4. The role of government and the contribution of science and technology

The current structure of market incentives and regulatory conditions in much of the world will not, by itself, produce sustainable outcomes or socially optimal investment decisions. Alternatives to today's dominant technologies may exist, but there is no certainty that they will be deployed on the scale and in the timeframe necessary to avoid some of the most troubling consequences of the world's current energy trajectory.

The energy picture will surely change—but, without policy intervention and technological innovation, not necessarily for the better. If the aim is to simultaneously address climate-change risks, improve energy security, and expand access to modern energy services for the world's poor—while at the same time improving environmental quality and protecting public health—governments will need to act now and technology will need to improve.

This chapter discusses the role of government and the contribution of science and technology (S&T) in initiating and sustaining a broad-based transformation of the world's energy systems. Certainly, government—with its ability to influence markets, technology, and behavior through policies and regulations—has a critical role to play. Judicious policy interventions, far from interfering with the proper functioning of markets, may be necessary to address pervasive market failures and to ensure that private incentives align with societal imperatives to produce economically and environmentally sustainable outcomes. Experience has shown that purely free market economies seldom deal adequately with macroeconomic or international problems (such as water and air pollution or open sea fishing) that exhibit 'tragedy of the commons' characteristics. At the same time, the process of technological innovation to develop new energy options for the next generation and beyond must also accelerate. Public and private sector investments in energy research, development, and demonstration (RD&D) have been inadequate to the world's energy challenges for some time now and this will have to change as soon as possible.

At the same time, a more widespread deployment of existing technologies should be pushed by governments even earlier.

At their best, government policy and technology RD&D interact in complementary and mutually reinforcing ways. Well-designed policies and regulations can generate a market *pull* for technologies that are already developed and close to commercialization. At the same time, concerted public and private investments in energy RD&D can *push* the process of innovation, expanding the menu of technology options that will be available in the future. Related policies—with respect to educating the public, issuing patents, and developing human capital by nurturing a new generation of professionals and scientist with energy expertise—also have a critical role to play. Several recent reports argue that the combination of pull and push mechanisms is likely to be more effective than either approach alone (NCEP, 2004; CBO, 2006).

This chapter also reviews, in general terms, some of the policy levers available to government for advancing sustainable energy objectives, as well as the role of science and technology and some near-term RD&D priorities. At the outset, it is worth remembering that while interest in reducing greenhouse gas emissions per se is relatively new, the history of energy policy and of energy RD&D around the world is rich with experience. Many nations have, at one time or other, sought to advance indigenous fuel sources, reduce conventional energy-related pollutant emissions, develop new technology options, or make energy more widely available. A wide variety of strategies to advance these and other energy-related objectives have been employed, with varying degrees of success. On the one hand, bad energy planning and poorly designed price controls and subsidies, at a rate of more than US$200 billion per year, have distorted markets, produced unintended consequences, and in some cases led to artificial shortages (UNDP, UNDESA, and WEC, 2004). Similarly, the fact that large sums of public money have been expended on technology programs that have yielded, at best, disappointing results points to the need for improved management of future research & development (R&D) efforts, which should be subjected to continual expert cost/benefit analysis, and to the importance of pursuing the end-goal of shifting technology investments to the private sector.

On the other hand, the record of accomplishment is also impressive. Rural electrification programs have given hundreds of millions more people access to modern energy services. Many countries have successfully nurtured new energy industries, and environmental laws and standards

have prompted the development of radically cleaner and more efficient technologies. Around the world, the amount of energy used and pollution generated to produce a dollar of wealth has declined steadily, even as quality of life and access to energy amenities has improved for large segments (though by no means all) of the world's population.

4.1 Policy options

Governments have many options for advancing a sustainable energy agenda. Table 4.1 provides a basic taxonomy of policy approaches, along with numerous specific examples: it is intended to suggest the breadth and variety of strategies that are available and is by no means exhaustive. Importantly, most of the policy options noted in the table could be applied to promote solutions on both the supply and the end-use side of the energy equation. Within the broad category of 'carrots' are policies that rely on positive incentives to stimulate desired activities or technologies; examples include grants, loan guarantees, subsidies, or information and technical assistance programs. Efforts to raise public awareness, provide training (especially to energy professionals), and educate building designers and architects can also help to advance a sustainable energy agenda. Public infrastructure investments, while they do not exactly constitute an incentive, are included here because such investments can help overcome economic or technical obstacles that would otherwise impede the adoption of new technologies. For example, efficient, long-distance electricity transmission systems can open new markets for renewable energy resources while sophisticated metering networks could help homeowners and businesses manage their energy consumption more efficiently.

Policies that create positive incentives tend to be politically popular (or at least relatively uncontroversial) but usually require government to expend revenues, often with uncertain results. Like nearly all policy options, they impose opportunity costs on society (in the sense that the money spent could be put to other uses). But because those costs are diffuse and borne by taxpayers, they are often, in a political sense, hidden. The effectiveness of voluntary, incentive-based or information-based programs depends on the scale of the resources that are brought to bear and on how efficiently those resources are deployed: targeting social spending so that it achieves maximum public benefits at lowest cost is often a significant challenge. Subsidies, for example, can be quite effective in accelerating the adoption of certain technologies. But subsidies can also be inefficient (to the extent that they benefit households or industries that do not need them) and difficult to remove, unless an eventual phase-out is part of the policy from the

Table 4.1 Policy options for promoting a transition to a sustainable energy future

Incentives: 'Carrots'			
Financial incentives • tax credits • subsidies • grants, other direct funding • loan guarantees • procurement policies • feed-in tariffs		**Non-financial incentives** • publicly-funded RD&D • infrastructure investments • education/information/labeling • technical assistance • award/recognition programs • grid access	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Potentially useful to advance 'cutting-edge' technologies. • Often politically popular. • Can be targeted to overcome particular market obstacles or promote specific technologies.	• Require government to spend money. • Spending may be politically influenced and not always cost-effective (e.g., subsidies continue even when no longer needed). • Results are difficult to predict. They tend to be biased toward well-understood options.	• Provide means to address other market failures/ barriers. • Usually politically popular. • May have a variety of spillover benefits. • Can help address competitiveness concerns.	• Difficult to target RD&D, infrastructure investments. • Institutional and technical capacity required to develop and deliver programs. • Benefits/impacts may be limited, especially without complementary financial incentives.
Disincentives: 'Sticks'			
Market-based policies • energy or emissions taxes • emissions cap-and-trade programs		**Prescriptive regulations** • emissions standards • efficiency standards • portfolio standards	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Can be applied economy-wide. • Markets deliver least costly reductions. • Individual firms, consumers retain choice, flexibility. • Generate revenues that can be used for other purposes. • Consistent price signals yield economically rational outcomes across all covered sectors. • Can be designed to meet specific objectives in terms of cost, emissions reductions, etc.	• May generate strong political opposition because they raise prices. • Energy-price impacts on poor households will be a concern (though should note that revenues generated by policy can be used to address this issue). • May raise concerns about impacts on domestic industry in terms of jobs and competitiveness in world markets. • Price signals may be inadequate to overcome other market failures or stimulate new technologies.	• Effective where price signals alone would not elicit all cost-effective responses (e.g., car, building, appliance markets). • Policy outcomes are relatively certain (though costs may not be). • Many manufacturers, industries already subject to some regulation. • Costs are less evident, potentially reducing political opposition. • No action needed on part of consumer.	• Usually do not encourage or reward better than minimal compliance. • Require technical and institutional capacity to develop, enforce standards. • Different policies needed for different sectors. • Defining cost-effectiveness is uncertain and often contentious, especially if regulators have to project future tech development. • Less flexible and (potentially) more costly than market-based approaches. • Policies need to be updated over time.

outset. Also, subsidies that are too large discourage innovation to lower costs and can freeze development

One issue that has not been solved is how to more closely couple capital investments in energy-efficient commercial and residential building budgets with savings that would be accrued in operation and maintenance costs. In industrialized countries, additional investments are seldom made unless the pay-back time is less than one to two years; and in developing countries, the initial cost dominates virtually all investment decisions. If the payback time on energy efficiency investments were extended to 6–10 years, the building industry would be transformed. Regulations such as energy-efficient building codes are a partial solution; access to low-cost capital targeted for energy-efficiency investments in both new construction and in building retrofits is also needed.

Governments also have the option of deploying policy 'sticks' to compel changes in technology and behavior. This category of approaches can achieve desired results more expeditiously and more efficiently (that is, at lower net social cost), and typically does not involve large outlays from the public treasury. Some options, like fuel taxes, actually generate revenues. Removing subsidies to conventional energy sources or ensuring that energy prices reflect external costs and benefits can also produce effective results by shifting the market incentives for different technologies. (The failure to include externalities in market prices by itself often constitutes a form of subsidy for entrenched technologies.) Not surprisingly, however, policies that are perceived as raising prices are also more likely to confront organized political resistance from affected interests and to give rise to concerns about the potential for regressive impacts on poor households and for adverse effects on industry competitiveness. Many of these concerns can be ameliorated by careful policy design, but it will also be critically important to educate the public and foster greater awareness of the energy-sustainability challenge so as to build political support for difficult policy choices.

Policymakers should also recognize that energy markets are extremely volatile, and hence quite sensitive to supply disruptions and/or manipulation. A significant number of energy technology investments initiated during the spike in oil prices that began in the mid-1970s were wiped out when the cost of oil dropped to US$20 per barrel in 1980s and remained at that level for most of the 1990s (Figure 4.1). The private sector is less likely to make long-term investments in new energy technologies if there is a real possibility that the price of oil will again decline from current

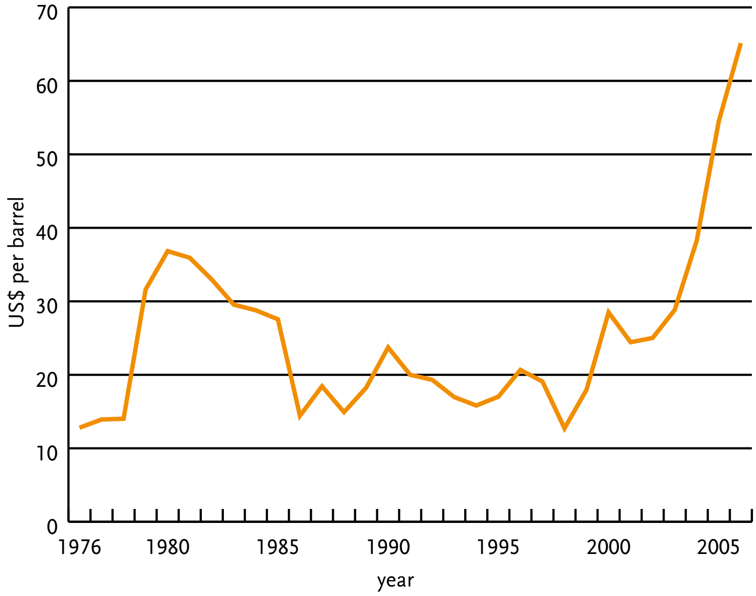

Figure 4.1 The development of crude oil prices over the last three decades

Note: Shown are nominal (not inflation-adjusted) spot prices for Brent crude.

Source: Platts, 2007.

levels of US$60–70 per barrel to below US$30 per barrel. Indeed, existing stakeholders in a given industry have sometimes sought to protect their economic interests against a threatening new technology by dropping the price of their product before the infant competition can advance too far down the learning curve.

Science and technology policies are not individually identified as distinct options in Table 4.1, though nearly all of the examples listed could be used to directly or indirectly spur the development and deployment of more sustainable energy technologies. Clearly, public support for research and development (included under policy 'carrots' in Table 4.1) is among the most important tools available to government for influencing future energy developments. Because of its importance and complementarity with other policy options, however, publicly funded research and development (R&D) is included with a broader discussion of the role of science and technology in the second half of this chapter.

4.2 Policy choices in context

The best mix of strategies for promoting sustainable energy objectives will vary depending on a given country's policy priorities; its financial, institu-

tional, and technical capacities; its political and regulatory traditions and market structure; and other factors. For many wealthy, industrialized countries, the chief objective will be to maximize cost-effective, energy-efficiency improvements; accelerate the adoption of low- and non-carbon technologies; and address energy-security concerns (especially related to dependence on oil and natural gas and nuclear non-proliferation). Policies well-suited to advancing these objectives are likely to include standards, environmental regulations, and market-based programs (such as a carbon tax or emissions-trading program.

The situation for developing countries, by contrast, is likely to be complicated by additional imperatives and constraints. To the extent that some sectors of the economy and segments of the population consume energy in much the same way as in industrialized countries, developing countries may share similar objectives—and confront similar opportunities—in terms of addressing energy-related environmental externalities and energy-security concerns. For this reason, policies aimed at promoting alternative fuels, low-carbon technologies, or improved efficiency are needed as urgently in developing countries as in industrialized countries.

In these situations, pricing or other policies can be used to promote investments in energy efficiency and alternative technologies. Where price signals are used to discourage consumption and/or produce more sustainable technology choices, it may be necessary to ameliorate potentially regressive impacts on lower-income households; this can often be accomplished using a variety of policy mechanisms. At the same time, other policies—such as appliance and equipment standards—can help to ensure that, as developing economies industrialize, they 'leapfrog' to cleaner, more efficient technologies. Countries that are rapidly expanding their stock of buildings, infrastructure, and capital assets have a unique opportunity to 'build in' improved energy performance at lower cost and with greater long-term benefits than would be possible if energy and environmental liabilities are addressed only as an afterthought.

The list of available policy options is long and lends itself to virtually endless variations, as indicated in Table 4.1. Most of these options have strengths and disadvantages. And it is unlikely that a single policy will achieve all desired objectives. A policy designed to create a consistent, economy-wide price signals for reducing greenhouse gas emissions (such as a carbon tax or cap-and-trade program) may not be sufficient to ensure that all cost-effective efficiency opportunities are captured or to overcome barriers to entry for new technologies. Complementary policies (such as

vehicle and appliance efficiency standards) may be appropriate. Subsidies or tax credits used to stimulate innovation should be invoked with built-in 'sunset' clauses.

Often, thoughtful policy design can overcome some of the drawbacks of a particular approach, producing hybrid strategies that combine the best features from multiple options. A portfolio standard can be used to require that a specific percentage of electricity production is derived from renewable or non-carbon resources while still allowing the market to sort out what mix of those resources would meet that requirement most cost-effectively. Similarly, innovative mechanisms such as a 'reverse auction'—in which providers of clean energy bid for a share of some available limited-term incentive pool based on the minimum subsidy required to successfully compete in the market—can help to maximize the benefits achieved using scarce public resources. In addition, trading or averaging can be used to implement an efficiency standard while incorporating some of the flexibility and cost-reduction benefits associated with market-based programs.

Individual countries will, of course, need to evaluate their options and their priorities and decide on a mix of approaches that suit their specific circumstances. Even as different countries pursue different approaches, however, it is likely that significant benefits can be achieved by maximizing coordination and information-sharing, where feasible. For example, manufacturers that sell products all over the world may benefit from harmonized efficiency or emissions standards while certain economic sectors, such as marine shipping and aviation, may be most effectively regulated at an international level. Similarly, the ability to trade well-defined and reliably-documented emission-reduction credits across national boundaries could allow for significant cost reductions in reducing global greenhouse gas emissions while providing an important mechanism for facilitating technology transfer to poorer nations.

An important related question arises: *how can companies be encouraged in rich countries to share advanced technologies—both end-use and supply technologies—with developing countries?* Businesses are not charities and requiring them to share intellectual property at below 'market value' will discourage investment in the development of new technologies. On the other hand, without subsidizing the cost, superior technology alternatives may go unused in such countries as China and India. It would therefore be useful to explore options for providing low-cost access to intellectual property related to sustainable energy technologies and practices. For example, it

might be possible to devise a mechanism for compensating intellectual-property holders from an international fund established by wealthier countries.

4.3 The importance of market signals

Although few specific policy recommendations can be ventured at an international level, certain policies are likely to have widespread applicability. Efficiency standards and building codes have been implemented cost-effectively in many industrialized countries. The knowledge gained there can be emulated and improved upon to help moderate energy demand growth in rapidly industrializing economies. Subsidies that distort energy markets, particularly when they do so in ways that favor increased fossil-fuel consumption, should be reduced and reformed; instead energy prices should reflect, to the maximum extent feasible, environmental and other externalities.

The point is critical: without market incentives to prompt different behaviors and investment decisions, policies that focus solely or primarily on voluntary reductions in greenhouse gas emissions and technology R&D are unlikely to promote change on a scale commensurate with the environmental challenge at hand. Opinions vary as to the level of price signals that are warranted, but many experts believe that a price on the order of US$100–150 per ton of carbon equivalent emissions (in other widely used units, US$27–41 per ton of carbon dioxide equivalent emissions) may be necessary to overcome current cost differentials for many low- and non-carbon technologies and to stimulate the large-scale changes that will be required to eventually stabilize atmospheric concentrations of greenhouse gases. The two policy options that are most frequently proposed to address climate concerns are energy or carbon taxes and cap-and-trade programs; important features of each approach are discussed in Box 4.1.

It is important here to emphasize, however, that establishing in every market that there eventually will be an emissions price—in the range of US$100–150 per avoided metric ton of carbon equivalent (US$27–41 per ton of carbon dioxide equivalent)—is more important than establishing exactly the number of years in which such a transition will occur. For many countries, pragmatic considerations are likely to argue for a phased and multi-pronged approach, wherein an initial carbon price signal is gradually increased over time and complemented by other policies to address remaining market barriers and accelerate the commercialization of more efficient, lower-carbon technologies. Complementary policies, such as

appliance and building standards and air pollution control requirements, can likewise be introduced slowly but inexorably. By making resistance from entrenched stakeholders begin to appear futile, this approach can effectively stimulate innovation and reduce transition costs. In sum, given that the world's energy infrastructure includes many long-lived, capital-intensive assets, it would be extremely expensive and probably infeasible to

Box 4.1 Reducing emissions: Taxes vs. cap-and-trade programs

Carbon taxes and cap-and-trade programs are the two market-based regulatory options most often advanced for limiting greenhouse gas emissions. Both options are well-suited to situations where there are a large number and variety of emissions sources that must be regulated and where the opportunities for mitigation are similarly diverse and characterized by a wide range of costs. Indeed, the salient argument in favor of either approach is precisely that they rely on market forces to produce emissions reductions at the lowest marginal cost and without relying on policymakers to identify the optimal set of technology pathways.

The carbon tax recommended by neoclassical theory is one that accurately reflects the environmental damage or 'externality ' associated with each ton of emissions and that therefore produces the socially optimal level of emissions. That is, society as a whole will spend only as much to reduce emissions as those reductions are worth in terms of avoided damages. A carbon tax would have the effect of raising prices on fossil fuels in proportion to their carbon content and—assuming properly functioning markets—should stimulate users of fossil fuels to reduce their consumption wherever it is cheaper to do so than to pay tax.[a] The cost of a tax policy is transparent and known in advance. What is not known in advance is how much emissions abatement will occur in response since this depends on the cost and magnitude of mitigation opportunities available throughout the economy. Another noteworthy feature of a carbon tax is that it generates revenues for the government that could be used for other socially productive purposes.

Monetizing the environmental damages associated with carbon emissions is a necessary, albeit difficult, first step. Even where this is done, however, there is abundant evidence to suggest that markets will respond only imperfectly to a carbon price signal. For reasons discussed in Chapter 3, cost-effective energy-efficiency opportunities are routinely overlooked by large corporations and individual consumers alike, and new technologies often face barriers to entry that are not strictly a function of cost. Carbon or energy taxes have proved politically unpalatable in some countries—notably the United States—though they have been accepted more readily elsewhere.

A carbon cap-and-trade system functions, in many ways, like a tax. The recent experience of the European Union, which has created a market for carbon with values in the realm of US$100 per ton through a cap-and-trade-type program for large industrial emitters of carbon dioxide, provides a useful, real-world example of how this approach can work in practice. In principle, the mechanism is simple: government requires that each ton of emissions be accompanied by a permit and then constrains the quantity of permits available to emitters. As with a tax, this approach effectively raises the price of fossil fuels and—provided permits can be freely traded—stimulates the lowest cost emissions reductions. In addition, some cap-and-trade programs provide for 'offset credits ' to stimulate mitigation activities in sectors not covered by the cap. Companies will use permits only when the cost of doing so is lower than the cost of avoiding emissions. Like a tax, a cap-and-trade program can generate revenues if government chooses to auction permits, although past programs of this type have typically allocated most permits for free to regulated entities.[b]

The key difference between the two approaches is that, under a tax, costs are known but final emissions are not. By contrast, under a cap-and-trade program, final emissions are known (assuming requirements are enforced, they are determined by the cap) and costs are uncertain. In theory, a tax could be adjusted to achieve a desired emissions goal. Similarly, it is possible to design a cap-and-trade system that improves price certainty by building in a 'safety valve '—essentially a promise that government will sell additional permits and allow emissions to rise above the cap if the market price of permits exceeds a certain threshold. The latter approach may be attractive in situations where political considerations favor a cap-and-trade approach but there are also significant concerns about cost and competitiveness.

[a] Additional provisions might be necessary under a tax-based system to recognize emissions avoided by carbon capture and sequestration. A tax rebate, for example, might be used to accommodate this form of mitigation.

[b] Giving permits for free to regulated entities may seem to 'mask ' the cost impacts of a cap-and-trade program, but in practice both policies will raise energy prices and generate revenues. In a cap-and-trade program with a free allocation those revenues simply go to the recipients of permits, rather than to the public treasury.

transform that infrastructure overnight. But for precisely the same reason, policies that allow for continued expansion of carbon-intensive energy systems are also unwise and—as climate-related policies are introduced—will also prove costly. Thus, the process of initiating change must begin soon.

4.4 The role of science and technology

Over the past 150 years, progress in science and technology has been a key driver of human and societal development, vastly expanding the horizons of human potential and enabling radical transformations in the quality of life enjoyed by millions of people. The harnessing of modern sources of energy counts among the major accomplishments of past scientific and technological progress. And expanding access to modern forms of energy is itself essential to create the conditions for further progress. All available forecasts point to continued rapid growth in global demand for energy to fuel economic growth and meet the needs of a still-expanding world population. In this context, few questions are more urgent than *how can science and technology can be enlisted to meet the challenge of long-term energy sustainability?*

As a starting point for exploring that question, it is useful to distinguish between several generally accepted phases of technological evolution, beginning with basic scientific research and followed by development and demonstration, RD&D. When all goes well, RD&D is followed by a 'third D'—the deployment phase— wherein demonstrated technologies cross the threshold to commercial viability and gain acceptance in the marketplace. Typically, government's role is most pronounced in the early *research* and *development* phases of this progression while the private sector plays a larger role in the *demonstration* and *deployment* phases. Nevertheless, government can also make an important contribution in the demonstration and early deployment phases, for example, by funding demonstration projects, providing financial incentives to overcome early deployment hurdles, and helping to create a market for new technologies through purchasing and other policies.

The remainder of this section focuses on the pre-deployment phases when issues of science and technology are most central. Nevertheless it is worth emphasizing that the deployment/commercialization step is crucial, and that it generates much information and insight that can benefit the R&D focused on in the early steps, in a process of refinement and adoption that is fundamentally iterative. Many demonstrated technologies encoun-

ter significant market hurdles as they approach the deployment phase; for some—hybrid vehicles, hydrogen as a transport fuel, solar energy, coal-based integrated gasification combined cycle (IGCC), and fuel cells— cost rather than technological feasibility becomes the central issue. Established private-sector stakeholders can be expected to resist, or even actively undermine, the deployment of new technologies, thus necessitating additional policy interventions.

Most of the energy technologies that are now in some phase of the RD&D process have something in common: either by themselves or in combination with each other, they hold significant promise for reducing carbon dioxide emissions (Table 4.2). New technology that promotes end-use efficiency (in buildings and appliances, vehicles, and processes) probably offers the most cost-effective opportunities, relative to technology on the supply side. Within the large set of supply options noted in Table 4.2, the use of biofuels in the transport sector may offer the most leverage, at least within the next ten to twenty years, while—in a somewhat longer timeframe—carbon capture and storage may play a major role. But these changes will occur within the next several decades only if decisive, initial action is undertaken at a global level within the next five to ten years. Further RD&D in third-and fourth-generation nuclear reactors can help diversify the world's future low-carbon energy portfolio, but only if solid, enforceable worldwide agreements can be reached on non-proliferation and on the disposal/storage of spent nuclear fuel. Further RD&D attention should also be focused on improving the efficiency and reducing the cost of energy conversion and storage technologies, including fuel cells, conventional batteries, and compressed air.

It should be emphasized that Table 4.2 lists only some of the promising RD&D opportunities that exist on the end-use side of the energy equation. With further technology investments, significant advances could be achieved in the efficiency of key energy-using devices, such as vehicles, appliances, and equipment, as well as in larger energy systems, such as cities, transportation systems, industrial processes, and whole buildings. The requisite technologies are still in a basic research phase in some promising areas, including:

- efficiently extracting useful energy from the lignocellulosic part of biomass,
- increasing biomass yields by boosting photosynthetic water and nutrient efficiencies through genetic engineering,
- applying nanotechnology and/or using new materials to improve the energy conversion efficiency of photovoltaic devices, and
- developing solid-state storage options for hydrogen.

Table 4.2 Energy R&D opportunities

Technologies	R&D	Demonstration
Transport sector		
Hybrid vehicle	Yellow	
Hydrogen fuel cell vehicle	Yellow	
Fuel – ethanol (cellulosic)	Orange	Orange
Fuel – Hydrogen	Orange	Orange
Industry sector		
Materials production process	Orange	Orange
Materials/product efficiency	Yellow	Orange
Feedstock substitution	Orange	Orange
Carbon dioxide capture and storage	Orange	Orange
Buildings and appliances sector		
Heating and cooling technologies	Yellow	
Building energy management systems	Yellow	Yellow
Lighting systems	Yellow	Yellow
Reduce stand-by losses		Yellow
Building envelope measures	Yellow	Yellow
Solar heating and cooling		Yellow
Power generation sector		
Biomass	Yellow	Yellow
Geothermal	Yellow	Yellow
Wind (onshore and offshore)		Yellow
Solar photovoltaics	Orange	Orange
Concentrating solar power	Yellow	Orange
Ocean energy	Orange	Orange
Advanced steam cycles (coal)		Yellow
Integrated gasification combined cycle (coal)	Yellow	Orange
Fuel cells	Orange	Orange
Carbon capture and storage + Advanced steam cycle with flue-gas separation (coal)	Yellow	Orange
Carbon capture and storage + Advanced steam cycle with oxyfueling (coal)	Orange	Orange
Carbon capture and storage + Integrated gasification combined cycle (coal)	Orange	Orange
Carbon capture and storage + Chemical absorption flue-gas separation (natural gas)	Yellow	Orange
Nuclear – Generation II and III	Yellow	Yellow
Nuclear – Generation IV	Orange	Orange

Orange: indicate significant opportunities and needs.

Yellow: Indicate that the technology under scrutiny would benefit from further R&D and/or demonstration.

Source: IEA, 2006.

Other technologies require more applied research or further development, including scale-up to a working, experimental laboratory model. The transition to demonstration, which is the prerequisite for eventual deployment, is critical and often gets insufficient attention from those who are or have been engaged in funding the R&D phase.

In sum, the world's S&T community has a central role to play in enabling the transition to sustainable energy systems. At least two conditions however must be met:

- Funding (both public and private) for energy RD&D must be sufficient.
- RD&D efforts must be effectively targeted and internationally coordinated to address both the supply and demand sides of the energy equation.

With regard to the first condition, it should be noted that global average public and private expenditures on energy R&D have declined over the last two decades, with a tendency to level off over the last decade, whereas total average public expenditures on all forms of R&D increased over the same time period (Kammen and Nemet, 2005; Nature, 2006). Figure 4.2 shows total public energy R&D expenditures by IEA member countries, and compares them to the global price of oil (in U.S. dollar per barrel) over the period 1974–2004. In 2005, total R&D expenditures (on the same purchasing power parity basis and adjusted for inflation to the value of the U.S. dollar in the year 2000) amounted to US$726 billion for OECD countries and US$155 billion for non-OECD countries. Governments' shares in these expenditures were 30 percent and 40 percent, respectively; hence total public R&D expenditures amounted to US$280 billion (OECD, 2006a). At approximately US$9 billion,[62] the share of these expenditures specifically directed to energy technologies accounts for a mere 3.2 percent of all public R&D funding.

The development of a diverse portfolio of sustainable energy technologies will require a sizeable boost—on the order of a doubling—in worldwide public investments in energy R&D. Such an increase in energy R&D funding should occur within the next five years and will most likely need to be sustained for at least several decades, if not longer. At the same time, governments must promote the expansion of private-sector investments in long-term energy R&D. Industry can bring crucial expertise and insights to the RD&D process (especially since deployment usually occurs through the private sector), as well as resources greater than those available to governments once the deployment stage has been reached. Government

62 This number excludes expenditures for basic research but includes funding of demonstration projects.

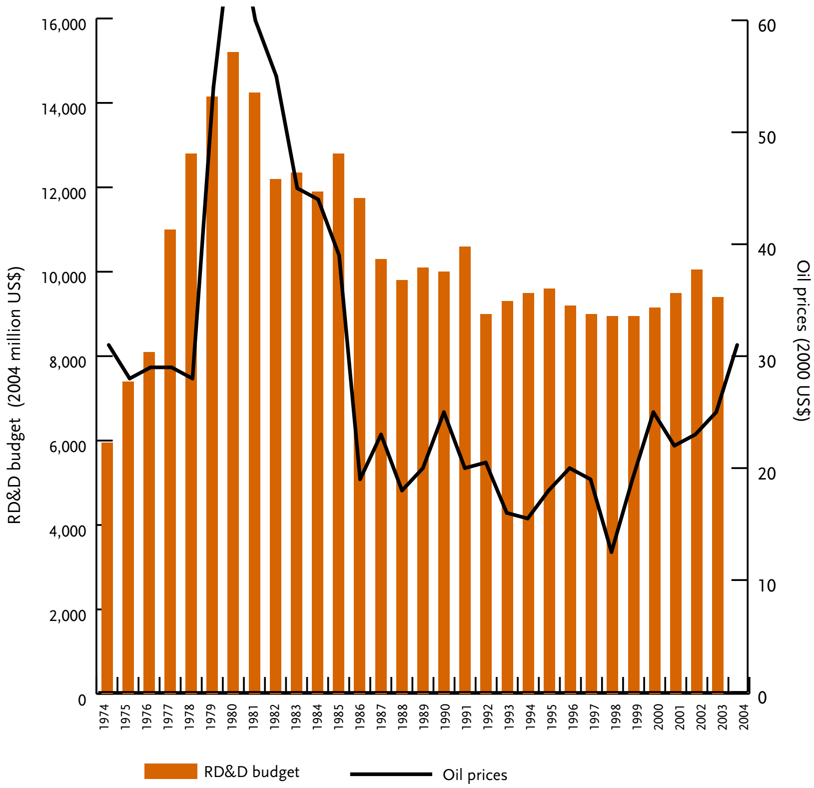

Figure 4.2 Public energy R&D expenditures in IEA countries and real oil price 1974–2004

Note: Total R&D budget includes conservation, fossil fuels, nuclear fussion, nuclear fission, renewable energy, power and storage technologies, amd other technology and research.

*Source*s: IEA, 2005; and OECD, 2006b

policies—such as a cap-and-trade program for limiting emissions or a carbon tax—would be hugely instrumental in creating incentives for the private sector to increase its RD&D investments. Thus, for example, a policy designed to expand the contribution from new renewable, carbon-neutral energy sources will force 'traditional' energy companies to rethink their future product portfolio and marketing strategies.

Continued policy uncertainty makes it difficult for energy companies to develop mid- and long-term business strategies. During the often protracted period required to formulate a comprehensive new policy, governments can reduce this uncertainty by adopting legislation that awards early action in the right direction while penalizing further activities that are counterproductive to achieving sustainability objectives.

Increased public funding for energy RD&D can come from a variety of sources. In many industrialized and large developing countries, much could be accomplished by refocusing or redirecting funds that are already in the national budget.[63] Additional funds could be obtained by rationalizing existing subsidy programs and/or by raising new revenues through energy consumption or pollution taxes (usually of the excise type) or by auctioning permits-to-emit under an emissions trading program.

Success depends, of course, not only on funding but on well-managed programs. Given that the scale of the challenge is likely to continue to exceed the public resources made available to address it, energy RD&D efforts around the world must be thoughtfully focused and aimed at answering concrete questions and solving defined problems. Energy RD&D should also be coordinated internationally and conducted in a framework of collaboration—both between countries and between the public and private sectors—to avoid unnecessary duplication and inefficient use of funds. International efforts to promote coordination and collaboration should thoroughly involve developing countries, not least to help them leapfrog to more advanced energy technologies and systems. Implicitly, this requires concerted efforts to facilitate technology transfer. The scientific community can play a moderating role in the often thorny debate about how best to accomplish this; developing countries, in turn, should create the right conditions for technology transfer.

The stakes are very high. Bringing the combined energies and expertise of the world's S&T community to bear on finding solutions is essential and will likely demand new international institutions or mechanisms to better leverage and harmonize global efforts.

4.5 The role of policy and technology in a developing country context

More than 2 billion people in developing countries lack access to either (or both) clean cooking and heating fuels and electricity. It is estimated that roughly 1.5 million people die each year due to respiratory illness and carbon-monoxide poisoning caused by indoor air pollution associated with the use of solid fuels such as twigs, dung, and brown coal for cooking. Access to modern energy services would also have a profound impact on other critical aspects of human development and quality of life for the

63 A public energy RD&D investment of US$20 billion per year would amount to an annual contribution of approximately US$27 per person in the United States and the European Union combined.

world's poorest citizens, including access to clean drinking water, irrigation, pollution-free indoor lighting, education, and communications.

Few priorities are therefore more important—both to the governments of developing countries and in terms of fulfilling international commitments to broadly held development goals—than expanding access to modern energy services and ensuring that developing nations have the energy infrastructure needed to sustain economic growth and raise living standards for their poorest citizens. Here policy and technology clearly have critical roles to play, especially in helping developing nations transition directly to cleaner and more efficient energy options. Just as it has been possible for many countries to go directly to cellular phones without having to lay telephone cables, it is becoming possible for many rural areas to be electrified using mini-grids or completely distributed systems without having to wait for expensive grid extensions. Technology innovation can also produce promising synergies for developing country applications. For example, efforts to develop liquid transport fuels from lignocellulosic biomass have driven research on enzymes and new, self-sustaining, microbial approaches that could eventually improve the performance of low-cost biogas digesters useful in rural areas of tropical developing countries. Moreover, development of such enzymes can be pursued not only in industrialized countries but in leading developing country laboratories as well.

Successfully transferring technology innovations from the prosperous to the poor presents its own, often formidable, challenges. The rural areas of many developing countries are littered with the remnants of energy demonstration projects that have failed—creating veritable technology graveyards. This is not the place to apportion blame or to list causes for these failures. Suffice it to say that researchers working on the development of sustainable energy technologies must avoid the tendency to understate costs, or belittle potential practical problems with the technologies they promote. Instead it will be critical to build on successes and learn from experience with past development projects. This, in turn, requires independent assessment or tracking of project performance with subsequent dissemination of results. Developing countries themselves must not be viewed as bystanders in this process. Though assistance from industrialized countries—especially in the form of financial resources but also to facilitate the sharing of intellectual property and technical expertise—is critical, developing countries must assume responsibility for effective technology transfer and poverty alleviation if the needs of the poor are to be met.

Human and institutional capacity building is also a critical issue in many developing country contexts. Research has shown that technology transfer is more successful and innovation is more likely to occur when host institutions have the requisite technical and managerial skills to manage new energy systems. Without those skills, new technologies often fail to deliver expected services. Capacity building is needed within the companies that produce, market, install, and maintain sustainable energy technologies and within the communities that will manage and operate those technologies. The latter need can be met by establishing regional institutes to provide training in basic technology management skills. Such institutes could also help to provide independent assessments of alternative technologies and policy choices, and explore strategies for overcoming barriers inhibiting the large-scale implementation of sustainable energy technologies.

Yet another issue is financing. In the recent past, governments usually relied on cross-subsidies (charging higher prices to one set of customers to reduce costs for another set of customers) to extend electricity or telecommunications services to remote areas. More recently cross-subsidies have fallen out of favor, in part because there is a limit to how much one class of consumers can be charged to bring service to another class of customers (especially when some high-use energy customers have the option to switch to other power sources or to off-grid generators). Many governments, however, continue to directly subsidize electricity sales to farmers, often because it is easier than providing direct income support. Often, electricity charges are flat, un-metered, and decoupled from actual consumption. This can produce a number of undesirable outcomes: when pumping costs are low, for example, farmers tend to over-use or inefficiently use water. Because of limits to cross-subsidization between customer classes and the growing financial burden of direct subsidies, new approaches will be needed to further grid expansions to rural areas in a number of developing countries.

More broadly, subsidies can be an effective mechanism for overcoming deployment hurdles for new technologies or to advance other societal goals. When subsidies are used to support already entrenched or unsustainable technologies, however, they produce a number of undesirable effects. Some of the generic problems with conventional-energy subsidies—which remain in widespread use around the world—are discussed in more detail in Box 4.2.

Given the resource constraints faced by many developing countries, there is an urgent need for greater international support for sustainable

Box 4.2 Energy subsidies

Although subsidies on fossil fuels have been declining over the last decade or so, they are pervasive and remain widely used around the world. On a global basis, fossil-fuel subsidies still amount to several hundreds of billions of U.S. dollars in industrialized and (to a lesser extent) developing countries (Table 4.3).

While cumulative funds expended on energy subsidies are often less than the revenues collected through taxes on other fossil fuels, such as petrol (gasoline), subsidies for established sources of energy lead to at least the following two problems:

- The common feature of all subsidies is that they distort market signals and influence consumer and producer behavior.
- Subsidies for conventional fuel often have the effect of further tilting the playing field against energy efficiency and cleaner sources.

Subsidies are addictive, and those who benefit from them do not easily acquiesce in their cessation without some other inducement. Commitments to eliminate or reduce subsidies may be adopted but they are notoriously difficult to implement for politicians who have to renew their mandates periodically. Moreover, as noted earlier in this chapter, failure to include environmental, energy security, and other externalities in market prices itself constitutes a form of subsidy that is common to conventional fuels in many countries. (Another example of this form of subsidy is the Price-Anderson Act in the United States, which indemnifies the nuclear industry against liability claims arising from accidents at civilian nuclear power plants).

Direct fuel subsidies rarely go to the most needy, as in the case of many current subsidies for diesel and kerosene. Governments should seek to eliminate or phase out subsidies that no longer serve the public interest. Conventional sources of energy, in particular, should at least be sold at the cost of production and ideally at a cost that also reflects associated environmental and other externalities. Where unsubsidized prices would impose excessive burdens on the poor, these burdens should be cushioned with direct income supports. Again, such recommendations are easy to make, but harder to implement. Since they lack reliable implementation mechanisms to transfer resources to the truly needy, many governments prefer to mask transfer payments by using subsidies over which they have some control. There is an urgent need for experimentation in such transfer mechanisms. This is a challenge both for the research community and for the NGO community.

In most countries, subsidies on some fuels, taxes on other fuels, and some public support for renewables co-exist in varying degrees. It is well known that 'incentives ' are required to motivate the private sector to invest in providing services to the often remote and underdeveloped areas where the poor reside. Wherever absolute poverty prevails, there is a long history of applying intelligently designed subsidies, which are targeted, simple, competitive, and time-limited. This can often be accomplished, at least in part, by shifting current subsidies for fossil fuel use to sustainable energy systems.

Table 4.3 Cost of energy subsidies by source, 1995-1998 (US$ billion/year)

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

[(a)] Subsidies for electricity in OECD countries are included in fossil fuel subsidies, by energy source.

[(b)] Subsidies from non-payments and bail out operations are not included in data by energy source.

Source: UNDP, UNDESA, and WEC, 2004.

Box 4.3 The Grameen experience with photovoltaics

The Grameen Bank of Bangladesh (Grameen Shakti), a micro-lending agency set up a non-profit subsidiary in 1996 to administer loans for photovoltaic solar home systems to serve those without access to electricity. Initially, Grameen Shakti found many obstacles—long distances, poor transport infrastructure, periodically flooded and impassable roads, low literacy rates, lack of technical skills, transactions based on barters—that contributed to high transaction costs and difficulty in building consumer confidence in their product.

In 1998, a Global Environment Facility grant through International Finance Corporation's Small and Medium Enterprises Program enabled Grameen Shakti to offer improved credit terms to its customers and install thousands of systems. They also found that after a critical mass of installations in an area (around 100 systems), building consumer confidence and demand became less time consuming.

Grameen Shakti now expects to be able to draw additional financing for scale-up activities from commercial banks.

For more information on Grameen Bank, go to www.gshakti.org.

energy projects. As the Policy Report at the World Summit on Sustainable Development concluded, 'The scale and magnitude of tasks involved in progressing towards the objective and goals of energy for sustainable development are so enormous that, in addition to national efforts, international, regional, and sub-regional co-operation are of critical importance' (WSSD, 2002). There is also an urgent need to ensure that future efforts in this direction are well-designed, thoughtfully implemented, and focused on technologies that are appropriate to the situation in which they are being deployed.[64]

Realistically, industrialized countries will have to provide much of the investment needed to move new energy technologies up the learning curve and bring down their marginal costs, in parallel with their phased deployment, before those technologies can be used in developing countries. Meanwhile, substantial opportunities exist to facilitate the transfer of sustainable technologies that are already cost-effective, especially in more remote and currently underserved areas, using innovative program designs and financing mechanisms. An example of one such successful program, involving the dissemination of small solar photovoltaic home systems in Bangladesh, is described in Box 4.3.

4.6 Summary points

Governments around the world must act now to initiate a transition to sustainable energy systems.

- **Though specific policy choices must take into account each country's unique circumstances, efforts to introduce a market signal for reducing carbon emissions, promote investments in improved energy efficiency, and reduce or eliminate distorting subsidies (especially for fossil fuel consumption), must be broadly undertaken.**
- **Science and technology have an indispensable role to play in improving the sustainable energy options that are available today and in developing new options for tomorrow.** Given the scale and urgency of the challenge at hand, public and private-sector investments in energy technology RD&D must be substantially increased (to at least a doubling of current levels, if not more) and consistently maintained over the next several decades. Putting necessary efforts into R&D does not provide an accept-

64 Many policy options are potentially relevant in developing country contexts: the Global Network on Energy for Sustainable Development, for example, has published analyses of strategies for reforming the electric power sector and enhancing access to energy services (www.gnesd.org).

able reason to postpone strong action now to make use of already existing technologies and to correct existing distortions in the energy market place.

- **Extending access to modern forms of energy for billions of the world's poorest citizens is necessary to meet basic human needs (clean cooking fuels and clean water) and to achieve broader development goals (night-time lighting, communication, economic opportunity)**. More broadly, advancing sustainability objectives in developing countries will require policies and technologies that reflect the particular needs and opportunities of those countries, along with an increased commitment on the part of the S&T community to develop and help deploy effective technology for the rural and urban poor.
- **Concerns about affordability, especially in developing countries, should be addressed by developing mechanisms that subsidize consumption only up to a threshold level adequate to serve basic needs.**

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