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Prepared by
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act as organizing partners for the Scientific and Technological Community

INTRODUCTION

This paper, prepared by the Scientific and Technological (S&T) Community, provides an overview of recent scientific and technological developments in the fields of energy, climate change, air pollution, and other atmosphere-related concerns - representing thematic foci of the14th and 15th session of the Commission on Sustainable Development (CSD). Following from Agenda 21, in the Johannesburg Plan of Implementation (JPOI), the sections dealing with energy, climate change, and air pollution call for numerous actions focused on science and technology. In this paper we discuss the progress that has been made, and the obstacles that still exist, in implementing such actions.

While not discussed in depth in this paper, the CSD theme of industrial development is indeed recognized as a central component of essentially all sustainable development efforts, and it is closely linked to the themes of energy, climate change, and atmosphere. Increased efforts must be made to ensure that future industrial development is based on environmentally sustainable and economically appropriate production systems. Scientific research and technological innovation will continue to be an essential foundation for such developments.

As with all major sustainable development challenges, the issues of energy, climate change, atmosphere, and industrial development must be addressed in a way that integrates the 'three pillars' of social development, environmental protection, and economic growth. In order to help decision-makers define and implement these integrated approaches, the S&T community must continue striving to become more policy relevant, participatory, and able to address issues at geographical scales ranging from local to global. There is also a strong need for more integrative, interdisciplinary approaches, which will require continuing efforts to overcome persistent barriers that exist among the natural, social, engineering, and health science domains.

The ever-increasing global demand for energy and industrial goods and services represents a daunting challenge. Basic energy services and industrial goods are urgently needed by billions of impoverished people around the world, as a necessary foundation for achieving socio-economic development. However, meeting the basic needs and the social and economic aspirations of society has traditionally required a heavy dependence upon highly polluting energy and industrial technologies, primarily through the burning of fossil fuels. This has led to dramatic changes in the composition of the Earth’s atmosphere - affecting the very air we breathe and the climate that shapes the life of every human being on the planet. Whether the impacts of these changes are immediate (e.g., urban air pollution) or more slowly evolving (e.g., climate change), they affect the well-being of people in all nations and all sectors of society. The different CSD14/15 focal topics - energy, industrial development, climate, and atmosphere - are thus part of a complex, evolving system that must be understood and addressed in an integrated fashion.

ENERGY

There is an urgent need to transform global energy systems towards sustainable pathways, as current approaches are causing serious harm to human health and to the Earth's climate and ecological systems on which all life depends; and because access to clean, reliable energy services is a vital prerequisite for alleviating poverty. At the 2002 World Summit on Sustainable Development (WSSD), Member States of the United Nations agreed to improve access to “reliable, affordable, economically viable, socially acceptable and environmentally sound energy services and resources”. While in some parts of the world, there has been notable progress towards this goal, a great deal more effort is needed, both to enhance the implementation of existing clean energy technologies and to spur further scientific understanding and technological development. Meeting the world's rapidly growing energy demands in a sustainable manner will require drastically increasing the efficiency with which energy is produced, delivered, and used; and will require utilizing a diverse mix of energy sources and technologies.

Energy conservation and efficiency

Enhancing energy conservation and efficiency are key for decoupling economic growth from increased energy use, and thus for driving sustainable development worldwide. The World Energy Council estimates that nearly two-thirds of all primary energy is lost before it is converted to useful energy. There is a clear need to continue making advances in areas such as: the efficiency of various energy conversion systems (e.g., burners, turbines, motors); low-energy designs for electrical appliances and for heating, cooling, and lighting of buildings; the dematerialization and recycling of energy intensive material; and designing land-use and transportation systems that minimize demand for personal vehicle travel.

Fossil fuels

About 80% of world primary energy is supplied from fossil fuels. However, fossil fuels are a finite resource, although the exact timeframe over which this resource base will be depleted varies among different forms of reserves (i.e., oil, coal, natural gas) and is a function of highly uncertain estimates of actual geological reserves, costs and feasibility of new extraction techniques, and future geo-political dynamics and energy demand. Regardless, fossil fuels will remain as an important part of the global energy mix for the foreseeable future, and it is thus critical that fossil energy technologies continue to evolve towards cleaner, more efficient, less carbon-intensive systems. A number of current technological developments offer promising steps in the right direction (e.g., co-generation of heat and power based on gas turbines and combined cycles; emerging micro-turbine and fuel cell technologies; coal gasification to make 'syngas'). In the longer term, it is hoped that carbon capture and sequestration will offer a means for zero-emissions fossil fuel energy systems.

Nuclear energy

Projections of the future contributions of nuclear energy are highly uncertain, due to the concerns that exist about safety, radioactive waste management, potential proliferation of nuclear weapons, and vulnerability to terrorists. It is important, however, to continue developing waste disposal strategies and reactor designs that address these concerns, because nuclear technologies offer a means to provide energy without greenhouse gas emissions, and because a growing number of countries appear strongly committed to pursing nuclear energy options. In the longer term, some scientists view nuclear fusion as a potentially inexhaustible and emission-free means to meet the world's energy needs. The ITER international experimental reactor is considered to be the next major step in fusion research. The timeframe for carrying out the ITER experiments, developing a prototype fusion power plant and then commercial power plants, is at least 50 years or longer.

Renewables

A particularly urgent priority must be placed on increasing the share of modern renewable technologies in the world's energy mix. Some encouraging progress is being made in this respect. The International Action Programme from the 2004 Conference for Renewable Energies (Bonn) contains ambitious national targets for the expansion of renewable energy in more than 20 countries, including many initiatives for increased co-operation with developing countries.

However, while the absolute amount of worldwide renewable energy use has been rising significantly, the overall share of renewables in the world's total primary energy supply has increased only marginally over the past three decades. Scenarios produced by entities such as the International Energy Agency, the World Energy Council, and the Intergovernmental Panel on Climate Change (IPCC) all suggest that renewable energy sources could provide a much greater share of global primary energy demand in the coming decades, if the appropriate investment and incentive structures are put into place.

Renewable energy systems encompass a broad, diverse array of technologies, including for instance, solar photovoltaics, solar thermal power plants and heating/cooling systems, and wind, hydro, geothermal, biomass, and marine/tidal power systems. The current status of these different technologies varies considerably. Some technologies are already mature and economically competitive, other technologies need only minor additional development steps to become ready for the market, and yet other technologies are still too expensive and may require a few decades of continued R&D efforts in order to make large contributions on a global scale. In some cases, the 'technical potential' of particular energy technologies may be much greater than the actual 'sustainable potential'. For instance, the large-scale use of biomass energy requires consideration of the competing land-use needs (i.e., for fuel crops vs. agricultural crops), and the further expansion of large-hydro projects may be limited by unacceptable ecological and social impacts. On the other hand, some renewable energy technologies, such as solar photovoltaics, appear to have virtually unlimited sustainable potential, and thus should be vigorously pursued.

Transportation

The transportation sector plays a crucial role in all of the CSD14/15 focal themes, as it accounts for a large proportion of worldwide energy demand, is a major source of air pollution and greenhouse gas emissions, and is an important element of effective industrial development. The challenge is to enable freedom of mobility while reducing the consumption of fossil fuels. This requires making transport technologies more clean and efficient, as well as reducing the demand for personal motorized vehicle transport.

Transportation technologies are progressing on many fronts towards lower emissions of air pollutants and greenhouse gases. This includes for instance: cars powered by electricity, hybrid electric engines, and fuel cells; buses and commercial vehicles powered by compressed natural gas; the use of alternative fuels derived from various biomass sources; and continued improvements in the fuel efficiency and emissions of standard gasoline and diesel-powered vehicles. These various technological innovations are all gaining commercial success at differing rates. Their continued market penetration needs to be encouraged through appropriate economic incentive programmes, and ongoing research, development, and deployment efforts.

Even with the aggressive implementation of cleaner vehicle technologies, there remains a strong motivation to reduce demand for personal vehicle transport, because crippling traffic congestion is a serious impediment to economic growth, quality of life, and personal safety in countless places around the world. A growing number of communities are implementing effective public transportation systems, but at present, discouraging trends still dominate. Public transport options remain inadequate, and demand for private vehicles continues to grow dramatically, in many places across industrialized and developing countries alike. This challenge must be addressed on several fronts, such as subsidizing of mass transit development and use, encouraging 'smart growth' urban development patterns, and enacting public communication and incentive programmes to influence personal transport choices.

The role of science and technology

Although energy technologies are rapidly developing, it is widely acknowledged that existing solutions are not yet sufficient for meeting the world's growing energy needs in a sustainable manner. Much more work will be needed for a new generation of clean technologies for heat, fuels, and electricity to reach the mainstream market. These advancements must be supported with great urgency, because it will take decades to realize the necessary technological innovations, to develop related markets for new technologies, and to expand related production capabilities.

Advancing cost effectiveness and market penetration of sustainable energy systems will require technical research aimed at improved energy conversion techniques, supply structures, and end-user technologies, as well as non-technical research on a wide array of related social, political, and economic issues. Strategies for enabling widespread diffusion of advanced energy technologies need to encompass the whole 'innovation chain', from basic research to early deployment and development of niche markets. There is a need to expand and deepen the community of scientists and engineers who work on energy issues, for instance within the disciplines of physics, chemistry, biotechnology, and the social and economic sciences.

Given the highly complex nature and rapid evolution of energy R&D, it is important that decision-makers at all levels have access to the most recent and accurate scientific and technological information. Hence there is an ongoing need for review and assessment reports, such as those produced by the World Energy Council, the International Energy Agency, and the Intergovernmental Panel on Climate Change. In addition, we note that a report on R&D of Energy Technologies was recently produced by the International Union of Pure and Applied Physics (www.iupap.org/wg/energy/tech.pdf), and that a major new assessment effort on 'Transitions to Sustainable Energy' is currently underway by the InterAcademy Council (www.interacademycouncil.net).

Some examples of important energy R&D topics.

Photovoltaics. Achieving cost reductions for crystalline silicon and thin-film solar cells.

Wind. Developing multi-megawatt turbines and robust systems for offshore applications.

Biomass. Increasing the efficiency and versatility of combustion and gasification systems. Developing commercially feasible methods for production of ethanol from cellulosic materials.

Hydrogen. Advancing technologies for H_2 storage, and H_2 production from renewable energy sources.

Carbon sequestration. Continuing pilot studies of the technical feasibility and ecological impacts of C sequestration. Advancing techniques for CO_2 separation and capture from waste streams.

Cross-cutting. Integrating decentralized, intermittent energy sources into electricity grid structures. Advancing systems for co-generation of heat and power. Understanding the factors that motivate energy conservation efforts at the individual and community levels. Identifying novel financing mechanisms to overcome the economic barriers to market penetration of new energy technologies.

Obstacles to accelerated progress

Some key barriers to the achievement of sustainable energy goals include:

- *Needs for appropriate economic incentives*. Economic incentive systems need to be directed towards encouraging the implementation of clean energy technologies. This requires for instance, including the costs of externalities such as environmental degradation in energy pricing, and using subsidies to bring down the initial costs of new technologies and thus make them more competitive. Steady progress in lowering costs can then be expected to continue occurring through economies of scale, as market share increases. The historical learning curves for many renewable technologies teach us that costs per unit power fall approximately 20% every time the accumulated production doubles.

- *Needs for enhanced R&D funding.* Government investments in energy R&D, particularly for renewable energy sources, have been declining since the mid-1980s, and currently only a minor share of public energy R&D support is directed towards renewables. At the same time, deregulation and competitive forces in the energy industry have led to private sector R&D investments being redirected from longer-term, basic research towards low-risk, market-oriented research. There is a clear need for stronger, more consistent public support for R&D efforts, together with a policy environment that encourages private sector investments in the desired direction.

- *Needs for capacity building***.** Although a few developing countries do have notable energy R&D programmes, the vast majority of R&D work is carried out by a small number of industrialized nations. Many efforts to disseminate clean energy technologies within developing countries have limited or no success, because the introduced technologies are poorly adapted for local needs, and/or because there is insufficient local capacity to maintain the systems over the long-term. This points to a need for moving beyond a traditional 'technology transfer' mentality, towards a greater focus on building the endogenous scientific and technical capacity of all nations, and integrating these S&T capacity-building efforts into long-term economic development programmes.

- *Needs for stronger sectoral interactions***.** The different energy supply sectors (fossil, nuclear, various renewable sources) generally have little interaction, and sometimes act as competing 'lobbies'. Energy efficiency is, likewise, rarely addressed as a cross-cutting, strategic issue. When development prospects for different energy options are viewed in isolation from each other, one misses opportunities for effective synergies in R&D strategies. For instance, related developments in hydrogen transport and storage, fuel cells, turbines, batteries, etc. are needed for numerous renewable and fossil fuel-based energy systems.

- *Needs for greater international cooperation*. Lack of coordination among national R&D programmes can lead to unnecessary redundancies, missed opportunities for productive collaboration, and problems of critical R&D topics 'falling through the cracks' between programmes. The transformation of the global energy system is an issue of critical concern for the entire world community, and the development of technological capabilities and scientific knowledge must be encouraged in an equitable, open manner among all countries. Regional-level initiatives and networking between centers of excellence can be particularly effective strategies for exchange of information and expertise.

To help overcome these barriers, there is a need for stronger mechanisms of interaction among national- and sectoral- based energy R&D efforts, and for objective international bodies that can provide leadership and guidance in the development of coherent global strategies for advancing energy systems. This need is particularly great in the realm of new renewable technologies, where the institutions and infrastructures for information sharing are less mature than for more traditional energy technologies. In response to this need, ICSU is currently exploring the idea of establishing an International Science Panel on Renewable Energy.

CLIMATE CHANGE

Progress in climate science

There is scientific consensus, documented in the Assessment Reports of the IPCC, that the increase in greenhouse gases in the atmosphere due to human activities is altering the Earth's climate, bringing about a general global warming. Human activities are producing these changes, in addition to natural climate variability.

Global level scientific simulation models have become more robust during the last decade. Hence, our capacity to anticipate future risks related to climate change impacts has also improved significantly, while still remaining insufficient as regards projections for specific regional and subregional patterns of climate change and their impacts.

Even though a long-term (say 50 -100 years) prediction of exactly what will happen at a specific location on the planet is not yet possible, scientists do have the ability to paint a picture of how our environment is likely to evolve in response to anthropogenic climate change. There exist sufficiently confident projections of future climate change. These projections include the following:

- Depending on the emission scenarios and climate models used, the globally averaged surface temperature is projected to increase by 1.4 to 5.8 ° C above 1990 levels, by 2100. It is very likely that nearly all land areas will warm more rapidly than the global average, particularly those at northern high latitudes in the cold season. In winter the warming for all high-latitude northern regions exceeds the global mean warming in each model by more than 40%.
- For high greenhouse gas emission scenarios, global climate change is projected to raise sea level by up to 0.88 m over the current century. This would put vast, often densely populated, coastal areas in all parts of the world in danger of permanent flooding. Numerous nations that live on archipelagos and coral atolls would be at risk of disappearing.
- Projections indicate that extreme weather events will become more common in the future. For instance, temperature extremes, such as the 2003 heat wave in Europe, are projected to become more common in the next 50 years. There is evidence that the frequency and intensity of extreme precipitation events will increase over many areas worldwide, notably over many Northern Hemisphere mid-to high latitude land areas. Hurricane intensity is expected to increase as greenhouse gas concentrations in the atmosphere rise.
- In addition, projections show that the range of environmental effects goes far beyond the kinds of "weather-related" events described above. Examples of other effects include diminishing freshwater supply in many regions, due to extended droughts and as high-altitude glaciers melt and snow cover in mountain areas decreases.
- Another example is the increasing acidification of the oceans due to increased CO_2 absorption, with far reaching consequences for the survival of coral reefs and the dynamics of organisms in the oceans that are the basis of the marine food chain. This implies serious risks for a primary source of protein needed for a growing world population.

Even if greenhouse gas emissions were stabilized at present levels, the global warming trend and sea level rise would continue for hundreds of years, due to the atmospheric lifetime of some greenhouse gases and the long timescales on which the deep ocean adjusts to climate change. The continuing increase in emissions will augment the intensity and duration of the impacts.

Progress in knowledge of climate change was recently summarized in a Joint Statement of the Science Academies of the G8 countries, as well as of Brazil, China and India, on Global Response to Climate Change, issued on the occasion of the G8 Heads of State and Government meeting in Gleneagles, UK, July 2005 (www.royalsoc.ac.uk/document.asp?id=1170).

Relevant ongoing international scientific cooperation programmes

Most of the recent advances in climate science have been generated within international scientific cooperation programmes established throughout the 1980s and 1990s. These programmes are the World Climate Research Programme [WCRP, jointly undertaken by ICSU, the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO], the International Geosphere-Biosphere Programme [IGBP of ICSU], and the International Human Dimensions Programme on Global Environmental Change [IHDP, jointly undertaken by the International Social Science Council (ISSC) and ICSU]. In the years to come also DIVERSITAS, another international global change research programme, dealing with biodiversity, will provide data and enhanced knowledge on the links between climate change and biological diversity.

Moreover, WMO, UNEP, IOC and ICSU established the Global Climate Observing System (GCOS) in 1992 to ensure that the high-quality observations and information needed to address climate related issues are obtained and made available to all potential users. Also the Global Terrestrial Observing System [GTOS, co-sponsored by FAO, UNESCO, UNEP, WMO and ICSU] and the Global Ocean Observing System [GOOS, co-sponsored by IOC of UNESCO, WMO, UNEP and ICSU] have important climate related components.

The WCRP and the IGBP must be seen as the main mechanisms by which the scientific community worldwide is mobilized to provide improved understanding of the climate system. Moreover, it must be much more strongly recognized that the major foundation of the natural science assessment of the IPCC is the collaborative work of many scientists and countries through WCRP and IGBP, as well as through the global environmental observing systems.

Some of the research undertaken through the WCRP and IGPB has had major immediate socio-economic benefits. For example, with the advances in forecasting El Nino/Southern Oscillation (ENSO) events, fishermen and farmers in the Andean coastal zones, but also communities in Asia and Africa usually affected by ENSO events, are able to benefit from early warning and thus are better able to mitigate the impacts of these events.

Obstacles to accelerated progress

In its Third Assessment Report in 2001, the IPCC reported that observational networks were declining in many parts of the world and that additional and sustained climate observations would be required to improve the ability to detect, attribute, and understand climate change. While some improvements to networks have been made since the Third Assessment Report, the overall trend has not changed significantly. Following the Second Adequacy Report on climate observations commissioned by the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC), an Implementation Plan for the Global Observing System for Climate in Support of UNFCCC has been prepared and was approved by COP in 2004.

This Plan, available on the GCOS website (www.wmo.ch/web/gcos/gcoshome.html), identifies 131 actions needed over the next 5 to 10 years to address the critical issues related to global observing systems for climate.

While the Plan outlines the actions needed to make the Global Climate Observing System, fully operational and efficient, it also highlights the importance of climate related data to be provided by the Global Terrestrial Observing System, and the Global Ocean Observing System. The need for strengthening observing systems for climate data was one reason for the recent establishment of the Global Earth Observation System of System (GEOSS). While the coming of GEOSS represents an important step forward, sizeable resources will need to be made available by governments and considerable work will need to be carried out in order to realize the goals set for GEOSS and the climate components therein.

Remaining important gaps in our knowledge on climate change, its impacts, and on adaptation strategies represent obstacles to improving and accelerating implementation of climate policies. Consequently, the relevant scientific communities do need to continue to increase significantly understanding of the climate and the Earth system, refine our predictive tools and thus reduce remaining uncertainties in efforts to project future climate, and impacts of change, particularly at the regional level.

In its Fourth Assessment Report, due for completion in 2007, the IPCC will address the state of knowledge since 2001 on some of the most important unresolved issues, such as:

(i) Will changes in cloud cover and characteristics, and in atmospheric aerosols, amplify or moderate the rate of climate change?

(ii) Will as much as about half of the human-caused emissions of CO_2 continue to be taken up by the oceans and biosphere? If ocean circulation slows (as warming might induce) or CO_2 fertilisation of the biosphere saturates (as may happen), much more of the emitted CO_2 would remain in the atmosphere. The rate of warming would further accelerate, and the emission cutbacks required would need to be increased if dangerous anthropogenic interference is to be avoided.

(iii) How fast is the ocean taking up the heat trapped by the increased concentration of greenhouse gases? Lack of knowledge on ocean heat uptake limit our ability to pin down more precisely the amount of future global temperature rise in the 21^{st} century due to projected emissions.

(iv) How will global climate change alter climates at the regional level? For example, given that the monsoons provide water to more than half of the global population, any changes could have dramatic impacts. What will happen to the monsoons?

(v) Will countries, in particular those in the developing world, be able to adapt their agriculture as rapidly as the climate changes? How will infectious and vector-borne diseases be affected in different parts of the world?

Action needed now by society and in science

There is broad consensus among scientists that the scientific understanding of the ongoing climate change is sufficient to warrant taking urgent action in order to mitigate future climate change impacts. We must mitigate both environmental impacts and socio-economic consequences. Not taking action now will aggravate environmental impacts. It will also make socio-economic costs even higher.

Action is needed in order to reduce greenhouse gas emissions. It is projected that world energy demand will continue to grow rapidly in the coming decades. Meeting this demand in a sustainable manner will require drastically increasing the efficiency with which energy is produced, delivered and used. At least for the next few decades, it will also require accepting a diverse mix of energy sources and technologies, with increased attention to be given to renewable sources of energy (see sections on energy in this paper).

Action is needed by countries and regions to design and start implementing strategies to adapt to the consequences of climate change. Enhancement of adaptive capacity is a condition for reducing vulnerability, particularly for the most vulnerable regions, nations and socio-economic groups. Developing best practises and effectiveness of strategic approaches to climate change adaptation will gain significantly from international collaboration. At all levels, participation of a broad range of stakeholder groups will be essential in this undertaking.

As regards science, we do need to continue to increase our understanding of the climate and the Earth system, and to refine our predictive tools and reduce still existing uncertainties in projections of future climate, and its impacts, particularly at the regional level. In this respect, important priorities during the coming years are:

- to enhance long-term observations of the Earth system by making the global environmental observing systems fully operational through implementation of the Global Earth Observing System of Systems (GEOSS),
- to vigorously pursue the implementation of the WCRP and the related global environmental change research programmes, including the IGBP, DIVERSITAS and IHDP.

As importantly, however, will be to open up vigorously a new line of interdisciplinary research, involving natural, social and economic sciences, aimed at a better identification and understanding of coupled environmental and socio-economic impacts and vulnerabilities, and at increasing knowledge needed for drawing up possible adaptation strategies to climate change. As climate change is going on now, we must become better prepared for adapting to it and for limiting its socio-economic costs in societies worldwide.

The UNFCCC has in principle agreed on the development of a Five-Year Programme of Work on Impacts, Vulnerability and Adaptation. A workshop convened by the UNFCCC Secretariat in October 2005 in Bonn, Germany, was dedicated to defining what the content of the five-year programme of work of the Subsidiary Body of Scientific and Technological Advice of UNFCCC might be. Needs identified at this workshop include:

- promoting development and dissemination of impact and vulnerability assessment tools and methods;
- improving access to high quality data and information on current and future climate variability and extreme events;
- improving availability of socioeconomic information on vulnerable populations and economic sectors and on the economic impacts of climate change;
- stimulating adaptation research and technology; and
- promoting international cooperation to assist vulnerable countries in enhancing their resilience and managing climate risks, giving priority to the most vulnerable countries.

The polar regions are a unique barometer of environmental change due to global warming. In the Arctic and in regions of Antarctica, average surface temperatures have risen much faster than in the rest of the world in the past decades. This fact has also been confirmed by the results of the independent Arctic Climate Impact Assessment published in 2004. Consequently, among the topics to be investigated by the upcoming International Polar Year 2007-2008, sponsored by ICSU and WMO, climate change investigations must be supported strongly, as well as the development of polar components of the global environmental observing systems.

The scientific and technological community also calls for continued support to the highly important work of the IPCC as a forum for carrying out independent scientific assessments and enabling interaction between natural and social scientists, policy makers, and other stakeholders, thus strengthening participatory approaches.

The links between research, long-term monitoring, integrated assessments and policy making have been considerably improved during the last 10 – 15 years at the global level. However, these links are still lacking in most regions and, in particular, most often at the country level.

ATMOSPHERE

One of the most profound ways in which human activity affects the natural environment is through changes in the composition and chemistry of the atmosphere. Of greatest concern are three closely-intertwined issues: the occurrence of health-damaging air pollution, the build up of heat-trapping greenhouse gases, and depletion of the Earth's protective stratospheric ozone layer.

Air Pollution

Clean air is a basic requirement for human health and welfare, and an important prerequisite for sustainable economic development. Air pollution[1] results primarily from the combustion of fossil fuels in transportation and power generation, from various industrial emissions, and from large-scale biomass burning in some parts of the world. Air pollution is known to be a major factor in respiratory and heart disease, and a number of air pollutants are known or probable carcinogens. Though very difficult to quantify, it is estimated that millions of people die prematurely due to air pollution each year worldwide. Air pollution also adversely affects natural ecosystems, for instance, though damage to plant growth, acidification of waterways, accumulation of mercury in food chain, and eutrophication of coastal ecosystems, all leading to impacts on agriculture, fisheries, forests, and a host of 'ecosystems services' upon which all life depends. Much still needs to be learned about the specific details and mechanisms of air pollution exposure and impacts on both human and ecosystem health; however, current scientific understanding provides ample evidence to warrant urgent action.

In most developing countries, air pollution is a serious problem, resulting from rapid urbanization and population growth, and consequent growth in demands for energy and automobile transportation, combined with poor environmental regulation and highly polluting vehicles and industrial production systems.   In many rural areas, a major health threat (particularly among women and children) is chronic exposure to indoor air pollution, resulting from the combustion of

[1] The World Health Organization recognizes six main types of air pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter (PM), sulfur dioxide (SO_2), tropospheric ozone (O_3) , and suspended particulate matter (SPM).   In addition, some countries specify as air pollutants: heavy metals (such as lead and mercury), volatile organic compounds (such as benzene and formaldehyde), and a broad array of other chemical compounds classified as air toxics.

biomass and coal in rudimentary, inefficient systems for cooking and heating. In this context, relatively small investments in implementing existing pollution control technologies could have huge environmental and public health benefits.

In most industrialized countries, effective regulatory programmes implemented over the past few decades have led to the introduction of cleaner technology, especially in the power generation and transport sectors, and this in turn has led to significant improvements in overall air quality. In many places, however, the gains made by tighter regulations and improved energy efficiency and pollution control technologies have been offset by ever-increasing growth in energy demand and vehicle-miles-traveled. The emission of fine particulates from diesel engines and power plants is seen as a significant health risk that remains inadequately addressed.

A matter of growing attention and concern is the long-range transport of air pollutants across national boundaries and between continents, which can raise background pollution levels over large regions of the globe, and make it impossible for any one country to fully address its air quality concerns in isolation. In the 1980s and 90s, widespread concern about acid rain pollution in North America and Europe led to extensive research and assessment efforts, which greatly enhanced understanding of long-distance transport of sulfur and nitrogen oxide pollution. More recently, the scientific community is striving to develop robust techniques for documenting long-distance transport of ozone, particulates, and persistent organic pollutants. The Convention on Long-range Transboundary Air Pollution and associated Protocols have been important instruments for enhancing international collaboration; and there has been significant progress in the development of integrated regional policies for air pollution assessment and control across Europe and North America. There is still a great need, however, for comparable types of efforts in other parts of the world, for instance across Asia and Latin America, where there is clear evidence that regional-level atmospheric pollution is a significant and growing problem[2].

Greenhouse Gases

The build up of long-lived greenhouse gases[3] in the atmosphere is well documented, and is well-understood to result from human activities. Further details about the consequences of this profound change in global atmospheric composition, and about scientific progress and obstacles in addressing such issues, are covered in the section on climate change in this Discussion Paper.

The issues of air quality and climate change are closely coupled on several levels. Most notable is the fact that the major anthropogenic greenhouse gas (CO_2) and many conventional air pollutants come from the same sources (i.e., burning of fossil fuels), and thus can be simultaneously addressed

[2] For instance, the INDOEX field experiment (http://www-indoex.ucsd.edu/) led to the discovery of a massive pollution 'cloud' extending over the Indian Ocean, South and Southeast Asia, and China, with serious potential impacts on marine life, agricultural productivity, and climate and monsoon hydrological cycles. This phenomenon is currently being studied further under UNEP's Asian Brown Cloud Project.

[3] The anthropogenically produced greenhouse gases include carbon dioxide (CO_2) methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

through mitigation of those sources. There are also some contexts, however, that can require trade-offs between efforts to reduce emissions of greenhouse gases and emissions of conventional air pollutants. Climate change and air pollution are also linked through chemical and physical processes in the atmosphere. For instance, tropospheric ozone is a powerful greenhouse gas, and particulate pollutants can have strong effects on local and regional climate. In turn, climate patterns directly affect the sources, transport, and deposition of air pollutants; and a major concern is that global warming will exacerbate the problem of urban air pollution in many parts of the world.

Stratospheric Ozone

The actions taken to preserve the stratospheric ozone layer provide an example of remarkable success in scientific and political cooperation for addressing a major environmental threat. As a result of the successful implementation of the Montreal Protocol and its Amendments, the atmospheric concentration of CFCs (the man-made chemicals that destroy stratospheric ozone) has generally begun to decline. However, stratospheric ozone destruction in the polar regions, and consequent rise in dangerous UV radiation, is still occurring at near record levels. It is anticipated that near-complete recovery of the Antarctic ozone layer will occur by ~ 2050. Future evolution of ozone in the Arctic is more difficult to estimate, due to the more complex feedback processes involved. Some key remaining needs/challenges include:

- reducing international trafficking of existing CFCs, and ensuring a timely phase-out of methyl bromide and HCFCs;
- further advancing scientific understanding of how climate change can affect the dynamics of stratospheric ozone loss and recovery;
- ensuring that the effective atmospheric monitoring systems put into place over the past few decades are maintained.

The stratospheric ozone example is often cited as a model for the effective use of scientific information in guiding policy responses to global change concerns. It must be acknowledged, however, that other global change issues pose far more complex challenges in this respect. For instance, effectively responding to climate change requires understanding highly complex cause-and-effect relationships and feedbacks, and controlling emissions from a wide array of sources and sectors that are of central importance to social and economic development.

The role of science and technology

Effective air quality management systems are developed in the context of diverse social, economic, and political considerations. However, a strong scientific and technical base is indispensable as a foundation for such systems, for instance, playing a critical role in setting appropriate emission standards and ambient air quality objectives, designing and implementing effective air pollution control strategies and technologies, and assessing emissions, ambient air quality, exposure patterns, and impacts on human and ecosystem health.

Observing systems. Understanding atmospheric change requires an integrated system for collecting data on a wide array of parameters, including: greenhouse gases, ozone, solar radiation, precipitation chemistry, aerosols, reactive gases, and meteorology. Such data is collected through surface-based monitoring networks; through aircraft- and balloon-based measurements in the lower atmosphere; and increasingly, through space-based satellite observations. The atmospheric science community has made great progress in advancing and coordinating these complex observational networks, and applying them to study air pollution transport, to map and assess pollutant emissions, to develop air quality forecasting systems, and to support international policy formulation. The WMO's Global Atmosphere Watch programme has recently developed a proposal for an Integrated Global Atmospheric Chemistry Observation System, to ensure more accurate and comprehensive global observations of key atmospheric gases and aerosols, and to make these observations accessible to users. This new initiative could become part of GEOSS.

Likewise, ecological and human health research communities continue to advance systems for monitoring air pollution impacts. Such systems are critically important for determining priorities and evaluating the effectiveness of air quality control measures. However, linking observed trends in human and ecological health with ambient air quality trends presents a major scientific challenge, given the multiple stressors to which these systems are exposed, and the wide variety of systems and responses involved.

Modeling tools. There also continues to be a great deal of progress in developing advanced atmospheric modeling tools, ranging from local to global scale. Notable examples include the U.S. Environmental Protection Agency's Community Multiscale Air Quality modeling system; and the RAINS (Regional Air Pollution and Simulation) and GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) models from IIASA, which allow the user to examine the costs and effectiveness of different emission control strategies, and to design emission control strategies that simultaneously meet air quality targets and limit the emissions of greenhouse gases. A wide array of ecological and biological/epidemiological models are likewise continuing to be developed for studies of air pollution impacts.

International cooperation and capacity building. Almost all nations share similar challenges in dealing with air pollution, but the capacity to address these challenges varies tremendously. In many developing countries, there is a need to better characterize the current impacts of air pollution, and to better illustrate the future risks that may result from different development pathways, in order for decision-makers to design effective policy responses. There is a need to encourage the education and training of more scientists and engineers, in order to carry out basic research and observations, to implement and maintain emission control technologies, and to give competent advice to policy makers and the public. The most advanced observational and modeling tools, pollution prevention and control technologies, and knowledge about best practices in air quality management, must be shared effectively among industrialized and developing nations. Efforts of the International Union of Pollution Prevention Associations, the International Global Atmospheric Chemistry Project, the Global Atmosphere Watch Programme, and other organizations, play an important role in advancing this international cooperation.

EDUCATION, TRAINING AND S&T INSTITUTIONAL CAPACITY BUILDING

Addressing the challenges of developing sustainable energy systems, mitigating and adapting to climate change, reducing atmospheric pollution and promoting a sustainable path to industrial development requires strong and focused national, regional and global S&T systems. However, it is now clearer than ever that these challenges have thus far outstripped the capacities both of the S&T community and of society to forge effective and comprehensive responses. Nothing less than a massive effort will be needed in order to strengthen scientific and technological capacity in all regions of the world, and in particular in developing countries.

Bridging the North-South divide in scientific and technological capacity

The Organization for Economic Cooperation and Development (OECD) countries spend annually more on research and development (R&D) than the economic output of the world's 61 least developed countries. Developed countries employ 12 times the per capita number of scientists and engineers in R&D than developing countries, where there is often woefully weak institutional capacity. This gap in S&T capacity between the developed countries and a majority of developing countries is generally still widening.

Developing countries must address this problem and significantly enhance investment in higher education and S&T capacity. Bi-lateral donors and other funding mechanisms should include S&T capacity building among their priority areas of development cooperation and substantially increase the funds they allocate to S&T for sustainable development. Special attention should be given to the areas of energy, climate change, air pollution and industrial development. A critical mass of scientific and technical skills and infrastructure (e.g. laboratories, equipment and supporting institutions) is required for all countries to develop, adapt, and produce the technologies specific to their needs; to introduce these technologies effectively into the market; and to provide the needed maintenance on an ongoing basis. Capacity building at the international, regional, and sub-regional levels must also be given increased attention as it is often the most cost-efficient way to build a critical mass of capacity.

Recent initiatives and ongoing programmes

At the end of August 2005, the world's leading international scientific, engineering and medical organizations issued a joint statement on science, technology, and innovation for achieving United Nations Millennium Development Goals (www.icsu.org/9_latestnews/latest_5.html). The statement was addressed to the Heads of State and Government gathered at the UN Millennium Goals Summit in New York in September 2005. The Summit participants recognized that science and technology, including Information and Communication Technologies (ICT), are vital for the achievement of the development goals and adopted a number of commitments in this regard. Two of the commitments refer specifically to:

- Assist developing countries in their efforts to promote and develop national strategies for human resources and science and technology, which are primary drivers of national capacity building for development;

- Promote and support greater efforts to develop renewable sources of energy, such as solar, wind and geothermal;

The importance to address S&T capacity building issues worldwide has been highlighted in a 2004 report from the InterAcademy Council (*Inventing a Better Future. A Strategy for Building Worldwide Capacities in Science and Technology*). The report provides a blueprint of action needed to enhance the S&T capacity of those developing countries that still lack this capacity.

At the January 2004 meeting of the OECD Committee for Scientific and Technological Policy at the ministerial level, Ministers adopted the *Declaration on International Science and Technology Cooperation for Sustainable Development.* The Declaration states that moving toward sustainable development objectives requires better ways of cooperating internationally to build capacities in science and technology, enhancing knowledge and technology transfer and creating effective networks, in the developing countries. Governments, academia as well as businesses in both OECD member countries and developing countries have important roles to play. In order to follow-up on the Declaration an international workshop, co-organised by the Government of South Africa and

OECD, will take place in South Africa in November 2005. The workshop will include a particular focus on identifying good practices in international science and technology co-operation in the areas of energy and climate change. It is expected that results of this workshop will be fed into the CSD-14/15 processes.

In science related to climate change, the SysTem for Analysis, Research and Training (START) acts as a platform to enhance the scientific capacity of developing countries to participate in the global environmental change research programmes and to address issues of impacts and vulnerability, and mitigation and adaptation at the national, subregional and regional levels. START is co-sponsored by the WCRP, IGBP and IHDP. It seeks to establish and foster regional networks of collaborating scientists and institutions in developing countries and undertakes a wide variety of training and career development programmes. Increased financial support for START is necessary in order to enable the programme to better fulfil its tasks.

Detailed needs in S&T capacity building in the broad area of climate change and reduction of greenhouse gas emissions have also been drawn up by the Subsidiary Body of Scientific and Technical Advice to the UN Framework Convention on Climate Change.

A major instrument for enhancing education focused on energy, climate change, air pollution and atmosphere issues will be the UN Decade of Education for Sustainable Development 2005-2014. Within different domains of education for sustainable development (basic education; higher education; reorienting existing education programmes; developing public awareness and understanding of sustainability; specialised training) the specific themes of sustainable energy, mitigation of and adaptation to climate change, air pollution/atmosphere and industrial development should receive particularly high attention. The S&T community for its part is committed to make an active and important contribution to the Decade in this respect.

CONCLUSIONS

This Discussion Paper demonstrates that science and technology are essential means for accelerating the implementation of actions agreed in the Johannesburg Plan of Implementation, aimed at addressing the problems of climate change and air pollution, and at meeting the world’s growing energy demands in a sustainable manner. Progress in meeting sustainable development goals in these fields will require substantive further advances in science and technology and a massive effort in order to strengthen scientific and technological capacity in all regions of the world, and in particular in developing countries.

The S&T community remains committed to helping identify and implement sustainable solutions to the pressing problems highlighted here. To this end, our community seeks to enhance further cooperation with governments, business and industry, and civil society, in taking research to action. We are also striving to develop new platforms for ongoing dialogue with policy makers, development specialists, and the wide array of other stakeholder groups that are directly involved in meeting sustainable development challenges. These dialogue efforts are aimed at providing more open, participatory mechanisms of defining key needs for new scientific knowledge and technological innovation.

Acronym Definitions

CFC	Chlorofluorocarbons
COP	Conference of Parties
CSD	Commission on Sustainable Development
ENSO	El Niño-Southern Oscillation
GCOS	Global Climate Observing System
GEOSS	Global Earth Observation System of Systems
GOOS	Global Ocean Observing System
GTOS	Global Terrestrial Observing System
IAC	Inter Academy Council
ICSU	International Council for Science
ICT	Information and Communication Technologies
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions of Global Change Programme
IIASA	International Institute for Applied Systems Analysis
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
ISSC	International Social Science Council
JPOI	Johannesburg Plan of Implementation
OECD	Organization for Economic Cooperation and Development
RAINS / GAINS	Regional Air Pollution and Simulation / Greenhouse Gas and Air Pollution Interactions and Synergies
R&D	Research and Development
START	SysTem for Analysis Research and Training
S&T	Science and Technology
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WCRP	World Climate Research Programme
WFEO	World Federation of Engineering Organizations
WMO	World Meteorological Organization
WSSD	World Summit on Sustainable Development