ENERGY FOR THE NEW MILLENNIUM

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A collaboration greater than the sum of its parts

The collaboration that is now being honoured began more than twenty years ago. At that time, energy security concerns were paramount; the fact that billions of people in the developing countries relied on traditional and inefficient energy sources for cooking, heating, and working was just starting to come into focus as a policy concern; and environmental issues were getting increasing attention, though climate change was not yet listed high on the public policy agenda. Most experts considered energy from a growth-oriented, supply-side perspective, focusing on consumption trends and how to expand supplies to meet rising demand, without addressing the mounting environmental impacts and security concerns associated with energy production and use. For example, in 1981, the International Institute of Applied Systems Analysis published Energy in a Finite World, *which envisioned an energy future in which thousands of plutonium breeder reactors producing annually thousands of tonnes of weapons-usable material would be introduced early in the 21st century. The prospect that the energy system might be made sustainable using such technology while the world served by this energy would become more and more unsustainable was frightening.*

The four of us believed it was important to establish a different way of thinking about energy. We shared a vision of energy as an instrument of global and national development and of technology as a crucial mechanism for making this possible. Our thinking was bolstered by energy use trends in the wake of the oil shocks of the 1970s, which showed that the link between energy consumption and economic growth could be substantially weakened. The challenge of trying to change the energy paradigm was the catalyst for our collaboration on Energy for a Sustainable World, *in which we showed how new patterns of energy production and use could further economic efficiency, equity, empowerment and environmental soundness.*

Each of us had an established track record in energy analysis before we started collaborating. Although we had scientific backgrounds, we were sensitive to socio-economic issues.

Our shared commitment to economically viable, need-oriented, self-reliant and environmentally sound development convinced us to work together as peers in an informal partnership that was independent of institutional pressures. Our differences in terms of perspectives, experience and expertise were complementary, and together we were able to produce what none of us could have produced alone. Our collaboration has continued to this day without a conventional organizational or institutional umbrella, in parallel with our work on our own individual projects.

In our first project, *Energy for a Sustainable World,* for which our collaboration is perhaps best known, we looked at energy, not in isolation, but in relation to global issues, such as poverty, population growth, food and under-nutrition and environmental degradation, to which energy is inextricably linked. We believed that new approaches to energy must not aggravate these other problems. Instead, solving the energy problem should contribute to, and be consistent with, the solutions to the other major issues. Energy, we argued, must be an instrument of need-oriented, self-reliant and environmentally sound development—what has come to be referred to as *sustainable development*.

The emphasis on using energy to serve needs meant that the focus must not be on energy consumption, but on the end-uses of energy—that is, the tasks that energy performs and the utility it provides to human beings. The switch in focus from energy consumption to energy services was not a semantic trick. It emphasised the fact that enhancement of energy services does not necessarily require expanding supplies. It can also be achieved by using energy more efficiently. Technological opportunities abound for enhancing energy services without a corresponding increase in primary use. Indeed, over the long-term, efficiency increases of an order of magnitude are theoretically possible. In addition to many other collaborative efforts, the four of us have just served, along with many other scientists and researchers, on the editorial board of the *World Energy Assessment*. We discovered that our vision of energy as a force for sustainable development has gained currency in many circles, including among industry leaders who served with us on the editorial board. Still, the assessment revealed major contradictions between the current energy path and the ideal of a sustainable world:

- Modern energy carriers are still not accessible to some two billion people, severely limiting their choices and opportunities. The wide disparities in access to and use of affordable commercial energy runs counter to the concept of equitable human development and threatens social stability.

- Energy activities are major contributors to indoor air pollution, urban air pollution, acidification and global warming. For example, they contribute 85 per cent of anthropogenic emissions of sulphur dioxide and a significant fraction of emissions of small particulate matter, and their contribution to greenhouse gas emission is also very significant—78 per cent of CO_2, and 23 per cent of methane.

- Unreliable energy supplies pose a hardship and economic burden for a substantial portion of the world's population. And the fact that the world is becoming increasingly dependent on oil from politically troubled regions leaves many countries vulnerable to disruptions in supply.

As recently as 25 years ago, it was widely believed that a shortage of fossil fuels might constrain global economic development. Current analysis refutes this notion. Physical limitations of fossil fuel resources are not likely to constrain energy development; rather a departure from the current energy path will probably be required in response to social, environmental and security concerns. Fortunately, there *are* ways to reconcile these concerns—even the daunting challenge of climate change mitigation—with the need for more energy services. However, despite good technical and economic prospects for shifting to a sustainable path, this will not be easy. The current path is supported by weighty infrastructures and powerful vested interests.

Moving toward energy systems that support a sustainable world

The following patterns characterize primary energy consumption in both industrialized and developing countries:

- Per capita primary energy consumption per year in developing countries averages less than 30 gigajoules, compared to about 380 gigajoules for the United States plus Canada.

- Fossil fuels represent 81 percent of primary energy consumption in industrialized countries and 70 percent in developing countries where three quarters of the world population lives.

- Biomass represents only 4 percent of primary energy consumption in industrialized countries and is the most widely used form of energy elsewhere. (Traditional biomass represents about 90 percent of total energy consumption in some least developed countries.) Although modern biomass energy conversion technologies can be clean and environmentally friendly, in the developing world, biomass tends to be used very inefficiently, with serious environmental and health consequences.

- Energy growth was about 1.5 percent in OECD countries in the period 1987-1997 and 4.5 percent in developing countries. The increase in global energy demand in the next 15 to 20 years will be largely from these developing countries as they strive to meet the basic needs of and improve living standards for their growing populations.

- There is now widespread agreement on the broad strategies needed to steer the present energy system in a more sustainable direction. They include:

- *Improving efficiency of energy use to help reduce costs and environmental damage.* Many cost effective steps have already been taken in this direction since the oil crises of the 1970s, but these have not been sufficient to reduce the rate of growth of energy consumption. Tremendous energy savings (from 25 to 35 percent in many countries) are cost-effectively possible with available technologies. And greater potential exists over the long term.

- *Increasing the contribution of renewable energy sources such as wind, photovoltaics, and modernized biomass*. These renewable energy sources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Furthermore, they are based on the use of indigenous resources. New renewable energy sources contribute about 2 percent of total primary energy. Substantial price reductions in the last decades have made these sources competitive with fossil fuels in certain applications in growing markets. Modernized biomass energy is especially important for developing countries. Solar photovoltaics and grid-connected wind technologies are growing at a rate of 30 percent per year.

- *Increasing the share of the cleaner and more-efficient fossil fuel technologies in the energy mix*. In transportation new hybrid electric cars offer a 50 per cent reduction in gasoline requirements, along with a 1/3 reduction in air pollution damage costs compared to conventional cars. In power generation, new natural gas combined cycle power plants are highly cost-competitive, with air pollution damage costs and CO_2 emission rates less than 10 per cent and 40 per cent, respectively, of those for new coal steam-electric plants with pollution controls. Combined heat and power systems based on gas turbines, combined cycles, and microturbines, and, in the years immediately ahead fuel cells as well, offer substantial energy-saving, environmental, and economic benefits compared to the production of electricity and heat in separate facilities; use of such technologies is growing rapidly, especially where market reforms encourage competition in power generation. Moreover, new coal integrated gasifier combined cycle power plants that are becoming cost competitive with coal steam-electric plants offer damage costs from air pollutant emissions as low as those for natural gas combined cycles and CO_2 emissions that are 80 per cent of those for new coal steam-electric plants. Costs for coal gasification technologies are especially attractive in “polygeneration” configurations, in which various mixes of chemicals, fuels, and industrial process heat are coproduced with electricity.

§ *Accelerating development and deployment of new energy technologies.* Many advanced energy technologies will be much less environmentally damaging and more cost-competitive than technologies available on the market today. Some examples are: fuels cells for transportation; fuels cell hybrids with gas and/or steam turbines for stationary power and combined heat and power; fossil fuel-derived hydrogen with geological sequestration of the separated carbon dioxide; dimethyl ether produced from crop residues for use as a clean cooking fuel, village-scale power generation, and transportation in rural areas; wind and photovoltaic systems that provide dispatchable power by coupling to hydroelectric power or compressed air energy storage. Advanced nuclear technologies might also make contributions if the problems of cost, reactor safety, waste disposal, and the nuclear weapons link to nuclear power that presently stall the expansion of nuclear power can be satisfactorily resolved.

Opportunities

While the above strategies are straightforward in one sense, their implementation is handicapped in part because different parts of the world are so different in terms of resources, technical and institutional capacity and energy infrastructure. In many respects, the achievement of sustainable development depends on what happens in the developing world, where energy demands are set to grow substantially in any scenario of economic success. This observation is not meant to understate the responsibility that industrialized countries bear for most energy-linked global environmental problems to date, especially climate change and acidification, nor the right of developing countries to develop economically. Rather it is intended to point out that while the lack of large-scale energy systems is one of the problems faced by many developing countries, this relatively "blank slate" also affords some interesting possibilities. It means that many developing countries have the opportunity to “get energy right” at an early stage in their economic development, which will be less-expensive for them over the long term. It also means that developing countries have the chance to leapfrog over the many of the dirty and wasteful processes that industrialized countries adopted because of the limits of technology at the time. The combination of state-of-the-art and advanced energy-efficient end-use and clean modern energy supply technologies offers a promising energy path for developing countries. Because of their rapid energy demand growth, nascent infrastructures and large renewable energy potentials (e.g., typically much higher insolation levels than in most industrialized countries), these countries could become major theatres for energy technological innovation.

In industrialized countries, technological advance (mainly involving improved energy efficiency) has weakened the historically tight link between economic development and primary energy consumption. By shifting to more energy efficient processes and end-use devices and to modern energy carriers in the developing world, it would be possible to achieve dramatic improvements in living standards, with relatively small additional inputs of primary energy. For example, providing modern clean cooking fuels in the amount needed to satisfy the cooking needs of the two billion people deprived of today of such fuels would require a mere 1.3 per cent increment of global commercial energy, equivalent to 3 per cent of global oil consumption.

The early adoption of modern up-to-date technologies—tested and available in the industrialized countries—is one obvious option. An example, albeit outside the energy area, is the adoption of mobile phones as the preferred way of expanding the telephone system instead of following the path used in the past of extending lines for fixed telephones. The success of this strategy is evident all over the world, and the manufacture of these products via joint ventures in the developing countries themselves is perhaps an important contributor to success.

An example of "leapfrogging" in the energy area is the early transition to LPG (liquefied petroleum gas) as a fuel for cooking replacing inefficient and highly polluting fuelwood or coal cooking stoves. The success of such approach, especially in a number of Latin American countries, is very impressive.

In addition, developing countries can profit by developing technologies that are particularly suited to their needs and in which they might have comparative advantage. An example of success is the ethanol programme in Brazil based on the use of sugarcane which grows well in the particular geographical conditions of that country. The technology has desirable general characteristics of sustainability—the raw material is renewable; ethanol is far superior to leaded gasoline from an environmental perspective and generates less air pollution damage than reformulated gasoline; and the production of sugar cane-derived ethanol provides rural development benefits. Moreover, in contrast to the volatility of the world oil price, the price of this synthetic fuel has declined with experience, on average about __ per cent per year with cumulative production since 1978—as is typical of many manufactured products (see Figure 1). A more rapid rate of decline occurred after 1985, when competition was introduced.

A note of caution is warranted to avoid applying the "leapfrogging" concept indiscriminately. Advanced technologies should be pursued in a country or region only if they would help advance sustainable development objectives. What is required there is a high level of human technological capacity for enabling energy decisionmakers to make technological choices that are often not obvious.

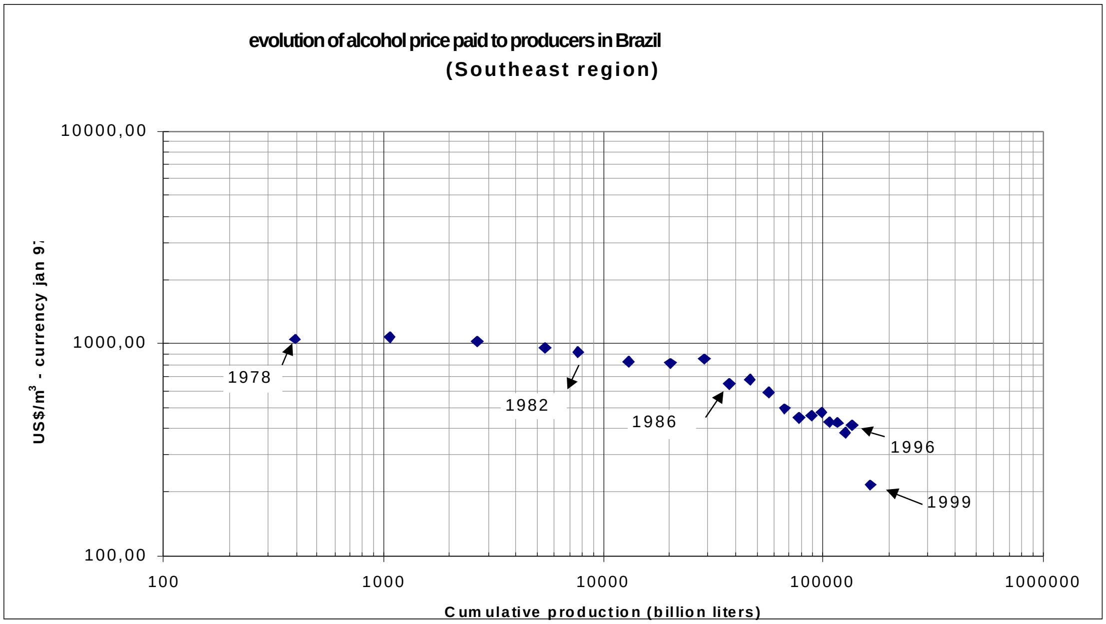

Figure 1: History of the Ethanol Price in Southeast Brazil and the World Oil Price [Jose: For you to redraw, putting both the world oil price ($ per barrel?) and the price of ethanol (cents per liter?) on the same graph. Can you provide ethanol data for 1997, 1998, and 2000? Can you give a separate experience curve fit to the ethanol data for the period beginning in 1985?

Clearly, developing (and transitional) countries need to further develop their own unique combinations of resources—human, natural and technological—so they can create energy systems appropriate to their own circumstances. But to do so, they need assistance in terms of technology transfers, financing and capacity building.

The declining share of official development assistance relative to other investment capital, especially foreign direct investment (FDI), suggests the importance of steering private sector resources toward these ends. International industrial collaborations (e.g., industrial joint ventures) and private/public sector partnerships are alternative attractive mechanisms that could both foster the migration of new technologies to developing countries and help build the capacity for indigenous technological innovation. Consider that for the 20 developing countries that account for about three quarters of GDP and four fifths of primary energy requirements of all developing countries, FDI as a percentage of gross domestic investment (GDI) was relatively stable at 2-3 per cent during the 15-year period ending in 1986 but then rose to about 4 per cent during the late 1980s and during the 1990s rose sharply, reaching 10 per cent in 1994. The massive infusion of FDI during the 1990s was strongly correlated with a drop in the energy intensity of the economy at a rate averaging about 1.5 per cent/year (see Figure 2), more than 50 per cent faster than the long term historical trend—probably due to the introduction of modern technologies that came with the FDI and thus leapfrogging over the traditional technologies in wide use in the countries.

The challenge of rural energy

A pressing concern is that some two billion people—mostly in rural areas of developing countries—do not have access to affordable modern energy services that could help them break out of cycles of poverty, ill-health and deprivation. It would be an enormous mistake—

on moral, political and economic grounds—to ignore the plight of this deprived segment of humanity.

Serving rural energy needs is a daunting challenge but is not technologically constrained. Technologies are available that could make significant improvements in living standards in just a few years. And looking ahead, many new technological options will become available. Table 1 outlines some of the prospects for meeting energy services for rural areas over the near-, medium- and long-terms. Some of the more advanced technologies are described in the next section.

The remote, dispersed character of rural populations makes provision of electrical energy services problematic. The extension of centralized, grid-based systems will probably not be economically feasible in the foreseeable future. Decentralized rural electrification—based on various combinations of wind turbines, mini-hydro turbines, village-scale biopower systems, solar photovoltaics, and diesel generators—may be the solution. Some of these technologies still need public-sector support for their development, but even for those decentralized power systems for which cost-effectiveness is proven, some public investment will probably be required to get systems up and running.

As a general rule, subsidies for commercially established energy technologies are ill-advised, for reasons discussed below. But an important exception is temporary subsidies to ensure that energy services from modern, clean energy supplies are available in quantities sufficient to satisfy basic needs of the poor, including the rural poor, as an element of an integrated development initiative that seeks to alleviate poverty in rural areas. Such subsidies should serve as an enabling transitional measure rather than a permanent crutch. It is useful, in this

Table 1: Some near-, medium-, and long-term technological options for rural energy

Energy source or task	Present	Near term	Medium term	Long term
Source				
Electricity	Grid or no electricity	Natural gas combined cycles, biomass-based generation using gasifiers coupled to internal combustion engines, photovoltaic, small wind, small hydroelectric for applications remote from grids	Biomass-based generation using gasifiers coupled to microturbines and integrated gasifier combined cycles, mini grids involving various combinations of photovoltaic, wind, small hydroelectric, batteries	Grid-connected photovoltaic and solar thermal, biomass-based generation using gasifiers coupled to fuel cells and fuel cell/turbine hybrids
Fuel	Wood, charcoal, dung, crop residues	Natural gas, LPG, producer gas, biogas	Syngas, DME	Biomass-derived DME with electricity coproduct
Cogeneration (combined heat and power)		Internal combustion engines, turbines	Microturbines and integrated gasifier combined cycles	Fuel cells, fuel cell/turbine hybrids
Task				
Cooking	Woodstoves	Improved woodstoves, LPG stoves, biogas	Producer gas, natural gas and DME stoves	Electric stoves, catalytic burners

Lighting	Oil and kerosene lamps	Electric lights	Fluorescent and compact fluorescent lamps	Improved fluorescent and compact fluorescent lamps
Motive power	Human- and animal-powered devices	Internal combustion engines, electric motors	Biofueled prime movers, improved motors	Fuel cells
Process heat	Wood, biomass	Electric furnaces, cogeneration, producer gas, NG/solar thermal furnaces	Induction furnaces, biomass/solar thermal furnaces	Solar thermal furnaces with heat storage

context, to recall that the extension of modern energy to the rural areas of the now-industrialised countries has often been accomplished through large government interventions. The current trend of corporatising inefficient public sector units may need to be coupled with imposed obligations to serve the underprivileged.

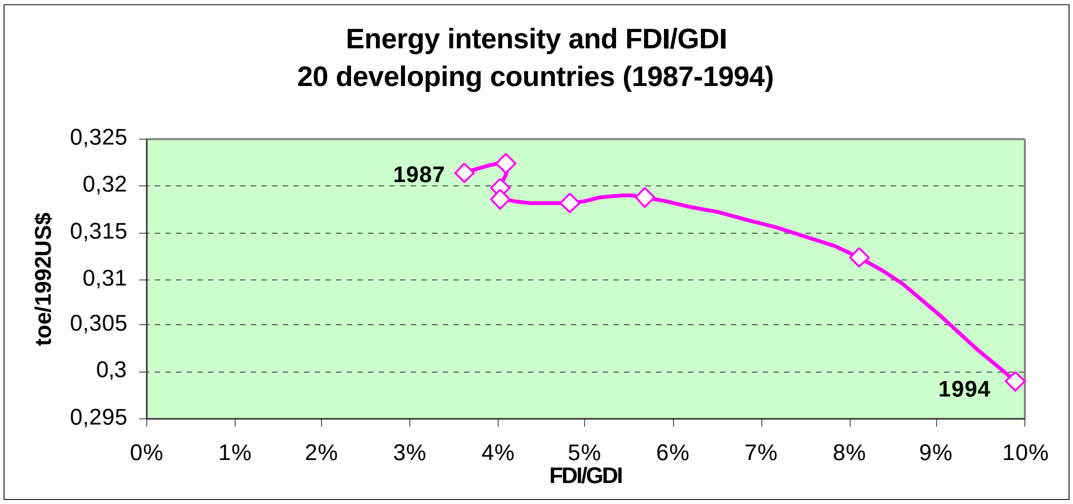

Figure 2: Energy Intensity of Economy for 20 Developing Countries vs. Percentage of FDI in GDI

GDP data are on a purchasing power parity basis, from the World Resources Institute. Energy, foreign direct investment (FDI), and gross domestic investment (GDI) data are from the World Bank report, World Development Indicators 1999.

Subsidizing rural energy would not necessarily mean abandoning the use of market mechanisms to efficiently allocate resources. Consider, for example, the rural energy concession, an arrangement in which a substantial market is awarded to a supplier, along with an obligation to serve all customers within a specified market. If such a concession were awarded competitively, market forces could hopefully be brought into play to find the least-costly mix of energy technologies. While some subsidy might still be necessary, competition would help ensure that public funds provided the minimum subsidy required to satisfy the concessionaire's obligation to provide modern energy to all. This rural energy concession concept is theoretically very appealing but requires testing and modification as needed in light of field tests, because successful experience is lacking.

Envisioning radical change in energy technologies worldwide for the long term

Over the long-term, *not just new but truly radical new* energy technologies will be needed in order to address effectively the challenges of air pollution, climate change, and energy supply insecurity while expanding energy service availability to all, including those who today do not enjoy the benefits of modern energy, and keeping the costs of energy services affordable to all. One hopes to see during the second quarter of this century technologies like (i) photovoltaic power, (ii) fuel cell cars, (iii) hydrogen derived from fossil fuels with sequestering of carbon dioxide in geological reservoirs, and (iv) dimethyl ether (or similar synthetic fuel) derived from biomass, become as commonplace as gasoline cars and coal-fired power plants are today. And if such technologies are to be commonplace during the second quarter of this century, they must be launched in the market during the first decade of this century. These are daunting challenges.

Realizing a future for energy that is supportive of sustainable development goals requires thinking seriously about the long term—say 2050 and beyond. A clear articulation of long-term goals is essential for prioritizing near-term activities for building the path to a sustainable future.

The long-term energy future must be both affordable and characterized by near-zero emissions of both air pollutants and greenhouse gases. It must also involve a diversification of the transportation energy supply system away from petroleum. Ideally, such a future would involve using only three energy carriers: electricity, hydrogen and a superclean carbon-based fluid fuel—perhaps dimethyl ether.

Electricity is a very familiar clean energy carrier that in principle might satisfy all energy needs. But storing electricity and using it to meet peaky energy demands (as in transportation) is difficult, so one or more fluid fuels will also be probably needed as well—although this judgment might change if there is a breakthrough in electric storage technology.

Hydrogen is a fluid fuel that can be derived from a wide range of primary energy sources. Its use can facilitate a shift to highly-efficient end-use devices such as fuel cell vehicles. Its production and use could satisfy the zero emissions criteria if the CO_2 co-product were sequestered securely in geological formations whenever the hydrogen is manufactured from fossil fuels. There is growing optimism in the scientific community that the global capacity for secure CO_2 storage in such formations is large, although more research is needed to be confident of this.

One drawback of hydrogen is its low volumetric energy density, which complicates storage issues. For this reason, hydrogen will probably be economically viable mainly in urban areas having high population densities where fuel infrastructure costs can be kept to relatively low levels. For rural areas, which characteristically have low population densities, an easily storable carbon-based fluid fuel will probably be needed—even in the long term. But if a new carbon-based fuel is to be introduced, it should probably be both far cleaner than today's hydrocarbon-based liquid fuels, derivable from a wide variety of primary feedstocks, and useful in a wide range of rural applications. To meet the near-zero greenhouse gas emissions criterion, the fuel should be derived from biomass. The energy carrier that comes closest to meeting these criteria is dimethyl ether. DME is not used today as fuel but rather as an aerosol spray-can propellant that has come to replace fluorinated hydrocarbons that were phased out because of ozone-layer depletion concerns. At ambient conditions, DME is a gas that must be stored at modest pressure, for example, in canisters very similar to the canisters now used for storing LPG. Like LPG, DME is an ideal cooking fuel. It is also a good energy carrier for use in compression-ignited engines—the combustion of which leads to zero soot formation. And it is well suited for use in fuel cells for stationary or mobile applications because it is even easier to reform than methanol.

In an energy future based on these energy carriers, electricity could be produced from renewable energy sources such as PV, wind, and hydroelectric power, or from hydrogen or DME in some applications.

The hydrogen for urban use might well be produced in large city-gate plants that produce electricity as co-product. Such plants would use as feedstock a variety of carbonaceous materials—natural gas, coal, heavy oils, municipal solid waste. Hydrogen would be delivered to refueling stations for hydrogen fuel cell vehicles and to buildings where it would be used both in fuel cells for CHP as well as for cooking and supplemental heating. The CO_2 byproduct of hydrogen production would be transported by pipeline to geological disposal sites such as deep saline formations located up to several hundred km from hydrogen/electricity production plants.

The DME for rural applications would probably be produced from biomass feedstocks (perhaps from crop residues) as a co-product with electricity in relatively small-scale plants (perhaps 10 megawatts of electricity plus 60 tonnes per day of DME) located near where the biomass is grown. Manufacture of these modern energy carriers from crop residues would create the opportunity for even the poorest households to afford the clean energy produced with income they might earn gathering residues from the fields of rich farmers and delivering them to energy conversion centers.

This vision for the long term is of course only one of many possible alternative futures for energy systems at mid-century that would be characterized by near-zero emissions and enhanced energy supply security. It has been chosen for illustrative purposes because, on the basis of preliminary calculations, it appears that there are reasonably good prospects that such clean/secure energy systems could be evolved at attractive costs compared to conventional energy systems and thus "affordable."

But would such systems be sustainable? To the extent that they rely on fossil fuels of course they would not be. Eventually both economically recoverable fossil fuels and secure CO_2 storage capacity will run out. It is not yet clear which limit will come first, but these physical constraints are likely to be manifest only in the very distant future. But these fossil energy systems with their characteristics of near zero emissions of air pollutants and greenhouse gases, diversified primary energy resource base, and affordability might suffice for a century or two.

Of course it might turn out that geological sequestration of CO_2 at large scales is not viable because of some environmental and/or storage security problems that are not currently foreseen. Under such conditions hydrogen could alternatively be provided by electrolysis using a renewable electric source. But electrolytic hydrogen would be much more costly—even under optimistic assumptions about long-term costs for renewable electricity and advances in electrolytic technology.

The detailed features of an energy future such as this one in which electricity, H_2 and DME are the dominant energy carriers can be described in technological terms in some detail based on present knowledge. Substantial cost reductions for proven technologies would be needed via exploitation of scale economies, learning, and continuing marginal technological improvements to realize such an energy future. Fundamental technological breakthoughs would of course be helpful but would not be necessary to move toward. But getting there will not be easy because fundamental redesign and rebuilding of the entire energy system are required. Perhaps most important, the process would have to be guided by public-sector leaders who would both set the goals for a clean and secure energy future and enact the facilitating policies, and by private- sector leaders who would show the way and begin making the needed investments.

Getting to a sustainable future demands action now

Many might think that putting in place an energy system like the one described above by the middle of this century should be the responsibility of the next generation. But that is not so. If we as a human society decide to pursue such a future or something similar we have to begin to shift to such a course very soon, because of the slow rate of turnover of the capital stock for the energy system. Long lead times for new technology dictate that intensive energy innovative activity is needed today in order to establish a portfolio of new energy technology options to choose from over the longer term. Effectively addressing such long-term technological challenges will require major new public policy initiatives. New public policy initiatives are also needed to encourage wider deployment of many commercially available clean and efficient energy technologies, with which much can be done in meeting sustainable development objectives.

Whatever is done to promote energy strategies and technologies for sustainable development must be carried out in the context of the evolving structure of the energy industry worldwide, which, in short, has involved a diminishing role for government in supplying and distributing energy. In the industrialized countries this has been driven largely by technological changes that undermine some of the natural monopoly features of the energy system and is leading to restructuring aimed at encouraging more competition in energy markets—most notably advances that make smaller scale systems for energy conversion more economically attractive. In developing countries energy sector restructuring toward corporatization or privatization, in some instances with elements of competition as well, are taking place—mainly as a response to inefficiencies and other difficulties with publicly run energy companies, although the technological advances that are driving change in industrialized countries are also relevant.

Some might view this diminished role for governments as a threat to the protection of public goods—especially in the face of the daunting requirements for making the energy system sustainable. However, ongoing structural changes in the energy sector also present an opportunity for a new role for government. Indeed, implementing regulatory and tax measures to protect societal objectives and ensure fair competition may be a more appropriate and effective role for government.

In the process of economic liberalization, corporations are created that act under the provisions of the legal, economic and regulatory systems of the country. Changes in these framework conditions often demand readjustments, with associated costs and changes in competitiveness, and are therefore often resisted. However, once a new framework is introduced to replace a monopoly situation, the process of change has already begun. This transitional period, while the rules are in flux, may present a timely opening in which to introduce and negotiate provisions that address social and environmental concerns. Because of ongoing market reforms, many countries are now in a position to take advantage of this window of opportunity.

One of the most obvious places to begin the process of redirecting the course of energy, in a world whose economic functioning is dictated by markets, is by making sure that the power of the market in efficiently allocating resources is working toward the efficient realization of societal aims. In the energy sector, economic efficiency is hampered by a lack of competition and huge price distortions. Its functioning would be enormously improved by promoting competition, removing subsidies, and internalizing externalities. The emergent new energy industry should be reregulated in ways that are consistent with this new, more efficient, more competitive market structure, to compensate for freemarket shortcomings in addressing sustainable development objectives.

Promoting competition to keep energy prices in check is complicated in the power sector by the high cost of electricity storage options, which dictates that most electricity must be consumed as soon as it it generated., so that reforms promoting competition must be shaped to ensure that reliable electricity supplies are adequate to meet demand. Such considerations highlight the importance of coupling measures promoting competiton to integrated resource planning activities that establish goals for capacity expansion and electricity supply reliability that would be met competitively.

Energy subsidies work at cross-purposes to the aims of sustainable development, representing public costs at the global level of the order of US$100-200 billion per year—not including those in the transport sector. Since these support conventional technologies, they create a huge hurdle for new technologies, especially energy efficiency improvements and renewables, to overcome.

However, as discussed above, an important exception to the general rule of removing subsidies is where the subsidy would be used to ensure that basic needs of the poorest and most vulnerable groups are met and provided in the context of broader programs designed to help such groups break out of a cycle of poverty. One possibility is “lifeline rates” for such groups, that is, the provision of small amounts (in the case of electricity, perhaps 50 kilowatt hours per household per month at little or no cost). Because the goal should be to satisfy basic needs at the least cost, a key part any scheme should be a one-time subsidy to assist in the purchase of energy-efficient capital equipment (e.g., compact fluorescent light bulbs, LPG stoves). Where such subsidies are well-targeted, and well-designed (to encourage use, but not inefficiency), the resulting benefits—including access to the outside world through radio and television, light for reading and studying, time savings, health benefits and so on—far outweigh the costs.

A second distortion occurs because externalities are often not reflected in prices (although many European countries, in particular, have made considerable progress in this). In the absence of government intervention, markets fail to account for environmental and other societal costs associated with energy production and use. Finding ways to accurately figure these negative externalities into the energy pricing equation is difficult, however, partially because there is no consensus on how to measure their costs in monetary terms. Nevertheless, the best estimates available of these "external" costs are that they can be substantial—in some cases comparable to, or in excess of, the direct private costs of the energy provided. Various approaches can be taken to integrate externalities into prices at the national level. One widely practiced approach is to regulate harmful emissions of energy systems to air, water, and solid waste streams. An alternative approach is to tax emissions. A carbon tax provides a simple and consistent method for internalizing the cost of mitigating climate change. A mix of carbon taxes and other pollution-impact-weighted energy taxes could address a wide range of environmental impacts associated with energy production and use; all or most of the revenues so generated should be used to offset revenues from conventional taxes that are regressive or otherwise unfair. Correct pricing signals can have a profound impact on measures to make renewable and advanced near-zero-emitting fossil energy systems more competitive and to overcome some of the obstacles standing in the way of energy efficiency improvements.

Unfortunately for the many strong candidate technologies for meeting sustainable development objectives that are already cost-effective, "getting the energy prices right" is not sufficient to ensure widespread deployment. It is now widely recognized that many cost-effective energy efficiency improvements are not readily implemented by market forces alone, because of a range of institutional barriers—barriers that are faced by many renewable and distributed energy systems as well. Barriers include lack of information about costs and benefits, high implicit consumer discount rates (potential benefits tend to be strongly discounted by individuals who have to invest time and money up front in order to realize long-term savings), inadequate financing opportunities, split responsibilities between those who make investments and those who pay operating costs, and high transaction costs because of a lack of market aggregration in the delivery of services provided, among others. Such problems call for government intervention. The needed programs can take various forms, including information programs, regulations (e.g., energy efficiency standards), tax incentives, subsidized loans or guaranteed prices, government procurement and competitive market transformation initiatives. To the extent that government intervention involves subsidies, the support should be temporary and part of a broader initiative aimed at eliminating the targeted barrier. "Green" pricing, whereby customers can choose to pay higher prices for environmentally friendly energy, is a market-based mechanism for helping overcome barriers to such technologies.

Another crucial area for public policy and investment is in helping to develop and launch some of the advanced technologies discussed above. Because the private firm cannot fully appropriate the benefits of R&D investments and the existence of environmental and other negative externalities, it is widely recognized that government has a major obligation to support research and development (R&D)—and the need for such support is especially great for energy R&D. What is not widely recognized is that government also has major obligations to encourage demonstration projects and early deployment of energy technologies that offer promise in addressing sustainable development objectives, because the market alone will typically not be able to overcome the higher initial costs of new energy technologies. Even after R&D has shown the viability of promising new technologies, demonstration projects and decades of market growth are typically required before new technologies can command major market shares.

Demonstration projects are generally costly, risky and difficult to finance, so that government support is crucial at this stage of the energy innovation process. One way of limiting risks and enhancing prospects that demonstration will be followed by commercialization is to insist on major roles for the private sector. Some of the most successful demonstration projects have been those where the government role has been to set performance and cost goals and to have only limited financial involvement (e.g., providing only a fraction of the needed capital investment or providing instead a price guarantee for the energy produced in the demonstration project), while the private sector has taken responsibility to decide how to meet the goals and has shouldered a substantial share of the financial risk.

Even after successful demonstration, incentives will often be needed to bring clean energy technologies to the point where they can compete with conventional energy. Radically new energy technologies offering significant potential in meeting sustainable development objectives are almost invariably initially more costly than the conventional energy technologies they would displace. But economies of scale in production, learning, and competition can all help drive the costs of new technologies down. Typically, manufactured goods show cost declines of about 20 percent for each cumulative doubling of production. Subsidies for “buying down costs” of such technologies to market clearing levels (see Figure 3) are warranted but should be crafted to be both effective and efficient. Mandated market share measures that use market competition to select among qualifying technologies those that warrant subsidy offer promise in these respects. The UK’s Renewables Non Fossil Fuel Obligation that was in place in the 1990s and the Renewal Portfolio Standard (known as the Green Certificate Market in Europe) being tried in several countries around the world are examples of such initiatives that encourage cost buy-downs by stipulating that a specified amount of renewable energy or percentage of renewables in the energy mix is provided by energy suppliers. Experience with the Non-Fossil Fuel Obligation illustrates both the efficacy and the economic efficiency of this approach: between 1991 and 1998, the average contract price for renewables purchased in a series of auctions declined nearly three-fold, yet the cost of buy down, paid for via a levy on fossil fuel power suppliers was never burdensome, resulting in a retail consumer rate increase of no more than 1 per cent in any year.

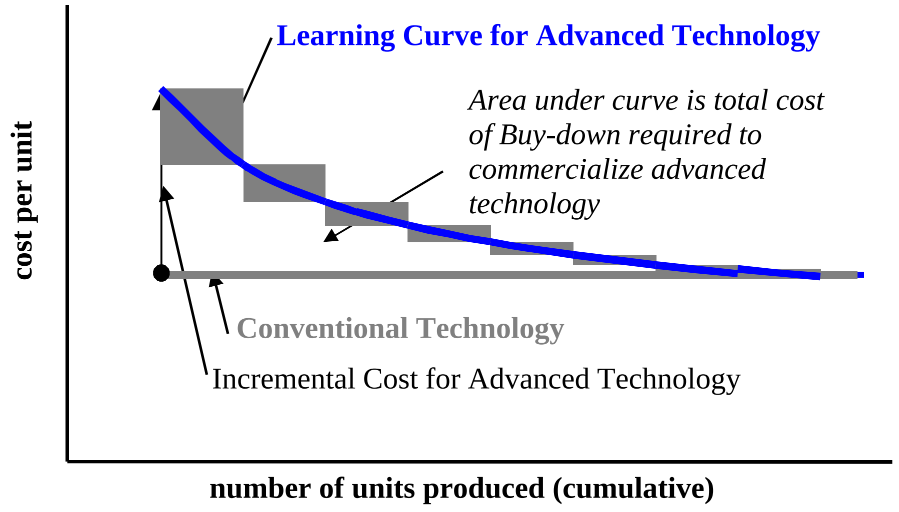

Figure 3: Learning Curve and Buy-Down Cost for an Advanced Energy Technology

The incremental cost for buying down the cost of the advanced technology relative to the conventional technology is shown, as the advanced technology moves along its learning curve. The triangular area between the curves indicates the total cost for buying down the cost of the advanced technology to the level at which the advanced technology is competitive with the conventional technology. The point where costs for advanced and conventional technologies are equal does not necessarily represent the asymptotic (long-term) market price for the advanced technology.

If developing countries are to meet their energy needs, they will also need more human capital and stronger institutions. Technological, entrepreneurial, and managerial capabilities are all critical for successful technology transfer and innovation. Such capacity building in developing countries is a sine qua non condition for technological leapfrogging. Yet, capacity building in developing countries is often given low priority even by organisations that are supposed to be committed to this challenge. Capacity building is a slow, time-consuming process, and program executives in a hurry for profits do not emphasize the task. However, without strong private- sector actors and markets as well as sustainable energy programs and agencies, sustainable energy initiatives in developing countries are likely to be ad hoc, limited in scope, and insufficient to overcome the full set of barriers inhibiting large scale implementation.

Strong government-private sector collaboration has been a key feature of many successful market development programmes. This means involving the private sector in programme design as well as implementation. Successful national energy efficiency and renewable energy centers and programs are already operating in Brazil, China, India, and Eastern Europe. These centers and programmes work with the private sector, utilities, and other entities to introduce and provide support for a variety of energy efficiency and renewable energy measures.

A tremendous challenge for human society is to move beyond the tangible pressures experienced today and to manage global resources with future generations in mind. Taking such actions, in the face of competing short-term interests, will require a paradigm shift. For this shift to occur, the sustainability debate must move to centre stage and be accompanied by greatly raised levels of public awareness, information and commitment. Continued dialogue and consensus building within the international community, between the public and private sectors, and within society at large is needed to advance sustainable energy policies at the national, regional and global levels. A goal-oriented, strategy-based policy driven approach to energy in the new paradigm implies that the future is a matter of choice rather than business-as-usual destiny. In this sense, we continue to be the optimists we were when *Energy for a Sustainable World* was first written—harbingers of hope rather than prophets of doom.

Further Reading

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