Environment and Health in the Twenty-First Century

Challenges and Solutions

Jill Holdren,[a] Shu Tao,[b] and David O. Carpenter[c]

[a]*Pacific Basin Consortium for Environment and Health, East-West Center, Honolulu, Hawaii, USA*

[b]*Peking University, Beijing, China*

[c]*Institute for Health and the Environment, University at Albany, Rensselaer, New York, USA*

There are major challenges facing the countries in the Pacific Basin. These include issues of hazardous waste management and the consequent adverse effects of hazardous wastes on human health, the potential disruption of our whole way of life as a consequence of global climate change, and the increasing problem on human health of air pollution and the effects of breathing polluted air. These issues and others were the focus of the 12th meeting of the Pacific Basin Consortium for Environment and Health Sciences, held in Beijing in late 2007. This volume is a collection of papers presented at that meeting, and this introductory chapter provides some perspective on three of the major issues that are of concern in all of the countries in this region. This meeting provided an opportunity for Chinese scientists and those from other countries in the Pacific Basin to share perspectives and possible solutions with others from the international community, and these various approaches are reflected in these proceedings.

Key words: **e-waste; hazardous wastes; climate change; air pollution**

Introduction

The Pacific Basin Consortium for Environment and Health (Pacific Basin Consortium, or PBC) is an international not-for-profit organization with the mission of increasing cooperation among the countries of the Pacific Basin to address environmental health issues, including human exposures to toxic substances; hazardous and solid-waste remediation; climate change; occupational exposures; and food, air, and water pollution. The PBC was established in 1986, and has facilitated information exchange and cooperative research on issues related to environmental pollutants and human health for more than 20 years through 12 international conferences and numerous training programs. As the body of research supporting the relationship between environmental contaminants and adverse human and ecological health effects grows, it becomes ever more critical that scientists, engineers, policymakers, and government representatives from nations across the globe bring together their diverse expertise and perspectives to share ideas and knowledge and develop effective, affordable solutions.

A unique strength of the PBC is its international, interdisciplinary approach to problems of health and the environment. The 12th International Conference of the PBC, "Environment and Health in the 21st Century: Challenges and Solutions," held in Beijing, China, in October of 2007 exemplified this focus. The nearly 200 attendees came from more than 20 countries and represented at least as many disciplines. Toxicologists,

Address for correspondence: David O. Carpenter, Director, Institute for Health and the Environment, University at Albany, 5 University Place, Rensselaer, NY 12144. Voice: 518-525-2660; fax: 518-525-2665. carpent@uamail.albany.edu

Ann. N.Y. Acad. Sci. 1140: 1–21 (2008). © 2008 New York Academy of Sciences.
doi: 10.1196/annals.1454.048

epidemiologists, chemical engineers, government representatives, physicians, chemists, environmental attorneys, nongovernmental organization (NGO) representatives, economists, public health professionals, and others shared research, technological innovations, regulatory frameworks, and perspectives on a diverse range of environmental health problems. Financial and logistic support came from the National Institute for Environmental Health Sciences, the World Health Organization (WHO), the Institute for Geochemistry of the Chinese Academy of Sciences, the International Copper Association, the East-West Center, the Institute for Health and the Environment at the University of Albany, the University of Arizona, Tucson, Global Environment and Energy in the 21st Century, and Peking University.

The primary objectives of the conference were to: (1) present research related to: (a) sources of environmental pollutants, human exposure to pollutants, and the health effects of exposure, (b) advances in reducing the generation of hazardous chemical pollutants, methods for destroying or capturing them, and technology for the remediation of contaminated soils, hazardous wastes, and contaminated groundwater, and (c) climate change, including ecology and health effects; (2) increase interdisciplinary and international cooperation in understanding and addressing threats to human and environmental health in the region, with a special emphasis on ensuring that lessons learned in the development process by industrialized countries are passed on to countries currently in the midst of rapid industrialization; and (3) discuss ways to reduce risks to human and environmental health within a larger context that recognizes the importance of addressing issues of development, poverty, equity, and sustainability. The conference technical program included two plenary sessions, a poster session, a student session, and 15 technical sessions on a variety of environmental health topics, including: persistent organic pollutants and health; sustainability and environmental management; arsenic: sources and health effects; metals: sources and health effects; hazardous and solid wastes; indoor and outdoor air pollution; global climate change; children's environmental health and genotoxicity; water pollution and health; and cultivation, environment, and health.

The papers included in this volume are ones submitted by the authors and are only a fraction of the many presented at the conference. As would be expected from a conference of this type, some of the technologies and projects presented are extremely sophisticated and require advanced technology and significant resources to implement, while others are simple and affordable and can be applied at the village level.

While most, though not all, of the broad session topics at the conference are represented by at least one paper in this volume, the contents of this volume provide by no means a complete overview of conference discussions or the concerns of the PBC and its members. Rather than provide an exhaustive overview of the papers that follow we have chosen to limit this introduction to a discussion of three topics of great concern in the region: hazardous wastes, with a specific focus on electronic wastes (e-wastes); global climate change; and air pollution, with a particular focus on China and the United States.

Hazardous Wastes

Hazardous wastes are a growing problem today, with an estimated annual worldwide production of well over 400 million tons.[1] Some hazardous wastes are by-products of manufacturing; some are leftover pesticides, solvents, and other chemicals; still others are components of abandoned consumer products, such as electronics and appliances. Hazardous wastes, by definition have serious implications for human health and the environment.[2] Furthermore, the risks of exposure to and dangers associated with hazardous wastes are not spread equitably across nations and within nations. Not only are the poorest inhabitants of the poorest countries at the highest risk of exposure to hazardous materials because of substandard living and working conditions and trans- and intranational movements of wastes from rich to poor countries and rich to poor communities, they are also most likely to suffer adverse effects due to coexisting factors, such as malnutrition, unsafe water, and comorbidity with other diseases. The Basel Convention estimates that from 1993 to 2001 the amount of waste traveling between countries more than quadrupled.[3] Despite laws that expressly prohibit it, most of the international movement of hazardous waste is from rich countries to poor ones.

Clearly, the most effective way to address the problem of hazardous wastes is not to produce them in the first place. This goal is inarguably a laudable one, and in pursuit of it, nations must develop and use whatever technological innovations, economic incentives, and regulatory frameworks they can. It is nevertheless a distant one, and in the meantime, development of innovative and affordable technologies for remediation and safe disposal of hazardous wastes, particularly ones that can be applied in developing countries, is a critical component in addressing the issue. This volume contains a number of papers that propose technological solutions to specific problems of hazardous waste disposal and remediation, many of which are applicable even in remote and rural areas of developing (and developed) countries. The global issue of hazardous wastes cannot be solved simply by developing effective and accessible remediation technologies, however. Any long-term progress in addressing this issue will have to take a multipronged approach, which in addition to development of appropriate remediation technology must include (1) understanding the flows of hazardous wastes—where they are generated, where they end up—and the economic and political disparities that drive them; (2) understanding the specific health and environmental effects associated with different wastes; (3) addressing the question of responsibility—who is responsible for products through their lifecycles and how to both encourage and enforce that responsibility, which in turn has implications for cleaner and greener design; (4) encouraging and, where appropriate, enforcing, a host of producer changes, such as the use of less- or nontoxic product components, greater recyclability of products, longer lifetime of products, and greater ease of repair of products; and finally, (5) develop ways to ensure that the factors in play in (1) do not prevail over (3) and (4).

An area of hazardous wastes not well represented in the papers in this volume that provides a particularly good example of the complexity and global nature of environmental health problems in general and hazardous wastes in particular is the e-wastes industry. E-waste consists of electronic devices, such as computers, monitors, TVs, cell phones, mp3 players, DVD and CD players, VHS players, printers, and copy machines, that have been discarded (sent to a landfill or recycler). The United Nations Environment Programme (UNEP) estimated in 2005 that 20–50 million tons of e-waste was produced annually around the globe and that e-waste is growing at an annual rate of 3–5%.[4]

According to the U.S. Environmental Protection Agency (EPA), e-waste is the fastest growing component of municipal solid waste in the United States. While e-wastes are considered hazardous waste by federal law, households and small businesses in most states are exempt from this law and so can and do send these wastes directly to landfills. E-waste that ends up in landfills may leach heavy metals, dioxins, and flame retardants into soil, groundwater, or air, depending on the specific features of the landfill.[5] According to the EPA, an estimated 80% of e-waste generated in the United States each year is sent to landfills and only 20% is recycled.[6] The EPA estimates that in the United States alone between 2000 and 2007 around 500 million personal computers were discarded (sent to landfills or "recycled").[7] The average computer monitor contains a little more than two pounds of lead. Thus, discarded computers in the United States alone during this 7-year period mobilized more than a billion pounds of lead, in addition to a host of other heavy metals and toxic materials, such as flame retardants and dioxins—toxins that may end up in our—or our poorer neighbors'—water, food, and consumer products. The Silicon Valley Toxics Coalition estimates that more than a third of the lead and more than two-thirds of the heavy metals found in landfills originate in electronic products.[8]

Other products are sent to recycling programs where they may be domestically recycled, or more commonly, exported to China, India, or another developing country for processing. While it is extremely difficult to determine exactly how much e-waste is exported and imported globally and where it ultimately ends up, the nonprofit Basel Action Network, which has studied the issue closely, estimates that around 80% of e-waste that is recycled in the United States ends up in Asia, mainly China.[9] The U.S. EPA estimates more conservatively that at least 60% of e-waste recycled in the United States is exported to developing countries[6] where labor is cheap, environmental controls are either minimal or poorly enforced, and there is high demand for scrap metals.

Guiyu in Guiyang Province of China is an infamous example of the type of environmental and public health disaster that can be expected in the face of unregulated e-waste dumping and processing. The estimated 150,000 workers in this cottage industry generally have little or no protective gear, and in the processes of extracting precious metals and disposing of the remaining wastes they are exposed to often staggeringly high levels of such toxic substances as lead, cadmium, mercury, polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs), among others.[9,10] In addition, the soils, water, and air in the areas in which e-wastes are processed have become heavily contaminated, with potentially devastating consequences for both human health and the environment.[11] Plastics and copper wires are burned in open fires. Acid baths, used to extract precious metals from circuit boards, are dumped directly into the rivers, and circuit boards are cooked over coal fires to extract computer components.[9,10] A growing body of research indicates that not only industry workers but the other inhabitants of the area, the nearby rivers, sediments, and air are all heavily polluted.[12,13] Studies on river sediment in the two main rivers running through Guiyu, the Nanying and the Liangjiang, have found elevated levels of copper, cadmium, nickel, lead, and zinc.[13] Similarly, water samples in the rivers have been found to contain significantly elevated levels of cadmium, copper, nickel, and silver.[10] Soils have also been examined and found to contain high levels of brominated flame retardants and dioxins,[12] both of which have serious implications for human and environmental health.

Research has shown, too, that workers in Guiyu have extremely elevated blood levels of brominated flame retardants, specifically BDE-209, up to 50–200 times higher than seen previously in workers exposed to PBDE.[14]

Studies on atmospheric concentrations of dioxins (PCDD/F and PBDD/F) around Guiyu have found the highest concentrations of these toxins ever documented in the world. Dioxins are released when certain types of plastics are burned; since there are no municipal or medical solid-waste incinerators in or near Guiyu, the researchers surmise that the dioxins are likely released by the e-waste dismantling industry. PCB concentrations in Guiyu air samples were 12–18 times higher than those in Chendian, 9 km away, and 37–133 times higher than samples taken in Guangzhou, a town located 450 km from Guiyu, indicating that e-waste pollution is likely traveling beyond the immediate industry environs. The researchers further determined that, based on dioxin concentrations in Guiyu air, adult exposure to dioxins through inhalation is many tens of times higher than the WHO guidelines for maximum exposure (WHO guidelines: 1–4 pg TEQ/kg/day; Guiyu adult resident inhalation exposure: 68.9 pg TEQ/kg/day in summer; 126 pg TEQ/kg/day in winter).[15]

Children's blood-lead levels in Guiyu are also indicative of a heavily polluted environment.

A recent study found a mean blood-lead level of 15.3 μg/dL in Guiyu children, significantly higher than the Centers for Disease Control guideline of <10 μg/dL.[16] Extensive research has demonstrated that children with elevated blood levels (10–15 μg/dL) are more likely to experience adverse cognitive and neurobehavioral effects, such as poorer attention span, fine motor skill, and lower intelligence quotient scores.[17] Moreover, a growing body of research suggests that lead is unsafe even at very low levels.[18,19] In addition, blood-lead levels are only representative of recent lead exposure. Long-term lead in the body may concentrate in the brain or elsewhere and not be reflected in lead levels in serum samples.[20]

While all of this paints a bleak portrait of the e-waste situation, there are reasons to be cautiously optimistic. A number of countries (and, in the United States and Canada, states and provinces, respectively) and political entities have implemented laws and entered into treaties and agreements that attempt to address some of the many problems associated with hazardous wastes, including smart and green design, environmentally sound recycling, end producer responsibility, and cessation of transport of hazardous waste to developing countries from developed ones. A growing number of manufacturers, in large part to meet the new more stringent requirements many countries and states have implemented, have also made commitments to reducing waste, decreasing the use of toxic materials, including avoiding certain materials altogether, and accepting their products back at the end of the lifecycle.

The first major step to combat the rising trade in hazardous waste was the 1989 signing, and 1992 entry into force, of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention). The convention was prompted by several high-profile incidents involving shipments of highly toxic wastes to developing countries. Stricter environmental regulations regarding hazardous wastes in developed countries in the 1980s translated into higher costs for domestic recyclers, disposers, and processors, which in turn made the export of wastes to developing countries an increasingly attractive proposition.[21] The convention was intended to minimize the movement of wastes internationally, particularly from developed to less developed countries, to establish notification, consent, and tracking rules for import and export of waste, to ensure environmentally sustainable processing and disposal of waste, and to encourage reduction in the generation of wastes. Of the 170 countries that signed the convention, the United States is the only developed country that has not yet ratified the convention, and so has been able to continue to ship hazardous wastes both to parties of the convention and countries not part of it.[9,21,22] Afghanistan and Haiti are the only others of the 170 countries who signed the convention but have not ratified it. In 1995, due to pressure from some developing countries, certain European countries and NGOs, the Basel Ban Amendment was accepted, which expressly bans hazardous waste export, including for recycling purposes, from developed countries to developing countries. Sixty-three countries have ratified the Basel Ban, and the European Union has incorporated it into waste shipment law, despite the fact that the ban has not been ratified by sufficient parties to enter into force.[21]

Many nations have taken significant steps to address the problems of e-waste domestically. Japan, the European Union, South Korea, China, and Taiwan have laws under which the manufacturer is responsible for taking back its products and responsibly recycling them. In some cases, consumers pay a fee when they purchase the product to cover end-of-life recovery and disposal; in other cases the manufacturers are responsible. In all cases, one of the results has been to prompt manufacturers to develop more easily recycled, less toxic, more resilient products.

In 1998, Switzerland passed the first e-wastes recycling law, the Swiss Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment, which, as its name implies, requires manufacturers to take back and responsibly dispose of unwanted electronic consumer products.[23] Also in 1998, Japan passed the Home Appliances Recycling Law, which went into effect in 2001. The law applies to four types of household appliances: air conditioners, refrigerators, washing machines, and televisions. Consumers pay a surcharge when they purchase the appliance, and in return are guaranteed that their appliance, when they discard it, will be picked up and responsibly recycled and processed.[24] In 2001, Japan passed the computer recycling law for businesses in which businesses have to pay a surcharge up front, as in the case of household appliances, to help defray the cost of taking back and recycling later. Since 2003, the law has also applied to individual consumers. An explicitly stated purpose of the laws is to encourage manufacturers to develop more easily recyclable or reusable, longer-lived, nonhazardous products.[25] Another positive outcome of such laws is the significant reduction in greenhouse gas (GHG) emissions that can be achieved through recycling and reusing appliances and their components.[26] Other studies have noted an increase in products made with plastics recycled from these efforts and major progress in environment-friendly design.[27]

In 2003, the European Union followed Switzerland and Japan's lead in this area by establishing the European Directive on Waste Electrical and Electronic Equipment (WEEE) and the associated Directive on the Restriction on the Use of Hazardous Substances in Electrical and Electronic Equipment (RoHS). WEEE holds manufacturers financially responsible for collecting, recycling, processing, and disposing of e-waste in environmentally sound manners. By making producers responsible for their products through their lifecycles, the intent of this law was to give incentive to design less toxic, more easily recyclable, sturdier products. The directive also specifies increasing recycling rates over time—by 2006, for example, producers had to be recycling 50% of collected products. RoHS explicitly requires that manufacturers cease, or in some cases, limit (by weight) their use of certain hazardous materials in new products, including lead, mercury, cadmium, hexavalent chromium, and brominated flame retardants as of July 2006. This requirement has been a major inspiration for manufacture changes, since any electronics equipment imported by European Union countries fall under the ban.[28]

South Korea and Taiwan also have enacted mandatory take-back laws focused on producer responsibility for electronics, and several other countries have national legislation in progress.[29,30]

In early 2007, China's version of the European Union's RoHS directive, the Administrative Measure on the Control of Pollution Caused by Electronic Information Products, went into effect. The first phase of the law requires labeling of products containing any of the identified toxic materials, and the second will ban the use of these materials in new products. Most of the same hazardous materials, including cadmium, mercury, lead, hexavalent chromium, and brominated flame retardants, identified in the European Union's RoHS directive are the focus of the Chinese law.[31]

In the United States, national-level legislation has failed to pass through Congress to date, but an increasing number of states are passing their own laws. Twelve U.S. states now have e-waste regulations that require manufacturer take-back and have banned e-wastes from landfills. Five of these states have also banned e-wastes from incinerators. Sixteen other U.S. states have bills under consideration. Electronics manufacturers in the United States are actually pushing for national legislation so that they are not forced to meet different requirements in every state.[32,33]

Numerous domestic and international efforts focused on addressing e-waste and its attendant problems have emerged. A prominent international effort is StEP (Solving the E-waste Problem). StEP, initiated in 2004, comprises UN agencies, government organizations, industry, scientists, and NGOs, and has as its primary objectives increasing the life span of electric and electronic equipment; encouraging reuse of equipment and materials; engaging in efforts to address inequity between developed and developing countries; and expanding knowledge of consumers, businesses, and professionals.[34] Many international and national NGOs in both developed and developing countries are also involved in education and activity in these areas.

Most major manufacturers of electrical and electronic equipment, in large part in response to stricter laws in the European Union, Asia, and elsewhere, are starting to make significant changes to their designs, using less toxic materials and more easily recycled components, as well as to their take-back policies. Government agencies as well as NGOs, such as Greenpeace and others, have published consumer guides to greener electronics, and the motivation for companies to change their practices is high.

While all of these regulations and efforts have led to important changes on many levels, one problem that they are unable to effectively address is the fundamental economic disparities that have driven the hazardous waste trade from the beginning. China, for example, has had a ban on imports of e-waste since 2000. But in part due to the difficulty and expense of enforcing such a ban, and in part due to the enormous economic gains that can be made by individuals working in the e-waste cottage industry in China, the official ban has had little impact on slowing down imports of e-waste.[9] Similarly, as more stringent e-waste laws are enacted in developing countries, causing rising prices and greater quantities of obsolete waste, the motivation to illegally export e-waste to China and other cheap-labor developing economies grows higher. Until some of these basic issues of inequity are addressed, it is likely some level of legal or illegal hazardous waste trade will persist.

While a significant proportion of hazardous wastes remains in landfills domestically and has the potential to contaminate water, soil, and air in the country of origin, even the wastes exported to the impoverished people of the developing world may come back to haunt those in the developed world who discarded them to begin with. Some e-waste components, lead prime among them, are finding their way back into the homes of people in developed countries in the form of children's toys and jewelry.[22] Others are surely returning in food items produced in contaminated soils and waters and shipped and consumed around the world. Still other pollutants originating in discarded electronics migrate around the world in plumes of air pollution, elements of which settle into lakes and rivers and soils far from the places they were processed, but perhaps very near to the places they were used as components in the first place.

While the poor are disproportionately adversely affected by the global e-wastes trade, the health of the earth and all of its inhabitants ultimately is impacted by continued generation and irresponsible disposal of toxic wastes. Addressing this issue requires an interdisciplinary effort: it requires scientific understanding of the health and ecological risks associated with these wastes; technological innovations that tackle hazardous waste in the most effective ways possible; green design, which identifies alternatives to the most toxic components of products, manufacturing processes, and electricity generation; regulatory frameworks for ensuring that companies be responsible for their products from inception to grave; resource and technology transfer to assist with sustainable and equitable development in developing countries; and rich countries agreeing to be responsible for dealing with their own wastes and assisting in developing environmentally sound recycling and processing programs in developing countries.

Climate Change

Atmospheric GHG levels have risen significantly from preindustrial times to the present, and it is now clear that the primary cause of this increase is anthropogenic in nature, specifically fossil-fuel use and, to a lesser extent, land-use changes and agriculture. CO_2 makes up the largest share, about 75%, of GHG emissions, methane the next largest share at around 15%, and nitrous oxide about 10%.[35] From 1970 to 2004, GHG emissions rose by 70%. Preindustrial CO_2 concentrations in the atmosphere averaged 280 ppm; today, CO_2 concentrations are around 385 ppm, well over the natural range of 180–300 ppm over the past 650,000 years.[36] Similarly, methane concentrations have risen from 715 ppb preindustrially to around 1792 ppb in 2007 (range of 320–790 ppb over 650,000 years), mainly from agriculture, and to a lesser extent, fossil-fuel use, and perhaps, though it is too early to know for sure, from thawing artic permafrost.[36,37] As atmospheric GHG concentrations have risen, so too have the global average surface temperatures of the earth. In the past century, the average global air temperature near the earth's surface has risen $0.74 \pm 0.18°C$ ($1.33 \pm 0.32°F$).[36] The Intergovernmental Panel on Climate Change (IPCC) predicts, based on climate modeling, that the average global surface temperature is likely to rise an additional 1.1–6.4°C (2.0–11.5°F) during the next century, depending on future emissions, carbon sequestering activities, and releases of stored GHGs from sinks like the oceans and the arctic. If humans continue on their current trajectory of energy use, CO_2 emissions are expected to increase between 40 to 110% from 2000 to 2030. The bulk (two-thirds to three-quarters) of this increase is likely to be generated by population-heavy developing countries despite their lower per capita emissions.[38] The IPCC predicts that even if GHG concentrations were stabilized at today's levels, temperatures would rise an additional 0.6°C, reaching 1.4°C over preindustrial levels, uncomfortably close to the 2°C above preindustrial levels that some climate scientists believe represents a tipping point beyond which we must expect catastrophic change.[38,39] James Hansen, NASA's chief climate scientist, has gone so far as to say in a recent submission to *Science* that in order to maintain life on the planet as we currently know it, current atmospheric CO_2 concentrations of 385 ppm must be reduced to 350 ppm and soon.[40]

It is thus no longer a question of whether global climate change is real or largely fueled by human activities. The questions we now face are primarily how fast is it happening? what are its effects (current and projected)? and what can we do—indeed what must we do—as individuals, institutions, businesses, governments, and collectively to halt or even reverse the warming of the planet and adapt to changes already underway? Global climate change has the potential to adversely impact nearly every facet of life—from where we and other species can (and cannot) live; to the availability of freshwater; to agricultural production; to biodiversity; to the health of the oceans; to the patterns, frequency, and intensity of precipitation and extreme weather; to patterns of infectious disease. As with many environmental problems, the poorest countries and the poorest people within those countries (especially those living in coastal areas of tropical countries) are the ones that will suffer the most serious adverse effects of climate change despite the fact that it is the richest countries that are responsible for most of the carbon emissions over the past 200 years.

The single largest contributor to global climate change is energy consumption, specifically in the form of the burning of fossil fuels. Fossil fuels account for around 82% of China's energy supply (70% supplied by coal), 88% of U.S. energy supply, and 81% of global energy supply.[41] As world population grows, so too does energy demand, and as countries develop, per capita energy demand increases. Currently, 50% of the world's wealth is concentrated in the hands of 2% of the people, most of them in North America, Japan, and Europe[42] and an estimated 40% of the world population lives on less than \$2 a day.[43] In China, home of one of every five human beings, an estimated 35%—or 560 million people—live in poverty on less than \$2 a day.[43] As nations and the international community work to reduce such gross inequities and as populations grow, we must expect to see global energy demand rise. This is true even assuming decreased energy intensity through conservation and even if efficiency measures can be achieved. Clearly, in order to simultaneously meet the goals of increasing the standard of living of a majority of the world's inhabitants, meeting the energy demands of a growing world population, and slowing CO_2 emissions to reduce GHG concentrations, a multitude of solutions will need to be implemented.

Climate Change in China

China, the most rapidly growing major economy in the world, is believed to have overtaken the United States recently as the single largest emitter of CO_2.[44] It is notable, however, that the United States has per capita emissions (19.4 tC/p/year) more than quintuple those of China [3.84 tonnes of carbon/part/year (tC/p/year)][45] and is expected to continue to far surpass China in per capita emissions for the foreseeable future, despite rapid growth in energy demand in China over the same period.[46]

The majority of China's CO_2 emissions stem from its reliance on fossil fuels, mainly coal, to supply about 82% of its energy needs, although agriculture, deforestation, and the burning of other fossil fuels also contribute. China's energy demands are expected to double between 2005 and 2030, and much of that increased energy demand will be met by coal.[46] China is both the world's largest producer and consumer of coal and the second largest consumer of oil (the United States is the first).[47] China is currently building the equivalent of two 500-MW capacity coal-fired power plants per week and has plans to continue on this trajectory for the next several years.[48] The vast majority of China's coal-fired power plants rely on pulverized rather than gasified coal. Gasified coal is cleaner-burning and associated power plants are easier to outfit with carbon capture and storage (CCS) technology, but gasified coal is more expensive to produce.[49] While coal is a relatively cheap source of energy from one vantage point, it is extremely costly from another: the effects that coal-induced pollution have on human and environmental health are devastating. Coal burning is responsible for an estimated 75% of China's contribution to global GHG emissions.[49] An estimated 90% of China's sulfur dioxide emissions and 70% of China's particulates and other air pollutants are derived from coal burning.[50]

While the United States derives 20% less of its total energy from coal than does China, coal still supplies a significant 50% of U.S. energy.[51] Given the continued instability in oil-rich countries and abundant domestic coal resources, it is likely that the United States also will experience a future that continues to depend heavily on coal.

Given coal's significant contributions to GHG emissions worldwide and the likelihood that as a relatively cheap and locally abundant source of energy in three of the most energy-intensive countries in the world (the United States, China, and India) it will continue to play a major role in power generation, many experts believe developing sound and effective CCS technology for coal-fired power plants is a critical component of averting disastrous climate change.[48] It will be up to the United States to lead the way in this arena, with the development of effective technologies and demonstration projects, and the dissemination of these technologies and resources to implement them to China and other developing countries. A large study undertaken by MIT suggests that over the long term CO_2 or C emissions will have to have a substantial price, $30 and $100 per ton, respectively, to make these clean technologies cost-competitive.[48]

In addition to a heavy reliance on coal for energy production, China also faces a growing demand for another fossil fuel, oil, to power its transport sector. China's demand for oil is expected to quadruple by 2030, largely driven by an enormous increase in the number of vehicles used in the country by 2030, an estimated 270 million, or seven times more than in 2005.[46]

China is already experiencing what Chinese and other scientists believe to be the effects of global climate change, including 20 consecutive warm winters between 1986 and 2005; changes in precipitation patterns around the country; an increased incidence of drought and flood; land desertification (increasing at a rate of 1300 square miles each year, causing migration to cities, less farmland, and more intense and frequent sandstorms); and sea-level rise affecting China's coasts over the past 50 years at a rate of 2.5 mm/annum, which is slightly higher than the global average.[52,53] Moreover, as a developing country with hundreds of millions of people living in poverty, China is especially vulnerable to many of the likely impacts of climate change, including food and freshwater shortages, sea-level rise, and greater ranges for disease vectors.

While China, like the United States, is sending hundreds of millions of tons of CO_2 and other GHGs into the atmosphere each year, it is also making serious attempts to start addressing the problem in meaningful ways. In keeping with the recommendations of the UN Framework Convention on Climate Change (UNFCCC), China in 2007 became the first developing country to instate a National Climate Change Plan.[52,53] Although the plan does not set emissions reduction targets, it does set specific goals for increasing energy efficiency, increasing the use of clean coal technology, increasing nuclear energy, and developing renewable energy sources. China has also committed to forestry practices that will assist in reducing CO_2 emissions; notably, the plan calls for the percentage of forested land to increase from 18% to 20% by 2010. Prior to the National Climate Action Plan, China passed the Renewable Energy Law of the People's Republic of China, which outlined tax breaks, target volumes for renewables, management, and pricing strategies. China points to its one child policy as further evidence of its commitment to environmental sustainability, including climate-change mitigation. In 2005, 7.5% of China's energy came from renewables,[53] very close to the 7% supplied by renewables in the United States.[54] China's national climate-change plan calls for doubling the percentage of energy supplied by renewables by 2030 and for a 20% reduction in energy consumption per GDP by 2010.[53,55] Because of these goals and a constellation of policies geared toward achieving them, businesses and government in China are expected to spend approximately US$300 billion on products, technologies, and services that improve energy efficiency over the next 5 years.[56]

Part of China's move toward greater energy efficiency is manifesting in the closure of many older, less-efficient, and higher-polluting coal-fired power plants. Newer plants can be three times as efficient and much cleaner than older ones.[57] According to China's National Climate Change Plan, the percentage of energy derived from coal has decreased from 76% in 1990 to 70% in 2005. In addition, China is launching several joint clean-coal technology plants with foreign investors and governments. The first of China's coal power plants that will use carbon capture and sequestration, a partnership between Chinese government organizations and a private U.S. company, is expected to begin operation in 2009.[58] Moreover, recent figures suggest that China achieved significant reductions in energy intensity and increases in efficiency in 2007, a key element of the National Climate Change Plan.[56]

International Efforts

Since climate change is so clearly a global problem with global impacts, it will take the world working together, including significant resource and technology transfer from richer to poorer countries, to effect the kinds of changes that are necessary to drastically reduce emissions and develop and adopt sound adaptation strategies for the changes that are already inevitably underway. The UNFCCC was the first step toward this end. The UNFCCC was adopted in 1992 as a treaty agreement in which signatories committed to examine global climate-change issues and start to address them. The Kyoto Protocol, originating in the objectives of the UNFCCC, was adopted in 1997 and entered into force 8 years later in 2005, and is a more specific, rigorous, and legally binding effort to address the climate change problem. Unlike in the case of the UNFCCC, developed country signatories to the Kyoto Protocol are legally committed to reducing GHG emissions by certain country-specific amounts within a specified time period (by 2012).[59] Several market-based mechanisms, including joint implementation, emissions trading, and the Clean Development Mechanism, were designed to allow parties to the protocol to meet their emissions reductions targets in creative ways.[60]

A key point of both the UNFCCC and the Kyoto Protocol is that developed countries must take the lead in emissions reductions, both because they have contributed the most to the problem and because they have the resources to do so. The United States is one of the only countries that has not ratified the Kyoto Protocol, despite (or because of) its status until very recently as the single largest emitter of GHGs in the world. Ironically, as the largest GHG emitter and as an undisputed global power, it has the greatest responsibility to do so both because of the impact of these emissions on hastening global climate change and because until it does, most developing countries, China among them, are unlikely to commit to specific emissions reductions.

Many joint-venture projects involving government agencies, academic institutions, international aid organizations, NGOs, and private companies are also under way to address climate change and energy issues in both developed and developing countries. UNEP, for example, is spearheading an initiative, the Campaign on Cities and Climate Change, that seeks to empower cities to reduce GHG emissions through workshops, meetings, and materials.[61] The U.S. EPA also has worked closely with Chinese government entities for many years on issues of climate change and energy.[62] The China Certification Center for Energy Efficient Products has partnered with the EPA's energy star program to learn from the EPA program's successes and failures.[63]

A host of mitigation strategies, some affordable and easy to implement and others that will be quite costly, must be implemented immediately if we are to halt the warming of the planet. Some of the mitigation strategies with the most hope of success have been mentioned in the discussion on China. Certainly, developing effective CCS technologies is an essential part of controlling emissions over the coming years, given the inevitability of continued high coal use in China, the United States, India, and elsewhere. Increased energy efficiency in automobiles, appliances, buildings, and manufacturing processes has large potential to affect emissions levels over the near term and must be a major focus of research and development. Many experts have pointed to the need to set a high price on each ton of GHG emitted so that the more expensive but essential measures become cost effective and attractive. Greater investment in research and development is also needed in the areas of renewables, such as photovoltaic cells; safe nuclear power; and biofuels that do not compete with food production and availability.[64,65] Deforestation, especially of tropical forests, must be halted and even reversed. Deforestation is responsible for 15–20% of CO_2 emissions worldwide.[66,67] Tropical forests must start to be valued for their intact status as carbon sinks, repositories of biodiversity, and protectors of land quality and stability.[67] The incentives to keep forests intact must come from developed countries; that is, developed countries must provide financial compensation to developing countries for keeping their forests whole and healthy.[64,65] Many studies have demonstrated that protection of forests through such financial incentives may be one of the cheapest ways of reducing emissions into the atmosphere, and certain institutions like the World Bank have developed initiatives to do just that.[68,69] Mitigation measures must also be put into place in agricultural production. Specifically, methods must be explored for reduction of methane emissions, including different diets for livestock, increasing nitrogen fertilization efficiency, restoring degraded lands to allow for carbon sequestration, and increasing efficiency of agricultural instruments and production.[65] Consumers and businesses also need to be encouraged to make good choices and discouraged from making poor ones. These incentives and disincentives can come in the form of taxes on energy-intensive consumption, tax rebates on energy-efficient products, and consumer and business education programs. Cap and trade programs, portfolio standards and performance, and emission standards also are all necessary elements in a successful mitigation strategy.[64]

Additionally, significant resources must go into developing and improving technologies, such as renewable energy resources, coal gasification, fusion energy, sequestration of CO_2, and possible geoengineering solutions to increasing GHG in the atmosphere. Finally, an essential component of the mitigation piece of the climate-change solution is that developed countries must take the lead in developing innovative (and sometimes costly) solutions and share these advances and the resources to implement them with the developing world.[64]

In addition to the mitigation measures discussed previously, the global community must prepare adaptation strategies for dealing with an already changing climate, including (1) developing measures for handling increased incidences of tropical diseases; (2) developing new agriculture patterns and crop varieties that are resistant to heat and drought; (3) establishing systems that can help countries and regions deal with clean water and other basic needs in flood and drought conditions; (4) preparing for sea-level rise by building dikes and other barriers; (5) developing improved responses, especially among the most vulnerable countries and communities, to natural disasters; and (6) preparing for climate refugees.[39,64,65]

The UNFCCC has implemented a number of programs around these issues. The Nairobi Work Programme on Impacts, Vulnerability and Adaptation is a 5-year program begun in 2005 to help countries identify their particular vulnerabilities and develop adaptive strategies for dealing with them. National Adaptation Programmes of Action, part of UNFCCC, were developed so that the least developed countries can identify their most urgent needs for adaptation. Another program of the UNFCCC is a local coping strategies database that allows communities that are facing the imminent threat of specific changes from climate change to access coping strategies used by other communities that have faced these same climatic conditions or limitations and developed strategies over time to deal with them. There are also several funding mechanisms for adaptation measure for the least developed countries under the convention and the Kyoto Protocol.[60]

Finally, as John Holdren argues in his 2008 article on science and technology for sustainable well-being and his presentation at the PBC conference, the reductions necessary to ensure a viable planet for our children and grandchildren will only be achieved through a binding post-Kyoto global treaty on emission levels per country. Holdren suggests that the most likely way to achieve some sort of agreement in the near future is to set emission intensity (GHG per unit GDP) reduction targets, but that ultimately the only fair solution will be the establishment of per capita emissions quotas.[64]

Air Pollution

Everyone must breathe to live, and unfortunately many things can be in the air we breathe in addition to the nitrogen, oxygen, and CO_2 that are the natural components. Air can contain other gases, such as sulfur and nitrogen oxides (NO_x and SO_x), ozone, and CO, and radioactive gases, such as radon. There may be biological particulates, such as plant pollens, and natural particulates coming from soils and rocks and carried by wind and air currents. It has been estimated that some two billion metric tons of dust are lifted into the air by wind and storms each year.[70] There may be man-made particulates resulting from incomplete combustion of fuels, and these particulates may contain a variety of organic compounds and metals. In areas where gasoline still contains lead, airborne lead remains a major problem. There may be vapor-phase concentrations of volatile organic compounds and semivolatile compounds, such as pesticides, and organochlorine compounds, such as PCBs and dioxins. Some of the volatile organic compounds may be of natural origin, such as methane coming from decay of organic material, whereas others may be released from human-made products. All of these pollutants have the potential to affect human health.

Air pollution may occur in either outdoor or indoor environments, and often the contaminants present are different in these two settings. About three billion people, or half the world's population, are dependent upon solid fuels, such as biomass (wood, dung, plant materials), to supply their energy for cooking and heating. The use of solid fuels on fires or unventilated indoor stoves results in dangerously high levels of indoor air pollutants; pollutants that can cause severe adverse health effects among the people exposed to them.[71] A very important source of air pollutants, especially in the indoor environment, is cigarette smoke, which is known to release more than 50 different gases with known toxic effects and a total of about 4000 total chemicals. Carpets made from synthetic materials may also release more than 30 different volatile organic chemicals (VOCs); in addition, many other products manufactured from petroleum also release VOCs. Organic compounds are released from many common household products, such as linoleum, paints, vinyl tile, particleboard, adhesives, cleaners, and caulk.[72]

The WHO attributes 2.7% of the global burden of disease to indoor air pollution.[73] An estimated one to two million people a year die prematurely each year due to exposure to indoor smoke from burning biomass fuels (wood, dung, grasses, crops). Indoor burning of coal leads to an additional 200,000 deaths per year, mainly in China. Indoor air pollution is the second greatest environmental risk factor, and tenth in overall risk factors.[73] Since it is primarily women cooking and caring for young children in unventilated indoor spaces, these two groups are the ones most at risk for the many health effects of indoor air pollution.[74]

Urban air pollution is also a significant cause of mortality and morbidity worldwide. There have been several episodes of air inversion events that have resulted in the accumulation of pollutants, leading to a large number of deaths. One of the worse occurred in London in 1952, where more than 4000 persons died from smoke from coal burning. But there is strong evidence that air pollution causes elevated death rates at ambient levels commonly found in urban areas. Indeed, studies have not detected any threshold concentration of inhalable particulates <10 μm, which does not increase risk of mortality.[75] The WHO estimates that outdoor air pollution is responsible for about 800,000 deaths and 4.6 million lost life-years per year globally. About two-thirds of the deaths and lost life-years happen in Asian developing countries.[73]

Particulates in air are known factors associated with many different diseases. Best documented is increased hospitalization and deaths from cardiovascular and respiratory disease on days with elevated pollution.[76] While this may be "harvesting," which is to say death of individuals with existing disease that would die anyway in some period of time, this shows clearly that particulates can cause real harm. In the usual urban environment much of the pollution comes from traffic.[77] In addition some particulates contain carcinogenic compounds, such as polycyclic aromatic hydrocarbons, increasing risk of cancer. While particle size is important, since particles larger than 10 μm are usually cleared from the respiratory track, while those less than 10 μm, and especially those less than 2.5 μm, penetrate more deeply into the respiratory track and are not readily removed, the composition of the particulates is perhaps as important, since it can vary greatly.[78]

Air pollution is usually a mixture of particulates and other pollutants, and it is likely that several of them (particulates, ozone, NO_2, and CO) contribute to the increased mortality.[79] Exposure to air pollution also results in elevated asthma attacks,[80] respiratory infections,[81,82] and chronic obstructive pulmonary disease (COPD),[83,84] and elevated incidence of low birth-weight infants.[85] Some indoor air pollutants, such as environmental tobacco smoke, have been demonstrated to reduce cognitive ability in children.[86]

There remains some uncertainly as to which air pollutants are responsible for the elevations in cancer, but there is little question but that they do increase cancer risk. Klein *et al.*[87] have reported that ambient air contaminants show significant dioxin-like and estrogen-like activity, both of which are associated with cancer risk. Sax *et al.*[88] investigated cancer risk to inner-city teenagers in New York and Los Angeles from VOCs and particulates. They report that the greater cancer risk from VOCs were due to 1,4-dichlorobenzene, formaldehyde, chloroform, acetaldehyde, and benzene, with exposures to all but benzene coming primarily from indoor air. Chromium, nickel, and arsenic from particulates were also important risks for cancer. Loh *et al.*[89] used national U.S. data, and reached the conclusion that dioxin, benzene, formaldehyde, and chloroform were most significant, and that outdoor air contributed about 50% of the total cancer risk, while in California they found 1,3-butadiene, formaldehyde, benzene, and dioxin to be most significant.

Air Pollution in China

While indoor and outdoor air pollution are problems nearly everywhere in the world, there is no question that developing countries face the greatest challenges in both realms. China exemplifies the type of environmental degradation, including severe outdoor air pollution, which accompanies very rapid industrialization. The same factors that are leading to China's enormous contributions to global climate change are also contributing to increasingly dirty air in China, and, through atmospheric transport, many other locations, including North America. China, with its rapidly expanding coal-intensive energy economy, is now the largest emitter worldwide of sulfur dioxide[90] and is responsible for an estimated 25% of global mercury emissions.[91] Due to the lack of pollutant capture technology in place on most Chinese coal power plants and the frequent use of unwashed coal, Chinese coal burning produces an estimated three times more mercury per ton than does U.S. coal burning.[92] China's emissions of black carbon, a by-product of the combustion of fossil fuels and biomass, are also substantial, and research at NASA suggests that it may be contributing significantly to increased incidence in drought and flood in China by affecting the hydrologic cycle.[93] All of these emissions are contributing to extremely dirty—and dangerous—air. According to the World Bank,[94] nine of the top 10 most polluted cities in terms of particulate matter in the world are in Asia, specifically China and India. The World Bank estimates that only 1% of people residing in urban areas in China breathe air considered safe by international standards.[94] Outdoor urban air pollution is estimated to cause about 300,000 deaths per year in China.[71]

In addition, hundreds of millions of Chinese are dependent upon the burning of biomass fuel and coal for cooking and heating—and suffer severe consequences. Approximately 60% of the Chinese populace lives in rural areas, and about 90% of their energy needs are met through the burning of solid fuels (biomass predominantly and, to a much lesser extent, coal). While the majority of Chinese cities are phasing out residential coal use, coal is still used in many urban households. Indoor air pollution from the burning of biomass fuels and coal causes an estimated 420,000 premature deaths per year in China and many more cases of morbidity, including pneumonia and other respiratory diseases, in children, and COPD, lung cancer, and chronic respiratory disease in adults.[71,95]

Moreover, the impacts from air pollution extend beyond human health effects and include decreased crop yields due to acid rain caused largely by sulfur dioxide emissions[96]; changes in weather patterns, including extreme weather events, from black carbon emissions[93]; and contamination of fish and other species with metals and other toxins emitted by the burning of coal and other products.[97] These adverse impacts combined with those stemming from water pollution cost China an estimated 6% of its GDP according to the World Bank.[98] As an example of the economic (and human) costs of air pollution in China, adverse health effects from the coal-reliant city of Zaozhuang in eastern China were estimated to be costing the city 10% of its GDP in 2000, a figure that was projected to grow to 16% if significant pollution controls were not implemented.[99]

Furthermore, emissions do not respect national boundaries. Increasingly sophisticated modeling techniques, air sampling programs and satellite tracking studies have provided evidence that great plumes of pollutants are being transported through the atmosphere from China to other parts of Asia and across the Pacific to the western United States, depositing mercury and other pollutants in streams, lakes, and soils, and negatively impacting air quality.[100–103] Ironically, the United States' insatiable demand for cheap goods is partially fueling this pollution. A study looking at pollution in the Pearl River Delta area of China found that 10–40% of emissions of sulfur dioxide, volatile organic compounds, nitrogen oxide, and respirable particles in the region resulted directly from export activities.[104] The researchers further determined that for a very low cost, 0.3–3.0% of the product value, ambient air quality could be significantly enhanced through the implementation of a variety of pollution-control technologies.[104]

Clean Air Projects in China

The primary air pollutants China monitors are suspended particulates, sulfur dioxide, and nitrogen oxide. As with climate change, China has undertaken to enact some aggressive legislation to address these pollutants. China became the first developing country to attempt to limit sulfur dioxide emissions on a large scale, for example.[96] While methods to reduce sulfur dioxide pollution from coal combustion, its major source in China, can include fuel switching, flue gas desulfurization, and removal of sulfur during coal combustion, China has mainly achieved improvements in ambient sulfur dioxide levels through the use of fuel switching in households and businesses.[96] Despite the fact that China has some of the strictest environmental laws anywhere, many of them are poorly enforced, in large part because the State Environmental Protection Administration (SEPA), the body that governs environmental concerns in China, has neither the financial resources nor the infrastructural capacity countrywide to undertake the kind of monitoring, enforcement, and evaluation necessary to ensure compliance with the laws. Nevertheless, China has set itself ambitious goals and has successfully transformed its overall environmental strategy from one focusing on cleaning up pollution at endpoints to one focusing on reducing and preventing pollution in the various sectors in which it originates, with some significant successes.[90]

China has also partnered with many groups to develop effective and affordable strategies for tackling air pollution issues. The U.S. EPA has been working with SEPA and other Chinese government entities for more than 20 years to address air-pollution and climate-change issues, and has a number of joint projects under way. Certainly, much can be learned from the U.S. experience with air pollution—as much about what not to do as what to do. One recent effort is the establishment of the Working Group on Clean Air and Clean Energy, which focuses on improving regional collaboration in the areas of air quality and energy management. Specific focus areas include collaborative work on regional air quality, the transportation sector, the energy sector, and the cement sector. Other partnerships between EPA and other entities in China focus on indoor air quality, methane, energy efficiency, and wind power.[62]

China is also part of UNEP's Partnership for Clean Fuels and Vehicles, a program that focuses on establishing stricter vehicle emission standards and more advanced clean-vehicle technology, and replacing dirtier fuels with lead-free, low-sulfur ones.[105] An example of an area in which such efforts have resulted in significantly lower air pollution levels is Bangkok, Thailand, where by establishing strict vehicle emission standards and placing a heavy tax on two-stroke motorcycles, pollution levels have been reduced by 50% over a 10-year period. Similarly, Singapore has been able to address pollution problems by taxing cars, limiting traffic in high congestion areas, and providing good public transportation.[106]

Many other governments, institutions and NGOs are working with Chinese entities to address the problems of air pollution through a variety of mechanisms.

A host of other efforts have been targeted at addressing the even deadlier indoor air pollution that plagues many of the homes in China. The WHO has been working for some time with developing countries like China to address the challenge of indoor air pollution. Tackling indoor air pollution through interventions, such as fuel replacement, is a critical component of achieving multiple millennium development goals, including reducing child mortality, improving environmental sustainability, empowering women, and contributing to the eradication of poverty. WHO's indoor air-pollution efforts include: sponsoring research into health effects, sponsoring and disseminating evaluations of interventions and cost-benefit analyses of interventions, providing workshops and trainings on capacity building for professionals at the regional and national levels, and providing policymakers with tools for evaluating which interventions make the most sense in a given situation.[107] In its 2006 report, *Fuel for Life: Household Energy and Health*, WHO emphasizes the importance and cost-effectiveness of substantial investment in cleaner energy fuels, such as liquid gas rather than solid fuels, a switch that will require financial assistance from developed countries.[95]

While the ideal solution to indoor air pollution associated with the burning of biomass and coal is to substitute cleaner-burning fuels, such as liquid petroleum gas, the expense and relative scarcity of the latter in China make it an impractical solution in the near term and point to the continued need to develop interventions that are both affordable and effective in reducing indoor air-pollutant levels.[71] The Chinese government has made some efforts to address indoor air pollution, starting with the National Improved Stoves Program (NISP) that operated from the early 1980s to the mid-1990s, which provided almost 200 million greater-efficiency stoves with chimneys to rural citizens. While air quality appeared to improve as a result of the stove introduction, it still failed to meet national standards, which suggests that over the long term other interventions are needed. More recently, the government has instituted a program in certain areas of endemic arsenicosis and fluorosis to provide cleaner-burning coal stoves, but the program has been inadequately funded and thus had limited success.[71]

The Institute for Environmental Health & Related Product Safety (IEHS), a department within the Chinese Center for Disease Control, is promoting healthier indoor air through improved-efficiency stoves for burning biomass and coal. While this program does not operate on the same level that the NISP did, it is still an important effort and includes additional strategies for addressing the indoor air-pollution problem. Working with the EPA, IEHS focuses on providing more efficient stoves, implementing environmental education in schools, providing training to local people in stove maintenance, encouraging local businesses to produce and sell efficient stoves, and introducing other clean-energy solutions, such as solar stoves and biogas digesters.[61,108]

Numerous other NGOs and collaborative initiatives have been established to address various aspects of indoor air pollution in China and other developing countries, including the Asian Regional Cookstove Program, the Partnership for Clean Indoor Air, the Clean Air Initiative, and the Nature Conservancy China Program, to name but a few, but there is much work yet to be done.

Conclusion

It is urgent that we address each of these problems—hazardous (especially electronic) wastes, climate change, and air pollution—effectively, affordably, and quickly. Each presents a formidable set of challenges to China, the United States, and the other countries of the world. Success depends upon international cooperation, including sharing not only lessons learned but technological innovations and the financial resources necessary to implement them. It will also require the implementation of international binding agreements that strictly limit emissions of pollutants, exports of wastes, the use of specific toxics in manufacturing processes and emission of pollutants. Developing national and international policies that address issues of inequity and poverty are an integral component of the solution. Developing international market-incentives for reductions in pollution is essential. Protection of the earth means not contaminating the air, soils, and waters with our wastes. The health of those living on earth and the generations that follow depends on our removing the contaminants we have already produced and finding ways to allow economic development and reduce existing health and economic disparities without further contaminating our environment.

Conflicts of Interest

The authors declare no conflicts of interest.

References

1. United Nations Environment Programme. 2000. Toxic Chemicals and Hazardous Waste. http://www.unep.org/GEO2000/english/0037.htm.
2. Environmental Protection Agency. 2008. Solid Waste in New England: Electronic Waste and Ecycling. http://www.epa.gov/region1/solidwaste/electronic/index.html.
3. United Nations Environment Programme. 2004. Trends in transboundary movement of waste among parties to the Basel convention. In *UNEP/GRID-Arendal Maps and Graphics Library*. http://maps.grida.no/go/graphic/trends-in-transboundary-movement-of-waste-among-parties-to-the-basel-convention.
4. United Nations Environment Programme. 2006. Basel Conference Addresses Electronic Wastes Challenge. http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=485&ArticleID=5431&l=en.
5. Benisch, P.A., K. Fujii, K. Shiozaki, *et al.* 2001. Estrogenic and dioxin-like potency in each step of a controlled landfill leachate treatment plant in Japan. *Chemosphere* **43:** 977–984.
6. Environmental Protection Agency. 2008. Ecycling. http://www.epa.gov/epaoswer/hazwaste/recycle/ecycling/index.htm.
7. Environmental Protection Agency. 2008. Hazardous Wastes. http://www.epa.gov/osw/hazwaste. htm.
8. Schmidt, C.W. 2002. E-junk explosion. *Environ. Health Perspect.* **110:** A188–A194.
9. Puckett, J., L. Byster, S. Westervelt, *et al.* 2002. *Exporting Harm: The High-Tech Trashing of Asia*. Basel Action Network and Silicon Valley Toxics Coalition. Seattle and San Jose, February 25, 2002. http://www.ban.org/E-waste/technotrashfinalcomp.pdf.
10. Wong, C.S.C., N.S. Duzgoren-Aydin, A. Aydin & M.S. Wong. 2007. Evidence of excessive releases of metals from primitive e-waste processing in Guiyu, China. *Environ. Pollut.* **148:** 62–72.
11. Wong, M.H., S.C. Wu, W.J. Deng, *et al.* 2007. Export of toxic chemicals—A review of the case of uncontrolled electronic-waste recycling. *Environ. Pollut.* **149:** 131–140.
12. Leung, A.O.W., W.J. Luksemburg, A.S. Wong & M.H. Wong. 2007. Spatial distribution of polybrominated diphenyl ethers and polychlorinated dibenzo-p-dioxins and dibenzofurans in soil and combusted residue at Guiyu, an electronic waste recycling site in Southeast China. *Environ. Sci. Technol.* **41:** 2730–2737.
13. Wong, C.S.C., S.C. Wu, N.S. Duzgoren-Aydin, *et al.* 2007. Trace metal contamination of sediments in an

e-waste processing village in China. *Environ. Pollut.* **145:** 434–442.
14. Bi, X., G.O. Thomas, K.C. Jones, *et al.* 2007. Exposure of electronics dismantling workers to polybrominated diphenyl ethers, polychlorinated biphenyls, and organochlorine pesticides in South China. *Environ. Sci. Technol.* **41:** 5647–5653.
15. Li, H., L.P. Yu, G.Y. Sheng, *et al.* 2007. Severe PCDD/F and PBDD/F pollution in air around an electronic waste dismantling area in China. *Environ. Sci. Technol.* **41:** 5641–5646.
16. Huo, X., L. Peng, X. Xu, *et al.* 2007. Elevated blood lead levels of children in Guiyu, an electronic waste recycling town in China. *Environ. Health Perspect.* **115:** 1113–1117.
17. Wasserman, G.A., X. Liu, N.J. Lolaconno, *et al.* 1997. Lead exposure and intelligence in 7-year-old children: the Yugoslavia Prospective Study. *Environ. Health Perspect.* **105:** 956–962.
18. Lanphear, B.P., K. Dietrich, P. Auinger & C. Cox. 2000. Cognitive deficits associated with blood lead concentrations $< 10\ \mu g/dL$ in US children and adolescents. *Public Health Rep.* **115:** 521–529.
19. Schwartz, J. 1994. Low-level lead exposure and children's IQ: a meta-analysis and search for a threshold. *Environ. Res.* **65:** 42–55.
20. Agency for Toxic Substances and Disease Registry. 2007. Lead Toxicity. http://www.atsdr.cdc.gov/csem/lead/pbbiologic_fate2.html.
21. Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention). 2008. http://www.basel.int.
22. Weidenhamer, J.D. & M.L. Clement. 2007. Widespread lead contamination of imported low-cost jewelry in the US. *Chemosphere* **67:** 961–965.
23. Bornand, P. 2007. The Swiss experience and its global partnerships in e-waste recycling, Taiwan recycling forum, 2007. http://www. 2007recyclingconference.com/download/paper/C/13-Paper-Peter%20Bornand.pdf 10/03/-10/05/2007.
24. Japanese Government 3R Initiative Website. No Date. http://www.env.go.jp/recycle/3r/en/approach.html.
25. Tokyo Metropolitan Government Overview of Waste Management in Japan. (TMG). http://www2.kankyo.metro.tokyo.jp/anmc21_WM/legislation.htm.
26. Nakano, K., R. Aoki, H. Aoki & N. Narita. 2007. Evaluating the reduction in green house gas emissions achieved by the implementation of the household appliance recycling in Japan. *J. Lifecycles Mater. Assess.* **2 LCA:** 289–298.
27. Ueno, K. 2005. Establishment of household electric appliances recycling low and breakthroughs. Papers of Technical Meeting on Dielectrics and Electrical Insulation, IEE, Japan.
28. European Commission Waste Electrical and Electronic Equipment (EC WEEE). 2008. http://ec.europa.eu/environment/waste/weee/index_en.htm.
29. Lu, L., I.K. Wernick, T.Y. Hsiao, *et al.* 2006. Balancing the life cycle impacts of notebook computers: Taiwan's experience. *Resour. Conserv. Recycling* **48:** 13–25.
30. Realff, M.J, M. Raymond & J.C. Ammons. 2004. E-waste: an opportunity. *Mater. Today* **7:** 40–45.
31. Kirschner, M. 2007. RoHS and WEEE Regulations and Standards: RoHS in China. 2007 Annual Guide, Conformity.
32. National Electronics Recycling Infrastructure Clearinghouse. 2008. Current Electronics Recycling Laws in Effect. http://www.ecyclingresource.org/ContentPage.aspx?Pageid=28&ParentID=0.
33. Northwest Product Stewardship Council. 2008. www.productstewardship.net.
34. Solving the E-Waste Problem Initiative. 2008. http://www.step-initiative.org/initiative/index.php.
35. Environmental Protection Agency. 2008. Climate Change Greenhouse Gas Emissions. http://www.epa.gov/climatechange/emissions/globalghg.html.
36. Intergovernmental Panel on Climate Change. 2007. Summary for policy makers. In *Climate Change, 2007: The Physical Science Basis, Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. S.D. Solomon, M. Qin, Z. Manning, *et al.*, Eds. Cambridge: Cambridge University Press.
37. National Oceanic and Atmospheric Administration. 2008. Carbon Dioxide, Methane Rise Sharply in 2007. http://www.noaanews.noaa.gov/stories2008/20080423_methane.html.
38. Intergovernmental Panel on Climate Change. 2007. Summary for policy makers. In *Climate Change, 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. B. Metz, O.R. Davidson, P.R. Bosch, *et al.*, Eds. Cambridge: Cambridge University Press.
39. United Nations Scientific Experts Group. 2007. Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable. United Nations Scientific Expert Group Report on Climate Change and Sustainable Development. Executive Summary. February 2007. United Nations.
40. Hansen, J., M. Sato, P. Karecha, *et al.* 2008. *Target Atmospheric CO_2: Where Should Humanity Aim?* http://www.columbia.edu/~jeh1/ and http://arxiv.org/abs/0804.1126.

41. International Energy Agency. 2007. *Key World Energy Statistics*. 82 pp. http://www.iea.org/textbase/nppdf/free/2007/key_stats_2007.pdf.
42. Davies, J.B., S. Sandström, A. Shorrocks & E. Wolff. 2008. *The World Distribution of Household Wealth*. United Nations University World Institute for Development Economics Research (UNU-WIDER). Helsinki, Finland.
43. United Nations Development Program. 2007/2008. Human Development Report, United Nations Development Program.
44. Netherlands Environmental Assessment Agency. published 2007-06-19, http://www.mnp.nl/en/dossiers/Climatechange/moreinfo/Chinanowno1inCO2emissionsUSAinsecondposition.html.
45. United Nations. 2004. United Nations Statistics Division: Environmental Indicators, Climate Change. http://unstats.un.org/unsd/environment/air_co2_emissions.htm.
46. International Energy Agency. 2007. World Energy Outlook 2007. *Executive Summary*. 18 pp. http://www.iea.org/Textbase/npsum/WEO2007SUM.pdf.
47. Energy Information Administration. 2008. China Energy Profile. http://tonto.eia.doe.gov/country/country_energy_data.cfm?fips=CH.
48. Massachusetts Institute of Technology. 2007. The Future of Coal: Options for a Carbon Constrained World. An interdisciplinary MIT Study, Summary Report. pp. 1–19.
49. Fairley, P. 2007. China's coal future. *Technol. Rev.* http://www.technologyreview.com/Energy/17964/.
50. Hou, Y. & M. Hu. 2007. China and her coal. *World Watch Mag.* **20:** 14–17.
51. Energy Information Administration. 2005. EIA Annual Statistics, 2005. www.eia.doe.gov.
52. China National Climate Change Programme (CNCCP). www.ccchina.gov.cn/WebSite/CCChina/UpFile/File188.pdf.
53. Xinhua, Z. 2007. China's National Climate Change Program (CNCCP). http://news.xinhuanet.com/english/2007-06/04/content_6197309.htm.
54. Energy Information Administration. 2008. How Much Renewable Energy Do We Use? Release date: May 01, 2008. http://tonto.eia.doe.gov/energy_in_brief/renewable_energy.cfm.
55. Zhang, Y. & Y. Zheng. 2007. University of New South Wales, University of New South Wales Law Series, Year 2007, Paper 73, New Developments in China's Climate Change Policy. Hosted by Berkeley Electronic Press. http://law.bepress.com/cgi/viewcontent.cgi?article=1075&context=unswwps.
56. Cheung, R. & A. Kang. 2008. China's Booming Energy Efficiency Industry, World Resources Institute (WRI). http://pdf.wri.org/chinas_booming_energy_efficiency_industry.pdf.
57. Liu, Y. 2007. *China to Shut Down Smaller Power Plants; Effects Remain to Be Seen*. Worldwatch Institute. Washington, DC. http://www.worldwatch.org/node/4899.
58. Power Engineering International. 2007. China's First Carbon Capture & Storage Plant to be Operational by 2009. http://pepei.pennnet.com/display_article/315797/6/ARTCL/none/PRODJ/1/China's-first-carbon-capture-&-storage-plant-to-be-operational-by-2009/.
59. International Energy Outlook. 2007. http://www.eia.doe.gov/oiaf/ieo/emissions.html.
60. United Nations Framework Convention on Climate Change. No Date. Kyoto Protocol. http://unfccc.int/kyoto_protocol/items/2830.php.
61. United Nations Energy Programme. No Date. Campaign on Cities and Climate Change. http://www.unep.org/urban_environment/issues/climate_change.asp.
62. Environmental Protection Agency. 2007. Clean Air and Energy Projects in China. http://epa.gov/oia/airandclimate/byregion/chinaair.html.
63. Hathaway, D. & G. McNeil. 2005. E-buildings: sharing strategies for improving building performance in Shanghai. *China Environ.* Ser., 104.
64. Holdren, J.P. 2008. Science and technology for sustainable well-being. *Science* **319:** 424–434.
65. United Nations Framework Convention on Climate Change. 2007. Scientific, Technical and Socio-Economic Aspects of Mitigation of Climate Change: Information Presented by Parties During the Workshops on Mitigation— UNFCC Document. http://unfccc.int/resource/docs/2007/sbsta/eng/inf03.pdf.
66. Gullison, R.E., P.C. Frumhoff, J.G. Canadell, *et al.* 2007. Tropical forests and climate policy. *Science* **316:** 985–986.
67. Moutinho, P. & S. Shwartzman (Eds.) 2005. *Tropical Deforestation and Climate Change*. Instituto de Pesquisa Ambiental de Amazonia, Belem, Environmental Defense. Washington, DC. www.edf.org/documents/4930_TropicalDeforestation_and_ClimateChange.pdf.
68. Sheeran, K.A. 2006. Forest conservation in the Philippines: a cost-effective approach to mitigating climate change? *Ecolog. Econ.* **58:** 338–349.
69. World Bank. 2004. *Sustaining Forests: A Development Strategy*. The International Bank for Reconstruction and Development/The World Bank. Washington, DC. http://siteresources.worldbank.org/INTFORESTS/Resources/SustainingForests.pdf.

70. Griffin, D.W., C.A. Kellogg, V.H. Garrison & E.A. Shinn. 2002. The global transport of dust. *Am. Sci.* **90:** 228–235.
71. Zhang, J. & K.R. Smith. 2005. Indoor air pollution from household fuel combustion in China: a review. Proc. the 10th International Conference on Indoor Air Quality and Climate, pp. 1–26.
72. Zhang, J. & K.R. Smith. 2003. Indoor air pollution: a global health concern. *Br. Med. Bull.* **68:** 209–225.
73. World Health Organization. 2002. World Health Report. http://www.who.int/indoorair/en/.
74. Wilkinson, P., K. Smith, M. Joffe & A. Haines. 2007. A global perspective on energy: Health effects and injustices. *Lancet* **370:** 965–968.
75. Vedal, S., M. Brauer, R. White & J. Petkau. 2003. Air pollution and daily mortality in a city with low levels of pollution. *Environ. Health Perspect.* **111:** 45–51.
76. Delfino, R.J., C. Sioutas & S. Malik. 2005. Potential role of ultrafine particles in associations between airborne particle mass and cardiovascular health. *Environ. Health Perspect.* **113:** 934–946.
77. Beelen, R., G. Hoek, P.A. Van Den Brandt, *et al.* 2008. Long-term effects of traffic-related air pollution on mortality in a Dutch cohort (NLCD-AIR Study). *Environ. Health Perspect.* **116:** 196–202.
78. Alfaro-Moreno, E., L. Martinez, C. Garcia-Cuellar, *et al.* 2002. Biologic effects induced in vitro by PM10 from three different zones of Mexico City. *Environ. Health Perspect.* **110:** 715–720.
79. Katsouyanni, K. 2003. Ambient air pollution and health. *Br. Med. Bull.* **68:** 143–156.
80. McCreanor, J., P. Cullinan, M.J. Nieuwenhuijsen, *et al.* 2007. Respiratory effects of exposure to diesel traffic in persons with asthma. *N. Engl. J. Med.* **357:** 2348–2358.
81. Chen, P.-C., J.-D. Wang, C.-Y. Yang, *et al.* 1998. Adverse effects of air pollution on respiratory health of primary school children in Taiwan. *Environ. Health Perspect.* **106:** 331–335.
82. Hertz-Picciotto, I., R.J. Baker, P.-S. Yap, *et al.* 2007. Early childhood lower respiratory illness and air pollution. *Environ. Health Perspect.* **115:** 1510–1518.
83. Moolgavkar, S.H. 2000. Air pollution and hospital admissions for chronic obstructive pulmonary disease in three metropolitan areas in the United States. *Inhal. Toxicol.* **12**(Suppl. 4): 75–90.
84. Chen, Y., Q. Yang, D. Krewski, *et al.* 2004. Influence of relatively low level of particulate air pollution on hospitalization for COPD in elderly people. *Inhal. Toxicol.* **16:** 21–25.
85. Bell, M.L., K. Ebisu & K. Belanger. 2007. Ambient air pollution and low birth weight in Connecticut and Massachusetts. *Environ. Health Perspect.* **115:** 1118–1125.
86. Yolton, K., K. Dietrich, P. Auinger, *et al.* 2004. Exposure to environmental tobacco smoke and cognitive abilities among U.S. children and adolescents. *Environ. Health Perspect.* **113:** 98–103.
87. Klein, G.P., E.M. Hodge, M.L. Diamond, *et al.* 2006. Gas-phase ambient air contaminants exhibit significant dioxin-like and estrogen-like activity in vitro. *Environ. Health Perspect* **114:** 697–703.
88. Sax, S.N., D.H. Bennett, S.N. Chillrud, *et al.* 2006. A cancer risk assessment of inner-city teenagers living in New York City and Los Angeles. *Environ. Health Perspect.* **114:** 1558–1566.
89. Loh, M.M., J.I. Levy, J.D. Spengler, *et al.* 2007. Ranking cancer risks of organic hazardous air pollutants in the United States. *Environ. Health Perspect.* **115:** 1160–1168.
90. National Academy of Sciences. 2007. *Report in Brief: Energy Futures and Urban Air Pollution: Challenges for China and the United States*. Washington, DC: The National Academies Press.
91. Streets, D.G., J. Hao, Y. Wu, *et al.* 2005. Anthropogenic mercury emissions in China. *Atmos. Environ.* **40:** 7789–7806.
92. United Sstates Geological Survey. Mercury Emissions from China. http://energy.er.usgs.gov/health_environment/mercury/mercury_china_emissions.html.
93. Menon, S., J. Hansen, L. Nazarenko & Y. Luo. 2002. Climate effects of black carbon Aerosols in China and India. *Science* **297:** 2250–2253.
94. World Bank. 2007. World Development Indicators. http://siteresources.worldbank.org/DATASTATISTICS/Resources/table3_13.pdf.
95. World Health Organization. 2006. Fuel for Life: Household Energy and Health. http://www.who.int/indoorair/publications/fuelforlife/en/index.html. Geneva, Switzerland.
96. Guttikunda, S.K., T.M. Johnson, F. Liu & J.J. Shah. 2004. *Programs to Control Air Pollution and Acid Rain in Urbanization, Energy, and Air Pollution in China: The Challenges Ahead. Proceedings of a Symposium*. Washington, DC: National Academies Press.
97. Zhang, L. & L.M. Wong. 2007. Environmental mercury contamination in China: sources and impacts. *Environ. Int.* **33:** 108–121.
98. World Bank, State Environmental Protection Administration. 2007. Cost of Pollution in China: Economic Estimates of Physical Damages. http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/China_Cost_of_Pollution.pdf.
99. Wang, X.P. & D.L. Mauzerall. 2004. Characterizing distributions of surface ozone and its impact on grain production in China, Japan and South Korea: 1990 and 2020. *Atmos. Environ.* **38:** 4383–4402.

100. Seigneur, C., K. Vijayaraghavan, K. Lohman, *et al.* 2003. Global source attribution for mercury deposition in the United States. *Environ. Sci. Technol.* **38:** 555–569.
101. Travnikov, O. 2005. Contribution of the global atmospheric transport to mercury pollution in the northern hemisphere. *Atmos. Environ.* **39:** 7541–7548.
102. Hadley, O.L., V. Ramanathan, G.R. Carmichael, *et al.* 2007. Trans-Pacific transport of black carbon and fine aerosols (D < 2.5 μm) into North America. *J. Geophys. Res.* **112:** Article D05309.
103. Strode, S., L. Jaeglé, D.A. Jaffe, *et al.* 2008. Trans-Pacific transport of mercury. *J. Geophys. Res.* In press. http://www.atmos.washington.edu/~jaegle/Strode2007b.pdf.
104. Streets, D.G., C. Yu, M.H. Bergin, *et al.* 2006. Modeling study of air pollution due to the manufacture of export goods in China's Pearl River delta. *Environ. Sci. Technol.* **40:** 2099–2107.
105. United Nations Energy Programme. No Date. Partnership for Clean Fuels. http://www.unep.org/pcfv/.
106. Fuller, T. 2006. Asian conference focuses on worsening air pollution: Large cities faring far worse than those in Europe and U.S. International Herald Tribune, December 15, 2006. http://www.iht.com/articles/2006/12/15/news/pollute.php.
107. World Health Organization. 2008. Indoor Air Pollution. http://www.who.int/indoorair/en/.
108. Kim, J.S. & J.L. Turner. 2006. China Environment Forum—Partnership for Clean Indoor Air in Guizhou Province: Promoting Environmental Health in Rural China. *Event Summary* http://www.wilsoncenter.org/index.cfm?topic_id=1421&fuseaction=topics.event_summary&event_id=186073.