



Chapter 3

Technological innovation

Authors: Richard Connor and Walter Rast

Contributor: Gunilla Björklund

Coordinator: Tim Kasten (UNEP)

Facilitator: Richard Connor

Key messages

- ◆ Technological innovation is driven largely by both human wants and needs.
- ◆ Technological innovation can create both positive and negative pressures, sometimes simultaneously, resulting in increased or decreased water demand, supply and quality.
- ◆ Technological innovation is one of the most unpredictable drivers. It can create rapid, dramatic and unexpected changes, both in pressures and solutions.
- ◆ Impediments to the dissemination of technology must be overcome if developing countries are to benefit from innovations developed in richer countries.

Technological change takes different forms, each with different potential impacts on the environment. Some innovations reduce environmental pressures (by lowering emissions or using water resources more efficiently, for example), while others increase them (by increasing water demands for their production, for example). Most innovations create both positive and negative pressures on the environment, while the main purpose of technology is to make processes (production, transformation and communication, for example) more efficient, which generally means more cost-effective, the environmental benefits of some technologies have also yielded broader economic benefits. In recent decades, for example, greater environmental regulation and corporate social responsibility, combined with pressures from society, have prompted cleaner and more environmentally friendly technologies and increased their overall value.

Disseminating technology is as important as developing it. Controls on the dissemination of technology, especially from

developed countries (where much of the technology is generated) to developing countries (which are less able to afford or generate it), inhibit the ability of developing countries to stay economically and environmentally competitive.

In the water sector the expansion of scientific knowledge and technological applications is changing the way water is used, cleaned and reused to meet human, economic and environmental needs. Industries are investing in new technologies and processes that reduce water use and wastewater discharges. Household consumers are being offered water-saving technologies such as low-flush toilets, low-flow showers and faucet aerators. Agricultural productivity is being leveraged by drip irrigation and maintained by soil fertility and conservation techniques. Water supplies are being enhanced in many countries through innovative wastewater treatment and reuse techniques. And breakthroughs continue in desalination: advances in technologies and energy efficiency in the past decade have made



Water supplies are being enhanced in many countries through innovative wastewater treatment and reuse techniques

desalination an economic option for water supplies in coastal cities (see figure 9.3 and box 9.5 in chapter 9).¹

This chapter looks at six areas – in which water-related technologies are emerging rapidly – that are likely to exert strong pressures on the supply, use and management of water resources: environmental research and development, renewable energy, information and communications technology, biotechnology, bioenergy and nanotechnology. It also describes the challenges and difficulties associated with the dissemination of technology, which is especially important for developing countries.

Recent trends and advances in science and technology

Key message

- Technological innovation is driven largely by both human wants and needs.

People are the ultimate drivers of change on a global scale, through both their needs (their requirements for survival) and their wants (their desires for products and services that enhance safety, comfort and well-being). Although not true everywhere or to the same degree, technological advances that address these wants and needs are a major reason why many people enjoy a standard of living that includes access to safe drinking water and adequate sanitation.

It is sometimes difficult to determine whether technology development drives water demands or whether increasing water demands associated with human activities drive technology. Some new technologies

can have positive benefits – reducing water demand and increasing water availability (for example, rainwater harvesting) – while others can increase water demands (such as using crops to produce bioenergy). In analysing technological advances and interventions, it is also useful to distinguish their structural elements (such as construction of a plant, dam or irrigation system) and their non-structural elements (including public awareness campaigns, educational programmes and information sharing). This section outlines some key technology areas and provides some insight on how new developments can affect water resources.

Environmental research and development

Many developed countries have increased their investment in environmental research and development (R&D) to encourage new technologies to improve environmental quality (figure 3.1). Perhaps more important, developed countries also encourage research by the private sector through subsidies and tax incentives for specific types of research. This has been much less the case in most developing countries, however, because of the many competing claims on their limited financial resources. Thus, the main path of technology transfer is from developed countries to developing countries.

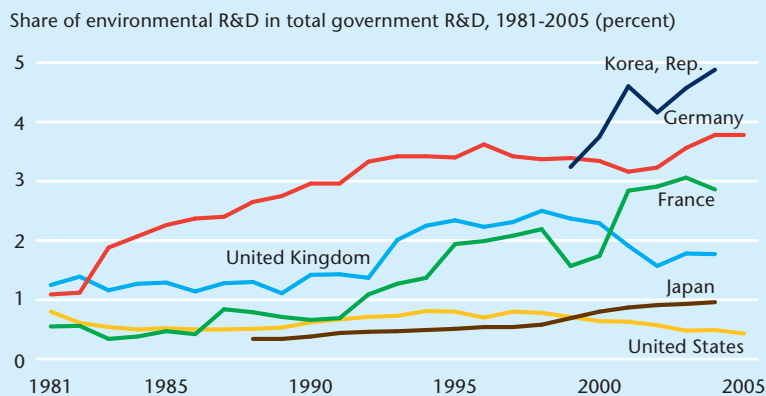
The focus of the R&D activities varies with national sustainable development priorities and interests and available funding. Germany, for example, has focused on clean processes and production technologies, Norway on energy and the environment and the United States on climate, water and hydrogen as an energy source.

There also appears to be a correlation between environmental regulations and environmental technology, with regulation spurring industries and water use sectors to address water availability and water quality. Environmental regulations may be counterproductive in facilitating environmental technology in some situations, however, since once required standards are met, incentives to engage in further technology development may dissipate.

Renewable energy

The renewable energy sector has seen remarkable innovation over the past two decades. Innovation has accelerated in response to recent public and political pressure to reduce greenhouse gas emissions thought to be contributing to global climate change. First-generation

Figure 3.1 Many developed countries have increased their investment in environmental research and development



Source: Based on OECD 2008.



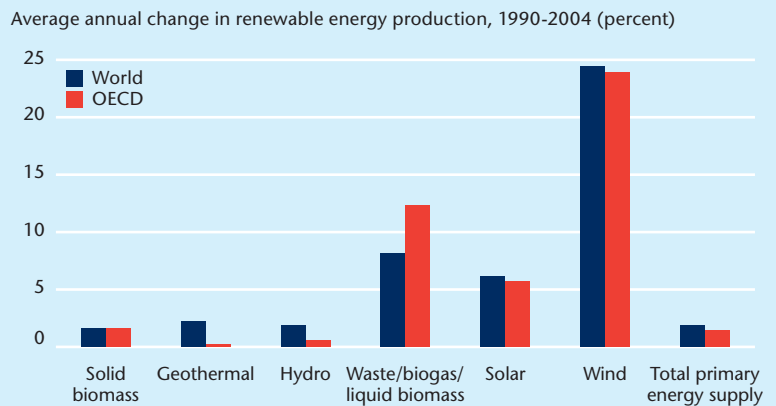
(hydropower and biomass combustion) and second-generation (solar heating and wind power) technologies are now being followed by third-generation technologies such as concentrated solar power, ocean energy, enhanced geothermal systems and integrated bioenergy systems. As these innovations have lowered relative costs, the use of renewable energy resources has risen worldwide (figure 3.2).

If current policies are maintained, global energy demands are expected to grow by as much as 55% through 2030, according to the International Energy Agency.² China and India alone would account for about 45% of this projected increase (based on conservative economic growth figures), and developing countries overall for 74%. Electricity generation from hydroelectric and other renewable energy resources is projected to increase at an average annual rate of 1.7% between 2004 and 2030, for an overall increase of 60%. Although renewable energy would still account for only a small part of total energy demand, the increase in renewable energy production could have a large impact on water resources, especially increases in hydropower generation.

Future development of hydropower will be limited by two main factors. One is the spatial and geophysical potential for new hydropower installations. In many developed countries, including Australia, the United States and much of Western Europe, most of the suitable sites for hydropower installations have already been developed (see map 7.6 in chapter 7). The second limiting factor is financial investment capacity, which has been the primary constraint in developing countries, including in most of Africa. Pressure from environmental groups opposed to dams, particularly to large dams, may also constrain future hydropower development.

Since renewable energy resources alone are not sufficient to meet the predicted dramatic increase in energy demands through 2030, fossil fuel extraction and development of nuclear energy will continue to increase, as will their impacts on water resources and the environment. Coal consumes about 2 cubic metres (m³) of water per megawatt hour of electricity generated, nuclear power about 2.5 m³ and petroleum about 4 m³. Extracting petroleum from Canada's tar sands, which have received much criticism as an 'unclean' source of oil, consumes an estimated 20-45 m³ of water per megawatt hour, nearly 10 times that for conventional oil extraction. Thus, as fossil fuel sources become increasingly

Figure 3.2 The use of renewable energy sources rose worldwide between 1990 and 2004



Source: Based on OECD 2008.

inaccessible, the water footprint of oil tar sands is likely to increase dramatically.

Information and communications technology

Advances in information and communications technology can affect the cost and effectiveness of monitoring ecosystem health and quality. Reductions in the costs of sensors, coupled with satellite-based wireless data transfer, have greatly facilitated the monitoring of water resources (water quality, water levels, flow rates and so on) and the delivery of water-related services, all in real time.

Improved monitoring through advanced information and communications technology can intensify the environmental effectiveness of policy measures, from the improved tracking of potentially hazardous materials to the monitoring of emissions from large stationary and smaller diffuse (non-point) and mobile sources. The greatest number of patents for monitoring environmental impacts between 1978 and 2002 was granted for water pollution treatment, attesting to the importance of information and communications technology innovations in the sustainable management of water resources. Still lacking, however, are adequate original field data required for ground-proofing, monitoring and forecasting data and for informed decision-making (see also chapter 14).

Biotechnology and genetically modified organisms

Plant and animal breeding has increased agricultural productivity and therefore affected water productivity. Progress has been concentrated in crop and animal productivity and resistance to pests, disease and weather extremes.



Biotechnology can have a valuable role in addressing water scarcity and quality challenges in both developed and developing countries, especially in agriculture

The green revolution of the 1970s and 1980s is an example of the dramatic effects of how taking advantage of technological advances can improve the livelihoods and incomes of the poor. The principal technologies involved in the green revolution were irrigation, fertilizer and pest control, together with high-yielding varieties of maize, wheat and rice. The green revolution in Asia doubled cereal production during 1970-95, while increasing the land area devoted to cereals by only 4%. By the late-1990s it was clear that many people, including segments of the poorest population groups, had reaped substantial benefits from higher incomes, less expensive food and increased demand for their labour associated with the green revolution.

The green revolution also demonstrates that unintended consequences can accompany new technologies. The excessive use of agrochemicals has polluted waterways, while wasteful irrigation has contributed to water scarcity in some areas and to water logging and soil salinization in others. High livestock concentrations have contributed to the spread of disease. As monoculture of crops for export or for use as animal feed replaced traditional polyculture techniques, the economic outcomes for some small farmers deteriorated as increased production of cereal crops caused prices to fall and crop susceptibility to pests and plant diseases spread. Increased agricultural production also led to higher water demands, exacerbating water scarcity problems in some arid and semi-arid regions (see chapter 8).

Genetically modified organisms are a more recent agricultural advance. A genetically modified organism is an organism whose genome has been altered through genetic engineering. A large share of food crops, such as corn, cotton and soybeans, have been genetically modified to increase yields and resistance to pests and chemical herbicides. Although this technology offers the potential for developing drought-resistant crops, with obvious advantages for water-scarce regions, little progress has been made towards this goal, and no breakthrough is expected in the near future.

Micro-organisms are an especially promising avenue, since there is considerable knowledge and experience in genetic experimentation with them. As decomposers of organic material, they are capable of breaking down or otherwise neutralizing many types of polluting materials in the environment. Micro-organisms are

currently used, for example, in biological processes in municipal wastewater treatment plants to treat or break down organic materials in wastewater. Micro-organisms that can more efficiently break down oil pollution in aquatic ecosystems and soils following oil spills or other industrial accidents are receiving attention. Similar avenues may become evident for research into the treatment of other types of water pollutants.

Bioenergy

Bioenergy, derived most commonly from plant materials, is a renewable energy source that is less likely to increase carbon dioxide emissions that contribute to global warming (in contrast to fossil fuels, which return long-stored carbon to the atmosphere). Cellulose, including agricultural residues, waste products and woody biomass, is also showing promise as a bioenergy source (see chapter 7).

This new technology is not without problems. For maize and sugarcane used to create bioenergy, a major problem is the need for large quantities of water to grow the crops (see box 7.2 in chapter 7) and for considerable quantities of fossil fuel energy for tillage, fertilizers, pesticides, irrigation, harvesting and transport machinery, and processing.³ Research is currently focused on the development of second-generation bioenergy, converting wood, crop residues and other biomass sources into liquid biofuel. Non-food crops such as jatropha do not require the intensive management and soil quality that food crops need and therefore may not compete directly with food crops for resources (water and good agricultural land). Second-generation bioenergy technology has the potential to increase energy yields significantly, but may not be commercially viable for 5-10 years.

Producing bioenergy from crops traditionally grown as food will require additional agricultural production to make up for the lost food sources, and more water as well. Increased bioenergy production has also resulted in a significant increase in some food prices by diverting grain traditionally grown for food.⁴ More than one-third of maize production in the United States in 2008 was being used to produce ethanol⁵ and about half the vegetable oils produced in the European Union were being used for biodiesel fuel.⁶ Although the impact is extremely difficult to assess, bioenergy production is estimated to have caused up to 70%-75% of the rise in the global prices of some food stocks, including approximately 70% of the increase in maize



prices.⁷ Higher energy prices worldwide and a weak US dollar are believed to have caused the remainder.⁸

Bioenergy production also causes environmental impacts unrelated to climate, particularly impacts arising from agricultural practices (see chapter 7). Examples include tillage-based soil erosion, eutrophication from fertilizer runoff, increased pesticide loads to aquatic habitats and biodiversity loss from land use changes. Further, the use of bioenergy could spawn other problems, as reductions in greenhouse gas emissions (from switching from fossil fuels to biofuels) could be offset by the clearing of new land to make room for more crop production. Cutting down forests could release carbon dioxide and reduce biodiversity. Under conditions of water scarcity, producing fuel for automobiles instead of producing food to feed a growing population becomes less socially acceptable, especially in developing countries.

Nanotechnology

Nanotechnology, the design and manufacture of extremely small electronic circuits and mechanical devices built at the molecular level of matter, shows particular promise for water resources. Key areas are desalination (see box 9.5 in chapter 9), water purification, wastewater treatment and monitoring. The first three areas involve the use of nanofiltration technology, nanomaterials and nanoparticles to remove or reduce water contaminants. Monitoring involves the use of nanosensors.

Many nanotechnology-based approaches are less a major departure from traditional methods of addressing such issues than a means of improving existing applications and devices.⁹ Seawater desalination plants are already in operation around the world, and many technologies can effectively remove microbes and other contaminants from water. And although operation efficiencies vary, wastewater treatment plants also exist in many developed and developing countries.

Nanotechnology has the potential to greatly improve water quality and quantity through water treatment or remediation. Nanofiltration membranes and other advanced filtration materials can facilitate water desalination and increased water reuse and recycling, improving desalination efficiency and reducing associated costs (especially for energy). Another emerging area is the development of nanomaterials, which can act as a 'sponge' to enhance the removal of specific heavy

metals from water supplies. Research is exploring the use of nanoparticles as catalysts for chemical reactions of other materials as a means of degrading them and for removing salts and heavy metals. Such treatments could be targeted to chemicals for which existing technologies are inefficient or costly and could eventually permit human use of heavily polluted and saline water for drinking, sanitation and irrigation.

For water monitoring nanotechnology encompasses new and enhanced sensors for detecting biological and chemical water contaminants present in very low concentrations. New sensor technology, coupled with micro- and nanofabrication technology, may eventually lead to the development of highly accurate and portable sensors.

There are also impediments to the large-scale use of nanotechnologies to address water resources issues. While many nanotechnologies are already in use, many are still at varying stages of research or development. Thus, although such technology could help developing countries increase water treatment or remediation efficiency and reduce costs associated with traditional treatment methodologies, it is unclear when nanotechnology-based applications will be ready for wide-scale use. And even though nanotechnologies may prove very efficient and cost-effective over the long term, initial acquisition and application costs are high in many cases. Using such technologies also will require the technical capacity to maintain and operate them.

There also are some risks associated with nanotechnology-based approaches, specifically the possibility that engineered nanoparticles used to catalyse chemical reactions may end up in water systems. Little is yet known about how such materials may interact with biological organisms, so the possibility of toxicity to humans and ecosystems must be considered.

The technology dissemination challenge

Key message

- Technology is constantly evolving, and the availability of technologies can differ widely between developed and developing countries because of impediments to dissemination of research and adaptation to local conditions.

Nanotechnology shows particular promise for desalination, water purification, wastewater treatment and monitoring



With the bulk of technological innovation originating in developed countries, introducing appropriate technologies into developing countries is a key challenge of development

Technological progress is both a determinant and an outcome of rising incomes. At the national level it can occur through invention and innovation, the adoption and adaptation of existing but new-to-the-market technologies and the spread of technologies across individuals, firms and the public sector within a country.

With the bulk of technological innovation originating in developed countries, introducing appropriate technologies into developing countries is a key challenge of development. It requires both the willingness to transfer the technology and the capacity to pay for, absorb, adapt and use the technology so that it generates long-term benefits.

Exporting technology to developing countries

The number of patents and scientific journal articles focusing on technology is strongly correlated with GDP per capita.¹⁰ Most developing countries lack the ability to generate innovations at the technological frontier. Moreover, relatively undeveloped domestic technology sectors and the lure of better economic and scientific opportunities abroad draw highly educated nationals from many developing countries to cutting-edge research sectors in high-income countries.

The lack of advanced technological competence in developing countries means that technological progress occurs there mainly through the adoption and adaptation of existing technologies. The penetration of older technologies, such as fixed-line telephones, electric power networks, transportation, health care and water services – many ultimately provided by governments – has tended to lag behind

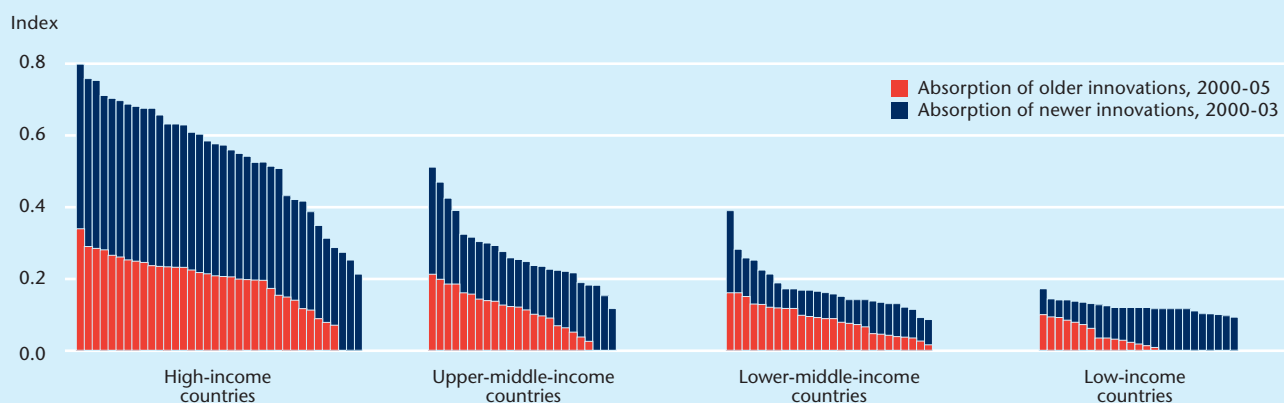
that of newer technologies (figure 3.3). Many of these older technologies require infrastructure that is expensive to create and maintain and that relies on large numbers of people with scarce technical skills. In addition, the diffusion of older technologies today depends on the intensity and efficiency with which government services were delivered in the past, many of which have a poor record.

The rates of acceptance and application of newer technologies have been higher than those of older technologies because rates of acceptance and application are more directly correlated with income. The infrastructure for newer technologies such as mobile phones and the Internet is generally less expensive to create and requires fewer (although more skilled) workers to operate and maintain. Moreover, with regulatory reform in many countries the private sector now offers these services in a competitive environment, rather than in the state-owned, monopolistic environments of the past. Supplying such new technologies has thus been more responsive to market demands and less constrained by the stringencies of government budgets or state enterprises. Furthermore, demands for such products have been boosted by low end-user costs, resulting from competitive pricing strategies, and the characteristics of some newer technologies that lend themselves to sharing more readily than do some older technologies.

Absorptive capacity for technology

Most technological progress in developing countries has been achieved through absorption and adaptation. A country's ability to absorb, adapt and apply foreign technologies depends mainly on its exposure to foreign technologies (the pace at

Figure 3.3 The absorption of older and more recent technologies depends on more than income



Note: Each bar represents a single country.

Source: Based on World Bank 2008.



which technologies diffuse across countries) and its ability to absorb, adapt and use the technologies to which it is exposed (the pace at which technologies diffuse within a country). Successful use depends on the technological absorptive capacity of the economy – the macroeconomic and governance environment, which influences the willingness of entrepreneurs to take risks on new and new-to-the-market technologies – and the level of technological literacy and advanced skills in the population.

Government policy also has a crucial role. Governments are often the primary delivery channel for technologies such as electricity, fixed-line telephones, transportation infrastructure and medical and educational services. And government policy can create a business environment that facilitates firm entry and exit and that is not hostile to exploiting new technologies. Too often, government regulations or features of the domestic market prevent firms from making money by exploiting a new technology, thus impeding the spread of technology within a country. Policy should also ensure that R&D and dissemination efforts give priority to creating and introducing products for which a market (domestic or foreign) exists and to helping firms exploit those opportunities.

Investing in research and development

Countries do well to invest in technology research and development. Research and extension programmes in agriculture, the sector that consumes the most water, have exceptionally high internal economic rates of return (table 3.1).

Many resource constraints can be overcome by technological capital and supporting institutions. Productivity gains, including genetic improvements that enable more production per unit of land, also enable more production per unit of water. For most developing countries gains in agricultural productivity arise from investments in adaptations of inventions produced in developed countries.

Challenges

A major technology challenge is how to balance the benefits and risks of new technologies. For the first time in human history, technology has provided humanity with the means to reshape the structure and functioning of the natural environment and thus to alter the possibilities for future development. The natural

environment has an internal system of checks and balances for its own maintenance and that of the animals and plants that inhabit it. Humanity has acquired technologies that can radically affect these natural checks and balances.

Many positive impacts are associated with technological advances, such as a reduced burden of disease and loss of life due to medical advances, decreased malnutrition due to the green revolution and other agricultural advances, and increased economic livelihoods due to industrialization and urbanization and attendant technologies. But maintaining a sustainable relationship between people and the natural environment requires maintaining a balance between the technologies we develop to meet human needs and nature's ability to supply them. And there is ample evidence that this balance is not being achieved in many places around the world, as demonstrated by excessive water abstractions, degraded water quality, and damaged aquatic ecosystems and biological communities. Some of these impacts result from ignoring the environmental consequences of human development actions. Others result from ignorance of the many, often subtle, interactions between the natural environment and the human activities that fundamentally affect it.

Consider crop-based bioenergy production. The increased production and use of bioenergy to reduce greenhouse gas emissions associated with the burning of fossil fuels must be balanced against the rising need for water resources, associated pollution and sufficient agricultural land on which to grow the crops to supply crop-based bioenergy. An unintended impact has been rising prices for some foods, as cereal crops are currently used for the production of bioenergy rather than for food. Our choices of technology require appropriate consideration of their benefits and costs, including their negative environmental impacts.

Maintaining a sustainable relationship between people and the natural environment requires maintaining a balance between the technologies we develop to meet human needs and nature's ability to supply them

Table 3.1 Return on investments in agricultural research and extension

Investment	Median internal rate of return (percent) ^a
Agricultural extension programmes	41
Applied research	49
Pre-invention science	60

a. The internal rate of return is the rate of discount at which the present value of benefits is equal to the present value of costs.

Source: FAO 2000.



Notes

1. Bergkamp and Sadoff 2008.
2. IEA 2007.
3. Pimentel and Patzek 2005.
4. Mitchell 2008.
5. US Department of Agriculture 2008.
6. Mitchell 2008.
7. Mitchell 2008.
8. FAO 2008.
9. Hillie et al. 2005, p. 43; Berger 2008.
10. World Bank 2008.

References

- Berger, M. 2008.** Nanotechnology and Water Treatment. Nanowerk website. www.nanowerk.com/spotlight/spotid=4662.php.
- Bergkamp, G., and C. W. Sadoff. 2008.** Water in a Sustainable Economy. In *State of the World: Innovations for a Sustainable Economy*. Washington, DC: Worldwatch Institute.
- FAO (Food and Agriculture Organization of the United Nations). 2000.** Agricultural Production and Productivity in Developing Countries. In *The State of Food and Agriculture 2000*. Rome: Food and Agriculture Organization of the United Nations.
- . **2008.** Soaring Food Prices: Facts, Perspectives, Impacts and Actions Required. HLC/08/INF/1. Background paper for the High-Level Conference on World Food Security: The Challenges of Climate Change and Bioenergy, Rome, 3-5 June 2008.
- Hillie, T., M. Munasinghe, M. Hlope, and Y. Deraniyagala. 2005.** Nanotechnology, Water and Development. Global Dialogue on Nanotechnology and the Poor: Opportunities and Risks. Meridian Institute, Washington, DC.
- . **2007.** *World Energy Outlook 2007*. Paris: Organisation for Economic Co-operation and Development and International Energy Agency.
- Mitchell, Donald. 2008.** A Note on Rising Food Prices. Policy Research Working Paper 4682, Development Prospects Group, World Bank, Washington, DC.
- OECD (Organisation for Economic Co-operation and Development). 2008.** *OECD Environmental Outlook to 2030*. Paris: Organisation for Economic Co-operation and Development.
- Pimentel, D., and T. W. Patzek. 2005.** Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower. *Natural Resources Research* 14 (1, March): 65-76.
- US Department of Agriculture. 2008.** Grain and Oilseeds Outlook for 2008. Prepared for the Agricultural Outlook Forum, February 21-22, Crystal City, VA. www.usda.gov/oce/forum/2008_Speeches/Commodity/GrainsandOilseeds.pdf.
- World Bank. 2008.** *Global Economic Prospects 2008: Technology Diffusion in the Developing World*. Washington, DC: World Bank.