. And, of course, much agricultural R&D remains to be done to develop and optimize energy crops for bioenergy production.

Building science has emerged as an important scientific and engineering discipline. Tools for "whole building" design, to facilitate systems integrations of compatible energy and architectural components, are being developed and refined and made ever more "user friendly", in order to be useful in the actual design process. The result is today that major energy savings can be realized with relatively minor overall cost impacts. In some cases energy efficiency and renewable energy collection in large buildings can be accomplished within the same budget for a "standard" building without those features.

These design tools need to be further developed and validated against measured building performance. The monitoring of buildings must also be continued and expanded to develop a data base from actual experience. And research on new building technologies, such as lights and glazings, is already producing huge gains in efficiency and performance.

The largest single investment of the European Union's five-year Frameworks has been energy research, spurred by the world oil shock of 1973. Energy research was first seen "as a matter of survival" for the EU. By the late 1990's the proportion of EU funding for R&D in renewables had grown to 14 %, and 12 % for R&D in efficiency.

The European research focus today is changing. Energy security remains a primary driver for EU R&D in renewables, but environmental protection and economic competitiveness are now the important drivers. The focus of EU R&D funding has been to "help European firms to capture a major portion of the growing worldwide market for renewable energy technologies".

As such, the EU R&D budget for renewables has become more oriented toward applied R&D, rather than to basic research. In this context it is highly significant that the European Commission has agreed to invest US$ 2 billion in sustainable energy research for the next five-year period, an amount that is 20 times the expenditure for the 1997-2001 five-year period. Japan combines support for R&D with the "promotion" of PV, with budgets of US$ 302.4 million in 2002, and US$ 218.6 million in 2003.

The G8 Renewable Energy Task Force, in its July, 2001 Final Report, urged that "The G8 countries should continue and expand support for R&D of renewable energy technologies that address all sectors of the energy economy – buildings, industry, transport, and utility energy services." They also urged cooperation on R&D with developing countries to help with technology transfer tailored to developing country use.

Two Comprehensive National Energy Policy Models

It is instructive to present two comprehensive national energy policy models, to demonstrate the integration of policies in a way that can produce major economic and environmental benefits simultaneously, while also leading countries into the renewable energy transition. The United States is presently being led by State policies, so the following proposed national model is presently hypothetical, yet realistic, holding great promise for future U.S. federal governments more enlightened than the present one. The German model, on the other hand, is an actual national framework for German energy policy, taking Germany deep into the renewable energy transition.

The United States: Leadership from the States, and a clean energy blueprint for an alternative future

Present (2003) status of renewable energy policies in the U.S.

The United States (2003) has no significant national energy efficiency and renewable energy policy. Even though it was acknowledged in the 2001 National Energy Plan that, without the efficiencies introduced in the U.S. following the oil crisis of 1973, the U.S. would be using 30 % to 50 % more energy today than it does, the U.S. has no stable, long-term policies to continue to reap these benefits in the future. This is particularly true with regard to renewable energy, for the Administration's prediction in the 2001 National Energy Plan that renewable energy use would grow from 2 % today to about 2.8 % in 2020 is hardly what is needed to energize investor confidence.

That is not to say that there is no federal support for renewable energy applications. The production tax credit of 1.8 US cents/kWh for energy produced by wind turbines and dedicated biomass plants, for example, has played a very important role in the renewed development of the U.S. wind-electric industry. But even this support has been on-again and off-again, voted in or out on a year-by-year basis, without the policy assurance needed to attract new business development and investments.

Fortunately, a number of the state governments have decided not to wait for a lagging federal government, and have moved decisively to take responsibility for the energy security and economic futures of their states. Those state governments have enacted legislation to promote the accelerated application of renewable energy. Enough state programs have been developed to confirm the feasibility of aggressive national renewable energy goals, and to begin to suggest a *de facto* national policy emerging from outside of the federal government.

By mid-2003, thirteen states had implemented minimum renewable energy standards (RPS) which will produce over 14,230 MW of new renewable power by 2017 – a 105 % increase over 1997 levels. Eight of those states enacted the RPS legislation as part of restructuring their electric utilities. Wisconsin, a state that did not restructure their utilities, enacted the RPS in support of "electric reliability", explicitly incorporating one of the most important future benefits of renewable energy into early governmental energy policy.

California will be the numerical leader in U.S. development of new renewable energy resources, requiring the State's investor-owned electric utilities and energy providers to increase their renewable energy usage by not less than 1 % per year to a target of 20 % by 2017. The additional 21,000 gigawatt hours per year from renewable energy generation by 2017 amounts to a doubling of California's renewable energy usage, which will make serious inroads into California's dependence on natural gas for electricity production.

The California Energy Commission released an analysis in 2003 confirming that there would be sufficient renewable electricity generation in the State to reach that target, with possibly 25,000 gigawatt hours per year to come from projects *already under development in 2003.* That report also confirmed that abundant additional renewable energy resource capacity would still be available for development beyond the 2017 target. This report, in turn, confirmed the findings of the California Public Utilities Commission that transmission line planning for California's future will also need to be targeted to support the State's major renewable energy development areas.

Nevada has the second highest new U.S. statewide percentage goal, requiring 15 % of their electricity to come from renewables by 2013, with 5 % of that to be produced by solar-electric technologies. But Minnesota recently adopted an RPS requirement of 10 % of power production from renewable energy by 2015 for the State's largest electric utility. When added to their previous Prairie Island Nuclear Plant waste storage "settlement" requirement of 950 MW of wind and biomass energy, the utility will have a de facto RPS of 19 % by 2015. Texas will be second to California in total installed new renewable energy generation with a requirement of 2000 MW of new renewables by 2009, signed into law by then – Governor George W. Bush.

Fourteen states have also legislated renewable energy funds totaling US$ 4.5 billion by 2017. The combination of all RPS and renewable energy fund programs will develop 15,215 MW of new renewables, and protect 7,020 MW of existing renewables, by 2017. This will be equivalent in the reduction of CO_2 emissions to removing 7.4 million cars from the road, or planting11.2 millions acres (4.5 million hectares) of trees. These programs are complemented by other legislated state programs in support of energy efficiency, totaling US$ 8.6 billion by 2012, and for R&D, totaling US$ 1.1 billion by 2012.

The development of distributed generation (primarily PV and small wind) in the U.S. has been promoted by "net metering" legislation passed in 36 of the country's 50 states. Most of the PV systems allowed to be directly connected into the utility and to gain full retail credit by "running the meter backwards" are restricted in size in various state policies to 10 kW, or 25 kW, or a few up to 100 kW. California, however, allows PV systems up to 1 MW to qualify, leading to a boom of many hundreds of kW in commercial rooftop and parking lot systems.

It is now being seen that experience in constructing and operating renewable power installations builds confidence in the utilities. Enough new renewable energy generation had been added in Wisconsin by early 2003, for example, aided by a State policy that allows unlimited "banking" of renewable energy credits, to meet their RPS goals through 2011. Texas exceeded their 2002 RPS requirement by 150 % (installing 900 MW of new wind, while required only to install 400 MW), and is likely to reach their 2009 goal of 2000 MW several years in advance of the legislated requirement. Two states – Nevada and Utah – revisited their earlier conservative RPS legislated goals and dramatically increased their earlier standards. And Nevada will have nearly met their new 2013 solar power requirement by 2005, when their 50MW solar thermal-electric power plant goes on line.

A powerful clean energy blueprint for the US

The leadership provided by state governments in the U.S. is extremely important, filling the policy vacuum left by the federal government, but so much more could be accomplished with a national policy based upon national goals supported by facilitating legislation. To demonstrate this, and to provide incentive and support for national legislation, the Union of Concerned Scientists (UCS) – a national member organization of scientists and those who support them in promoting the public interest in several fields, including clean energy – developed in 2001 a "Clean Energy Blueprint". Based upon realistic appraisals of both technology costs and resource potential, the Clean Energy Blueprint reveals that a U.S. nationwide goal of 20 % of electricity from renewable energy by 2020 is feasible and would offer attractive economic and environmental benefits compared with the administration's "business as usual" policies.

It has been stressed in this White Paper that accelerating the application of renewable energy cannot result from just one or two adopted policies. The Clean Energy Blueprint integrates many energy and efficiency policies into a mutually supportive package. Specifically, the following policies are proposed, and the integrated impacts appraised analytically:

- A *renewable portfolio standard* would require utilities to increase the use of energy from wind, biomass, geothermal, solar and landfill gas from 2 percent in 2002 to 10 percent in 2010, and 20 percent by 2020. It would be supported by tradable energy credits to help assure compliance at the lowest possible cost.
- A *public benefits fund* would be created by a 0.2 cent/kWh surcharge on electricity, equivalent to about US$ 1/month for a typical household. It would be used to match state funding for energy efficiency, renewable energy, R&D, and low-income customer protection.
- *Production tax credits* of 1.8 US cents/kWh for renewable energy would be extended to 2006 and expanded to cover all clean, nonhydro renewable energy resources, helping to level the playing field with fossil fuel and nuclear generation subsidies.
- *Net metering* would be extended nationwide, to treat fairly those grid-connected consumers who generate their own electricity with renewable energy systems of up to 100kW, located on their own premises, by allowing them to feed surplus electricity back into the grid and spin their meters backwards.
- *Research and development* spending on renewable energy would increase 60 % over three years to US$ 652 million by 2005 (this is a little over twice the 2002 renewables R&D budget for Japan.) Energy efficiency R&D would grow by 50 % to US$ 900 million by 2005.
- *Combined heat and power:* investment tax credits and shortened depreciation periods would be provided, and regulatory barriers removed, for

power plants that produce both electricity and useful heat at efficiencies of 60 % to 70 %.

- *Improved efficiency standards:* national minimum efficiency standards would be established for a dozen products, generally to the level of good practices today. In addition, existing national standards would be revised to levels that are technically feasible and economically justified.
- *Enhanced building codes:* states would adopt model building codes established in 1999/2000, as well as new more advanced codes to be established by 2010 that would go well beyond today's "best practices" standards.
- *Tax incentives* would promote efficiency improvements for buildings, appliances and equipment beyond minimum standards, through rebates and investment tax credits.
- *Industrial energy efficiency measures:* industry would improve its efficiency by 1 to 2 percent per year through voluntary agreements, incentives, or national standards. The federal government would provide technical and financial assistance, and increase federal R&D and demonstration programs.

An economic analysis of the costs and benefits of the combination of all of these policies, using the U.S. Energy Information Administration's National Energy Modeling Systems (NEMS) computer model, produced the following results:

- The United States could indeed meet at least 20 % of its electricity needs by renewable energy sources – wind, biomass, geothermal and solar – by 2020.
- U.S. consumers would *save a total of US$ 440 billion by 2020,* with *annual net savings reaching US$ 105 billion per year, or US$ 350 per year* for a typical family.
- Monthly electricity bills for a typical household would *decline* from about US$ 40/month in 2000 to US$ 25/month in 2020.
- The Blueprint's efficiency and renewable energy policies could *reduce* natural gas prices by 27 percent by 2020, savings businesses and homes another US$ 30 billion per year by 2020.
- Demand for natural gas would be reduced by 30 % and for coal by nearly 60 % (reducing the burning of coal by 750 million tons per year) compared to business as usual projections for 2020. More oil would be saved in 18 years (400 million barrels per year by 2020) than could be recovered economically from the administration-proposed pipeline in the Artic National Wildlife Refuges (ANWR) in 60 years.
- The need for 975 new power plants (average 300 MW each), out of a projected 1,300 new plants under the National Energy Policy, could be *avoided,* and 180 old coal plants (average 500 MW each) and 14 existing nuclear plants (1,000 MW each) could be *retired.* 300,000 miles of new gas pipelines and 7000 miles of electricity transmission lines, both called for in the Administration's National Energy Policy, would not have to be built.
- Carbon dioxide emissions from power plants would be reduced by *two-thirds* compared to business-as-usual projections for 2020, and harmful emissions of sulfur dioxide and nitrogen oxides from power plants would be reduced by *55 percent.*

How realistic are these conclusions and benefits? The impact of a national requirement (RPS) for 20 % of U.S. electricity from renewable energy by 2020 was examined, using rather high cost assumptions for renewable energy and other conservative assumptions, by the U.S. Department of Energy's Energy Information Administration (EIA). Their results showed a modest *saving* in national energy bills by 2020. Other studies which included more realistic assumptions, and which combined energy efficiency measures with renewable energy development, showed *billions* of dollars of savings for U.S. consumers by 2020 compared with the Administration's National Energy Plan.

This model, then, reveals the kinds of benefits awaiting governments that decide to pursue an integrated set of policies leading toward the renewable energy transition. In order to reap those benefits, though, governments must be prepared to take long-range policy views, and to be willing to invest in the early implementation of those policies. The development of renewable energy in Germany, for example, has shown an almost steady growth over the past ten years, resulting from consistent policies, while the U.S. renewables industries flounder from year to year in a mire of an uncertain and inconsistent renewable energy policy framework with a very short time horizon.

The next example therefore looks at the model for Germany's long-range goals and strategies that is "pulling" German renewable energy policy and governmental investments toward a genuine renewable energy transition.

Germany: A significant long range renewable energy policy

Germany has adopted policies intended to dramatically reduce the emission of greenhouse gases and, as part of that policy, to develop its renewable energy resources on a fast track. The result has been a jump to leadership in the world of wind energy, with 12,000 MW installed in Germany by the end of 2002, and 3rd in the world in PV capacity.

Germany's policies are being driven and formulated in part by long-range sustainability models put forth by the German Federal Environment Ministry, supported by the analytical work of the Wuppertal Institute. The key elements of that Long-term Scenario "Solar Energy Economy in Germany" are, first, that energy productivity will improve by 3 to 3.5 % per year up to 2030. This means that, even though the Germany economy will continue to grow, total primary energy will actually diminish by a little over 30 % by 2030. *This is the energy efficiency and energy intensity policy underpinning of the renewable energy transition that makes the renewable energy contribution into a significant factor.*

By 2030, nuclear energy will have been completely phased out, and renewable energy could contribute possibly 25 % of national primary energy. This figure increases to 58 % by 2050, at which point Germany will essentially have engineered the renewable energy transition.

The model further envisions a transformation of the electricity sector by 2040, when renewable energies exceed 50 % of total electricity generation, expanding further to a 65 % renewable energy contribution by 2050. This transformation is enabled by structural changes from central power to heavy reliance on site-specific power generation, facilitated by phasing in many of these changes before 2020, during the period when 70 % of Germany's aging power plants would otherwise have to be replaced.

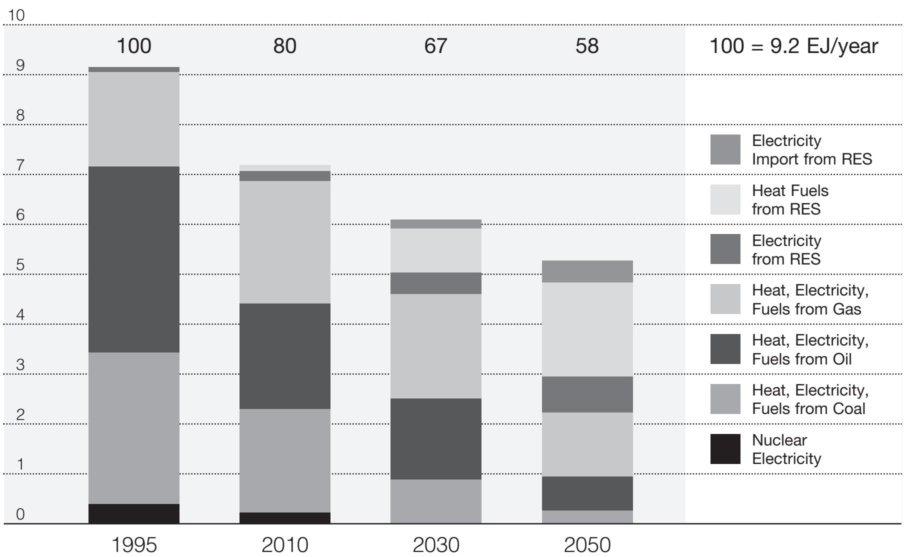
These results also assume energy-saving transformations in the buildings, transportation and heating sectors, with increasing reliance on renewable energy resources for all three. So, for example, according to the model the total amount of electricity required by Germany would be only about 12 % lower in 2050 than for the year 2000, because of the increasing share of electricity needed to produce hydrogen fuels.

These changes would not come without costs, but they are also balanced by cost savings, such as in fuel and avoided power plant construction. The estimate is that the discounted annual cost/year for this transition would be perhaps 3.8 billion EUR/year, or 48 EUR/year/person, representing about 0.14 % of the gross domestic product. And these figure do not take into account the economic benefits from the new renewable energy industries and jobs that would accrue. (The same analysis suggests that 85,000 to 200,000 jobs would be created or conserved in the building industry, and 250,000 to 350,000 new jobs created in the renewable energy industries.)

Finally, projecting the model still further, renewable energies could deliver 100 % of the power and energy required for Germany by 2070, with a continuing aggressive program, or at least by the end of the century with a more modest program.

The Germany Advisory Council on Global Change (WBGU), in a 2003 report, proposed that these kinds of measures and goals could move the world through the transition to energy security with environmental protection and energy equity between rich and poor nations. In addition to the efficiency and renewable energy goals, though, would need to be commitments to cut all fossil fuel subsidies to zero by 2020, investment in grid infrastructure to support distributed generation, and increasing R&D for renewables by *ten times*.

Longterm Scenario "Solar Energy Economy" in Germany – Final Energy by Sources



100	55	33	26	Energy-Intensity (1995=100)
0,284	0,273	0,265	0,238	CO_2-Intensity (fossil, kg/kWh)
1,5	4,5	25	58	Share of RES (%)

Fig. 19: A plausible long-term German plan to reduce energy use in an expanding economy, and to bring renewable energy use up to significant percentage levels
Source: Dr. Manfred Fischedick, Wuppertal Institute for Climate, Environment and Energy

Conclusion

No single renewable energy technology can be proclaimed to be more important than another in terms of delivering useful energy to society. Each has its place in the portfolio of technologies to meet societal needs and to provide societal, economic and environmental benefits. Just because PV is popular does not make it always more important to society or economies than sustainable building design or solar thermal technologies. And using solar energy to displace other energy resources, including electricity, is every bit as important for economies and the environment as creating new electricity by solar energy.

One square meter of surface area can deliver 100 AC watts of peak electrical power with PV technology. One square meter of mirror can also deliver about 100 watts of peak electrical energy through solar thermal electric technologies, and perhaps 200 watts of electricity with Dish-Stirling heat engines. But one square meter of intercepted solar energy can also deliver 300 watts of thermal power for heating domestic water or for active solar space heating, displacing 300 watts of electric water heating. And one square meter of intercepted solar radiation can deliver over 600 watts of heating energy, if the solar radiation is delivered directly into a building through a square meter of glass, displacing 600 watts of electric space heating. That same square meter of glass can deliver daylight with an efficiency of about twice the lumens/watt ratio of the very best interior artificial illumination technologies, displacing, with daylight-tracking lighting controls, 100 watts of electrical lighting energy.

All of those square meters of collectors and hectares of fields capturing solar energy, blades converting the power of the wind, wells delivering the Earth's thermal energy, and waters delivering the energy of river flows, waves and tides, will displace precious and dwindling fossil fuels and losses of energy from the worldwide phase-out of nuclear power. Sparing the use of fossil fuels for higher economic benefits, or using them in fuel-saving "hybrid" relationship with the intermittent renewable energy resources (sun and wind), will contribute to leaner, stronger, safer societies and economies. And, in the process, carbon and other emissions into the atmosphere will be greatly reduced, now as a result of economically attractive new activities, not as expensive environmental penalties.

Energy policy should be a policy in support of those integrated, interconnected pieces that define the energy systems on which society depends. It should steer the evolution of those systems in the public interest, away from environmental and social destruction, and toward compatible and restorative relationship with the natural world. Energy policy must be predicated on sustainability and opportunity for future generations or it will fail, and bring economies and societies down with it.

It is encouraging to see the emergence of region-wide renewable energy development policies, and the setting of rules to assure accomplishing those targets that apply across national boundaries. The proposed EU program, "Intelligent Energy for Europe", is aimed at consolidating various programmes from the 1998-2002 framework into a more efficient, and better funded, 2003-2006 framework. The name implies the "intelligent" role of energy efficiency and the renewable energy resources in the larger well being of all of Europe. The EU Parliament has also proposed a "European Intelligent Energy Agency", which would facilitate energy efficiency and renewable energy applications, and the replication of "best practices" learned by experience, throughout the EU.

Fig. 20: A story of a beginning. The Rancho Seco Nuclear Power Plant in Sacramento, Cal., was decommissioned because of excessive costs. Its power production has since been replaced by energy efficiency and the world's largest utility collection of photovoltaic solar-electric generation. The utility rates came back down to where they would have been if this courageous first step had not been taken. The first step is always the hardest.
Photograph by Dr. Donald Aitken

When these proposals are added to the January 23, 2002 EU Commission's environmental liability directive based on the "polluter pays" principle, it is becoming clear that, in a large part of the world, at least, "intelligent" energy efficiency and renewable energy policies are coming of age in packages that explicitly include environmental emissions reductions, protection of the environment, stimuli for regional economic gains, removal of existing barriers, and financing mechanisms.

Governments should also become their own best customers. The largest owner of buildings is usually the government. Governments should design and convert their own buildings to be examples of efficiency and sustainability. Governments need to stimulate bulk purchases and cost reductions of the renewable energy technologies by applying them to governmental safety and defense operations. In these kinds of ways governments can help to "pull" the solar technologies into the market place, to complement the "push" of their firm goals, policies and laws.

The renewable energy transition will happen city-by-city, region-by-region, country-by-country. It will be a process generated in each locale when a "critical mass" of the application of a renewable resource has been reached. These turning points happen when people, governments, regulators, utilities, and the financial community have all become familiar with the technology. With wind, this appears to be when 100 MW have been installed. With PV, it happens when PV roofs, for example, become not only pervasive but sources of personal pride. The City of Sacramento, California, with close to 1,000 PV roofs, has thousands of applicants for new ones. The same holds true for the Japanese and German solar roofs programs, except in those countries there are tens of thousands of applicants.

Governments need to set, assure and achieve goals to accomplish *simultaneously* aggressive efficiency and renewable energy objectives. The implementation mechanisms for achieving these goals must be a *packaged set of mutually supportive and self-consistent policies.* The best policy is a mix of policies, combining renewable energy standards with direct incentive and energy production payments, loan assistance, tax credits, development of tradable market instruments, removal of existing barriers, government leadership by example, and user education.

Furthermore, the legislative and financial mechanisms to achieve these goals must be *consistently applied, from year to year.* This will require the continuity of political will through many administrations and several generations. Achieving that alone will be a stunning advancement for society.

This White Paper demonstrates that *the renewable energy transition is not just a fantasy, but rather a real vision, which can be implemented by industrial nations with available technologies, in a reasonable time, and at reasonable costs. It is apparent that leadership arising from people and their governments, combined with the adaptability of utilities and societal institutions, will determine which countries succeed and which fail.*

The renewable energy transition must start now, or it will be too late. Governments, cities, companies, and people must cooperate in moving it beyond the first difficult steps, knowing that great societal, environmental and personal rewards will come. Solar energy, the source of all life on Earth, will be the underpinning of a sustainable, safe and sane future energy policy.

Fig. 21: Children can now touch, feel, and experience the beginning of the renewable energy transition, which will be so important to secure their own future well-being.
Photograph by Dr. Donald Aitken

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“The window of time during which convenient and affordable fossil energy resources are available to build the new technologies and devices to power a sustained and orderly energy transition is short...”

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