The Health Effects Institute

HEALTH IMPLICATIONS OF TECHNOLOGICAL RESPONSES TO CLIMATE CHANGE

Report of a
Workshop Held November 29–30, 2000

Sponsored by
The Heinz Center and the Health Effects Institute

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The H. John Heinz III Center for Science, Economics and the Environment was established in December 1995 in honor of Senator John Heinz. The Heinz Center is a nonprofit institution dedicated to improving the scientific and economic foundation for environmental policy through multisectoral collaboration. Focusing on issues that are likely to confront policymakers within two to five years, the Center creates and fosters collaboration among industry, environmental organizations, academia, and government in each of its program areas and projects. The membership of the Center's Board of Trustees, its steering committees, and all its committees and working groups reflects its guiding philosophy: that all relevant parties must be involved if the complex issues surrounding environmental policymaking are to be resolved. The Center's mission is to identify emerging environmental issues, conduct related scientific research and economic analyses, and create and disseminate nonpartisan policy options for solving environmental problems.

The Health Effects Institute (HEI) is an independent, nonprofit research institute chartered in 1980 to provide high-quality, impartial, and relevant science on the health effects of pollutants from motor vehicles and from other sources in the environment. Supported jointly and equally by the U.S. Environmental Protection Agency (EPA) and industry, HEI has funded over 200 studies in the US and around the world. We have published over 120 Research Reports and Special Reports, producing important findings on the health effects of a variety of pollutants, fuels, and technologies, including carbon monoxide, methanol and aldehydes, nitrogen oxides, diesel exhaust, ozone, and most recently, particulate matter. HEI has also been called upon periodically to produce special reports reviewing an entire area of scientific literature on topics such as the health effects of asbestos, diesel exhaust, and oxygenates in fuel.

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HEALTH IMPLICATIONS OF TECHNOLOGICAL RESPONSES TO CLIMATE CHANGE

Most research on global warming has focused on the effects of climate change itself and on ways of lowering carbon emissions to slow or reverse the course of such change. However, any new or significantly altered technology that is adopted as part of an effort to lower carbon emissions may have other consequences for human health and safety. Even though most candidate emission-lowering technologies are less harmful to human health than the technologies that they would replace, some may be better (cleaner) than others. Identifying and quantifying the full range of health and safety implications of emerging technologies will enable decision makers to make the best choice from among the many candidate technologies.

Unfortunately, the public health implications of technologies are usually recognized only after widespread adoption, and often by experts and individuals other than those responsible for the design and implementation of technological innovations. To explore the current state of understanding of low-carbon technologies and their effects on human health, The Heinz Center and the Health Effects Institute, with support from the National Institute of Environmental Health Sciences, hosted an exploratory workshop that brought together two sets of experts who rarely have the opportunity to communicate with each other: those able to forecast which energy technologies are likely to be adopted if reductions in carbon emissions are mandated, and those who can shed light on the health effects of the widespread adoption of those technologies. The 17 participants included public health specialists and experts in various emerging technologies (see the Appendix). Industry, environmental organizations, government, and universities were all represented at the workshop. The resulting interdisciplinary, intersectoral interaction produced unique insights into potential problems and possible ways of addressing them.

What are the potential health implications of alternative technological paths toward the goal of reducing carbon emissions? The workshop could not answer this important question in two days, but it could (and did) identify a set of eight technologies of top concern from a longer list of technologies that are likely to be commercial within the next 20 years. For these eight technologies, many of which have the potential for widespread use, the participants articulated the health concerns known to be associated with their use and pointed out key uncertainties and gaps in knowledge. The workshop identified gaps and uncertainties on both sides of the issue—that is, areas where a better understanding of life-cycle pollution (from extraction through manufacture and use to disposal) from new technologies is needed and areas of limited knowledge about the health consequences of that pollution.

Identifying Emerging Technologies and Potential Health and Safety Effects

Workshop planning discussions among the sponsors and presentations at the workshop produced a list of 21 technologies with higher efficiency and/or lower emissions of greenhouse gases that participants thought might (a) become commercial within 20 years and (b) present significant health hazards (see Box 1). Background papers on energy-

efficient building technology, mobile source technology, and stationary sources of emissions, along with published material on other relevant issues, informed the discussion.

The workshop also identified the potential health and safety considerations of greatest concern, including those from the manufacture and production of the technology and fuels, from the direct use of the technology, and from disposal of wastes (see Box 2). The group supported adding these potential health and safety considerations to the current criteria for technology development.

Based on these discussions, the workshop participants estimated the likelihood of widespread adoption of any particular technology within 20 years and then mapped the health and safety concerns onto the list of technologies. After each participant selected technologies of highest concern, a process of group voting and discussion identified the highest-priority technologies. The resulting list of eight technologies and the health and safety concerns associated with each is shown in Figure 1.

Box 1 Emerging Energy Technologies Intended To Limit Carbon Dioxide Emissions

Mobile Sources
Advanced gasoline engines using reformulated fuels (direct injection, others)
Newer diesel engines using reformulated (low-sulfur) diesel fuel
Newer diesel engines using Fischer-Tropsch fuel
Newer diesel engines using dimethyl ether
Newer diesel engines using biodiesel
Electric hybrid
CNG hybrid
Fuel cell using hydrogen
Fuel cell using methanol
Biomass-generated fuels (including ethanol)
Ethers and other fuel additives

Stationary Sources
Microturbines
Stationary fuel cells
Photovoltaics
Natural gas internal combustion engines
Advanced coal-fired electricity generation (e.g., fluidized bed combustion)
Advanced coal-fired electricity generation, with sequestration of carbon dioxide and coproduction of hydrogen
Increased use of nuclear electricity generation

Buildings/End-Use Efficiency
Reduced building ventilation rates for energy efficiency
Increased use of insulation and other materials
Higher-efficiency lighting

The High-Priority Technologies of Concern

Of the eight high-priority technologies chosen by participants, six are transportation technologies and/or fuels (one of the six, fuel cells that use hydrogen, is also applicable to stationary sources). This is likely indicative of the enormous amount of research and development on, and the high degree of uncertainty about the eventual choice of, future transportation technologies. Light-duty vehicles (cars and light-duty trucks) and freight trucks together currently account for about a quarter of energy-related carbon emissions in the United States (see Figure 2).

The remaining two priority technologies—advanced coal-fired electricity generation and reduced ventilation of buildings—are significant modifications to technologies in widespread use today.

About 35 percent of U.S. energy-related carbon emissions are from electricity generation; over 30 percent are from coal-fired power plants alone. The next generation of coal technologies will have somewhat lower carbon dioxide and criteria air pollutant emissions than today's, but higher emissions than other alternatives, such as natural-gas–fired generation or coal-fired electricity generation technologies that also generate hydrogen and sequester carbon.

The remaining high-priority technology is reduced ventilation to improve energy efficiency within buildings. The energy used to heat and cool buildings is responsible for about 15 percent of U.S. energy-related carbon emissions.

The reasons for including each of the eight technologies on the priority list are described briefly below.

Box 2 Potential Health and Safety Concerns

Increased air pollution exposure to
- Metals
- Air Toxics
- PM
- NOx
- Methanol

Increased water contamination from
- Toxics
- Ethers
- Alcohols

Worker exposures in production

Increased safety risk from fuel and material handling, technology use

Nuclear safety and disposal

New Diesel Engine Technologies Using Reformulated (Low-Sulfur) Fuel

Diesel engines are used today in a wide variety of mobile and stationary power sources, including autos, trucks and buses, marine vessels, construction and farm equipment, locomotives, and distributed power generation. Although diesel-fueled vehicles are more energy efficient and have relatively lower emissions of carbon monoxide (CO) and hydrocarbons (HC) than gasoline engines, emission levels of particulate matter (PM) and nitrogen oxides (NO_x) are relatively high.

To take advantage of higher fuel efficiency while at the same time lowering NO_x and PM emissions, manufacturers have been developing new diesel engine designs, including those that use reformulated low-sulfur fuels and control technologies such as filters (traps) and catalysts. Emissions from unconventional diesels, while lower overall, may differ from conventional diesels in several key ways. Pollutants of concern include the number of ultrafine particles, which may pose a greater risk to the lung and heart, and air toxics such as polycyclic aromatic hydrocarbons (PAHs) and aldehydes. More research is needed on the health effects of ultrafine PM, especially on effects other than cancer, such as respiratory tract irritation and immune and allergic response. PAHs and aldehydes are particularly important fractions of the gaseous emissions because they are probable

	Particulates	Nitrogen Oxides	Air Toxics	Metals	Methanol Toxicity	Water Quality	Safety	Production Exposure
Newer Diesel Engines Using Reformulated (Low Sulfur) Diesel Fuel	✓	✓	✓					
Advanced Gasoline Engines Using Reformulated Fuels	✓		✓					
Electric and Hybrid Vehicle Battery Technology				✓				✓
Mobile and Stationary Fuel Cells Using Hydrogen						✓	✓	
Methanol for Mobile Fuel Cells					✓			
Transportation Fuels from Biomass (ethanol, DME, biodiesel, etc.)		✓	✓			✓		
Advanced Coal Fired Electricity Generation	✓	✓		✓				✓
Reduced Ventilation of Buildings	✓		✓					

Figure 1 Highest-priority technologies and potential health and safety concerns.

carcinogens and also can cause produce noncancer health effects. Further research is also needed to determine the fuel and control technology "pairing" that will be required to control PM and NO_x emissions, and to characterize the full range of PM and air toxic emissions from the new technologies. New diesel technology may also find its way into hybrid vehicles—that is, vehicles that rely on small diesel or gasoline engines to recharge electric motors that are the direct source of power.

Advanced Gasoline Engines Using Reformulated Gasoline

Internal combustion gasoline engines made the priority list, in part because of the sheer magnitude of their use. While the health effects of gasoline engines are well documented, modifications to them, such as direct injection, could change the characteristics of their emissions. Of greatest concern are changes in the characteristics of particulate emissions (e.g., an increase in the number of ultrafine particles) and in the mix and quantities of air toxics such as butadiene, aldehydes, and other substances.

Electric Vehicles and Hybrids

Battery-powered electric vehicles and hybrid gasoline–electric vehicles have already been introduced into vehicle fleets and into the consumer transportation market, diesel–electric hybrids will follow shortly. Battery electrics will likely see greatest use in captive fleets because of limited vehicle range and recharging facilities. For both types of vehicle, health concerns center on the batteries that provide power to the electric motor.

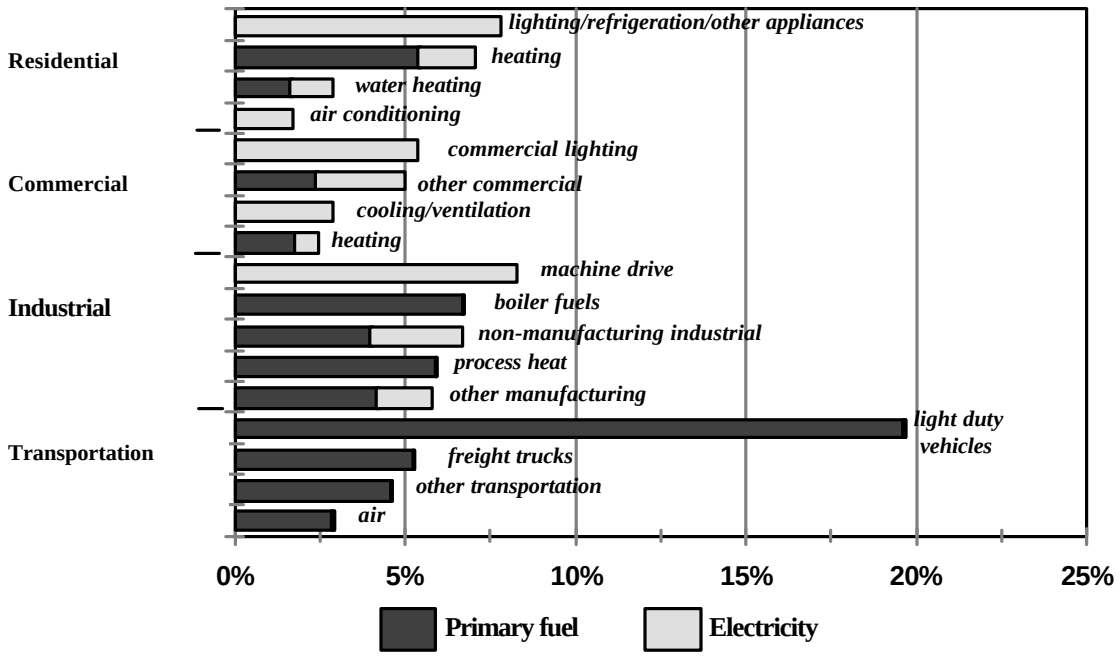

Figure 2 End use sources of carbon dioxide.

Batteries contain metals that may pose a risk to health in the manufacturing, in-use, and disposal phases of the product life-cycle. Metals of concern used in batteries include nickel, lithium, and lead, all of which are known to have diverse neurotoxic and other effects at high levels of exposure. Little is known about the likely exposure scenarios and levels, and the health consequences for the general public, resulting from their increased use. Hybrid vehicles contain smaller batteries, but, because these vehicles are more likely to be used by individuals, the batteries are more susceptible to improper maintenance and disposal.

Mobile and Stationary Fuel Cells Using Hydrogen

Fuel cells can generate electricity from hydrogen with virtually no emissions other than carbon dioxide and water. Hydrogen fuel cells are being developed both for use in vehicles and for small, distributed sources of electricity for commercial buildings.

Here, the primary concern is safety. This technology is likely to store hydrogen in canisters under high pressure, which increases the risk of explosion. Hydrogen also has a low ignition temperature and burns with an invisible flame; the risks of accidental are clear. Workshop participants were uncertain whether the safety risks associated with hydrogen were any greater than those associated with gasoline vehicles, but any accidental explosions and injuries that might occur with a new technology would attract considerable public attention.

Contamination of freshwater aquifers may also be a problem if the hydrogen fuel is generated from coal and the waste carbon dioxide is injected into deep aquifers. Little research has been done to date on the potential migration into drinking water of dissolved carbon dioxide that has been injected into deep aquifers. The probability of leaching of metals due to increased acidity in drinking water and the health effects of such leaching are also little understood.

Methanol for Mobile Fuel Cells

Methanol as an onboard source of hydrogen for fuel cells is being strongly advanced by some companies as a readily available fuel with high energy density compared to direct hydrogen. Little is known about the likely emissions of methanol either during refueling or from the onboard reformers proposed for vehicles.

Methanol (methyl alcohol) is a clear, colorless, flammable liquid. A major health concern with methanol is accidental ingestion—it is highly toxic, and when ingested in high doses, it can cause blindness and death. The most common route of occupational and environmental exposure is inhalation and skin absorption, and the level of exposure is generally low. The most serious concerns at lower levels of exposure are methanol's potential effects on reproduction and childhood development, although some recent research suggests that these effects may not be found at low levels of exposure.

Transportation Fuels from Biomass (Ethanol, DME, and Biodiesel)

Biomass-derived transportation fuels might be used as substitutes for gasoline and diesel fuel to lower carbon emissions. Among the most promising alternatives are ethanol, dimethyl ether (DME), and biodiesel.

Ethanol is often used today as a fuel additive, but it can also be used in purer forms as a substitute for gasoline. The increased use of E-85 (85 percent ethanol, 15 percent gasoline) could lead to greater emissions of acetaldehyde, a toxic air pollutant. Acetaldehyde emissions may be controlled through the use of advanced catalytic converters, but the effectiveness of these devices depends on proper maintenance and repair. Although ethanol itself is readily biodegraded if it leaks into groundwater, its presence may retard the degradation of more toxic compounds such as benzene, increasing the risk of groundwater contamination.

Dimethyl ether (DME), originally a derivative of methanol, can be used as a fuel for diesel engines. DME may be produced from either biomass (such as wood chips) or fossil fuels (natural gas or gasification of crude oil). Biodiesel a diesel fuel is produced from biological sources such as soybean oil or rapeseed oil. Both DME and biodiesel have lower emissions than conventional diesel fuel, but emissions of air toxics are still a concern. As an ether, DME may have groundwater characteristics (high solubility and low biodegradability) that could raise contamination questions if it leaks.

Advanced Coal-Fired Electricity Generation

Electricity generation accounts for 35 percent of U.S. energy-related carbon emissions, with over 30 percent from coal-fired power plants alone. The choice of new electric generation technology under carbon limits will depend on the type of limitation imposed (regulatory or market-based) and the relative price of coal and natural gas. High-efficiency coal-fired technologies, such as Pressurized Fluidized Bed Combustion (PFBC) and Integrated Gasification Combined Cycle (IGCC) plants, pose the greatest health concerns among the available choices.

These “clean coal” technologies have lower emissions of sulfur dioxide, nitrogen oxides, particulates, and mercury than today’s new coal-fired steam-electric plants with the best available control technologies. However, their emissions are higher than such other alternatives as natural gas combined cycle plants or IGCC plants that generate both electricity and hydrogen and sequester carbon dioxide. In addition to air pollution concerns, the participants noted health and safety concerns associated with the continued production of coal.

Reduced Ventilation of Buildings

Improvements in the energy efficiency of residential and commercial buildings, which account for about one-third of total U.S. energy consumption, are likely to occur in response to climate change. These changes include modifications to building materials (e.g., insulation, fluorescent lighting), building HVAC systems (e.g., efficiency improvements, alternative refrigerants), building envelope systems (e.g. tightening) and

building operation (e.g. reduced ventilation rates and ventilation system operating schedules). Modifications may include retrofits of existing buildings as well as improved design of new buildings.

These changes pose several health concerns because of the large population potentially exposed to a broad range of indoor air pollutants. Reduced ventilation rates may increase the concentrations of air pollutants generated indoors, which may in turn increase the incidence or severity of a wide range of respiratory ailments. Introduction of new materials to improve the energy efficiency of the building, such as thermal insulation, may also expose building occupants to air toxics whose effects are unclear. Finally, emissions of particulate matter and other pollutants from distributed power generators located in or close to buildings may enter buildings and increase occupant exposure.

Information Gaps and Research Needs

The participants identified information gaps and research needs for each of the high-priority technologies described above. These are summarized in Box 3. Three themes emerged:

- First, the emissions characteristics of many of the priority technologies are not known, in particular, emissions of air toxics and ultrafine particles. For transportation technologies, there is additional uncertainty about the effects on emissions of long-term use. In addition, poor maintenance by end users will cause emissions associated with many technologies to increase.
- Similarly, the safety risks (e.g., risk of explosion of hydrogen canisters) of poorly maintained or improperly operated vehicles are not well understood.
- Finally, little information exists about the health and safety concerns associated with production of new fuels and manufacture of batteries, fuel cells, and other new technologies.

Other Technologies and Issues of Note

Several other issues of note were raised at the meeting. Another five technologies from the list in Box 1 were flagged for health and safety concerns, but their priority was judged to be lower for a variety of reasons. A few other issues that were beyond the original scope of the meeting were identified as important but were not discussed in detail.

Other Energy Technologies of Concern

Two energy technologies from the original list were identified as having moderate health and safety concerns:

- Use of lightweight materials to improve transportation vehicle efficiency raised two concerns. First, passengers in lighter-weight vehicles are at greater risk if struck by heavier vehicles. In addition, the manufacture of some of these lightweight materials (e.g., plastics) may pose health risks for workers.

Box 3 High-Priority Technologies of Concern: Identified Information Gaps and Research Needs

New Diesel Engines Using Reformulated (Low-Sulfur) Fuel

- Emission characterization of new technologies (especially ultrafine PM, aldehydes, PAHs, dioxin)
- Better understanding of noncancer effects
- Health consequences of metal additives (e.g., cerium and ferrocene, which are in use in Europe, though unlikely to be used in the United States) and NOx control additives (e.g., urea) and emissions (ammonia).

Advanced Gasoline Engines Using Reformulated Gasoline

- Emissions characterization of latest technologies, with special attention to air toxics and ultrafine PM
- Health effects of any new or increased toxics

Electric Vehicles and Hybrids

- Better understanding of increased workplace exposure (during extraction, manufacture, and recycling, in both the United States and abroad)
- Health effects of most likely metals: nickel, lithium, lead
- Development of accident exposure scenarios during distribution and transport, including magnitude of accidents and likelihood of metals becoming biologically available.
- Questions about EMF exposure

Mobile and Stationary Fuel Cells Using Hydrogen

- Better understanding of safety issues in consumer use (e.g., pressurized fuel in the trunk for mobile use; storage issues in populated areas for stationary use)
- With carbon sequestration, questions of possible water contamination
- Better understanding of health and production exposures from likely fuel cell materials

Methanol for Mobile Fuel Cells

- Extent of likely opportunities for misuse (e.g., accidental drinking)
- Fate and effects in groundwater
- Characterization of likely in-use exposures at refueling stations for sensitive populations (e.g., pregnant women)
- Better understanding of health and production exposures from likely fuel cell materials

Transportation Fuels from Biomass (Ethanol, DME, and Biodiesel)

- Emission characteristics of fuel manufacture and in-use combustion
- Air quality effects for volatility and ozone levels (ethanol)
- Health effects of increased levels of aldehydes
- Potential water contamination effects (ethanol, ethers)
-

Advanced Coal-Fired Electricity Generation

- Emissions characterization of new coal technologies (with special attention to ultrafine PM and air toxics)
- Production exposures of continued and perhaps increased coal use

Reduced Building Ventilation Rates

- Much better characterization of the exposures to and sources of range of pollutants with differing ventilation levels (formaldehyde, NO_2, environmental tobacco smoke, volatile organic compounds, cooking emissions, bioaerosols, others)
- Improved health information for some of these pollutants (e.g. aldehydes, bioaerosols)

- One coal-fired electricity-generating technology was ranked as having only moderate health concerns. IGCC plants that generate both electricity and hydrogen and sequester carbon dioxide will produce minimal air pollution emissions. With this technology, carbon dioxide is injected into deep aquifers: the likelihood of this carbon dioxide making its way into drinking water aquifers is not well understood, and the effects of the possible resultant leaching of metals due to increased acidity are also unclear.

Several technologies from the original list were judged unlikely to be driven by climate change and thus were not discussed further. However, two of these might penetrate the market for other reasons, and raise some health concerns. Small distributed electricity-generating technologies such as fuel cells and microturbines using natural gas offer carbon benefits compared to central station, natural gas combined cycle plants only if a large fraction of the residual heat can be used for other purposes, such as process steam. These technologies may be attractive in commercial buildings for reasons other than climate change, and air pollution emissions in close proximity to people raises some health concerns. Dimethyl ether, a diesel substitute listed under transportation fuels made from biomass, can also be made from fossil fuel. The health concerns are the same as those discussed for biomass fuels, but without the carbon benefits.

Finally, increased use of nuclear power was listed in the second tier of concerns because of the time frame being considered. The group felt it unlikely that a new nuclear electricity generating facilities would be built over the next 20 years. However, if other low- and non-carbon electricity generation technologies prove unsuccessful over this time frame, then nuclear power may become a viable alternative, despite its well-known safety and disposal issues.

Other Issues and Technologies beyond the Scope of the Meeting

The participants identified three additional issues that were beyond the scope of the meeting but are important for future examination:

- The group identified the need for increased public health surveillance *before* new technologies are introduced. Evaluation of the effects of new technologies is often hampered by the lack of baseline data.

- The workshop focused on domestic health and safety concerns. However, potential impacts of new technologies in developing countries were also noted. These included worker exposure (e.g., to battery metals) and increased use of certain technologies (e.g., diesel).

- Finally, participants recognized that technological changes outside the energy sector were also likely if a commitment is made to lower atmospheric concentrations of greenhouse gases. Similar workshops were suggested for other sectors and for other impacts. For example, potential changes in agriculture (e.g., no-till agriculture and use of genetically modified crops) raise environmental and health concerns.

Looking Ahead

The workshop ended with a discussion of next steps. Participants identified three possibilities:

- Prepare a summary of the workshop for distribution to participants, funders, and others interested in the topic.
- Convene one or more workshops, each targeted on a single high-priority technology or on one of the broader issues that were raised.
- Hold a larger symposium discussing *all* high-priority technologies and issues.

Preparing a summary of the workshop's findings and conclusions received unanimous support—participants felt that the list of likely technologies, their potential health effects, and the gaps in current understanding would be of use to technologists, regulators, and health researchers.

There was also unanimity among the participants that a larger symposium would not be useful at this time. More information about the high-priority technologies and their effects on public health and safety is needed before such a symposium is held.

Participants overwhelmingly agreed that further follow-up workshops, targeted on specific aspects of the new technology/health effects issue, would be worthwhile. Decision makers who must deal with the effects of global climate change over the next twenty years need more information about the new technologies that are likely to be available and the effects of those technologies on public health. This workshop has defined the issue and raised questions that must be answered. Setting a research agenda that will answer those questions demands more in-depth discussion of the high-priority technologies and more specific information about their health effects. A series of targeted workshops would help provide the background information that NIEHS, EPA, DOE, other relevant government agencies, and industry need in order to set research priorities.

A series of targeted workshops would also promote continuing dialogue between technology developers and health effects researchers, which the participants saw as vital. The constant evolution of technologies in response to the desire for lower emissions means that periodic review is necessary. Such technology forecasting will allow research on health effects to begin before technologies are introduced. The proposed workshops would enable technology developers and health experts to benefit from each other's growing understanding of the nature and implications of emerging technologies.

While expressing their enthusiasm for targeted workshops, participants warned against losing focus on the larger goal—understanding whether there will be significant health implications, positive or negative, from technological changes in the major sources of carbon dioxide emissions. In addition, it was recommended that the targeted workshops be more quantitative than this exploratory meeting had been. Both carbon dioxide benefits and changes in exposure to pollutants of concern should be quantified so that decision makers can make informed choices about the technologies of the future. Explicit comparisons of new technologies with existing, baseline technologies are also crucial to such decisions.

Appendix: Workshop Participants

Health Implications of Technological Responses to Climate Change
Workshop Held November 29–30, 2000

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