



## Accelerating Innovation and Technology Diffusion

Windmills peppered European landscapes to provide energy for agricultural activities long before the discovery of electricity. Thanks to the forces of innovation and technology diffusion, wind is now powering the first stages of what could become a veritable energy revolution. Between 1996 and 2008 the global installed wind capacity increased twentyfold to stand at more than 120 gigawatts, displacing an estimated 158 million tons of carbon dioxide (CO<sub>2</sub>) a year while creating some 400,000 jobs (figure 7.1).<sup>1</sup> Much of this growth is attributable to government incentives and to publicly and privately funded research, driving down the cost of wind technology and driving up efficiency.

And although most installed capacity is in Europe and the United States, the pattern is shifting. In 2008 India and China each installed more wind capacity than any other country except the United States,

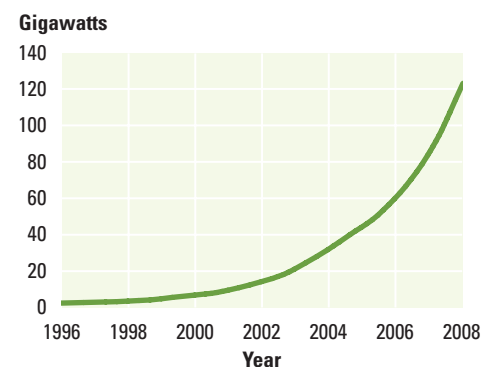
and together they host nearly 20 percent of the world's capacity. An Indian company, Suzlon, is one of the world's leading wind turbine manufacturers, employing 13,000 people across Asia. So the global takeoff of wind technology is setting an early precedent for climate-smart development. And complementary advances, such as global geospatial wind resource information, are making siting decisions easier (map 7.1).

Technological innovation and its associated institutional adjustments are key to managing climate change at reasonable cost. Strengthening national innovation and technology capacity can become a powerful catalyst for development.<sup>2</sup> High-income economies, the world's major emitters, can replace their stock of high-carbon technologies with climate-smart alternatives while massively investing in tomorrow's breakthrough innovations. Middle-income

### Key messages

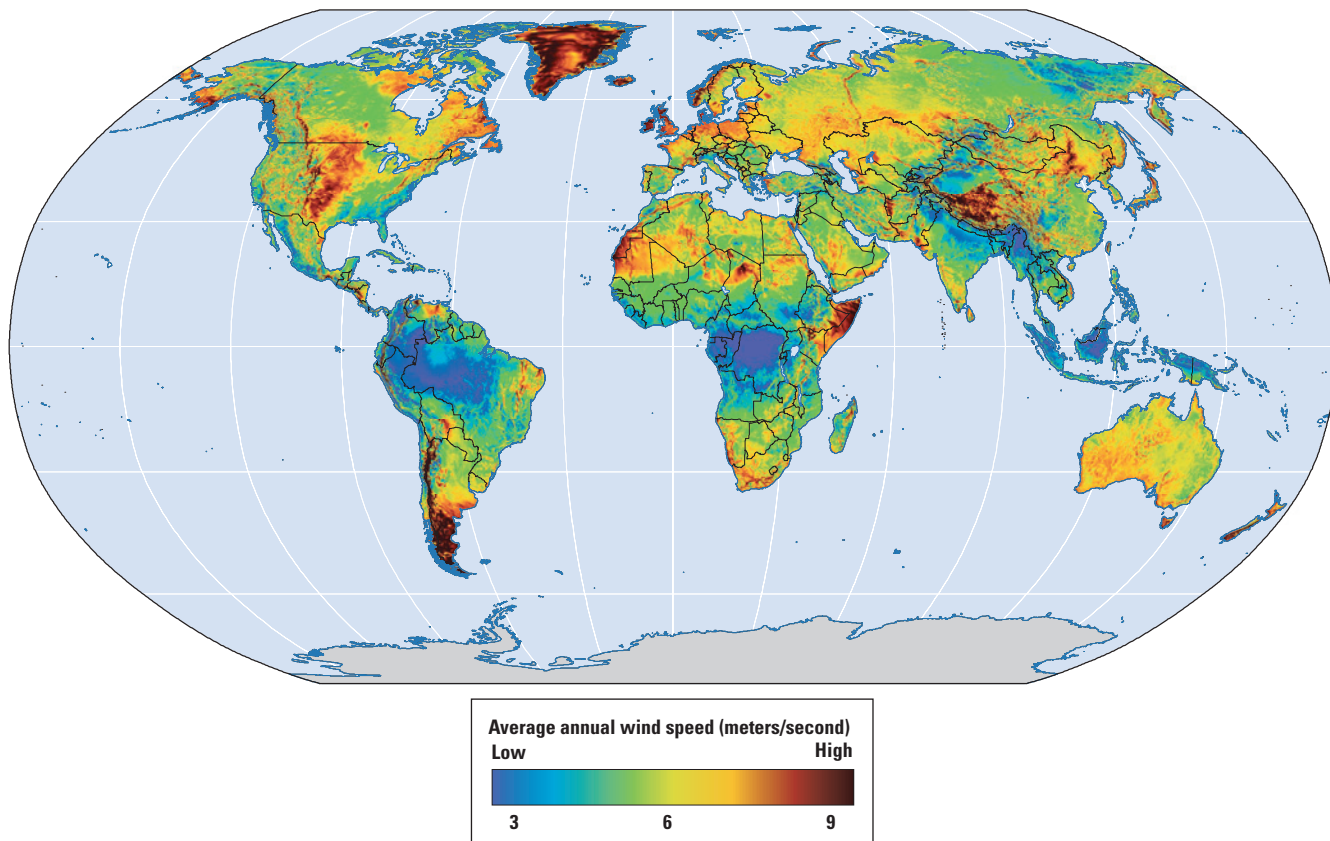
Meeting climate change and development goals requires significantly stepping up international efforts to diffuse existing technologies and develop and deploy new ones. Public and private investment—now in the tens of billions of dollars per year—need to be steeply ramped up to several hundreds of billions of dollars annually. “Technology-push” policies based on increasing public investments in R&D will not be sufficient. They need to be matched with “market-pull” policies that create public and private sector incentives for entrepreneurship, for collaboration, and to find innovative solutions in unlikely places. Diffusing climate-smart technology requires much more than shipping ready-to-use equipment to developing countries; it requires building absorptive capacity and enhancing the ability of the public and private sectors to identify, adopt, adapt, improve, and employ the most appropriate technologies.

**Figure 7.1** Global cumulative installed wind capacity has soared in the past decade



Source: Global Wind Energy Council 2009.

Map 7.1 Advances in wind mapping open up new opportunities



Source: Data provided by 3 Tier Inc.

Note: This is a 5-kilometer resolution map of average annual wind speed, with the average measured at a height of 80 meters (the height of some windmills), across the world's landmass.

countries can ensure that their investments take them in the direction of low-carbon growth and that their firms reap the benefits of existing technologies to compete globally. Low-income countries can ensure that they have the technological capacity to adapt to climate change, by identifying, assessing, adopting, and improving existing technologies with local knowledge and know-how. As chapter 8 points out, reaping the benefits of technological changes will require significant changes in human and organizational behavior, as well as a host of innovative supportive policies to reduce human vulnerability and manage natural resources.

Yet today's global efforts to innovate and diffuse climate-smart technologies fall far short of what is required for significant mitigation and adaptation in the coming decades. Investment in research, development, demonstration, and deployment

(RDD&D) is lacking, and the financial crisis is reducing private spending on climate-smart technology, delaying its diffusion. Mobilizing technology and fostering innovation on an adequate scale will require that countries not only cooperate and pool their resources but also craft domestic policies that promote a supportive knowledge infrastructure and business environment. And most developing countries, particularly low-income countries, have small market sizes which, taken individually, are unattractive to entrepreneurs wishing to introduce new technologies. But contiguous countries can achieve a critical mass through greater regional economic integration.

International cooperation must be scaled up to supply more financing and to formulate policy instruments that stimulate demand for climate-smart innovation, rather than simply focus on research

subsidies. The international harmonization of regulatory incentives (such as carbon pricing) can have a multiplier effect on investment by creating economies of scale and by building momentum in the direction of climate-smart technologies. Innovation prizes and procurement subsidies can build demand and stimulate ingenuity. And where research priorities coincide with high costs, joint RDD&D can push out the technical frontiers. The concept of technology transfer needs to be broadened to include country capacities to absorb existing technologies. In this respect an international climate treaty with a focus on specific technological systems or subsystems presents a unique opportunity. Bundling in cost-sharing and technology transfer provisions could facilitate an accord.

Complementary domestic policies can ensure that technology is effectively selected, adapted, and absorbed. But identifying, evaluating, and integrating foreign technologies impose oft-overlooked learning costs, as do their modification and improvement. So the knowledge infrastructure of universities, research institutes, and firms has to be supported to build this capacity.

This chapter draws on the analysis of systems in which technology has withered or thrived and on the plethora of policies and factors that have acted as barriers or catalysts, suggesting what can be achieved if selected policies are combined and scaled up. It first describes the importance of technology in lowering greenhouse gas emissions, the needed tools to advance adaptation to climate change, and the role of both in creating competitive economies. It next assesses the gap between invention, innovation, and widespread diffusion in the marketplace. It then examines how international and domestic policies can bridge that gap.

### **The right tools, technologies, and institutions can put a climate-smart world well within our reach**

To keep global temperatures from rising more than 2°C, global greenhouse gas emissions must come down by 50–80 percent in the coming decades. In the short term they can be drastically reduced by accelerating

the deployment of existing mitigation technologies in high-emitting countries.

But to achieve the more ambitious medium-term emission objectives will require breakthrough technologies. Models show that four future key technology areas could be at the core of a solution: energy efficiency; carbon capture and storage; next-generation renewables, including biomass, wind and solar power; and nuclear power (see chapter 4).<sup>3</sup> All four need more research, development, and demonstration (RD&D) to determine whether they can be rapidly deployed in the marketplace without adverse consequences.

Despite their great promise, both short- and medium-term emission reduction strategies face major challenges. End-use technologies that improve efficiency and use sources with low emissions can dampen total energy demand, but they require changing the behavior of individuals and firms (see chapter 8). Carbon capture and storage could play a large role if geologically appropriate sites can be identified near power plants and if governments provide resources and policies to enable long-term sequestration.<sup>4</sup> Biotechnology and second-generation biofuels have great potential for mitigating carbon emissions but with increasing demands on land use (see chapter 3). Wind and solar power (both photovoltaic and solar thermal) could expand faster if energy storage and transmission improve. A new generation of nuclear power plants could be deployed extensively throughout the world but would have to overcome institutional constraints, safety and proliferation issues, and popular resistance in some countries. In addition, some have proposed that geoengineering options could not only decrease emissions rates but also temper the impacts of climate change (box 7.1).

The role of technology and innovation in adaptation has been much less studied than for mitigation, but it is clear that future climate conditions will be fundamentally different from the ones today. Responding to changes outside of historic experience will require increased institutional coordination on a regional scale, new tools for planning, and the ability to respond to multiple

### BOX 7.1 *Geoengineering the world out of climate change*

Given the pace of climate change, current proposals for mitigation and adaptation may not be sufficient to avoid considerable impacts. Thus, possible geoengineering options are receiving increasing scrutiny. Geoengineering can be defined as actions or interventions taken for the primary purpose of limiting the causes of climate change or the impacts that result. They include mechanisms that could enhance carbon dioxide (CO<sub>2</sub>) absorption or sequestration by the oceans or by vegetation, deflect or reflect incoming sunlight, or store CO<sub>2</sub> produced by energy use in reservoirs. The last of these is discussed in chapter 4, so this box focuses on the other two classes of options.

Possible options for sequestering additional carbon dioxide include terrestrial management practices that increase carbon held in soils or trees, as discussed in chapter 3. It may also be possible to stimulate phytoplankton growth and algal blooms in the oceans by adding needed nutrients such as iron or urea. As these tiny plants photosynthesize, they take up carbon dioxide from surface waters. The effectiveness of such enhanced approaches will depend on what happens to the CO<sub>2</sub> over the longer term; if it is integrated into the waste products from animals that eat the plankton and settles to the seafloor, then the CO<sub>2</sub> will essentially be removed from the system for millennia. However, recent research shows that previous quantifications of carbon removal capacity may have been greatly overestimated. Also, more experiments need to be done on the duration of sequestration as well as the potential toxicological impacts of sudden increases in iron or urea in marine ecosystems. If further studies confirm its potential, this is one geoengineering option that could be started quickly and at relevant scale.

Bringing cool, nutrient-rich water to the ocean's surface could also stimulate increased marine productivity and potentially remove CO<sub>2</sub> from the surface water. Such cooling would also be beneficial for coral, which are very sensitive to higher temperatures. Finally, cooling surface water could also dampen hurricane intensities. Initial research on a wave-powered pump to bring cool water to the surface

suggests that the approach might work, but much more research and investigation is needed.

Other geoengineering options to remove greenhouse gases include scrubbing gases from the atmosphere with a CO<sub>2</sub> absorbing solution (and then sequestering the captured carbon below the land surface or in the deep ocean), or using lasers to destroy long-lived halocarbon molecules—best known as culprits in ozone depletion but also powerful greenhouse gases (see focus A on science). These options are still in the early experimental stage.

Several approaches to reflect incoming sunlight have been offered. Some of these could be targeted to particular regions, to prevent further melting of Arctic sea ice or the Greenland ice sheet, for example. One approach would be to inject sulfate aerosols into the atmosphere. This has shown to be an effective method for cooling—the 1991 eruption of Mount Pinatubo resulted in the earth cooling by nearly 1°C for about a year. To maintain this type of cooling, however, a constant stream or regular injections of aerosol must be released. Further, sulfate aerosols can exacerbate ozone depletion, increase acid rain, and cause adverse health impacts.

Alternatively, sea mist could be sprayed into the sky from a fleet of automated ships, thus “whitening” and increasing reflectivity of the low marine clouds that cover a quarter of the world's ocean. However, uneven cloud distribution could lead to regional cold and hot spots and droughts downwind of the spray vessels.

Increasing the reflectivity of the land surface would also help. Making roofs and pavements white or light-colored would help to reduce global warming by both conserving energy and reflecting sunlight back into space and would be the equivalent of taking all the cars in the world off the road for 11 years.

Another proposal would place a solar deflector disk between the Sun and Earth. A disk of approximately 1,400 kilometers in diameter could reduce solar radiation by approximately 1 percent, about equivalent to the radiative forcing of emissions projected for the 21st century.

But analysis shows that the most cost-effective approach for implementing this strategy is to set up a manufacturing plant for the deflector on the Moon, hardly a straightforward task. Similar ideas using multiple mirrors (such as 55,000 orbiting solar mirrors each roughly 10 square kilometers in size) have been discussed. However, when each of the orbiting mirrors passed between the Sun and Earth, they would eclipse the Sun, causing sunlight at the earth's surface to flicker.

There are even geoengineering proposals more akin to weather modification, such as attempting to push advancing tropical storms out to sea and away from human settlements to reduce damage. Although research on such ideas is in its very earliest stages, the newest climate models are becoming capable of analyzing the potential effectiveness of such proposals, something that was not possible when hurricane modification was first attempted several decades ago.

Although it may be possible for geoengineering to be undertaken by one nation, every nation would be affected by such actions taken. For this reason, it is essential that discussions begin on governance issues relating to geoengineering. Already, investor-funded experiments in support of iron fertilization have raised questions over what international entity or institution has jurisdiction. Questions about using geoengineering to limit the intensity of tropical cyclones or Arctic warming would add complexity. Thus, in addition to scientific research on possible approaches and their impacts, social, ethical, legal, and economic research should be supported to explore what geoengineering measures are and are not within the bounds of international acceptance.

Sources: S. Connor, “Climate Guru: ‘Paint Roofs White.’” *New Zealand Herald*, May 28, 2009; American Meteorological Association, [http://www.ametsoc.org/policy/2009geoengineeringclimate\\_amsstatement.html](http://www.ametsoc.org/policy/2009geoengineeringclimate_amsstatement.html) (accessed July 27, 2009); Atmocean, Inc., <http://www.atmocean.com/> (accessed July 27, 2009); MacCracken 2009; “Geoengineering: Every Silver Lining Has a Cloud,” *Economist*, January 29, 2009; see also U.S. Energy Secretary Steven Chu, <http://www.youtube.com/watch?v=5wDlkKroOUQ>.

environmental pressures occurring concomitantly with climate change. Greater investments are needed in understanding vulnerability, in conducting iterative assessments, and in developing strategies for helping societies cope with a changing climate.<sup>5</sup>

Integrating climate considerations into development strategies will foster thinking about adaptation.<sup>6</sup> Chapter 2 discusses how climate change will require designing appropriate physical infrastructure and protecting human health. Chapter 3 illustrates how adaptation will require new ways to manage natural resources. Promoting diversification—of energy systems, agricultural crops, and economic activities, for example—can also help communities cope with rapidly changing conditions. Innovation will be a necessary ingredient for all of these activities.

Research is also required to understand the effects of climate change and different adaptation options on individual countries. This research must characterize the effects of multiple stresses on natural and socioeconomic systems, biodiversity vulnerability and preservation, and changes in atmospheric and oceanic circulation. Such research has to produce new monitoring tools, new strategies to enhance resilience, and better contingency planning. Scientific capacity at the national level is thus required.

### ***The capacity to tackle mitigation and adaptation will help build strong competitive economies***

Many advanced technologies, such as information and communication technologies, can help specifically with climate change yet are generic enough for use across a wide range of productivity-enhancing areas. Sensors are valuable in industrial automation but can also help waste managers limit pollution. Mobile phones have helped in responding to impending disaster, as in the coastal village of Nallavadu, India, during the 2004 tsunami,<sup>7</sup> but they can also increase business productivity. In parts of Benin, Senegal, and Zambia mobile phones are used to disseminate information about food prices and innovations in farming techniques.<sup>8</sup>

Harnessing the technological opportunities arising from climate change concerns can also create opportunities for technological leadership and a new competitive edge. China, for example, has not yet locked in to carbon-intensive growth and has enormous (and economically attractive) potential for leapfrogging old inefficient technologies. Unlike in developed countries a large share of China's residential and industrial capital stock of the next decade is yet to be built. By using existing technologies, such as optimizing motor-driven systems (pumps and compressors), China could reduce its industrial energy demand in 2020 by 20 percent while increasing productivity.<sup>9</sup>

The current global recession can provide a platform for innovation and climate-smart growth. Crises can spur innovation because they cause an urgent focus on mobilizing resources and break down barriers that normally stand in the way of innovation.<sup>10</sup> And the opportunity cost of research and development (R&D), a long-term investment, is lower during an economic crisis.<sup>11</sup> In the early 1990s Finland's recovery from a severe economic recession was credited largely to its restructuring into an innovation-based economy, with sharp increases in government spending on R&D paving the way for the private sector. The same could be achieved with climate-smart R&D.

And with high rates of return, R&D presents untapped opportunities for economic growth. Most measures of rates of return on R&D are in the range of 20 to 50 percent, much higher than on investments in capital.<sup>12</sup> Estimates also show that developing countries could invest more than twice as much as they now do.<sup>13</sup> Yet, experience shows that R&D is procyclical, rising and falling with booms and busts, and firms tend to be short-sighted during recessions, limiting their investments in innovation, even though this is a suboptimal strategy.<sup>14</sup> The stimulus packages developed by many countries in reaction to the recession offer a timely opportunity for new investments in climate-smart innovation (see chapter 1).<sup>15</sup>

The current global recession also provides opportunities for economic restructuring in high-income countries that are locked into high-carbon lifestyles.

Overcoming technological inertia and institutional incumbency in these countries remains one of the most critical obstacles to the transition to a low-carbon economy.<sup>16</sup> Inertia and incumbency are themselves attributes of existing technoeconomic systems and cannot be wished away through diplomatic processes. Unseating them will entail actual changes in economic structures. Climate-smart policies will need to include mechanisms to identify those who stand to lose and to minimize socio-economic dislocations.

Although climate-smart innovation is concentrated mostly in high-income countries, developing countries are starting to make important contributions. Developing countries accounted for 23 percent (\$26 billion) of the new investments in energy efficiency and renewable energy in 2007, up from 13 percent in 2004.<sup>17</sup> Eighty-two percent of those investments were concentrated in three countries—Brazil, China, and India. The world’s best-selling developer and manufacturer of on-road electric cars is an Indian venture, the Reva Electric Car Company. As a first-mover it has penetrated the auto manufacturer market, including in high-income countries.<sup>18</sup>

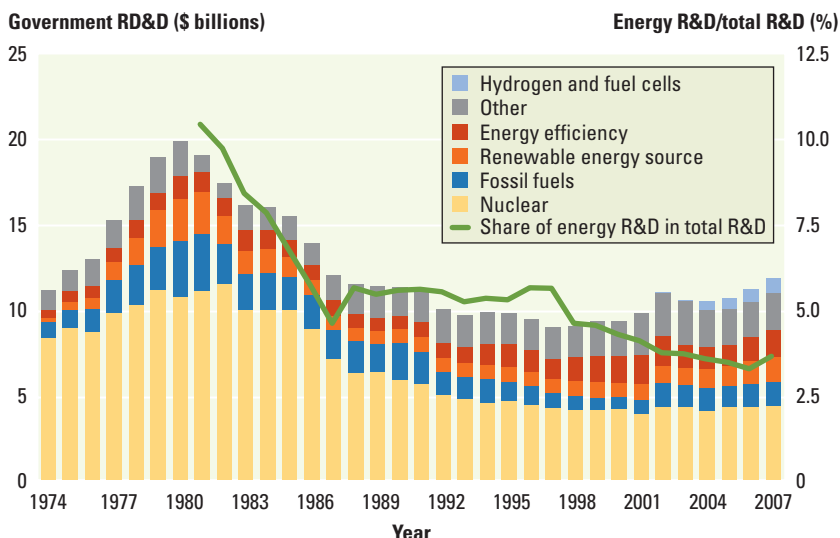
BRIICS countries (Brazil, the Russian Federation, India, Indonesia, China, and South Africa) accounted for only 6.5 percent of global renewable energy patents in 2005,<sup>19</sup> but they are quickly catching up to high-income countries, with annual patenting growth rates more than twice those of the European Union (EU) or the United States. And they are developing a technological edge in renewable energy technologies, with roughly 0.7 percent of their patents filed in this sector from 2003 to 2005, compared with less than 0.3 percent in the United States. In 2005 China was seventh in overall renewable energy patenting and second only to Japan in geothermal and cement inventions, two major potential sources of emission reductions.<sup>20</sup>

*All countries will need to step up their efforts to diffuse existing climate-smart technologies and create new ones*

Neither public nor private funding of energy-related research, development, and deployment is remotely close to the amounts needed for transitioning to a climate-smart world. In absolute terms, global government energy RD&D budgets have declined since the early 1980s, falling by almost half from 1980 to 2007 (figure 7.2). Energy’s share in government research and development budgets (not including demonstration) also plunged, from 11 percent in 1985 to less than 4 percent in 2007 (the green line in figure 7.2), heavily concentrated in nuclear power. Comparisons with public subsidies for energy or petroleum products are even more stark (figure 7.3). But recent calls for increases in energy research and development to \$100 billion to \$700 billion a year<sup>21</sup> are achievable. Japan is already taking the lead, spending 0.08 percent of its gross domestic product (GDP) on public energy RD&D, far ahead of the 0.03 average in the group of high-income and upper-middle-income-country members of the International Energy Agency.<sup>22</sup>

Given a recent upsurge, private spending on energy RD&D, at \$40 billion to \$60 billion a year, far exceeds public spending. Even so, at 0.5 percent of revenue, it remains an order of magnitude smaller than the 8 percent of revenue invested in RD&D in

**Figure 7.2 Government budgets for energy RD&D are near their lows, and nuclear dominates**



Sources: IEA 2008a; IEA, <http://www.iea.org/Textbase/stats/rd.asp> (accessed April 2, 2009); Organisation for Economic Co-operation and Development (OECD), <http://www.oecd.org/statsportal> (accessed April 2, 2009). Note: RD&D calculated at 2007 prices and exchange rates. Values on left axis are for RD&D (that is, including demonstration in addition to research and development), as is typical in the energy sector. However because totals of cross-sectoral R&D alone are available, the right axis only includes R&D.

the electronics industry and the 15 percent in the pharmaceuticals sector.<sup>23</sup>

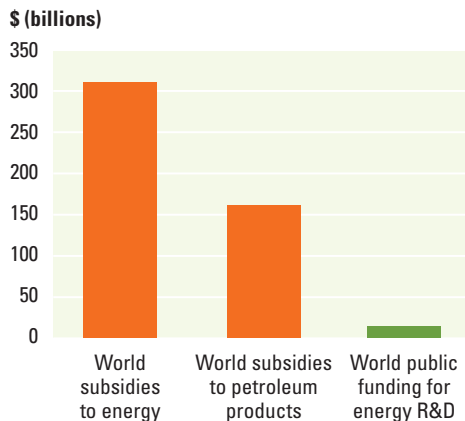
Progress in some technologies has just been too slow. Although patenting in renewable energy has grown rapidly since the mid-1990s, it was less than 0.4 percent of all patents in 2005, with only 700 applications.<sup>24</sup> Most growth in low-carbon technology patenting has been concentrated in the areas of waste, lighting, methane, and wind power, but improvement in many other promising technologies like solar, ocean, and geothermal power has been more limited (figure 7.4), with little of the needed progress toward steep cost reductions.

Developing countries are still lagging in innovation for adaptation. While it is more cost-effective to adopt technologies from abroad than to reinvent them, in some cases technological solutions for local problems do not exist.<sup>25</sup> So innovation is not only relevant to high-income economies. For example, advances in biotechnology offer potential for adapting to climate-related events (droughts, heat waves, pests, and diseases) affecting agriculture and forestry. But patents from developing countries still represent a negligible fraction of global biotechnology patents.<sup>26</sup> That will make it difficult to develop location-specific agricultural and health responses to climate change. Moreover, little spending on agricultural R&D—though on the rise since 1981—occurs in developing countries. High-income economies continue to account for more than 73 percent of investments in global agricultural R&D. In developing countries the public sector makes 93 percent of agricultural R&D investments, compared with 47 percent in high-income countries. But public sector organizations are typically less effective at commercializing research results than the private sector.<sup>27</sup>

### International collaboration and cost sharing can leverage domestic efforts to promote innovation

Cooperation to drive technological change covers legislative and regulatory harmonization, knowledge sharing and coordination, cost sharing, and technology transfer

**Figure 7.3 Annual spending for energy and climate change R&D pales against subsidies**



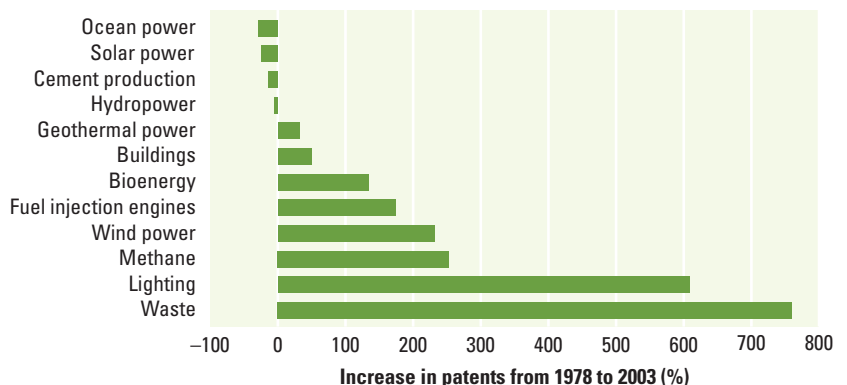
Sources: IEA 2008a; IEA 2008b; IEA, <http://www.iea.org/Textbase/stats/rd.asp> (accessed April 2, 2009).

Note: Global subsidy estimates are based on subsidies shown for 20 highest-subsidizing non-OECD countries only (energy subsidies in OECD countries are minimal).

(table 7.1). Some efforts are under way, while other opportunities are as yet untapped.

Because of the mix of required technologies and their stages of development and because their global adoption rates are so widely varied, all these approaches to cooperation will be required. Moreover, climate-smart technology cannot be produced through fragmented efforts. Innovation has to be seen as a system of multiple interacting actors and technologies, path dependency, and learning processes, not just as a product of R&D (box 7.2).<sup>28</sup> Subsidies for research, development, demonstration, and deployment have to be combined with market incentives for firms to innovate and

**Figure 7.4 The pace of invention is uneven across low-carbon technologies**



Source: Dechezleprêtre and others 2008.



**Table 7.1 International technology-oriented agreements specific to climate change**

Type of agreements	Subcategory	Existing agreements	Potential impact	Risk	Implementation	Target
Legislative and regulatory harmonization	Technology deployment and performance mandates	Very little (mainly EU)	High impact	Wrong technological choices made by government	Difficult	Energy technologies with strong lock-in effects (transport) and that are highly decentralized (energy efficiency)
Knowledge sharing and coordination	Knowledge exchange and research coordination	Many (such as International Energy Agency)	Low impact	No major risk	Easy	All sectors
	Voluntary standards and labels	Several (EnergyStar, ISO 14001)	Low impact	Limited adoption of standards and labeling by private sector	Easy	Industrial and consumer products; communication systems
Cost-sharing innovation	Subsidy-based "technology push" instruments	Very few (ITER)	High impact	Uncertainty of research outcomes	Difficult	Precompetitive RD&D with important economies of scale (carbon capture and storage, deep offshore wind)
	Reward-based "market pull" instruments	Very few (Ansari X-prize)	Medium impact	Compensation and required effort may result in inappropriate levels of innovation	Moderate	Specific medium-scale problems; solutions for developing-country markets; solutions not requiring fundamental R&D
	Bridge-the-gap instruments	Very few (Qatar-UK Clean Technology Investment Fund)	High impact	Funding remains unused due to lack of deal flow	Moderate	Technologies at the demonstration and deployment stage
Technology transfer	Technology transfer	Several (Clean Development Mechanism, Global Environment Facility)	High impact	Low absorptive capacities of recipient countries	Moderate	Established (wind, energy efficiency), region-specific (agriculture), and public sector (early-warning, coastal protection) technologies

Sources: Davis and Davis 2004; De Coninck and others 2007; Justus and Philibert 2005; Newell and Wilson 2005; Philibert 2004; World Bank 2008a.

move technologies along the innovation chain (figure 7.5).<sup>29</sup> And innovation has to rely on knowledge flows across sectors and on advances in such broad technologies as information and communications technologies and biotechnology.

*Regulatory harmonization across countries forms the backbone of any climate-smart technology agreement*

Harmonized incentives with a broad geographic reach can create large investor pools and markets for climate-smart innovation. Carbon pricing, renewable portfolio

standards that regulate the share of energy coming from renewable sources, and performance mandates such as automobile fuel economy standards (see chapter 4) are cost-effective and can promote the development and diffusion of low-carbon technologies. For example, a number of countries have initiated measures to phase out incandescent light bulbs, because more efficient technologies such as compact fluorescent lamps as well as light emitting diodes now exist. Harmonized at a global scale, these regulations can drive the market for low-carbon products in the same way that the

### BOX 7.2 *Innovation is a messy process and can be promoted only by policies that address multiple parts of a complex system*

In most countries, government policy is still driven by an outdated linear view of innovation, that perceives innovation as happening in four consecutive stages.

- R&D, to find solutions to specific technical problems and apply them to new technologies.
- Demonstration projects, to further adapt the technology and demonstrate its functioning in larger-scale and real-world applications.
- Deployment, once fundamental technical barriers have been resolved and the commercial potential of a technology becomes apparent.
- Diffusion, when technology becomes competitive in the market.

But experience shows that the process of innovation is much more complex.

Most innovations fail in one stage or another. Feedback from manufacturers in the deployment stage, or from retailers and consumers in the diffusion stage, trickles back to the earlier stages, completely modifying the course of innovation, leading to new, unexpected ideas and products and sometimes to unforeseen costs. Sometimes breakthrough innovations are driven not by R&D but by new business models that put together existing technologies. And learning curves, whereby unit costs decline as a function of cumulative production or cumulative R&D, are not well understood.

So why does this matter for policy? The linear view gives the misleading impression that innovation can be managed simply by supplying more research inputs

(technology push) and creating market demand (market pull). While both types of policy are extremely important, they ignore the contributions of the numerous interactions among the actors involved in the different stages of innovation: firms, consumers, governments, universities, and the like. Partnerships, learning by selling or buying a technology, and learning through imitation play critical roles. Equally critical are the forces that drive diffusion. The compatibility, perceived benefits, and learning costs of using a new product are all key factors for innovation. Effective policies must view innovation as part of a system and find ways to stimulate all these facets of the innovation process, particularly where there are market gaps.

Sources: Tidd 2006; World Bank 2008a.

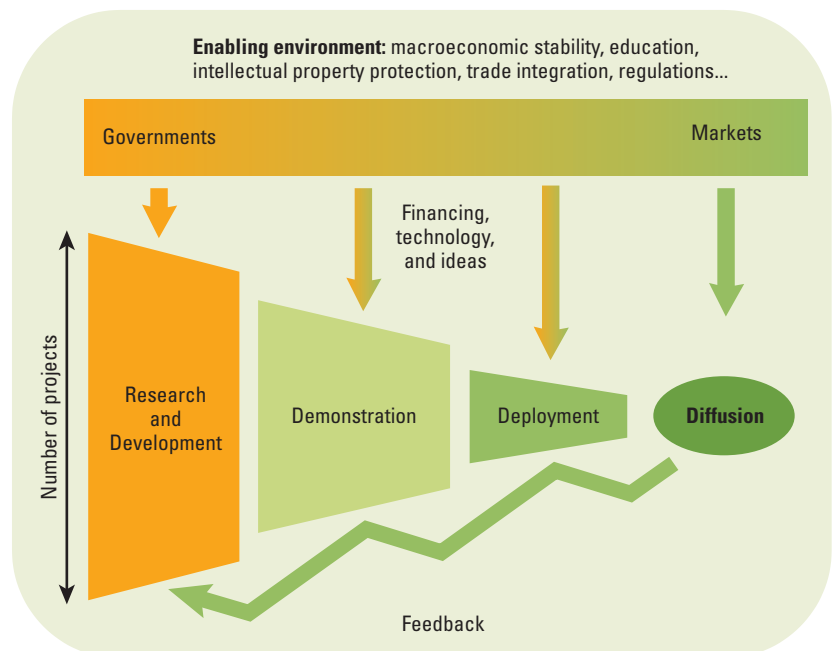
harmonization of GSM communications standards for mobile phones created a critical mass for the mobile phone market in Europe in the 1990s.

#### *Knowledge-sharing and coordination agreements are useful complements*

Knowledge agreements can address market and system failures in innovation and diffusion. Such agreements coordinate national research agendas, information exchange systems, and voluntary standards and labeling schemes. Research coordination agreements include many of the International Energy Agency's 42 technology agreements, where countries finance and implement their individual contributions to different sector-specific projects, ranging from advanced fuel cells to electric vehicles.<sup>30</sup> Such agreements can avoid duplicating investments across countries. They allow countries to jointly decide on who works on what, thus ensuring that no key technologies are ignored, particularly those relevant to developing countries (such as biofuels from developing-country feedstocks and lower-capacity power generation). Information exchange systems include the Global Earth Observation System of Systems, which will make data available from

various observation and measurement systems (box 7.3). Prominent examples of international coordination in labels are the Energy Star program agreements, whereby government agencies in various countries

Figure 7.5 Policy affects every link of the innovation chain



Source: Adapted from IEA 2008a.

### BOX 7.3 *Innovative monitoring: Creating a global climate service and a “system of systems”*

Demand for sustained and reliable data and information on trends, unusual events, and long-range predictions has never been greater than it is today. A number of public and private entities in sectors as diverse as transportation, insurance, energy, water, agriculture, and fisheries are increasingly incorporating climate information into their planning. Such forecasting has become a critical component of their adaptation strategies.

A global climate services enterprise (GCS) could provide the climate-relevant information that society needs to better plan for and anticipate climate conditions on timescales from months to decades. Such an enterprise would build on existing observation systems but must go far beyond them. A GCS would provide information to help answer questions about appropriate city infrastructure to cope with the 100-year extreme precipitation and storm surge events that will now occur at higher magnitude and greater frequency, help farmers decide on appropriate crops and water management during droughts, monitor changing stocks and flows of carbon in forests and soils, and evaluate efficacy of disaster response strategies under changing climate conditions.

A GCS will require innovative partnerships across governments, the private sector, and other institutions, and its design will be quite critical. Beginning with today's observations and modeling capacity, a connected multi-hub-and-spoke design should be developed whereby global services are provided to regional service providers that in turn deliver information to local providers. This eliminates the requirement that every community develop very sophisticated information on their own.

#### **Building the Components of a GCS**

Some of the necessary information to develop a GCS is being provided by United States National Meteorological and Hydrologic Service Centers and increasingly by Global Climate Observing System contributions through various government agencies and nongovernmental institutions. Also, a number of

other institutions, such as the World Data Centers and the International Research Institute, regularly provide climate-related data and products including forecasts on monthly to annual timescales.

There are also a few examples of fledgling regional climate services. One such example is the Pacific Climate Information System (PaCIS), which provides a regional framework to integrate ongoing and future climate observations, operational forecasting services, and climate projections. PaCIS facilitates the pooling of resources and expertise, and the identification of regional priorities. One of the highest priorities for this effort is the creation of a Web-based portal that will facilitate access to climate data, products, and services developed by the U.S. National Oceanic and Atmospheric Administration and its partners across the Pacific region.

Another example is the formation of regional climate centers, which the World Meteorological Organization (WMO) has formally sought to define and establish since 1999. The WMO has been sensitive to the idea that the responsibilities of regional centers should not duplicate or replace those of existing agencies but instead support five key areas: operational activities, including the interpretation of output from global prediction centers; coordination efforts that strengthen collaboration on observing, communication, and computing networks; data services involving providing data, archiving it and ensuring its quality; training and capacity building; and research on climate variability, predictability, and impacts in a region.

#### **Integrating climate services with other innovative monitoring systems**

Building a comprehensive and integrated system to monitor environmental changes across the planet is beyond the means of any single country, as is analyzing the wealth of data it would generate. That is why the Group on Earth Observation (GEO), a voluntary partnership of governments and international organizations, developed the concept of a Global Earth Observation System of Systems

(GEOSS). Providing the institutional mechanisms to ensure the coordination, strengthening, and supplementation of existing global Earth observation systems, GEOSS supports policy makers, resource managers, scientific researchers, and a broad spectrum of decision makers in nine areas: disaster risk mitigation; adaptation to climate change; integrated water resource management; management of marine resources; biodiversity conservation; sustainable agriculture and forestry; public health; distribution of energy resources; and weather monitoring. Information is combined from oceanic buoys, hydrological and meteorological stations, remote-sensing satellites, and internet-based Earth-monitoring portals.

Some early progress:

- In 2007 China and Brazil jointly launched a land-imaging satellite and committed to distribute their Earth observation data to Africa.
- The United States recently made available 40 years of data from the world's most extensive archive of remotely sensed imagery.
- A regional visualization and monitoring system for Mesoamerica, SERVIR, is the largest open-access repository of environmental data, satellite imagery, documents, metadata, and online mapping applications. SERVIR's regional node for Africa in Nairobi is predicting floods in high-risk areas and outbreaks of Rift Valley Fever.
- GEO is beginning to measure forest-related carbon stocks and emissions through integrated models, in situ monitoring, and remote sensing.

*Sources:* Global Earth Observation System of Systems, <http://www.epa.gov/geoss> (accessed January 2009); Group on Earth Observations, <http://www.earthobservations.org> (accessed January 2009); IRI 2006; note from Tom Karl, National Oceanic and Atmospheric Administration, National Climatic Data Center, 2009; Pacific Region Integrated Climatology Information Products, <http://www.pricip.org/> (accessed May 29, 2009); Rogers 2009; Westermeyer 2009.

unify certain voluntary energy-efficiency labeling schemes by providing a single set of energy-efficiency qualifications.<sup>31</sup>

The Montreal Protocol's Technology and Economic Assessment Panels offer a model for a technology agreement on climate change, in this case the effects of ozone depletion. The panels brought together governments, businesses, academic experts, and nongovernmental organizations into work groups to establish the technical feasibility of specific technologies and timetables for phasing out the production and use of chlorofluorocarbons and other ozone-depleting chemicals. The panels showed that technology coordination agreements work best when linked to emission mandates, which provided incentives for industry to participate.<sup>32</sup> One challenge to replicating this model for climate change is that a large number of panels would be required to tackle the wide range of technologies that affect climate change. A more feasible approach would be to initially limit this approach to several strategic sectors.

The European Union's "New Approach" to standardization also offers a model for harmonization of climate-smart standards. Goods traded within the EU must comply with basic safety, public health, consumer protection, and environmental protection rules. The EU first tackled this issue by requiring member states to harmonize legislation containing detailed technical specifications. But this approach caused deadlocks in the European Council and updating legislation to reflect technological progress was difficult. In 1985, the New Approach was designed to overcome this problem. Goods classified under the New Approach must simply comply with very broad, technology-neutral "essential requirements" enshrined in legislation that must be adopted by every EU member state. To meet the New Approach requirements, products can comply with harmonized European standards developed by one of the three regional voluntary standardization bodies. There, technical committees representing a mix of industry, governments, academia, and consumers from different EU countries agree on standards by consensus. Technical committees are open

to any stakeholder from any EU member state wishing to participate. A similar approach could harmonize broad climate-smart regulations across countries through a climate treaty supported by voluntary standards developed separately through an open-consensus process.<sup>33</sup>

Voluntary standards, labels, and research coordination are lower-cost means of technology cooperation, but it is difficult to assess whether they generate additional technology investments.<sup>34</sup> It is unlikely that they alone could address the massive investment needs, urgency, and learning-by-doing required for such technologies as carbon capture and storage.

***Cost-sharing agreements have the highest potential payoffs, if they can surmount implementation barriers***

Cost-sharing agreements can be "technology-push" agreements, where the joint development of promising technologies is subsidized by multiple countries (the top-down, left-most, orange arrow in figure 7.5) before knowing whether they will succeed. Or they can be "market-pull" agreements, where funding, pooled from multiple countries, rewards technologies that have demonstrated commercial potential—providing market signals through feedback loops. They can also bridge the gaps in the innovation chain between research and the market.

**Research agreements.** Only a few international cost-sharing programs support climate-change innovation, among them the \$12 billion ITER fusion reactor (box 7.4) and several technology agreements coordinated by the International Energy Agency, with budgets of several million dollars. Another partnership model of research institutions is the Inter-American Institute for Global Change Research, an intergovernmental organization supported by 19 countries in the Americas, with a focus on the exchange of scientific information among scientists and between scientists and policymakers. The mission of the center is to encourage a regional, rather than national, approach.

There is potential for massively scaling up cost-sharing research agreements for

#### BOX 7.4 ITER: A protracted start for energy R&D cost sharing

ITER is an international research and development project to demonstrate the scientific and technical feasibility of nuclear fusion to generate electricity without producing the radioactive waste associated with nuclear fission. The partners in the project are China, the European Union, India, Japan, the Republic of Korea, the Russian Federation, and the United States.

ITER was proposed in 1986, and the design of its facilities was finalized in 1990. The initial schedule anticipated construction of an experimental reactor beginning in 1997, but this was postponed by negotiations over experimental design, cost sharing, the design site, the construction site,

and staffing. Several countries pulled out of ITER, some later rejoined, and some temporarily withdrew their funding.

ITER shows the difficulties in negotiating a more than \$12 billion research project with uncertain outcomes. Funding for construction was finally approved in 2006. ITER is expected to be operational for 20 years, once construction is completed around 2017.

Source: <http://www.iter.org> (accessed December 12, 2008).

Note: ITER originally stood for International Thermonuclear Experimental Reactors but now is simply known as ITER.

fundamental research and demonstration projects, where expenses and uncertainty are high. Research consortia are also well suited to conduct long-term research with economies of scale and economies of learning, such as carbon capture and storage (box 7.5), third-generation photovoltaic, deep offshore wind, second-generation biofuels, and climate-monitoring technologies. The scope for cooperation is narrower for technologies closer to commercialization, when intellectual property rights become more problematic and when individual countries may want a first-mover advantage.

Cost-sharing agreements can focus on a few high-priority areas and be negotiated through centralized international institutions with existing negotiation structures. The ITER project shows that large-scale cost-sharing agreements are difficult to implement when countries can renege on their commitments or disagree on implementation. Ensuring the sustainability of funding for such agreements will require added incentives, such as withdrawal penalties or contractual commitments by each party to increase their funding (up to a cap) when new parties join, in order to discourage free-riding and lock cost-sharing agreements into a climate treaty.<sup>35</sup> Most of the technological efforts can be borne

by high-income countries. But to be effective, collaborative research agreements must subsidize the involvement of developing countries, particularly fast-growing middle-income countries that must start early to build technological capacity that will be essential for their long-term climate-smart development. The private sector must also be included in research partnerships to ensure technologies can later be diffused through the market.

#### *Market-pull, reward-based agreements.*

Many breakthrough innovations come from unlikely places that can be easily missed by grant funding programs. In 1993 Shuji Nakamura, a lone engineer working with a limited budget in a small company in the Japanese countryside, astonished the scientific community with the first successful blue-light-emitting diodes. This was the critical step for creating today's brilliant high-efficiency white-light-emitting diodes.<sup>36</sup> Many of the leading global innovators—including the computer giant Dell—spend much less than their industry peers on R&D as a share of sales.<sup>37</sup> But they are uniquely skilled at scoping the horizon for high-potential technologies and ideas, at collaborating with others on R&D, and at bringing new technologies to the market.<sup>38</sup> Some of the most promising climate-smart technologies are likely to come out of sectors that are typically not associated with climate change. For example, super-water-absorbent polymers could play a key role in promoting revegetation of drylands and other degraded ecosystems by holding water in the soil. But much of the interest in this technology is concentrated among manufacturers of products such as diapers. Similarly, producers of water repellent materials could manufacture clothing that requires less washing, with significant reductions in water and energy use.

Financial instruments that reward risk taking, rather than picking winners from the start, represent a tremendous unexploited opportunity. Solutions to technological problems can come from rapid advances in unexpected places or from new business models that traditional R&D subsidy programs can easily overlook. New

### BOX 7.5 *Technologies on the scale of carbon capture and storage require international efforts*

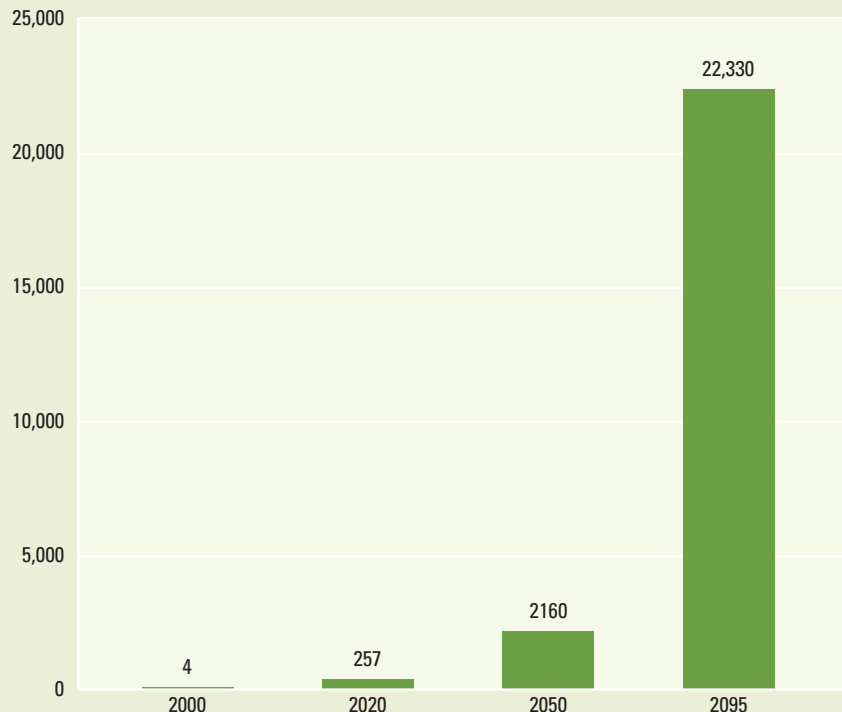
For carbon capture and storage to achieve a fifth of the emission reductions needed to limit atmospheric concentrations to, for example, 550 parts per million, the technology has to ramp up from the 3.7 million tons of carbon sequestered today<sup>a</sup> to more than 255 million tons by 2020 and at least 22 billion tons by the end of the century, or about the same amount of current global emissions from energy use today (figure). Each capture and storage plant costs between \$1.5 and \$2.5 billion to construct, and deploying the 20–30 needed by 2020 to prove the commercial viability of the technology would be prohibitive for a single country. There are only four commercial end-to-end carbon capture and storage projects, and their storage capacity is one to two orders of magnitude smaller than the capacity a commercial 1,000 megawatt plant would need over its expected operational lifetime.

Sources: Edmonds and others 2007; IEA 2006; IEA 2008b.

a. To convert tons of carbon to CO<sub>2</sub>, multiply by 3.67.

#### Carbon capture and storage technology requires massive additional efforts

CO<sub>2</sub> removed/year (millions of tons)



Note: Observed data for 2000. For all other years, projections based on needs in order to limit greenhouse gas concentrations to 550 ppm.

global financial instruments give markets the flexibility to find innovative solutions.

Inducement prizes and advanced market commitments are two closely related market-pull incentives for rewarding innovations that attain prespecified technological targets in a competition. Inducement prizes involve a known reward; advanced market commitments are financial commitments to subsidize future purchases of a product or service up to predetermined prices and volumes.

Although there are no examples of internationally funded climate-smart prizes, other recent national public and private initiatives have gathered growing interest. The \$10 million Ansari X-Prize was established in the mid-1990s to encourage non-governmental space flight. The competition induced \$100 million of private research investments across 26 teams, leveraging 10 times the prize investment, before the

winner was announced in 2004.<sup>39</sup> In March 2008 the X-Prize Foundation and a commercial partner announced a new \$10 million international competition to design, build, and bring to market high-fuel-mileage vehicles. One hundred and eleven teams from 14 countries have registered in the competition.<sup>40</sup>

Advanced market commitments, which encourage innovation by guaranteeing some minimum market demand to reduce uncertainty, have promoted climate-smart technologies through the U.S. Environmental Protection Agency, in partnership with nonprofit groups and utilities (box 7.6). A more recent international initiative is a pilot program for pneumococcal vaccines designed by the GAVI Alliance and the World Bank.<sup>41</sup> In 2007 donors pledged \$1.5 billion in advanced market commitments to the pilot. Vaccines are bought with donor-committed funds and with minor

### BOX 7.6 *The Super-Efficient Refrigerator: A pioneer advanced market commitment program?*

In 1991, under the Super-Efficient Refrigerator Program, a consortium of utilities agreed to pool more than \$30 million to reward a manufacturer that could produce and market a refrigerator free of ozone-depleting chlorofluorocarbons that used 25 percent less energy than required by existing regulations. The winner would receive a fixed reward for each unit sold, up to the cap set by the fund's size. The Whirlpool company

exceeded the performance requirements and won the prize and national publicity. However, because of low market acceptance the company could not sell enough refrigerators to claim the entire prize. Nonetheless, the competition likely produced spillovers, with competing manufacturers designing their own lines of efficient refrigerators.

Sources: Davis and Davis 2004; Newell and Wilson 2005.

funding from recipient countries if they meet specified performance objectives. It is still too early to judge probable success.<sup>42</sup>

Market-pull inducements can complement but not replace technology-push incentives. Market-pull techniques can multiply public financial resources and foster competition to develop proof-of-concept and working prototypes. They have low barriers to entry—because funding is not awarded on past research credentials, small organizations and organizations from developing countries can compete. But these incentives cannot reduce risk to a point that private investors would be willing to finance large-scale or very early stage research.

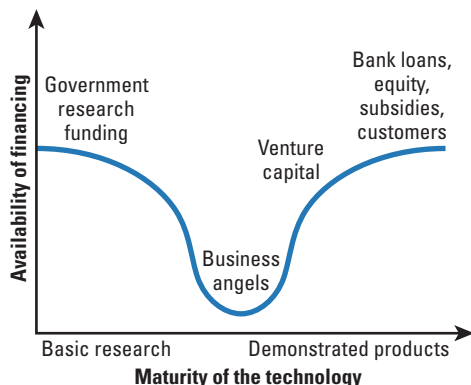
Prizes and advanced market commitments offer good potential for multilateral

funding. Since prizes do not entail commercialization, they could be offered to solve precommercial research problems in such technologies as battery storage or photovoltaics. Private and public organizations in search of technology solutions could post competitions for designated cash prizes in a global technology marketplace. The World Bank Group is exploring prize competitions for early-stage clean technology innovations supported by the new Earth Fund launched by the Global Environment Facility and the International Finance Corporation.

Advanced market commitments could be useful where deployment learning costs are prohibitive, where there are no lead users willing to pay initial premiums for the technology, or where the market is too small or risky. These include energy generation and use but also adaptation technologies (such as malaria treatments and drought-resistant crop varieties), where the demand side of the market is fragmented (individual governments), financial resources are limited (particularly for developing countries), and the potential size of the market is blurred (by long-term policy uncertainty).<sup>43</sup>

**Agreements to bridge the commercialization gap.** A major obstacle for innovation is the “valley of death,” the lack of financing for bringing applied research to the market (figure 7.6). Governments are typically willing to fund R&D for unproven technologies, and the private sector is willing to finance technologies that have been demonstrated in the marketplace—the R&D block in figure 7.3—but there is little funding for technologies at the demonstration and deployment stages.<sup>44</sup> Governments are often reluctant to fund early-stage ventures for fear of distorting the market, and private investors consider them too risky, with the exception of a limited number of independent investors termed “business angels” and some corporations. Venture capitalists, who typically only fund firms with demonstrated technologies, were able to deploy no more than 73 percent of capital available in the clean technology sector in 2006 because so few firms in this sector had survived the valley of death.<sup>45</sup>

**Figure 7.6** The “valley of death” between research and the market



Source: WDR team.

Venture capital funding is also lacking for many types of climate-smart technologies. Investors are unlikely to be attracted to market segments involving particularly high-risk and capital-intensive energy technologies where demonstration costs can be massive. And it is expected that today's financial crisis will slow corporate venture capital, given the higher cost of debt.<sup>46</sup> Moreover, the bulk of the global venture capital industry is in a few developed countries, far from opportunities in several rapidly growing middle-income countries.<sup>47</sup>

Programs to commercialize technology can also support links with potential users of climate-smart technologies, particularly for small firms where breakthrough innovations often occur but which face the greatest financial and market access constraints. To commercialize ideas that meet its technology needs, the U.S. Environmental Protection Agency provides funding to small firms through the Small Business Innovation Research Program.<sup>48</sup> The French government's Passerelle program provides cofunding to large enterprises willing to invest in innovation projects of potential interest in small firms.<sup>49</sup> Other programs provide special grants to collaborative projects to encourage technology spillovers.

Because the gap between research and the market is particularly wide in developing countries and because many solutions to local problems may come from foreign countries, special multilateral funding can support research projects that include developing-country participants. This funding can create incentives for conducting research relevant to developing-country needs such as drought-resistant crops. Multilateral efforts can also promote climate-smart venture capital funds in high-income countries and in the several rapidly growing middle-income countries that have the critical mass of innovative activity and financial infrastructure to attract venture capital investors. This latter group includes China and India. In Israel, the Republic of Korea, and Taiwan, China, the government provided venture capital, acting as a core investor and attracting other funds.<sup>50</sup> Such strategies can provide the "valley of life" needed to nurture nascent technologies to

levels where they can take root in the global economy.

### *The scale and scope of international efforts are far short of the challenge*

Technology transfer comprises the broad processes to support flows of information, know-how, experience, and equipment to governments, enterprises, nonprofits, and research and educational institutions. The absorption of foreign technologies depends on much more than financing physical equipment and technology licenses. It requires building national capacity to identify, understand, use, and replicate useful technology. As discussed below, international policies can work hand in hand with national efforts to improve national institutions and create an enabling environment for technology transfer.

**International organizations.** Many international organizations dealing with environmental challenges are mainly mission focused; these include the World Health Organization, the Food and Agriculture Organization, and the UN Environment Programme. But these entities can be encouraged to collectively enhance the adequacy and coherence of the existing institutions for addressing climate change.

Similarly, many international agreements exist to address particular environmental problems but as these are operationalized, they should be mutually reinforcing.<sup>51</sup> These can be evaluated in terms of goals and means to achieve them in relation to their ability to support mitigation and adaptation of the magnitude expected under a 2°C world or a 5°C or beyond world.

**Financing mechanisms.** The Clean Development Mechanism (CDM), the main channel for financing investments in low-carbon technologies in developing countries, has leveraged public and private capital to finance over 4,000 low-carbon projects. But the majority of its projects do not involve either knowledge or equipment transfer from abroad.<sup>52</sup> (Chapter 6 discusses the limits of scaling up the CDM to accelerate technology transfers.)



The Global Environment Facility (GEF) is today the largest funder of projects that promote environmental protection while supporting national sustainable development goals. The GEF functions as the financial arm of the UNFCCC and provides support for technology needs assessments for more than 130 countries. Most GEF mitigation funding between 1998 to 2006—about \$250 million a year—was directed at removing barriers to the diffusion of energy-efficient technologies.<sup>53</sup> The GEF's adaptation efforts focus on building capacity to identify the urgent and immediate needs of least developed countries. But its impact is limited by its modest proposed adaptation budget of \$500 million for the 2010–14 period.<sup>54</sup>

The new Carbon Partnership Facility will provide complementary assistance to developing countries by supporting large and risky investments in clean energy and infrastructure with good potential for long-term emission reductions.<sup>55</sup> The Clean Technology Fund, a \$5.2 billion multidonor initiative established in 2008, is another effort to provide low-interest financing for demonstration, deployment, and transfer of low-carbon technologies. In 2009 the Arab Republic of Egypt, Mexico, and Turkey are to be the first countries to benefit from a combined \$1 billion of financing from this fund.

The Montreal Protocol shows how sustained multilateral funding can be achieved by making the financing of incremental

costs of upgrading technology an obligation of an environmental treaty. The Multilateral Fund for Implementation of the Montreal Protocol provided developing countries with incentives to join the protocol by committing funds for incremental compliance costs.<sup>56</sup> In exchange, developing countries agreed to gradually phase out ozone-depleting substances. The fund provided grants or loans to cover the costs of facilities conversion, training, personnel, and licensing technologies. While the protocol is considered a successful model of technology diffusion, the sources of emissions of greenhouse gases are orders of magnitude larger than chlorofluorocarbons, and many greenhouse gas reduction technologies are not commercially available. A climate change fund similar to the Multilateral Fund would need to be scaled up appropriately.<sup>57</sup>

*Financial and technological resources.* As chapter 6 emphasizes, substantially more financing for developing countries is necessary. Estimates for additional required investments for mitigation and adaptation range from \$170 billion to \$765 billion annually by 2030. But financial transfers alone will not be enough. Acquiring technology, far from easy, is a long, costly, and risky process riddled with market failures. Adaptation technologies depend on local technical skills and indigenous knowledge because they involve designing systems tailored to local needs (box 7.7).

Even when technology can be imported, it involves a search process, prior technical knowledge, and the skills and resources necessary to use the technology efficiently. That capacity rests on various forms of knowledge, many of which are tacit and cannot be easily codified or transferred. Large-scale energy projects that can be contracted out to foreign firms, for example, require local capacity for policy makers to evaluate their merits, and for operation and maintenance. The European Union is developing legislation for managing risks associated with carbon capture and storage,<sup>58</sup> but few countries have the technical capacity to design such legislation, another barrier to deploying the technology.

### BOX 7.7 *A promising innovation for coastal adaptation*

Bangladesh's coastal regions expect more frequent storm surges and tidal floods as a result of climate change. The University of Alabama at Birmingham is working with Bangladeshi researchers on home foundations and frames built of a lightweight composite material that bends—but does not break—in a hurricane and that can float on the rising tide of a coastal surge. Fibers from jute, one of Bangladesh's common plants, are woven with recycled plastics to form an ultrastrong building material. Jute does not require fertilizer, pesticides,

or irrigation; is biodegradable; is inexpensive; and is already widely used to produce cloth, ropes, and other items in Bangladesh. Local architects are helping to incorporate the technology in local house designs. Bangladeshi researchers will contribute their expertise on the mass-manufacturing of jute products.

Sources: University of Alabama at Birmingham, <http://main.uab.edu/Sites/MediaRelations/articles/55613/> (accessed February 17, 2009); interview with Professor Nassim Uddin, University of Alabama at Birmingham, on March 4, 2009.

Multilateral funding can have a greater impact on technology transfer and absorption by extending its scope from transferring physical and codified technology to enhancing human and organizational absorptive capacities in developing countries. Technology absorption is about learning: learning by investing in foreign technologies, learning through training and education, learning by interacting and collaborating with others outside and inside one's country, and learning through R&D. Multilateral funding can support technology transfer in three ways: by subsidizing investments in homegrown or foreign technologies in developing countries; by subsidizing the involvement of developing countries in the types of knowledge exchange, coordination, and cost-sharing agreements as discussed above; and by

supporting national knowledge infrastructures and private sectors, as discussed in the following section.

### Public programs, policies, and institutions power innovation and accelerate its diffusion

Innovation is the outcome of a complex system that relies on the individual capacity of a multitude of actors, ranging from governments, universities, and research institutes to businesses, consumers, and nonprofits. Strengthening the capacity of this diverse set of actors, and how these actors interact, is a difficult but necessary task for tackling both development and climate change. Table 7.2 describes key policy priorities for encouraging innovation in countries of different income levels.

**Table 7.2 Key national policy priorities for innovation**

Countries	Main policies
Low-income	<ul style="list-style-type: none"> <li>Invest in engineering, design, and management skills</li> <li>Increase funding to research institutions for adaptation research, development, demonstration, and diffusion</li> <li>Increase links between academic and research institutions, the private sector, and public planning agencies</li> <li>Introduce subsidies for adopting adaptation technologies</li> <li>Improve the business environment</li> <li>Import outside knowledge and technology whenever possible</li> </ul>
Middle-income	<ul style="list-style-type: none"> <li>Introduce climate-smart standards</li> <li>Create incentives for imports of mitigation technologies and, in rapidly industrializing countries, create long-term conditions for local production</li> <li>Create incentives for climate-smart venture capital in rapidly industrializing countries with a critical density of innovation (such as China and India)</li> <li>Improve the business environment</li> <li>Strengthen the intellectual property rights regime</li> <li>Facilitate climate-smart foreign direct investment</li> <li>Increase links between academic and research institutions, the private sector, and public planning agencies</li> </ul>
High-income	<ul style="list-style-type: none"> <li>Introduce climate-smart performance standards and carbon pricing</li> <li>Increase mitigation and adaptation innovation and diffusion through subsidies, prizes, venture capital incentives, and policies to encourage collaboration among firms and other sources and users of climate-smart innovation</li> <li>Assist developing countries in enhancing their technological absorptive and innovative capacities</li> <li>Support transfers of know-how and technologies to developing countries</li> <li>Support middle-income-country participation in long-term energy RDD&amp;D projects</li> <li>Share climate change–related data with developing countries</li> </ul>
All countries	<ul style="list-style-type: none"> <li>Remove barriers to trade in climate-smart technologies</li> <li>Remove subsidies to high-carbon technologies</li> <li>Redefine knowledge-based institutions, especially universities, as loci of the diffusion of low-carbon practices</li> </ul>

Source: WDR team.

Skills and knowledge constitute a key pillar for building a climate-smart economy. Basic education provides the foundation of any technology absorption process and reduces economic inequity, but a large enough pool of qualified engineers and researchers is also crucial. Engineers, in particularly short supply in low-income countries, play a role in implementing context-specific technologies for adaptation and are critical to rebuilding efforts after natural disasters (figure 7.7). Bangladesh, particularly prone to hurricanes and sea-level rise, is an extreme example: university students enrolled in engineering represented barely 0.04 percent of the population in 2006, compared with 0.43 percent in the Kyrgyz Republic, a country with a very similar per capita GDP.<sup>59</sup> Equally important are the management and entrepreneurial skills that channel technical knowledge into practical applications in the private sector. And in the public sector, skills are required in a wide range of areas including utility regulation, communication, urban planning, and climate policy development.

Skills and knowledge can be acquired by investing in the institutions and programs that make up a country’s knowledge infrastructure. Institutions such as universities, schools, training institutes, R&D institutions, and laboratories, and such technological services as agricultural extension and business incubation<sup>60</sup> can support the private and public capacity to use climate-smart technologies and make decisions on the basis of sound science.

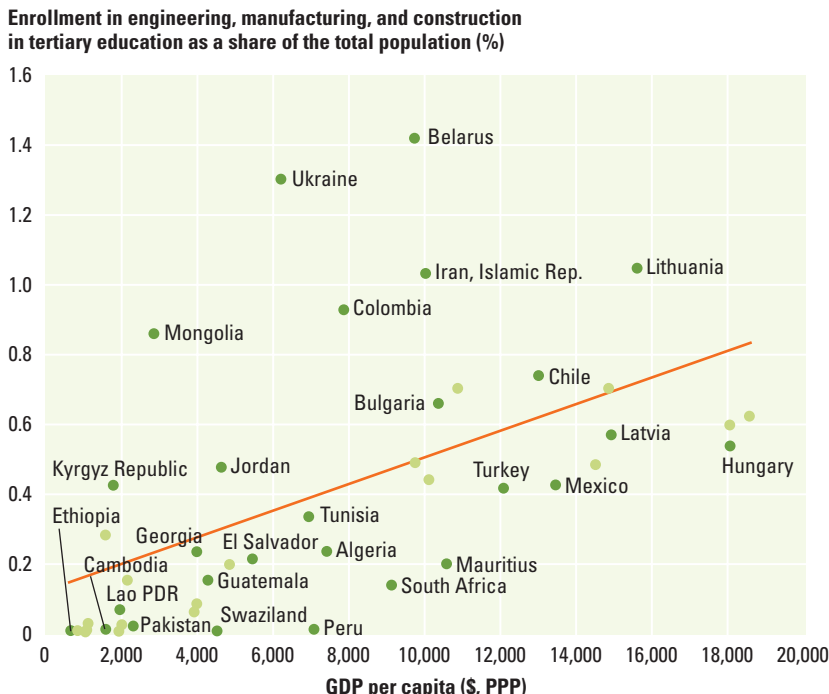
Another pillar for building a climate-smart economy is to create incentives for the private sector to invest in climate-smart technologies. This means creating not only regulatory incentives but also an enabling environment paired with public support programs for business innovation and technology absorption.

*Knowledge infrastructure is a key to creating and adapting local mitigation and adaptation systems*

Research institutes in developing countries can help governments better prepare for the consequences of climate change. In Indonesia and Thailand, for example, they are using NASA satellites to monitor environmental characteristics affecting malaria transmission in Southeast Asia, such as rainfall patterns and vegetation status.<sup>61</sup> Research institutes can partner with government agencies and private contractors to identify and design appropriate coastal adaptation technologies and to implement, operate, and maintain them. They can help devise adaptation strategies for farmers by combining local knowledge with scientific testing of alternative agroforestry systems or support forestry management by combining indigenous peoples’ knowledge of forest conservation with genetically superior planting material.<sup>62</sup> And they can help firms improve the energy efficiency of their processes through consultancy, testing, troubleshooting, and training.

In middle-income countries research institutions can also solve longer-term mitigation challenges. Mastering the energy technologies that will be useful involves a learning process that can take decades. Agriculture and health depend on biotechnology to develop new technologies

**Figure 7.7 Enrollment in engineering remains low in many developing countries**



Source: WDR team based on UNESCO Institute for Statistics, <http://stats.uis.unesco.org/unesco/ReportFolders/ReportFolders.aspx> (accessed August 30, 2009).

and climate science for planning purposes. Development of smart grids for national electricity distribution relies on mastering integrated communications, sensing, and measurement technologies.

Yet after investing in research and academic institutions, many governments have found the contributions to development minimal.<sup>63</sup> The reasons: the research typically is not demand-driven, and there are few links between research institutes, universities, the private sector, and the communities in which they operate (box 7.8).<sup>64</sup> In addition universities in many developing countries have historically focused on teaching and do little research.

Shifting the balance of government funding in favor of competitive research funding, instead of guaranteed institutional funding, can go a long way to increase the effectiveness of public research institutions. In Ecuador the government's Program for Modernization of Agricultural Services finances a competitive research grant program that supports strategic work on innovations to open new export markets by controlling fruit flies, reducing production costs for new export products, and controlling disease and pests in traditional exports crops. The program introduced a new research culture and brought new organizations into the research system. Cofinancing requirements helped increase

national research funding by 92 percent.<sup>65</sup> Institutional reforms that give the private sector a greater voice in the governance of research institutions and that reward transfer of knowledge and technology to external clients can also help.<sup>66</sup> In some cases "bridging institutions" such as business incubators can facilitate knowledge spillovers from research institutions. In 2007, 283 clean technology companies were under incubation worldwide (even before including China), twice as many as in 2005.<sup>67</sup>

High-income countries can support the global development and diffusion of climate-smart systems by helping build capacity and partnering with research institutions in developing countries. An example is the International Research Institute for Climate and Society at Columbia University in the United States, which collaborates with local institutions in Africa, Asia, and Latin America.

Another example is the Consultative Group on International Agricultural Research (CGIAR). A donor-funded, decentralized, and cooperative global structure of research institutions, the CGIAR already targets a number of topics relevant to climate adaptation (box 7.9). A similar approach can be used for other climate technologies. Lessons from CGIAR suggest that regional research centers can be funded in developing countries to focus on a limited number

### BOX 7.8 *Universities need to be innovative: The case of Africa*

Most donor assistance to Africa does not address the need to harness the world's existing fund of knowledge for long-term development. Higher education enrollments in Africa average close to 5 percent, compared with typical figures of more than 50 percent in developed economies. The challenge, however, is not only to increase access to African universities but also to make them function as engines of development.

There are opportunities for universities to forge closer links with the private sector, train more graduates for professional careers, and diffuse knowledge into the economy. As a model, the United States has a long tradition of land grant colleges,

which since the 19th century have been working directly with their communities to diffuse agricultural knowledge. The task ahead requires qualitative change in the goals, functions, and structure of the university. As part of this process, fundamental reforms will be needed in curriculum design, teaching, location, student selection, and university management.

Training will have to become more interdisciplinary to address the interconnected problems that transcend traditional disciplinary boundaries. South Africa's Stellenbosch University offers a shining example of how to adjust curricula to the needs of R&D organizations. It was the first university in the world to design and

launch an advanced microsatellite as part of its training. The aim for the program was to build competence in new technologies in the fields of remote sensing, spacecraft control, and earth sciences. Uganda's Makerere University has new teaching approaches that allow students to solve public health problems in their communities as part of their training. Similar approaches can be adopted by students in other technical fields, such as infrastructure development and maintenance.

Sources: Juma 2008; Land grant colleges, <https://www.aplu.org/NetCommunity/Page.aspx?pid=183>; sea grant colleges, <http://www.seagrant.noaa.gov/> (accessed August 31, 2009).

### BOX 7.9 *CGIAR: A model for climate change?*

The Consultative Group on International Agricultural Research (CGIAR) is a strategic partnership of 64 members from developing and industrial countries, foundations, and international organizations including the World Bank. Founded in 1971 in response to widespread concern that many developing countries were in danger of succumbing to famine, it has contributed significantly to agricultural productivity gains through improved crop varieties and played a pivotal role in bringing about the Green Revolution. Over time the CGIAR's mandate has expanded to include policy and institutional matters, conservation of biodiversity, and management of natural resources including fisheries, forests, soil, and water.

The CGIAR supports agricultural research by assisting 15 research centers, independent institutions with their own staff and governance structures, mostly in developing countries—and by running challenge programs. These are independently governed broad-based research partnerships designed to confront global or regional issues of vital importance,

such as genetic resource conservation and improvement, water scarcity, micronutrient deficiency, and climate change. In 2008 the CGIAR implemented an independent review of its governance, scientific work, and partnerships. The review concluded that CGIAR research has produced high overall returns since its inception, with benefits far exceeding costs. The benefit of yield-enhancing and yield-stabilizing crop varieties produced by the centers and their national partners is estimated at more than \$10 billion annually, attributable largely to improved staple crops such as wheat, rice, and maize. Natural resource management research also shows substantial benefits and high returns on investment. However, the impact of these efforts has varied geographically because of a complex of factors such as local collective action, extension services, or assignment of property rights. The review deemed the CGIAR “one of the world's most innovative development partnerships,” thanks to its multidisciplinary research activities and range of collaborations. But it also

found that the CGIAR has lost focus on its comparative advantages and that its growing mandate has diluted its impact. At the same time volatile food prices, more extreme weather patterns, growing global demand for food, and increasingly stressed natural resources are challenging the CGIAR like never before.

In December 2008 the CGIAR adopted a new business model. The reform entails a programmatic approach that will focus on a limited number of strategic “mega-programs” on key issues. The reforms also emphasize results-oriented research agenda setting and management, clear accountabilities, streamlined governance and programs, and stronger partnerships. The changes are expected to strengthen the CGIAR so that it can more effectively address many complex global issues, including climate change, but it is still too early to gauge their success.

*Sources:* Consultative Group on International Agricultural Research, <http://www.cgiar.org/> (accessed March 5, 2009); CGIAR Independent Review Panel 2008; CGIAR Science Council 2008; World Bank 2008a.

of well-defined, region-specific topics, such as biomass, bioenergy, energy-efficient buildings, methane mitigation, and forest management.

Knowledge institutions can help inform and coordinate policy, particularly context-specific adaptation policies. As adaptations to climate change begin to be considered within policy processes, it becomes important to share solutions and experiences.<sup>68</sup> When planners, managers, and policy makers begin to recognize how their individual decisions can combine to reduce vulnerability to climate change, there is a tremendous opportunity to enhance coordination among sectors to improve the use of resources and to share this valuable information with other nations, regions, and localities.<sup>69</sup> Establishing and managing a “clearinghouse” that processes and makes available adaptation success stories and options from around the world will help communities faced with adaptation decisions.<sup>70</sup>

### *Carbon pricing and regulations to mobilize the private sector*

As chapter 4 discusses, carbon pricing is essential for catalyzing market-driven innovation and adoption of mitigation technologies.<sup>71</sup> As relative prices change firms are likely to respond with new types of technological investments to economize on the factor that has become more expensive.<sup>72</sup> There is strong evidence that pricing can induce technological change.<sup>73</sup> One study found that if energy prices had remained at their low 1973 level until 1993, the energy efficiency of air conditioners would have been 16 percent lower in the United States.<sup>74</sup>

Regulation and its proper enforcement can also induce innovation. Performance standards for emissions or energy efficiency can induce technological change in much the same way as carbon pricing, because they can be associated with implicit prices that firms face in emitting pollutants.<sup>75</sup> In the United States patenting activity in sulfur dioxide (SO<sub>2</sub>) emissions technology started

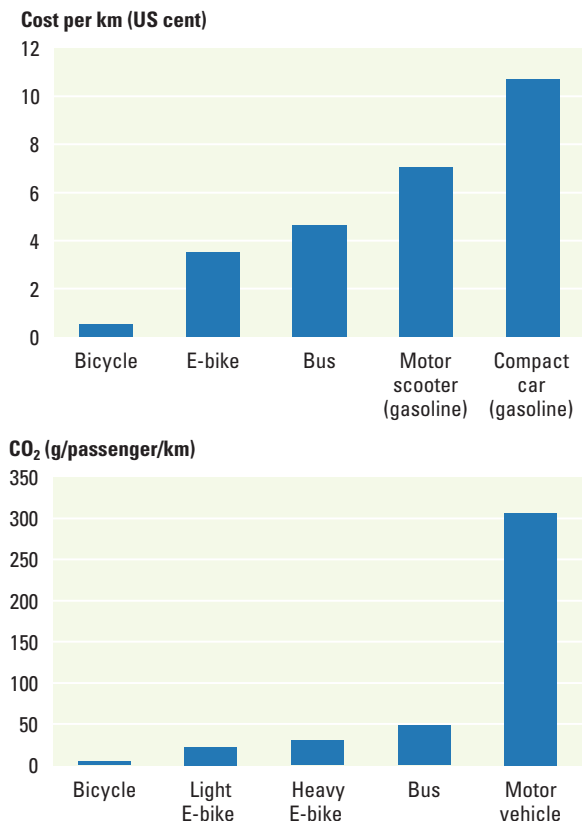
to increase only in the late 1960s in anticipation of new national standards on SO<sub>2</sub> control. From 1975 to 1995 technological improvements reduced the capital costs for removing SO<sub>2</sub> from power plant emissions by half, and the share of SO<sub>2</sub> removed rose from less than 75 percent to above 95 percent.<sup>76</sup> Regulations can also provide firms with niche markets to develop new technologies and allow countries to gain a competitive edge. A ban on gasoline-propelled motorbikes in several urban areas of China in 2004—which coincided with technological improvements in electric motor and battery technologies, faster urbanization, higher gasoline prices, and increases in purchasing power—boosted the electric bicycle market from a mere 40,000 in 1998 to 21 million in 2008. E-bikes are now cheaper and cleaner than other motorized modes of transportation, including buses (figure 7.8), and China is exporting these low-carbon vehicles to developed countries.<sup>77</sup>

But regulation alone can have its drawbacks. Unlike price signals, regulations can limit the flexibility of firms, especially when they are technology-specific. They can also result in mitigation options that are more costly for society. But they are a necessary complement to carbon pricing (see chapter 4). Studies have analyzed the comparative effects of environmental regulations and market-based incentives on innovation: the general view is that combining different policy instruments may be the most effective, so long as their development and enforcement are predictable to stakeholders.<sup>78</sup>

*An enabling business environment provides the basic framework for climate-smart technology diffusion and innovation*

Markets need to function properly to ensure that firms do not face unnecessary risk, have access to information, operate within a well-defined legal framework, and have supportive

**Figure 7.8** E-bikes are now among the cheapest and cleanest travel mode options in China



Sources: Cherry 2007; Weinert, Ma, and Cherry 2007; photograph from the Wikipedia Foundation.

Note: E-bike emissions refer to full life-cycle, which, in this case, includes production, energy production, and use. For the regular bicycle only emissions from production are included.

market institutions. Securing land tenure, documenting land rights, strengthening land rental and sale markets, and broadening access to financial services can create incentives for technology transfer for rural smallholders (see chapter 3).<sup>79</sup> But an enabling business environment needs to recognize the basic rights of vulnerable groups, particularly indigenous peoples, heavily dependent on land and natural resources. Many of them have become landless, live on small parcels of land, or do not have secure tenure.<sup>80</sup>

Reducing entry barriers for firms and offering a flexible labor market supports technology start-ups that can create breakthrough innovations and agribusinesses that can bring new types of fertilizers or seeds to farmers.<sup>81</sup> The case of hybrid pearl millet in India shows that market liberalization in the late 1980s increased not only the role of private companies in seed development and distribution but also the rates of innovation.<sup>82</sup> Macroeconomic stability is another pillar of the enabling environment, along with a well-functioning financial sector. Basic infrastructure services, such as continuous energy and water supplies, are also indispensable.

Eliminating tariff and nontariff barriers on clean energy technologies—such as cleaner coal, wind power, solar photovoltaics, and energy-efficient lighting—could increase their traded volume by 14 percent in the 18 developing countries that emit high levels of greenhouse gases.<sup>83</sup> Trade barriers on imports, such as quotas, rules of origin, or unclear customs code specifications, can impede the transfer of climate-smart technologies by raising their domestic prices and making them cost-ineffective. In Egypt the average tariffs on photovoltaic panels are 32 percent, 10 times the 3 percent tariff imposed in high-income members of the Organisation for Economic Co-operation and Development (OECD). In Nigeria potential users of photovoltaic panels face nontariff barriers of 70 percent in addition to a 20 percent tariff.<sup>84</sup> Biofuels are hit particularly hard by tariffs. Tariffs on ethanol and on some biodiesel feedstocks, including import and export duties on Brazilian ethanol, totaled \$6 billion in 2006. OECD country subsidies to their domestic biofuels producers came to \$11 billion in 2006.

As a result, investments are not being made where technology is the most cost-effective. Brazil, the world's lowest-cost ethanol producer, saw a modest 6 percent increase in its ethanol production between 2004 and 2005, whereas the United States and Germany saw production increases of 20 and 60 percent respectively, protected by tariffs of over 25 percent in the United States and over 50 percent in the EU.<sup>85</sup> Removing these tariffs and subsidies would likely reallocate production to the most efficient biofuel producers.<sup>86</sup>

An attractive investment climate for foreign direct investment (FDI) is critical to accelerating technology transfer and absorption.<sup>87</sup> In 2007 FDI accounted for 12.6 percent of total gross fixed capital formation in electricity, gas, and water in developing countries, three times the amount of multilateral and bilateral aid.<sup>88</sup> Transnational corporations based in high-income countries have invested massively in photovoltaic production in India (BP Solar), ethanol in Brazil (Archer Daniels Midland and Cargill), and wind power in China (Gamesa and Vestas). China had one foreign-owned R&D laboratory in 1993 and 700 in 2005.<sup>89</sup> General Electric, a world leader in energy generation and efficiency products, opened global R&D centers in India and China in 2000, centers that now employ thousands of researchers. Figure 7.9 highlights the opportunities brought about by the globalization of wind power equipment R&D and production in middle-income countries.

Developing local production capacity can help these countries ensure their long-term uptake of climate-smart technologies and compete in global markets, driving prices down and performance up. This will occur fastest through licensing or FDI.

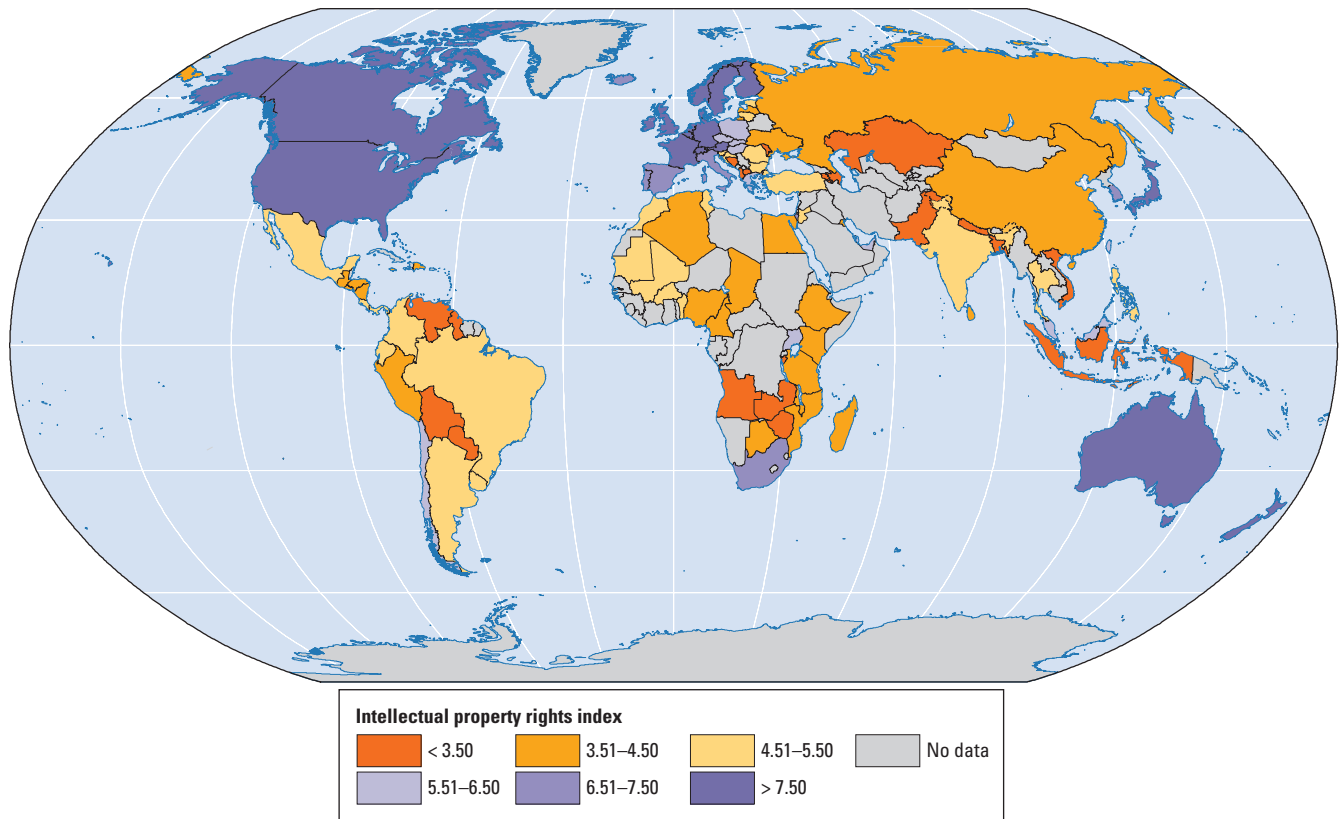
To facilitate the transfer of climate-smart technologies, middle-income countries can allow foreign firms to establish fully owned subsidiaries instead of mandating joint ventures or licensing. They can also build a base of local suppliers and potential partners for foreign-invested firms by investing in training and capacity building.<sup>90</sup> And they can ensure that their intellectual property rights adequately protect foreign technology transfer and R&D.

When enforcement of intellectual property rights (IPR) is perceived to be weak (see figure 7.9), foreign firms may not be willing to license their most sophisticated technologies, for fear that competitors will use it—which is the situation for wind equipment in China.<sup>91</sup> Weak IPR enforcement also discourages foreign subsidiaries from increasing the scale of their R&D activities

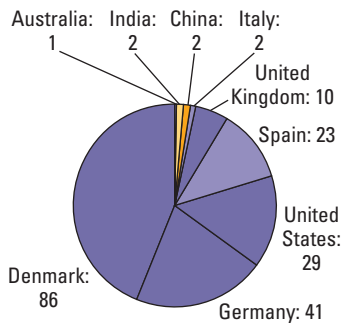
and foreign venture capitalists from investing in promising domestic enterprises.<sup>92</sup> Despite their investments in local manufacturing and R&D, foreign subsidiaries of global wind equipment producers register very few patents in Brazil, China, India, or Turkey. All these countries have weak IPR regimes that could discourage scaling up R&D.<sup>93</sup>

**Figure 7.9 Middle-income countries are attracting investments from the top five wind equipment firms, but weak intellectual property rights constrain technology transfers and R&D capacity**

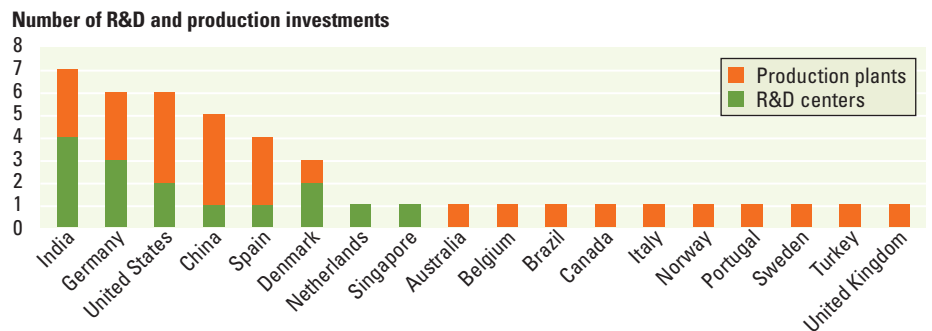
**a. Intellectual property rights performance**



**b. Number of wind power patents in 2007**



**c. Location of investments of top five wind firms**



Sources: Published patent data from U.S., Japanese, European, and international patent application databases, annual reports, and Web sites of Vestas, General Electric, Gamesa, Enercon, and Suzlon (accessed on March 4, 2009); Dedigama 2009.

Note: A country's IPR score reflects its ranking according to an IPR index based on the strength of its intellectual property protection policies and their enforcement.



Yet IPRs may also hamper innovation if a patent blocks other useful inventions because it is too broad in scope. Some patent claims on synthetic biology products and processes with promise for synthetic biofuels are perceived by critics to be so broad that scientists fear they may halt scientific progress in related fields.<sup>94</sup> Strong IPRs can also hamper technology transfer if firms refuse to license their technology to keep their market power.

There is no evidence that overly restrictive IPRs have been a big barrier to transferring renewable energy production capacity to middle-income countries, but there are fears that they could one day become so. Brazil, China, and India have joined the ranks of global industry leaders in photovoltaics, wind, and biofuels, often by acquiring licensed technologies. IPR issues may become more of a barrier to technology transfer as patenting activity accelerates in photovoltaics and biofuels and as equipment supplier consolidation continues in the wind sector.<sup>95</sup>

In low-income countries weak IPRs do not appear to be a barrier to deploying sophisticated climate-smart technologies. But predictable and clearly defined IPRs can still stimulate technology transfer from abroad. In these countries, licensing and building local versions of a technology is not a realistic option given the limited domestic production capacity.<sup>96</sup> The absorption of energy technologies generally occurs through imports of equipment. For climate adaptation, patents and plant variety rights held in developed countries are seldom a problem in small and lower-income countries. A patent registered in a specific country can only be protected in that market, and foreign companies do not register their intellectual property in many low-income countries, because they do not represent attractive markets or potential competitors. Poorer countries can thus decide to use a gene or tool from abroad.<sup>97</sup>

High-income countries can ensure that excessive industry consolidation in climate-smart sectors does not reduce incentives to license technology to developing countries. They can also ensure that national policies do not prevent foreign firms from licensing

publicly funded research for climate-smart technologies of global importance. In many countries, universities are not allowed to license technology funded by their national government to foreign firms.<sup>98</sup> Other proposals include patent buyouts and the transfer of climate-smart IPRs to the public domain by international organizations.

High-income countries can also ensure that concerns over IPRs and transfer and innovation of climate-smart technologies are considered in international treaties such as those of the World Trade Organization (WTO). The WTO's agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) establishes the minimum legal standards of protection for WTO members. But the TRIPS agreement also recognizes that patents should not be abused, namely, that they should not prevent technology from serving the urgent needs of developing countries. In fact, the TRIPS agreement includes provisions to allow developing countries to exploit patented inventions without the consent of the IPR owner.<sup>99</sup> The WTO and its members can limit abuses in IPR protection if they ensure that the TRIPS agreement grants such exceptions for mitigation and adaptation technologies.

On the whole however, the impact of IPRs on technology transfer may be overstated in comparison with other costs such as management and training and barriers such as limited absorptive capacity. Building engineering competence could go a long way in enhancing the absorptive capacity of developing countries.

***Public funding can help firms overcome market failures associated with innovation and technology diffusion***

There is a limit to how much carbon prices and emission standards can increase investments in low-carbon technology and innovation. New technologies are not always rapidly adopted even when they become economically attractive to potential users (see box 4.5 in chapter 4). Accelerating technological change requires supplementing carbon pricing and regulations with public funding to explore a wide portfolio of technological options.<sup>100</sup> Well-known

market failures leading to private underinvestment in innovation and diffusion have provided the basis for public funding policies for decades.<sup>101</sup>

In middle-income countries with industrial capacity, financial support can go to the local design, production, and export of climate-smart systems. Public funding policies can broadly define innovation to include adapting, improving, and developing products, processes, and services that are new to a firm, irrespective of whether they are new to their markets. This takes into account the spillover effects of R&D in helping build technological absorptive capacity.<sup>102</sup> For example, the Technology Development Foundation of Turkey provides zero-interest loans of up to \$1 million to companies that adopt or develop systems for energy efficiency, renewable energy, or cleaner production.<sup>103</sup> In small and low-income countries where there are even more market barriers to technology absorption, public financial support can selectively finance technology absorption in firms, along with related technical consulting and training.

Publicly supported technology diffusion programs bridge gaps in information and know-how among firms, farmers, and public agencies. The most effective programs respond to real demand, address multiple barriers, and include community institutions from the beginning. This creates local buy-in, builds sustainability, and ensures that the programs are compatible with local development goals.<sup>104</sup> In South Africa the Clean Production Demonstration project for metal finishers was successful precisely because it targeted a wide range of issues in parallel—from the lack of information about the advantages of cleaner technologies to the lack of legislation or its enforcement. The demand-driven project obtained the buy-in of all stakeholders—a broad range of company owners, managers, staff, consultants, regulators, and suppliers—and combined awareness campaigns, training, technical consulting, and financial assistance.<sup>105</sup> In China the government's strategy to improve and diffuse biomass cook stove technology was equally successful because it recognized the systems nature of

innovation and was largely demand-driven (box 7.10).

As already pointed out in chapter 4, government procurement is another market-pull instrument that can create market niches for climate-smart technology, but it relies on good governance and a sound institutional environment. Public purchasing preferences can stimulate climate-smart innovation and technology adoption when the government is a major customer in areas such as wastewater management, construction, and transport equipment and services. Germany and Sweden already include “green” criteria in more than 60 percent of their tenders.<sup>106</sup>

Preventing unmanageable climate change, coping with its unavoidable impacts on society, and meeting global development objectives requires significantly stepping up international efforts at diffusing existing technologies and deploying new ones. For ambitious high-priority initiatives, such as carbon capture and storage, countries can pool their resources, share the risks and share the learning benefits of joint RDD&D. They can create new global funding mechanisms. “Technology-push” policies based on increasing public investments in R&D will not be sufficient to reach our technological objectives. They need to be matched with “market-pull” policies that create public and private sector incentives for entrepreneurship, for collaboration, and to find innovative solutions in unlikely places.

The world must ensure that technological advances find their ways rapidly to countries that have the least ability to adopt them but the most need. Diffusing climate-smart technology will require much more than shipping ready-to-use equipment to developing countries. Namely, it will require building technological absorptive capacity—the ability of the public and private sectors to identify, adopt, adapt, improve, and employ the most appropriate technologies. It will also require creating environments that facilitate the transfer of mitigation and adaptation technologies from one country to the next through channels of trade and investment.

### BOX 7.10 *Improved cook stoves designs can reduce soot, producing important benefits for human health and for mitigation*

About 2 billion people in developing countries depend on biomass for heating and cooking. Rudimentary cookstoves in rural areas from Central America to Africa, India, and China release CO<sub>2</sub> along with black carbon (tiny particles of carbon in soot) and products of incomplete combustion (carbon monoxide, nitrogen compounds, methane, and volatile organic compounds). These products pose a serious health hazard. Inhalation of indoor smoke from burning of solid biomass is thought to contribute to the deaths of 1.6 million people a year globally, about 1 million of them children under five years of age.

Recent studies suggest that the power of black carbon as a driver for climate change could be as much as twice what the Intergovernmental Panel on Climate Change previously estimated. New analyses suggest that black carbon could have contributed more than 70 percent of the warming of the Arctic since 1976 and could have been a strong factor in the retreat of Himalayan glaciers.

Given that household solid fuel used in cookstoves in the developing world is responsible for 18 percent of the emissions of black carbon, new cookstove technologies that improve combustion and thus reduce soot and emissions of other gases can have benefits not only for human health but also for mitigation.

A lot of funding has been devoted to support the use of liquefied petroleum gas (LPG) stoves as a cleaner alternative to biomass stoves, mostly by subsidizing LPG, but that has proved ineffective at diffusing the technology widely in developing countries. Even with subsidies, most poor people cannot afford the fuel.

Public programs to introduce improved biomass cook stoves over the past two decades have produced mixed results. In India the government subsidized 50 percent of the cost of 8 million stoves that it distributed. Initially, the program encountered some difficulties because the stove design was not appropriate for the tools and foods used by the population, but during the past five years the government has launched new research to correct these problems. Improved cook stoves are gaining some ground in other countries. In China the government recognized that success hinged on meeting people's needs, and that this could not be achieved through a supply-driven top-down approach. It confined its role to research, technical training, setting manufacturing standards, and reducing bureaucratic impediments to the production and diffusion of new stoves. The enterprise sector was mobilized for local distribution.

Given recent technological progress in biomass cookstoves, their impact on health, and their recently revealed impact on climate change, it is appropriate to massively scale up and commercialize high-quality biomass-based cookstoves. The most effective stoves will be affordable to the poor, adaptable to local cooking needs, durable, and appealing to customers. Project Surya, a pilot evaluation program, is going to undertake the most comprehensive and rigorous scientific evaluation to date on the efficacy of improved cookstoves on climate warming and people's health. The project will support the introduction of new cookstove models in 15,000 households in three different regions of India. By monitoring

#### A woman cooks with her Envirofit G-3300 cookstove



Photo credit: Envirofit India.

pollutants through cutting edge sensor technologies, measuring solar heating of the air, and combining these data with measurements from NASA satellites, the project team hopes to observe a “black carbon hole”—the absence of the usual black carbon particles—in the atmosphere over the areas of intervention, and to measure how this impacts regional temperatures and people's health. The study will also improve understanding of how future cookstove programs should address households' needs and behaviors.

Sources: Bond and others 2004; Columbia Earthscape, <http://www.earthscape.org/r1/kad09/> (accessed May 14, 2009); Forster and others 2007; Hendriksen, Ruzibuka, and Rutagambwa 2007; Project Surya, <http://www.ramanathan.ucsd.edu/ProjectSurya.html> (accessed August 31, 2009); Ramanathan and Carmichael 2008; Ramanathan, Rehman, and Ramanathan 2009; Shindell and Faluvegi 2009; Smith, Rogers, and Cowlin 2005; UNEP 2008b; Watkins and Ehst 2008.

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*"Through my painting I would like to transmit to all the people, including world's leaders, my hope to stop global warming promoting the use of our sun because it is powerful, clean, and practically endless. . . . If we want, we could turn it to be our everyday energy source. Governments and companies should support the use of solar energy and scientists to find the best way so the people can easily use it in their homes, appliances, machines, factories, and vehicles."*

—Laura Paulina Tercero Araiza, Mexico, age 10



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