$50.00

# HUMAN SOURCES OF GLOBAL CHANGE: A REPORT ON PRIORITY RESEARCH INITIATIVES FOR 1990-1995

Robert W. Kates
William C. Clark
Vicki Norberg-Bohm
B.L. Turner, III

G-90-08 July 1990

The views expressed in this paper are the author's and do not necessarily reflect those of the Energy and Environmental Policy Center, of the Science, Technology and Public Policy Program, of the Global Environmental Policy Project, or of Harvard University. Reproduction of this paper is not permitted without permission of the Energy and Environmental Policy Center. For permission, contact the Publications Department, Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University, 79 John F. Kennedy Street, Cambridge, MA 02138.

# HUMAN SOURCES OF GLOBAL CHANGE

## A REPORT ON PRIORITY RESEARCH INITIATIVES FOR 1990-1995

**Robert W. Kates, William C. Clark, Vicki Norberg-Bohm, and B.L. Turner, III.**

Science, Technology and Public Policy Program
John F. Kennedy School of Government
Harvard University
Cambridge, Massachusetts 02138

May 10, 1990

## FOREWORD

This paper is being jointly released as Occasional Paper #3, Institute of International Studies, Brown University, Providence, RI and as Report 90-O8 in the Global Environmental Policy Project Discussion Series, Kennedy School of Government, Harvard University, Cambridge, MA. This paper has been submitted by the authors to the National Academy of Sciences (NAS) Committee on Global Change. This document has not yet been subjected to the NAS Report Review Process. The views expressed in this document are those of the authors and do not represent official views of the NAS. Subsequent to being reviewed and revised, this paper will appear as a chapter in an NAS book outlining the research agenda recommended by the NAS Committee on Global Change. The research for this paper was partially funded by the Sandia National Laboratories through the Massachusetts Institute of Technology Energy Lab.

## TABLE OF CONTENTS

SUMMARY RECOMMENDATIONS ..... 1

Industrial Metabolism ..... 2

Land Transformations ..... 3

Synthetic Studies ..... 5

Priority Recommendations ..... 7

1. INTRODUCTION ..... 9

2. THE RESEARCH PROGRAM ..... 10

3. INDUSTRIAL METABOLISM ..... 12

3.1. Integration and Synthesis ..... 13

3.2 Process Studies and New Data ..... 14

3.2.1 The Intensity of Energy and Materials Use ..... 15

3.2.2 The Dynamics of Industrial/Technological Change ..... 18

3.2.3 Regional Evolution of Industrial Metabolism ..... 20

4. LAND TRANSFORMATIONS ..... 21

4.1 Integration and Synthesis ..... 22

4.1.1 Global Agriculture Model ..... 22

4.1.2 Land Cover Projections for the 21st Century ..... 24

4.2 Process Studies ..... 26

4.2.1 Fertilization ..... 26

4.2.2 Biomass Burning ..... 27

4.2.3 Livestock Development ..... 27

4.3 Data Needs . . . . . 28

4.3.1 Landuse-Capability/Population Geographic Information System (GIS) . 29

4.3.2 Land Tenure and Size of Holdings . . . . . 30

4.3.3 Regional Case Studies and Research Centers . . . . . 30

5. INTEGRATIVE ACROSS LAND USE AND INDUSTRY . . . . . 31

5.1 Global Greenhouse Gas Emission Models . . . . . 31

5.2 Earth Systems Information Flow Diagram For Human Interactions . . . . . 32

5.3 Driving Forces: Population, Economy, Technology and Institutions . . . . . 33

6. IMPLEMENTATION REQUIREMENTS . . . . . 34

6.1 Related Institutional Efforts on Human Interactions with Global Change . . . . . 34

6.2 Investigator-Initiated Research . . . . . 34

6.3 Education and Training . . . . . 36

6.4 Data Preparation and Dissemination . . . . . 36

7. PROGRAM COSTS . . . . . 37

8. THE STEPS BEYOND . . . . . 37

## EXECUTIVE SUMMARY

In its 1988 report, the Committee on Global Change (CGC) concluded that human interactions with the earth system would be a central component of the US Global Change Program. It recommended that the initial priority for research on such interactions should be to obtain a better understanding of the human sources of global change. Other interactions -- in particular the human consequences and management of global change -- were recognized as being of fundamental importance. But the most immediate requirement for progress in the overall, interdisciplinary global change program was felt to be a more systematic understanding of how human activities altered chemical flows, energy fluxes and physical properties central to the operation of the earth system.

Over the year since the release of its 1988 report, the CGC has sought to formulate a research plan for achieving a better understanding of the human sources of global change by the end of the decade. In its deliberations, the Committee collaborated with a wide range of scholars and institutions, but worked particularly closely with the National Academy of Engineering's program on Technology and Environment and Social Science Research Council's program on Global Environmental Change. This report recommends priority research initiatives for implementation over the period 1990-1995.

As shown in the figure on the following page, the recommended program focuses on two principal human sources of global change: industrial metabolism and land transformation. For each source, the program recommends research on integrative

# HUMAN SOURCES OF GLOBAL CHANGE

## RESEARCH INITIATIVES: 1990 - 1995

DRIVING FORCES:
POPULATION, ECONOMY, TECHNOLOGY, AND INSTITUTIONS

| | INDUSTRIAL METABOLISM | | | | LAND TRANSFORMATIONS | |
|---|---|---|---|---|---|---|
| INTEGRATIVE MODELS | MATERIALS | GLOBAL ENERGY | GLOBAL GREENHOUSE GAS EMISSIONS | EARTH SYSTEM INFORMATION FLOWS: HUMAN INTERACTIONS | GLOBAL AGRICULTURE | LAND COVER CONVERSION:<br>- TROPICAL FORESTS<br>- WETLANDS |
| PROCESS STUDIES | - INTENSITY OF ENERGY AND MATERIALS USE<br>- DYNAMICS OF INDUSTRIAL/ TECHNOLOGICAL CHANGE<br>- REGIONAL EVOLUTION OF INDUSTRIAL METABOLISM | | | | - FERTILIZATION<br>- BIOMASS BURNING<br>- LIVESTOCK DEVELOPMENT | |
| DATA SOURCES | - ENERGY AND MATERIALS USE DATA<br>- INDUSTRIAL PROCESS DATA<br>- REGIONAL PRODUCTION, CONSUMPTION, AND INDUSTRIAL PROCESS DATA | | | | - LANDUSE CAPABILITY/ POPULATION GIS<br>- LAND TENURE AND SIZE OF HOLDINGS DATA BASE<br>- REGIONAL CASE STUDIES | |

models, process studies, and data base development. In addition, a small number of synthetic studies are proposed.

**Industrial Metabolism**

The term "industrial metabolism" has come in recent years to signify the total pattern of energy and materials flows through an industrial sector or region. The basic goal of research in this area is to understand how changing levels of human population, economic activity, technology and social institutions influence the pattern of such flows -- in particular the output of pollutant chemicals relevant to global change.

Integrative models: The Committee identified two integrative modeling goals in the area of industrial metabolism. The first, relatively well in hand, is the creation of global models of energy use and associated pollutant emissions. Such models have a long history of development in studies of the greenhouse effect. They have provided internally consistent and plausible scenarios at the decade to century scale of future carbon dioxide emissions under a range of policy and development assumptions. The need now is to refine those models to provide information on other gases of interest, perhaps at finer spatial scales of resolution than are now possible. The design of models focussing on the transformation of materials through industrial processes is a more complex task at a much earlier stage of development.

Process studies: Three areas of process studies were singled out as in special need of development to support the modeling work noted above. First, in certain regions and industrial sectors the amounts of energy and material being used per unit value of

production are rising, while in others they are falling. Needed is a better understanding of the human, cultural, and social factors responsible for these patterns. Second, research has shown that the emergence of lead technologies such as textiles, iron and steel, chemicals, and electronics has in the past led to radical transformations in the overall character of industrial metabolism. These historic cycles of technology dominance suggest the emergence of one, perhaps two, new lead technologies over the next century, with major implications for emissions and waste streams. The factors that determine the timing of these long term transformations need to be understood. Third, changes in industrial metabolism seem to occur as integrated regional phenomena, rather that on a sector by sector basis. Needed is a deeper understanding of the economic, technological and institutional processes that determine such regional integration.

Data sources: There is a need for data base developments related to each of the process studies noted above. Global, historical data are needed on the changing intensities of energy and material use across a range of human activities. Also required are global, long term records of the changing pattern of emissions from major transforming technologies. Finally, it will be necessary to document integrated histories of industrial input/ output characteristics for selected regions around the world.

**Land Transformations**

Throughout most of history, human transformation of the earth's land surface has been our primary means of affecting change in the global environment. In many less industrialized regions it remains so today. Land transformation, in the sense used here,

includes not only activities like forest clearing that change land cover type and physical properties, but also those like fertilizer use that change chemical flows.

Integrative models: The Committee identified two integrative modeling initiatives in the field of land transformation. The first is the creation of a global model of agricultural activities and their associated impacts on land use, earth surface properties, and chemical flows. Such a model would play a role in global change studies directly analogous to that already served by existing energy models that forecast $CO_2$ emissions. In particular, it would relate changes in human populations, economic activity, technology and institutional structures to changes in the extent of agricultural lands under various cropping regimes, in irrigation practices, in fertilizer use, and in other activities directly relevant to global change studies. The model should be global in scope, with a century forecasting horizon and regional resolution. A second group of models should address transformations in two land uses that the Committee has determined to be of particular relevance to global change studies: tropical forests and coastal wetlands. In both cases, the goal would be to provide regional forecasts of the impact of human activities on the extent of the affected land uses over decade to century scales.

Process studies: The Committee identified three land transformation processes for which deeper understanding is urgently required to promote the overall goals of global change research. The first is fertilization. Needed is a better understanding of the human determinants of the rates and character of fertilizers in major agroecosystems of the world. A second process requiring immediate attention is biomass burning. How do

population density, land tenure patterns, economic development opportunities and other human factors affect the frequency, character, and extent of biomass burning in major agroecosystems? Finally, better understanding is needed of livestock development. At the decadal scale, what large social forces control changes in the extent, character, and location of livestock utilization by humans?

Data sources: Three data base developments are required in support of a better understanding of land use transformation as a human source of global change. First is a capability to compare population census data, land cover data, land use data, and land capability data within a common information system. Second is development of a global data base on land tenure and size of holdings -- two variables of importance in determining patterns of land transformation. Finally, there is a need to assure that regional case study data collected in various aspects of the global change program dealing with land transformation are complementary to the maximum extent possible. The danger is an uncoordinated approach in which ecological data are collected at one site, tropospheric chemistry data at another, and human activity data at a third. Instead, plans should be advanced for establishment of long term regional resource sites where relevant studies from the natural and human sciences can be conducted in concert, and their data sets pooled.

**Synthetic Studies**

Our ultimate goal is not to understand just industiral metabolism or land transformation, but rather the ways in which human activities in general force changes in

the earth system. While it is too early in the overall research program to tackle this ultimate goal directly, three broadly synthetic studies that could usefully be undertaken in the 1990-1995 period have been recommended by the Committee.

Global model of greenhouse gas emissions: The first generation of global models applied to the greenhouse problem addressed a single human activity -- energy use -- and a single greenhouse gas -- carbon dioxide. The need is now clear for a second generation of models that address all the major gases and all the major human sources arising from both industrial and land use activities. Initial work has begun on such models and should be encouraged as part of the global change research program.

Earth system information flows: The global change program has benefitted tremendously from the early effort of the Earth Systems Science Committee (ESSC) to create a "wiring diagram" of key process connections and information flows among the climatic, biogeochemical, and ecological components of the earth system. The ESSC effort, however, treated humans as a external boundary condition, rather than as an integral component of the system. Scholarship on the human dimensions of global change is now sufficiently advanced that the diagram should be revised to reflect our conceptual understanding of the interactions between people and environment that constitute the earth system.

Driving forces: Human sources of global change arise from the needs of populations, their economies and technologies, and are mediated by their institutions. These driving forces of human sources are widely recognized by scholars of society and technology, who differ in emphasis and causal attribution given to each factor. Enough is already known

about the historical and geographic variation in driving forces to expect that a set of quite varied clusters of driving forces will emerge related to major regional and historical differences in population, economy and technology. Further and systematic study of these relations is needed to advance our conceptual understanding of the basic human driving forces of global change.

**Priority Recommendations**

From among the research initiatives summarized above, the Committee selected 8 to receive the highest and immediate priority:

To develop integrative models of human sources of emissions and land cover change for earth systems models:

1. Global Agriculture
2. Global Greenhouse Gas Emissions
3. Regional Land Cover Conversion: Tropical Forests and Wetlands

To support the model development with key studies of important processes:

1. Fertilization in Agriculture
2. Biomass Burning
3. Intensity of Energy and Materials Use

To provide critical data for model development and process studies:

1. Population/Land Cover-Use-Capability GIS

2. Global Historical Energy and Materials Use

Finally, the Committee urges that the plan of initiatives and recommendations advanced here should find their way into future program announcements and requests for proposals emanating from government and other funding sources.

## 1. INTRODUCTION

In its 1988 report (the "green book"), the U.S. Committee on Global Change (U.S. CGC) recommended the following research initiative on human interactions with the global environment[1]:

> This research initiative would focus on the relatively short-term record of the period of intensive human activities that have affected the global environment. Anthropogenic changes in the earth system need to be systematically documented over the past several hundred years and analyzed as a basis for developing useful reference scenarios of future change. In particular, two aspects of human activity are especially relevant to global change: land use changes, which influence both physical (e.g. albedo, evapotranspiration and trace gas flux) and biological (e.g. vegetative cover and biodiversity) variables; and the industrial metabolsim that transforms resources into emission that must be absorbed and processed by the environment.

The committee also made a recommendation related to building the scientific foundations for research into the human dimensions of global environmental change. The U.S. CGC recognized that research in the human dimensions of global change was relatively underdeveloped and thus there was a need to support discipline-oriented research in this area, with "the relevant research communities encouraged to develop their own internally justified research priorities relevant to global change." This is discussed further in section 6.2.

After the completion of the "green book", a Working Group on Human Interactions with Global Change was formed with the specific task of further defining a research agenda in the areas of land-transformations and industrial metabolism.[2] This group met in June to develop an initial list of priority research topics and to plan a larger workshop for September to bring together active researchers and representatives of related institutional efforts[3]. In preparation for this workshop, a background literature review

was prepared, as well as several brief statements describing key directions for future research.[4] The September workshop was attended by 28 people from a wide range of disciplinary backgrounds. This group was asked to define the highest priority research areas, and to identify specific research needs and opportunities that could be accomplished within the next five years. This document draws heavily on the discussions at the workshop and on written material submitted by workshop participants.[5]

## 2. THE RESEARCH PROGRAM

Over the next five years, the human interactions research program focuses on the agricultural, energy, and industrial activities that generate the crucial material flow and land use changes that are responsible for most of human-induced global change. The intent is to describe the distribution of these activities in detail appropriate for incorporation into the evolving earth system models and to understand the forces in society that drive them sufficient to create alternative projections of these activities over the time frame of a century. Beyond, this immediate task, the research effort should provide the foundation for subsequent studies of the impacts of human-induced change and efforts to control or to adapt to such change.

Three general levels of scholarship are required in this effort: data collection, process studies and synthesis.[6]

Data: Data collection has both a historical and current component. It includes data on human activities that lead to changes in the chemical flows, physical properties and surface covers of interest, as well as data on demographic, technical and socio-economic variables.

Process studies: There are two types of studies that fall under the heading "process". They are most easily distinguished by the following simple model of global environmental change.

Change in:

$$\begin{matrix}\text{Chemical flows} \\ \text{Physical properties} \\ \text{Surface cover}\end{matrix} = \begin{bmatrix}\text{emissions and conversions} \\ \text{per} \\ \text{unit human activity}\end{bmatrix} * \begin{bmatrix}\text{mix and level} \\ \text{of} \\ \text{activities}\end{bmatrix}$$

The first type of process study describes the emission and conversions per unit human activity. Currently there are important differences between the understanding of the emission coefficients for the transformation of materials and energy and for the transformation of land. Many of the coefficients for industrial processes, such as the $CO_2$ emission coefficients for various energy technologies, are well documented. In contrast, the emission coefficients on the land use side, such as $CH_4$ emissions from various rice cultivation techniques and animal husbandry, are not well understood.

The second type of process study describes the mix and level of activities (supply and demand) which transform the environment. Examples of these type of process studies include: studies on the determinants of the level of electricity consumption or

agricultural production; studies which shed light on the interrelationships between demand for various energy technologies, or for different crops or farming practices; and models of future levels of energy or agriculture production.

Synthesis: Finally, in the area of synthesis, our ultimate goal is to improve the capacity to describe a range of potential futures for the environmental components of interest. Thus we are looking here for models or analytical frameworks which allow for the development of consistent future scenarios of human activities which force global environmental change. Synthesis is required to combine the two types of process studies, and to develop approaches which integrate the changes from land use and industrial metabolism.

## 3. INDUSTRIAL METABOLISM

The term "industrial metabolism" has come in recent years to signify the total pattern of energy and materials flows through an industrial sector or region. The basic goal of research in this area is to understand how changing levels of human population, economic activity, technology and social organization influence the pattern of such flows -- in particular the output of pollutant chemicals relevant to global change.

### 3.1. Integration and Synthesis

The Committee identified two integrative modeling goals in the area of industrial metabolism. The first, relatively well in hand, is the creation of global models of energy use and associated pollutant emissions. Such models have a long history of development in studies of the greenhouse effect. They have provided internally consistent and plausible scenarios at the decade to century scale of future carbon dioxide emissions under a range of policy and development assumptions.[7]

In recognition of the importance of activities other than energy use as key contributors to climate change, the need now is to develop models which provide information on other gases of interest and thus include, in addition to energy use, industrial activity and agriculture. One such effort that is underway is a greenhouse gas model based on a general equilibrium framework. Because this model is synthetic across both land-use and industrial activity, it is discussed in Section 5.2.

Secondly, there is a need to develop models which focus on the transformation of materials through industrial processes. These models would be concerned not only with greenhouse gas emissions, but with other industrial emissions which contribute to global environmental change. This is a more complex task at a much earlier stage of development. One approach to this type of modeling is underway at the Institute for Economic Analysis at New York University. This effort builds on previous work on a world input-output model. This analysis will incorporate detailed technical process information and provide quantities and geographic distribution of pollutant emissions under various scenarios as one of its outputs. "The objective of the proposed study is to

identify and evaluate concrete, consistent, economically feasible strategies for environmentally sound development, that is, to examine alternative approaches to reducing poverty over the next 50 years while also reducing global pollution."[8]

### 3.2 Process Studies and New Data

Three areas of process studies were singled out as specifically needed to support the modeling work noted above. First, in certain regions and industrial sectors the amounts of energy and material being used per unit value of production are rising, while in others they are falling. Needed is a better understanding of the human factors responsible for these patterns. Second, research has shown that the emergence of lead technologies such as textiles, iron and steel, chemicals, and electronics has in the past led to radical transformations in the overall character of industrial metabolism. These historic cycles of technology dominance suggest the emergence of one, perhaps two, new lead technologies over the next century, with major implications for emissions and waste streams. The factors that determine the timing of these long term transformations need to be understood. Third, changes in industrial metabolism seem to occur as integrated regional phenomena, rather than on a sector by sector basis. Needed is a deeper understanding of the economic, technological and institutional processes that determine such regional integration.

There is a need for data base developments related to each of the process studies noted above. Global, historical data are needed on the changing intensities of energy and material use across a range of human activities. Also required are global,

long term records of the changing pattern of emissions from major transforming technologies. Finally, it will be necessary to document integrated histories of industrial input/output characteristics for selected regions around the world.

### 3.2.1 The Intensity of Energy and Materials Use

Material and energy intensity are defined as the quantity of material or energy consumed per unit of value created (e.g. per unit GNP or per unit end-use service), or as the quantity of material or energy consumed per capita. Studies seeking to understand the trends in energy and material intensities are critical to an understanding of the human forcing of global environmental change because these intensities are one of the key determinants of the environmental insult caused by economic or industrial activity.

There are three previous studies of particular relevance to this research area. The first is a study of trends in materials use which concludes that the U.S. is indeed experiencing a trend toward dematerialization.[9] This work is based on about 100 years of data on the consumption and prices of the following materials: steel, cement, paper, ammonia, chlorine, aluminum, and ethylene, as well as several low and intermediate volume metals. This study concludes that dematerialization is the result of a structural shift in the U.S. which is based on the level of income. It also concludes that dematerialization may cause the rate of growth in U.S. industrial demand for energy to become zero, or even negative.

A second study based on the U.S. data documents trends in U.S. energy intensity over the past 100 years. It concludes that the availability of abundant and low-cost electricity played an important role in the decline of energy intensity (measured as energy per unit GNP) which the U.S. has experienced since 1920.[10]

Both of these studies provide important starting points. However, there is a need to examine other countries, both in similar and different stages of development, to further identify and understand the trends in energy and materials use. Furthermore, as emphasized by a third study, it is necessary to consider what measures of dematerialization are meaningful with regard to the environment.[11] This study suggests that dematerialization be defined as the amount of waste generated per unit industrial product, and that distinctions need to be drawn between the dematerialization of production and consumption. It also suggests that several non-economic factors are relevant to trends in dematerialization.

To gain a better understanding of the determinants of energy and materials intensity, new data need to be developed, analyzed for trend, and placed within a broader framework of understanding economic development. Long term historical surveys of energy and materials use, by country, are needed. For energy, this would include data disaggregated by end use, fuel mix, energy carrier (electricity, steam loop, or on-site combustion), and the combustion or generating technology. For materials, the task is to determine the relevant materials to include in the data base, and the metric(s) to be used in accounting for them. Candidate materials of particular environmental concern include metals, paper, plastics, chemical commodities, and fertilizers. Accounting

schemes could be based on mass, as well as some other measure of environmental insult. In the case of materials, information on both the industries or economic sectors that produce the materials, and on the intermediate and final consumer is needed. In addition, it is important to properly account for the import and export of materials and energy, both in their raw state, and as embodied in products.

With an historical record of material and energy requirements for a number of countries at different stages of economic development available, analysis to understand the causes and implications of observed trends should follow. An important focus will be on the changes in energy or material requirements for providing end-use services.[12] This is of particular interest, as the well-being of societies is based on end-use values rather than primary inputs. Thus, if a good or service can be supplied with a lower energy or material intensity, the environmental insult can be lowered without any reduction in well-being. In addition, end-use analysis is critical for understanding what is technically possible, and therefore for developing future scenarios of material and energy use.

In examining the causes of observed trends in materials and energy intensity, key factors to consider include: stage of economic development, level of GNP, rate of growth of GNP, level and rate of change of economic productivity, product lifecycle, and the demography of infrastructure. The relevant economic data required for this analysis, such as prices, capital and labor inputs, and productivity are generally available. After developing an understanding of the causal factors underlying historical

trends in energy and materials intensity, the next step will be to explore the implications this has for the future by constructing plausible scenarios of future levels of energy and material use.

A final task would be exploratory in nature. Based on the insights gained from the above analysis, it would try to develop a theory or conceptual framework which explains the relationship between trends in material and energy use and economic development. Specifically, this theoretical work will describe the relationship between energy and material intensities and stages of economic development, the relationship between changes in energy and material intensity and changes in economic productivity, and the amount of energy or materials required to support economic growth.

### 3.2.2 The Dynamics of Industrial/Technological Change

"The two themes of ecological and economic interdependence are strongly linked through a third theme - the development and diffusion of technology."[13]
Because of this linkage, improved understanding of the factors which influence the development and diffusion of technology will significantly improve our understanding of the human forcing of global environmental change, and improve our ability to develop future scenarios of emissions from industry. Of particular relevance is research aimed at understanding what factors influence the timing of technological change at three levels of analysis: industry, socio-technical systems, and technological eras.

At the industry level, the effort will focus on case studies of specific industries that have particularly large environmental impact, either through high energy use (e.g. aluminum manufacture) or through emissions from specific manufacturing processes (e.g. smelters). The industries with the largest environmental effects include: electric power generation, chemical manufacturing, mining, mineral processing (including metal working), and paper manufacture.

The case studies of specific industries will include detailed information on the technologies in use, including all resources used in the production process and the waste streams created. Particular attention will be paid to technological changes which effect the environment, including materials substitution, the efficiency of materials and energy use, source (waste) reduction technologies, and recycling. The data will also include economic indicators of industry and individual firm performance. Data will be historical, documenting the changes in each industry's technological and economic characteristics over the past 150 years. Data also needs to be collected on promising new technologies for each industry examined.[14]

At the level of socio-technical systems, previous empirical work suggests there are long-term regularities in the evolution, diffusion, and replacement of these systems (i.e. there is a characteristic time-constant for substitution between technologies).[15] The goal of this effort is to understand the reasons for this time-constant, why it varies across countries, and whether it varies over time. Studies are needed both at the level of specific industries and for major socio-technical systems such as energy or

transportation systems. Factors to consider in this analysis include: economic growth, factor abundance and productivity, absolute wealth, and institutional and cultural factors.

Of particular interest are the ways in which individuals, firms, and governments influence the timing and direction of technological change. The study would seek to identify the factors which are most influential in the decision-making process at each of these levels, the relative importance of each set of actors in influencing technological change, and the importance of the interactions between these groups.

Finally, there are technological eras, in which previous research has shown that lead technologies such as textiles, iron and steel, chemicals, and electronics characterize major eras as do their power sources of water, steam, electricity, and the gasoline engine. Conflicting and somewhat controversial theories exist that purport to explain the assembly and differences of these lead technologies and their associated economic impacts but little has been done to examine their environmental import.[16] Of particular interest for global change is that the historic cycles of technology dominance suggest the emergence of one, perhaps two, new lead technologies over the next century, with major implications for emissions and waste streams. This project would identify candidate new lead technologies and their implications for emission coefficients and energy and systems intensity.

### 3.2.3 Regional Evolution of Industrial Metabolism

A proven approach for analyzing industrial metabolism is the materials balance method. This method is based on the concept of conservation of mass. It tracks the use

of materials and energy from "cradle to grave". In other words, it follows them from extraction through manufacturing, consumption, and disposal, and then to their final environmental destination. It is a tool which allows economic data to be used in conjunction with technical information on industrial processes, the use and disposal of products by consumers, and environmental transport to describe chemical flows to the environment.[17]

This type of analysis was used to study the Hudson-Raritan river basin. This study reconstructed the emissions of heavy metals and other chemical wastes for the past 100 years.[18] Some important conclusions that were drawn from this analysis are: (1) Major sources of environmental pollutants have been shifting from production to consumption processes. (2) Large numbers of materials' uses are inherently dissipative, spreading widely into the environment.

For comparison purposes, the next study should be of a river basin in a developing country. Possible candidates include the Ganges in India and the Zambezi in Zimbabwe and Mozambique. This would allow for a preliminary comparison of the environmental impacts of industrialization for different stages of development and under differing development paths. It will also contribute further to an understanding of how the sources of environmental perturbations shift between production and consumption during the development process. This project would require the development of two types of data bases. The first is a data base of economic statistics on production and

consumption. This data base must be sufficiently disaggregated, both geographically (regional rather than country level statistics) and by end use. The second is a data base of the relevant industrial processes for the region of study.

## 4. LAND TRANSFORMATIONS

Throughout most of history, human transformation of the earth's land surface has been our primary means of affecting change in the global environment. In many less industrialized regions it remains so today. Land transformation, in the sense used here, includes not only activities like forest clearing that change land cover type and physical properties, but also those like fertilizer use that change chemical flows.

### 4.1 Integration and Synthesis

The Committee identified two integrative modeling initiatives in the field of land transformation. The first is the creation of a global model of agricultural activities and their associated impacts on land use, land cover, earth surface properties, and chemical flows. Such a model would play a role in global change studies directly analogous to that already served by existing energy models that forecast $CO_2$ emissions. In particular, it would relate changes in human populations, economic activity, technology and institutional structures to changes in the extent of agricultural lands under various cropping regimes, in irrigation practices, in fertilizer use, and in other activities directly relevant to global change studies. The model should be global in scope, with a century forecasting horizon and regional resolution. A second group of models should address

transformations in two land uses that the Committee has determined to be of particular relevance to global change studies: tropical forests and coastal wetlands. In both cases, the goal would be to provide regional forecasts of the impact of human activities on the extent of the affected land uses over decade to century scales.

### 4.1.1 Global Agriculture Model

Agriculture (including pastoralism) is the human activity most closely associated with land transformation as well as a major source of nitrogen, phosphorus and methane. Existing models that project global agricultural activities rarely extend beyond 25 to 40 years and have been designed to answer questions of demand and trade in agricultural products or food security rather than as major sources of important emissions or spurs to land conversion.[19]

A new generation of models are required which can develop internally consistent scenarios of the expansion of agricultural production over the next century to meet the needs of a world population of ten billion. The major goal of this new modeling effort will be to estimate the bounds of environmental change emanating from agricultural land-use changes, including earth surface properties and chemical flows. The model would thus track the inputs required for the intensification of agriculture, including nitrogen and phosphorous from fertilizers, irrigation, and pesticides and herbicides as well as land transformations between agriculture and other uses.

In order to accomplish this, the model must incorporate resource opportunities/constraints (agro-ecological considerations) and socioeconomic trajectories (e.g. demand, technology, institutions) for the major facets of agricultural change (e.g. land expansion and intensification). In other words, the model must adequately represent the relationship between technical and institutional factors, land transformations, the global environmental impact of those transformations, and the impact on the local, national and international economies. The model must provide regional resolution representing technical, economic and institutional factors faced by different countries, particularly the current differences in agricultural development between the developed and developing nations. Other requirements of the model include: (1) that it be sufficiently open such that all parameters are subject to examination and change by the user. (2) that it be sufficiently generic to enable the user to respond to changes in the problems that will need to be addressed as perceptions of local and global agricultural production and environment assessment change over time.

### 4.1.2 Land Cover Projections for the 21st Century

Two types of land cover have been identified as especially important because of the degree of change that they are likely to experience and the impacts that these changes will have on global environmental systems. These are forests and wetlands.

Forest conversion includes deforestation and afforestation and focuses on tropical forests. This focus is taken because of the high rates of deforestation throughout the tropics and the projected negative environmental impacts of this phenomenon -- global

warming, species loss, sedimentation, soil degradation -- and because of the complexity of forces that are giving rise to it -- population pressures, technological capacity to deforest/afforest and transport resources, international demands for tropical products.

Wetland conversion involves the loss and gain of lands with standing water owing to such phenomena as drainage, wetland agriculture (e.g., field raising), irrigation, ponding, and reservoirs. Wetland conversions, particularly rice cultivation, are important in global change because of their impacts on atmospheric chemistry (such as methane), biodiversity, and water availability, and will be driven by the need to feed and provide water for the additional five billion people projected on earth by the year 2050, most of whom will be situated in the tropical realms where wet rice cultivation is climatically suitable.

Understanding of the rates and trajectories of these changes will follow from matching studies on the proximate sources of change (see below) with studies on the two land-cover changes. The latter will be developed by detailing the changes for a number of selected regions or countries that account for a large share of the conversion in question. For example, studies of forest conversion will focus on the transformations in Amazonia, Borneo-Malay Peninsula, and one or two other cases. Study of wetland conversion will focus on selected cases in South and Southeast Asia, West Africa, and perhaps Central America.

With data on the rates, trajectories, and processes of change, a number of scenarios for each of the cases of forest and wetland conversion will be developed. These scenarios will involve differing assumptions about the rates and trajectories of change as

they are affected by changes in the driving and mitigating forces of change (e.g., international markets, population, conservation laws, national park protection) and by estimates of the recoverability of the environment in question. One scenario for each case will focus on surprise, unsuspected rates or trajectories of change, and impacts of change.

These scenarios aim: (i) to develop the bounds and trajectories for the future and the consequent impacts that they will have on the global environmental systems through chemical emissions and through physical and biological changes; and (ii) to demonstrate the relative importance of the driving and mitigating forces of change by varying situation (also time- space scales), including the synergisms among them, such that the impacts of policy can be projected.

### 4.2 Process Studies

The Committee identified three land transformation processes for which deeper understanding is urgently required to promote the overall goals of global change research. The first is fertilization. Needed is a better understanding of the human determinants of rates and character of fertilizers in major agroecosystems of the world. A second process requiring immediate attention is biomass burning. How do population density, land tenure patterns, economic development opportunities and other human and cultural factors affect the frequency, character, and extent of biomass burning in major

agroecosystems? Finally, better understanding is needed of livestock development. At the decadal scale, what large social forces control changes in the extent, character, and location of livestock utilization by humans?

### 4.2.1 Fertilization

Fertilization refers to the use of synthetic fertilizers to increase agricultural output with possible expansion to include herbicides and pesticides. While this includes inputs to sustain grasslands or pastures, emphasis will be placed on the use of nitrogenous fertilizers associated with the intensification of production, particularly with the use of high yielding varieties. Currently, more nitrogen is fixed synthetically than naturally, with fertilizer use growing at 3 to 4 percent per year globally.[20] Increased use of synthetic fertilizers has direct impacts on emissions to the atmosphere, water quality, albedo, and biomass, and indirect impacts on alternative land uses and methane emissions through the use of wet rice production. The universal increase in fertilization is worldwide and occurs in very different socio-technical contexts. The driving forces for fertilization in different societies requires much more detailed understanding if they are to be projected over the long term. This study will examine fertilizer use trends in their differing socio-technical contexts.

### 4.2.2 Biomass Burning

Fire, as captured in biomass burning, is estimated to account for 25 to 30 percent of anthropogenic carbon dioxide emissions to the atmosphere.[21] In addition, it accounts

for a significant portion of the emissions of other greenhouse gases, including of methane, nitrous oxides, nitrogen oxide and carbon monoxide.[22] It is a critical element of landscape transformation because it is important to permanent and cyclical forest clearance, to grassland and some tree species maintenance/regeneration, and as a non-commercial fuel supply. Regardless of its purpose, under all circumstances it changes the albedo of the burn zone and increases particulates released to the atmosphere, and in many cases it leads to loss in biodiversity, soil quality, and water retention. The reasons for its use and the impacts that is has, of course, vary by circumstance. Broadly speaking, three types of uses can be recognized--land-use expansion, land intensification, and land maintenance. These can result from market pressures, local food pressures, lack of alternative fuels, and so forth. This study will situate biomass burning within these contexts and link burning to standardized measures, such as number of fire hours per annum, perhaps segregated into low and high intensity burns.

### 4.2.3 Livestock Development

Since the mid 1970's, livestock populations have risen by 6% worldwide, but by 11% in Africa and 19% in Latin America with subsequent increase in methane production and deforestation.[23] Thus, a perhaps overlooked element of change has been the expansion and intensification of livestock production, particularly in the developing world. These include the frontier expansion of pasture in Latin America and the intensification of livestock production within traditional systems, near urban areas for commerce, and within urban areas to meet the needs of the urban poor. The impacts on

the environment are both immediate and indirect. Frontier expansion typically involves deforestation and land conversion to crop and pasture, while intensification involves increased demands for food and fodder, which affects land use and quality. In either case, albedo and biodiversity changes follow. Overall increase in livestock also increases emissions from their waste. The reasons for livestock development go beyond commercial demand and local needs; in parts of Latin America, it may be associated with the social status gained from livestock ownership and in Africa, cattle are intimately involved in social relationships. Studies of this source of global changes must differentiate between cases of expansion and intensification, and identify the related environmental changes and forces that give rise to livestock development.

### 4.3 Data Needs

Three data base developments are required in support of a better understanding of land use transformation as a human source of global change. First is a capability to compare population census data, land cover data, land use data, and land capability data within a common information system. Second is development of a global data base on land tenure and size of holdings -- two variables of importance in determining patterns of land transformation. Finally, there is a need to assure that regional case study data collected in various aspects of the global change program dealing with land transformation are complementary to the maximum extent possible. The danger is an uncoordinated approach in which ecological data are collected at one site, tropospheric chemistry data at another, and human activity data at a third. Instead, plans should be

advanced for establishment of long term regional resource sites where relevant studies from the natural and human sciences can be conducted in concert, and their data sets pooled.

### 4.3.1 Landuse-Capability/Population Geographic Information System (GIS)

The universal measure of potential human activity is the number of persons within a unit area. Repeated censuses, usually on a decadal basis, take place in most countries of the world and their accuracy (3-20%) exceeds most other global data sets. Many flows and land use changes seem directly proportional to population changes, for others population may be the best available short-term surrogate for potential human impact. But population data are normally collected by administrative or political divisions of national territory and thus do not relate directly to land use or capability. Thus, the first candidate for a human interaction data set is an integrated land cover, land use, or land capability-population density geographic information system at a resolution of 10,000 to 100,000 $km^2$. Such work should merge the different global land surface data sets with new census results as they emerge and maintain and update the resulting geographic information system in an appropriate national or international institution. Once developed this GIS should also integrate data from industrial censuses around the world that can identify the geographic location of industries by four-digit SIC (Standard Industrial Classification) codes.

### 4.3.2 Land Tenure and Size of Holdings

In order to pursue studies into the causes for various land transformations, a data base of standardized information on land tenure and land holdings is needed. Currently, the best resource for this data is the Wisconsin Land Tenure Center at the University of Wisconsin in Madison. For over two decades, this center has been collecting land tenure data for parts of Latin America, the Caribbean, Africa, and Asia. Although these data are not available in tabulated or electronic forms, original data sources are kept in their library. This proposed project would include both the continued collection of land tenure and land holdings data, and the development of a readily available, standardized data base, one that would be related to the geographic information developed for land cover and population.

### 4.3.3 Regional Case Studies and Research Centers

The IGBP working group on data and information systems have identified a set of case studies in which efforts will be made to integrate remotely-imaged and field observed land use data. At the same time, investigator-initiated research projects on integrated case studies of global change and human impacts and response have been funded in several countries including in the U.S. the Critical Environmental Zones project[24]. The early regional case studies should be brought together to encourage parallel or joint natural and human science studies in the same regions. These should

serve as pilot efforts that lead to the development of regional research sites where research on long-term patterns of social, economic and ecological change can be brought together.

## 5. INTEGRATIVE ACROSS LAND USE AND INDUSTRY

Our ultimate goal is not to understand just industrial metabolism or land transformation, but rather the ways in which human activities in general force changes in the earth system. While it is too early in the overall research program to tackle this ultimate goal directly, three broadly synthetic studies that could usefully be undertaken in the 1990-1995 period have been recommended by the Committee. These initiatives are: a global model of greenhouse gas emissions, a diagram of earth system information flows for human interactions, and an analysis of the driving forces of human induced global change.

### 5.1 Global Greenhouse Gas Emission Models

The first generation of global models applied to the greenhouse problem addressed a single human activity -- energy use -- and a single greenhouse gas -- carbon dioxide. The need is now clear for a second generation of models that address all the major gases and all the major human sources arising from both industrial and land use activities. Initial work has begun on such models and should be encouraged as part of the global change research program.

Desirable characteristics of the new generation of models include: (1) Disaggregation by country or region. (2) Disaggregation by human activities leading to emissions, including energy, agriculture, manufacturing, transportation and services. (3) Provision of a link between the details of technology (engineering or micro-level studies) and the macro-economy. (4) Modeling of interactions between the different human activities leading to emissions of GHGs, e.g. the availability of biomass for energy use is dependent on agricultural technology and institutions. (5) Output in five or ten year steps, for 100 years. (6) Inclusion of institutional arrangements as one determinant of technological choices.

A "second-generation model" of greenhouse gas emissions, which represents an improvement over the current IEA/ORAU model[25], is being developed at Battelle Pacific Northwest Laboratories.[26] The new model will be an improvement over the existing model in the following respects: modeling of all greenhouse gases rather than only $CO_2$; a general equilibrium rather than partial equilibrium analytical structure; greater disaggregation of human activities, including agriculture, energy, transport, manufacture and services; interactions between managed and unmanaged ecosystems; improved modeling of resources, turnover in capital stocks, and international trade. Another approach is the input-output analysis described in section 3.1.1. While this analysis is not aimed solely at greenhouse gas emissions (GHGs), it will provide information on GHGs in addition to other pollutant emissions.

## 5.2 Earth Systems Information Flow Diagram For Human Interactions

The global change program has benefitted tremendously from the early effort of the Earth Systems Science Committee (ESSC) to create a "wiring diagram" of key process connections and information flows among the climatic, biogeochemical, and ecological components of the earth system. The ESSC effort, however, treated humans as a external boundary condition, rather than as an integral component of the system. Scholarship on the human dimensions of global change is now sufficiently advanced that the diagram should be revised to reflect our conceptual understanding of the interactions between people and environment that constitute the earth system. An initial contribution toward this goal can be found in the book Climate Impact Assessment, which explores the interaction of society and climate.[27]

## 5.3 Driving Forces: Population, Economy, Technology and Institutions

Human sources of global change arise from the needs of populations, their economies and technologies, and are mediated by their institutions. These driving forces of human sources are widely recognized by scientists of society and technology, who differ in emphasis and causal attribution given to each factor. Enough is already known about the historical and geographic variation in driving forces to expect that a set of quite varied clusters of driving forces will emerge related to major regional and historical differences in population, economy and technology.

For example, the Earth Transformed by Human Action Study of 13 key pollutant emissions and land use conversions over the past 300 years suggests three varied trajectories in which population, economy, and technology, each exercise successively greater influence as driving forces of these sources.[28] Regional case studies suggest that all three trajectories are currently at work in the world today. Thus, many places can be found in the world today with similar carbon emissions per unit area but driven by quite different combinations of forces. Further systematic study of these relations is needed.

## 6. IMPLEMENTATION REQUIREMENTS

### 6.1 Related Institutional Efforts on Human Interactions with Global Change

As discussed above, the research agenda defined in this document is sharply focused on better understanding the human forcing of global environmental change. This work is complemented and supported by the work of several other organizations which are involved in developing research agendas or sponsoring research into the human interactions with global environmental change. By far the largest domestic effort is being carried out in the executive branch agencies. Information on executive branch initiatives can be found in the CES document[29]. The activities of other organizations are briefly described in Appendix B, including the person to contact for further information.

There are two organizations which deserve particular mention as their agenda in part shares the focus of this committee. The Social Science Research Council has formed a

Committee for Research on Global Environmental Change which is examining six areas, one of which is land use. The National Academy of Engineering shares our interest in industrial metabolism as part of its program on Technology and the Environment.

### 6.2 Investigator-Initiated Research

A strong program of investigator initiated research is necessary to complement the highly-focused nature of the research program outlined in this chapter, concentrating as it does on the human sources as inputs to the evolving model of the earth system and leaving to investigator and agency initiated research, studies of the impacts of global change on human activities and on societal efforts to control or to adapt to global change.

As stated in the "green book"[30],

> The existing research program on the human components of global change is also inadequately developed, as discussed in the background paper on the human dimension. Efforts to bring together natural, social, behavioral, and engineering scientists to examine in-depth the research required on the human dimension of global change should be supported. Several research areas identified in the background paper - integrated methods to assess the risk and implications of long-term environmental change for resource availability at the regional scale; ways that knowledge, perceptions, and values related to global change can be more effectively brought to bear on human choices that affect global change; and evaluation and design of institutional mechanisms for better management of global change - require further development in close collaboration with those relevant scientific communities in the social, behavioral, and engineering sciences that were not adequately represented in current planning activities.

Currently, a major source of investigator-initiated research on human interactions is the National Science foundation interdisciplinary program in human dimensions of global change. In the initial round of awards, 1989, there were 35 applications and ten awards

totaling $0.75 million. Funding was awarded to four investigator initiated research projects as well as six programs for conferences, workshops, and institutionally based committees that were developing research agendas or research programs on global environmental change. These projects were of high scientific merit, diverse, and imaginative, spanning such topics as law and the transformation of water rights, social learning in the management of global environmental risks, critical zones in global environmental change, equity issues and the global greenhouse effect, and the economic impacts of global environmental change. A rapid expansion of this program is envisaged over the next five years.

### 6.3 Education and Training

The human sciences, social and behavioral, have special requirements for education and training. Unlike the earth and ecological sciences, global change phenomena are not at the core of their disciplines (except for some anthropology and geography), and the normal scientific program of incentives and support works poorly in mobilizing scientific effort on this vital concern. Thus, special emphasis needs to be given to encouraging younger human scientists to participate in global change research, to enable them to obtain training and research experience, even outside their own institutions and across disciplinary lines, if needed. A key feature for such an effort would be a pre-doctoral fellowship program, including cross-institutional internships, and a post-doctoral interdisciplinary program. Such a program should be institutionally based,

so that it can provide both essential training and support the development of the emerging centers of human interaction research in universities, institutes, and national laboratories.

### 6.4 Data Preparation and Dissemination

It is not too early to begin to plan for data preparation and dissemination. For the data projects outlined in this study, it is important that data be systematically archived, prepared, and disseminated at a central site and made readily accessible to interested researchers. This might be integrated within the designated U. S. IGBP Regional Resource Center, at one of the national laboratories, or in the emergent regional research centers described in 4.3.3. Oak Ridge National Laboratory has the greatest competence and experience in such archiving and dissemination through their handling of the Carbon Dioxide Information Analysis Center (CDIAC).

## 7. PROGRAM COSTS

The program described herein which is limited solely to research on human sources of global change (not consequences or mitigation), constitutes some 19 distinct activities. It would require, if fully supported, a minimal expenditure of 35 to 40 million constant dollars over a period of five years.

## 8. THE STEPS BEYOND

The initial research program on human interactions with global change will almost surely be overtaken by events: critical observations of ongoing global change, and rapidly increasing interest in impacts and policy research. Over the five year period of this focused research effort, there will be need to expand into these evolving research areas. We acknowledge and anticipate such expansion by emphasizing fundamental as well as focused research, an infrastructure for human interactions research, and maintaining close ties with the other initiatives of the human-science research community to understand and to respond to the challenge of global change.

## NOTES

1. Committee on Global Change (U.S. National Committee for the IGBP). 1988. Toward an Understanding of Global Change. Washington D.C.: National Academy Press.

2. A list of the working group members is provided in Appendix A.

3. Related institutional efforts on human interactions with global change are described in Appendix B.

4. This literature review is presented in Appendix D.

5. Appendix C provides a list of working group members and workshop participants. In addition to support from the National Research Council Committee of Global Change, funding for research assistance was provided in part by the Sandia National Laboratories through the Energy Laboratory at the Massachusetts Institute of Technology.

6. These three levels of scholarship correspond to the scientific objectives used by the Committee on Earth Sciences (CES) of documentation (observation/monitoring), improved understanding, and development of (predictive and conceptual) models. The FY 1990 initiatives for the human dimensions of global environmental change as specified by the CES are listed below:

> 1. Data Base Development. This consists of two projects:
> (a) Land Surface Data Systems. Provide for permanent archiving, management, access, and distribution of land Earth-science data sets for global change research on the interaction between human activities and environmental process.
> (b) Improvement of Social Data Systems. Improvement of data resources dealing with individual and institutional actions affecting environmental changes.
> 2. Understanding Processes of Change. Fundamental research on the relationships among global and environmental change and human activities, including social, economic, political, legal, and institutional processes.
> 3. Modeling Processes of Human Interactions with the Environment. Initial methodological and substantive research to develop more sophisticated models of human and institutional interactions in global change.

7. These models are generally economically based models, or of the engineering-economic type. In addition, there have been some efforts to integrate the macro- and micro-levels of analysis. A thorough review of these energy models in relationship to global environmental change can be found in: Toth, F.L., E. Hizsnyik, and W.C. Clark, eds. 1989. Scenarios of Socioeconomic Development for studies of Global Environmental Change: A Critical Review. RR-89-4. Laxenburg, Austria: International Institute for Applied Systems Analysis. These models are also reviewed in Appendix C of this report.
The most widely used economically based models is the IEA/ORAU model: Edmonds, J. and Reilly, J. Global Energy and $CO_2$ to the Year 2050. The Energy Journal, Vol. 4, No. 3.
A recent example of the engineering-economic type model is: Goldemberg, J., T.B. Johansson, A.K.N. Reddy, and R.H. Williams. 1988. Energy for a Sustainable World. New Delhi, India: Wiley Eastern Limited.

The most recent modeling efforts which integrate the macro- and micro-levels is: U.S. EPA (Environmental Protection Agency), Office of Policy, Planning, and Evaluation. February 1988. "Policy Options for Stabilizing Global Climate." DRAFT.

8. Duchin, F. 1989. Project Proposal: Strategies for Environmentally Sound Development: An Input-Output Analysis. Institute for Economic Analysis, New York University.

9. Williams, R. H., Eric D. Larson, and Marc H. Ross. 1987. "Materials, Affluence, and Industrial Energy Use" in Annual Review of Energy 1987. Annual Reviews Inc.

10. Schurr, S.H. 1984. "Energy Use, Technological Change, and Productive Efficiency: An Economic-Historical Interpretation" in Annual Review of Energy 1984. Annual Reviews, Inc.

11. Herman, R., S.A. Ardekani, and J.H. Ausubel. 1989. "Dematerialization" in Technology and Environment, Ausubel, Jesse H. and Hedy E. Sladovich, eds. Washington D.C.: National Academy Press.

12. Several studies of this type have been done in the area of energy, the most notable recent study being: Goldemberg, J., T.B. Johansson, A.K.N. Reddy, and R.H. Williams, Energy for a Sustainable World (New Delhi, India: Wiley Eastern Limited, 1988).

13. Brooks, H. 1986. "The typology of surprises in technology, institutions, and development" in Sustainable Development of the Biosphere, W.C. Clark and R.E.Munn, eds.

14. There exist today a family of empirically based engineering-economic energy and mass-balance models of conventional and advanced coal to electric conversion technologies. Two major efforts toward the development of process data bases were undertaken in the late 1970's and early 1980's, one at Statistics Canada and one at the International Institute for Applied Systems Analysis (IIASA). These are reviewed in Gault, F.D., R.B. Hoffman, and B.C. McInnis, "The Path to Process Data" in Futures, October 1985. The current recommendation differs from these previous efforts in one important way; we are interested in a process data base which describes not only current processes, but is also historical and forward looking.

15. Two sources of this work are: (1) Marchetti, C. and Nakicenovic, N. 1979. The Dynamics of Energy Systems and the Logistic Substitution Model. RR-79-13. Laxenburg, Austria: IIASA Research Report. (2) Marchetti, C. July 1983. The Automobile in a System Context: The Past 80 Years and the Next 20 Years. RR-83-18. Laxenburg, Austria: IIASA Research Report.

For a review of this work, see Ausubel, J.H. 1989. "Regularities in Technological Development: An Environmental View" in Technology and Environment, Ausubel, J. H. and Hedy E. Sladovich, eds. Washington D.C.: National Academy Press. 1989.

16. Ayres, R.U. 1989. Technological Transformations and Long Waves. Laxenberg: Austria, International Institute of Applied Systems Analysis. Research Report, 89-1.

17. For a discussion of this methodology see (1) Ayres, R.U., and S.R. Rod 1986. Reconstructing an environmental history: patterns of pollution in the Hudson-Raritan Basin. Environment 28(4):14-20, 39-43. (2) Ayres, R.U., Norberg-Bohm, V., Prince, J., Stigliani, W.M., Yanowitz, J. 1989. Industrial Metabolism, the Environment, and Application of Materials-Balance Principles for Selected Chemicals. RR-89-11. Laxenburg, Austria: IIASA Research Report.

18. Ayres, R.U., L.W. Ayres, J.A. Tarr, and R.C. Widgery. 1988. An Historical Reconstruction of Major Pollutant Levels in the Hudson-Raritan Basin: 1880-1980. NOAA Technical Memorandum NOS OMA 42. Washington, D.C.: United States Department of Commerce, National Oceanic and Atmospheric Administration.

19. For reviews of existing models, see Toth, F.L., E. Hizsnyik, and W.C. Clark, eds. 1989. Scenarios of Socioeconomic Development for studies of Global Environmental Change: A Critical Review. RR-89-4. Laxenburg, Austria: International Institute for Applied Systems Analysis.

20. Based on data for 1974 - 1976 and 1983 - 1985. World Resources Institute and the International Institute for Environment and Development. 1988. World Resources 1988 - 89. New York: Basic Books.

21. How, W.M., M.H. Liu, and P.J. Crutzen. Estimates of Annual and Regional Releases of $CO_2$ and Other Trace Gases to the Atmosphere from Fires in the Tropics Based on FAO Statistics, 1975-1980. Presented at Symposium on Fire Ecology at Frieberg University, Federal Republic of Germany, May 16-20, 1989. Proceedings to be published by Springer-Verlag, Berlin.

22. United States Environmental Protection Agency, Office of Policy, Planning and Evaluation. Policy Options for Stabilizing Global Climate. Draft Report to Congress. February 1989.

23. World Resources Institute and International Institute for Environment and Development. 1988. World Resources 1988 - 1989. New York: Basic Books, Inc.

24. R.E. Kasperson, principle investigator. Graduate School of Geography and Center for Environment, Technology and Development, Clark University, Worcester, Massachusetts.

25. Edmonds, J. and Reilly, J. Global Energy and $CO_2$ to the Year 2050. The Energy Journal, Vol. 4, No.3.

26. Edmonds, J.A., D.F. Barns, W.U. Chandler. September 1988. "Modeling Future Greenhouse Gas Emissions". Pacific Northwest Laboratory. Washington, D.C.

27. Kates, Robert W., Jesse H. Ausubel, and Mimi Berberian. 1985. Climate Impact Assessment (SCOPE 27). John Wiley & Sons, Chichester, UK. Published on behalf of Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU).

28. Turner II, B., R.W. Kates, W.C. Clark. "The Great Transformation", in Turner II, B., R.W. Kates, W.C. Clark, eds. The Earth as Transformed by Human Action. 1990 (in press).

29. Committee on Earth Sciences, Our Changing Planet: The FY 1990 Research Plan, July 1989.

30. Committee on Global Change. Op. Cit.

**APPENDIX A**
**Working Group Members**

Robert Kates, Chairman
World Hunger Program
Brown University
Box 1831
Providence, RI 02912
(401) 863-2700

William Clark
JFK School of Government
Harvard University
79 Kennedy Street
Cambridge, MA 02138
(617) 495-3981

Thomas Lee
Room 10-177
Massachusetts Institute of Technology
Cambridge, MA 02139

V.W. Ruttan
Department of Agricultural and
Applied Economics
231 Classroom Office Bldg
University of Minnesota
1994 Buford Avenue
Sanford, MN 55108
(612) 625-4701
Fax (612) 625-6245

Chauncey Starr
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303
(415) 855-2000

B.L. Turner
Graduate School of Geography
Clark University
950 Main Street
Worcester, MA 01610
(508) 793-7325

## APPENDIX B
## RELATED INSTITUTIONAL EFFORTS ON HUMAN INTERACTIONS WITH GLOBAL CHANGE

### OTHER ACADEMY EFFORTS

**The National Academy of Engineering (NAE)** (Samuel Rod, Program Office, National Academy of Engineering, NAS 310, 2101 Constitution Avenue, n.W., Washington, DC 20418)

The NAE has embarked on a major program to examine the ways in which innovative technology can be brought to bear on important environmental challenges. This program is organized along three broad themes:
(1) International cooperation and global incentives. This effort is concerned with policy options which can facilitate progress on transnational environmental issues. (2) Technological innovation: research and development and applications. This theme is particularly relevant to the work of the CGC. In this area, the NAE intends to further develop frameworks for analyzing the interactions between technology and the environment, and to apply these frameworks to specific industrial sector studies. Emphasis in these studies will be placed on the technology and economics of source reduction (waste minimization) processes. (3) Economic and institutional implications. This effort will explore both barriers and possible incentive schemes for explicitly including environmental costs in economic indicators and analysis, and also barriers and incentives for the commercialization of more environmentally compatible technologies. The program has received initial funding of $450,000 through a grant from the Mellon foundation.

**Commission on Behavioral and Social Sciences and Education (CBASSE)** (Daniel Druckman or Paul Stern, National Research Council, Commission on Behavioral and Social Sciences and Education, 2101 Constitution Avenue, N.W., Washington, DC 20418)

The Commission on Behavioral and Social Sciences and Education at the National Research Council (NRC) will undertake an eighteen-month study on the human dimensions of global change. The study will be conducted by a 15-member Committee on the Human Dimensions of Global Change chaired by Dr. Oran R. Young of Dartmouth College and directed at the NRC by Drs. Daniel Druckman and Paul C. Stern. The overall objective of the study is to develop guidelines for a national social science research program that would contribute to the goals of the International Geosphere-Biosphere Programme (IGBP). The committee will also consider issues of collaborative research between the social and natural sciences. Four tasks will be undertaken: an assessment of previous social science research on topics related to global change; an evaluation of extant data resources for social and behavioral research on global change; a consideration of how collaborative research of global change might influence the generation of knowledge in the social sciences as well as attract social and behavioral scientists to apply their knowledge to global issues; and the development of a research agenda that can be implemented over a period of several years. Each of these tasks will address the possibility that social science research can contribute to the international research effort on global change in the natural sciences. The results will also have implications for the future development of the social sciences.

**Committee on Science, Engineering and Public Policy (COSEPUP)** (Rob Copock, National Academy of Sciences, Committee on Science, Engineering and Public Policy, 2101 Constitution Avenue, N.W., Washington, D.C. 20418)

COSEPUP will be undertaking a study on the policy implications of greenhouse warming, as described below.[1]

"At the request of Congress, the U.S. Environmental Protection Agency has commissioned a study on policy implications of greenhouse warming by the Committee on Science, Engineering and

Public Policy, a unit of the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The panel is expected to prepare a report before the end of 1990.

"The study will review research and analysis relevant to greenhouse warming. A careful assessment will be made of existing data and what must be done to improve current understanding of the underlying phenomena. The report will include, if appropriate, recommendations for actions that would be needed to mitigate and adapt to greenhouse effects if such actions be warranted. It will examine both the underlying phenomena and the expected efficiency and effectiveness of policy interventions in a comprehensive analysis.

"A main focus of the study will be on policy interventions and their relative effectiveness. Although the study will be addressed in large part to U.S. policy officials, many of the options to be assessed may require multinational effort. The study is expected to contribute a careful, technically-sound review that will be of use to Congress as well as to the Executive Branch and the international community."

The study will be carried out by a synthesis panel and three groups looking at the interrelated issues of: direction and rate of change, mitigation policies and their effectiveness, and adaptation strategies.

OTHER DOMESTIC EFFORTS

The Social Science Research Council (SSRC) (Richard Rockwell, Social Science Research Council, 605 Third Avenue, New York, NY 10158)

The SSRC has formed a Committee for Research on Global Environmental Change. The program of this committee is given below:[2]

"The committee will foster collaborative interdisciplinary research in six major areas of large-scale, long-term change in the human environment. These areas include land use, global epidemiology, managing global change, security and the environment, sustainable development, and usable knowledge. The committee will advance the state of knowledge in these six areas through the research reviews that it commissions and its synthetic critique of these bodies of research. The committee will sponsor workshops, conferences, intensive working groups, networks, and review articles. Through these six working groups, some 50 researchers will design and execute individual projects that are integrated with those of their colleagues in other disciplines and institutions. The committee and its working groups will seek to construct common definitions, concepts, and methods in an enormous field now lacking such standards and to advance the development of shared data bases."

The SSRC has received initial core support of $127,166 from the National Science Foundation, for an 18 month program which began September 1989.

The working group on land use has a research agenda that overlaps substantially with the agenda outlined by this committee. It is important to recognize that while the SSRC will play a critical role in furthering this agenda through the program described above, it will not be funding investigator initiated research. The tentative plans of the working group on land-use are outlined below.

"Objective: (i) to develop an understanding of the associations among the driving and mitigating forces of land-use change, proximate sources of this change, and the land-use change-land cover connection; (ii) to 'test' for the variable dimensions of change by spatial scale and situation; (iii) to create likely scenarios of futures of selected land-use changes and environmental impacts.

Specific Objectives:

1. Refine and elaborate global land-use classification system
2. Identify 4-5 major classes in this system that are particularly significant to global environmental change and will undergo major change in the near future, some of which can be matched to forest and wetlands.
3. Identify the proximate sources of change for each land use, initiating case studies of the driving and mitigating forces that lead to the states of and rates of change in each proximate source. Presumably 4 of these to match those identified by HIB.
4. Integrate items 1-3 to create global and regional tests of the roles of each force in the aggregate and by circumstance.
5. Create scenarios of short- and long-term changes in the land uses from items 1-4 and associated with impacts on land cover."

**The National Science Foundation (NSF)** (Roberta Balstad Miller, Division of Social and Economic Science, National Science Foundation, 1800 G Street, N.W., Washington, D.C. 20550)

The NSF has a research program on the Human Dimensions of Global Environmental Change. The call for proposals describes this program as follows:

> "Recent interest in processes of global environmental change has led biological and geoscientists to undertake major new research efforts in the United States and elsewhere. A number of workshops and conferences have recently stressed that these inquiries into natural processes of change must be complemented by social science investigations to understand how human activity affects and is affected by global environmental change. To encourage research in this broad area, the Division of Social and Economic Science welcomes proposals for research on the human dimensions of global environmental change. These dimensions include but are not limited to such broad topics as the social, economic, demographic, governmental, and institutional components of global change. Studies of human influences on the environment and institutional responses to global changes are both appropriate for this initiative, but proposals must emphasize fundamental research into processes of change over time or space."

Awards for the fiscal year 1989 totaled $750,000. Funding was awarded to four investigator initiated research projects. The other six awards were for conferences, workshops, or support for institutionally based committees that were developing research agendas or research programs on global environmental change.

## OTHER INTERNATIONAL EFFORTS

**The Human Dimensions of Global Change, An International Programme on Human Interactions with the Earth.** (Peter Timmerman, Human Dimensions of Global Change, Interim Secretariat, c/o IFIAS, 39 Spadina Road, Toronto, Canada M5R 2S9)

The current steering committee for this program consists of the International Federation of Institutes for Advances Study (IFIAS), The International Social Science Council (ISSC), and the United Nations University (UNU), and the United Nations Educational, Scientific, and Cultural Organization (UNESCO). The objectives of the research program are:

> " - to improve scientific understanding and increase awareness of the complex dynamics governing human interaction with the total Earth system;
>
> " - to strengthen efforts to study, explore, and anticipate social change affecting the global environment;

" - to identify broad social strategies to prevent or mitigate undesirable impacts of global change, or to adapt to changes that are already unavoidable;

" - to analyze policy options for dealing with global environmental change and promoting the goal of sustainable development."[3]

**International Social Science Committee** (ISSC) (Harold Jacobson, Center for Political Studies/ISR, University of Michigan, P.O. Box 1248, Ann Arbor, MI 48106-1248)

The ISSC program is described in their recent document "Plan of Action for Research on the Human Dimensions of Global Environmental Change."[4] This program recognizes three broadly defined research areas: "the social dimensions of resource use; the perception and assessment of global environmental conditions and change; and the impacts of local, national, and international social, economic, and political structures and institutions on the global environment." Within these broad areas, seven research topics are outlined in the plan:

"1. social dimensions of resource use; 2. perception and assessment of global environmental conditions and change; 3. impacts of local, national and international social, economical and political structures and institutions; 4. land use; 5. energy production and consumption; 6. industrial growth; and 7. environmental security and sustainable development."

**European Science Foundation** (ESF) (Timothy O'Riordan, School of Environmental Sciences, University of East Anglia, Norwich, England
NR4 7TJ)

At its 1988 General Assembly, the European Science Foundation established a planning committee on environment and development. This committee is preparing a detailed research agenda in two areas: (1) environmental economics, with an emphasis on resource auditing, and (2) the theories and issues behind institutional adaptation to environmental change.

**International Institute for Applied Systems Analysis (IIASA)** (Robert H. Pry, Director, IIASA, A-2361 Laxenburg, AUSTRIA; Peter de Janosi, U.S. IIASA Council Member, Russell Sage Foundation, 112 East 64th Street, New York, NY 10021; Alan McDonald, Staff Director, U.S. Committee for IIASA, American Academy of ARts and Sciences, 136 Irving Street, Cambridge, MA 02138)

IIASA conducts research in five program areas, four of which undertake applied research which is relevant to human interactions with global environmental change. These programs are: Environment; Population; Technology, Economy and Society (TES); and Climate and Ecology Related Energy. IIASA is also the hub of an international network using the Basic LInked System (BLS) of agricultural models developed at the Institute between 1976 and 1985.

The Environment, Population and TES programs and the agricultural project maintain a number of data sets, and perform research that looks both at the human sources of global change, and the impacts of global change. The newest of IIASA's four applied programs, the Climate and Ecology Related Energy Program, was established in 1990 to integrate a number of the on-going lines of research at the Institute, and to sharpen their focus on the connection between patterns of energy technology, use, and emissions on the one hand, and international environmental changes on the other.

Research and data sets related to human sources of global change include:

- International population growth, migration, and demographics
- International agricultural production and fertilizer use.

- Consumption, efficiency, and emissions associated with different energy technologies.
- International patterns, and projections, of energy production, consumption, and emissions.
- Regional strategies for increasing energy efficiency and reducing emissions.
- Long-term regularities in technological and industrial evolution, diffusion, and replacement, with particular expertise in the energy and transportation sectors.
- European emission, transport and deposition of sulfur oxides, nitrogen oxides, photochemical oxidants, and heavy metals.
- European land use and forest resources.

Data sets and research activities related to the impacts of global change include:

- Climate change impacts on regional agriculture and on international agricultural trade.
- Climate change impacts on global vegetation patterns.
- Climate change impacts on the boreal forests.
- European soil and lake acidification
- International soil loss
- European toxic waste accumulations.
- Regional impacts of pollution on water resources, air quality, and public health.

The newest of IIASA's four applied programs, the Climate and Ecology Related Energy Program, was established in 1990 to integrate explicitly a number of the above lines of research and to sharpen their focus on the connection between patterns of energy technology , use, and emissions on the one hand, and international environmental changes on the other.

NOTES

1. National Academy of Sciences, National Academy of Engineering, Institute of Medicine. "NAS/NAE/IOM Study on Policy Implications of Greenhouse Warming".

2. Social Science Research Council Annual Report (draft), 1988 - 1989.

3. "The Human Dimensions of Global Change, An International Programme on Human Interactions with the Earth, Proposed Programme". Draft document prepared for the informal consultation of donor organizations, Ottawa, March 22 - 23, 1989.

4. International Social Science Council. "Plan of Action for Research on the Human Dimensions of Global Environmental Change". DRAFT 4.2. December 9, 1989.

**APPENDIX C**
**Participants in Workshop on Human Interactions with Global Change**
**September 26 and 27, 1989**

Richard Berk
Department of Sociology
University of California
405 Hilgard Avenue
Los Angeles, CA 90024-1551
(213) 825-1258

William Clark
Science, Technology & Public Policy Program
Kennedy School of Government
Harvard University
79 JFK Street
Cambridge, MA 02138
(617) 495-3981

Pierre Crosson
Resources for the Future
1616 P Street, N.W.
Washington, D.C. 20036
(202) 998-7485

Faye Duchin
Director of the Institute for Econoic
Analaysis
269 Mercer Street
New York, New York 10003

Jae Edmonds
BATELLE Pacific NW Laboratory
901 D Street SW, Suite 900
Washington, D.C. 20024
(202) 479-0500

Susana Hecht
GSAUP
UCLA
Los Angeles, Ca 90024
(213) 825-4676

Robert Kates
World Hunger Program
Brown University
Box 1831
Providence, RI 02912
(401) 863-2700

Roberta Balstad Miller
National Science Foundation (SES)
1800 G St. N.W., Room 316
Washington, D.C. 20550
(202) 357-7966

John D. Montgomery
KSG-Harvard University
79 JFK Street
Cambridge, MA 02138
(617) 495-1170

Dr. Harold Mooney*
Department of Biological Sciences
Stanford University
Stanford, CA 94305-2493
(415)723-1179

Granger Morgan
Dept. of Engineering and Public
Policy
Carnegie Mellon University
Shenley Park
Pittsburgh, PA 15213
(412) 268-2692

Vicki Norberg-Bohm
JFK School of Government
Harvard University
79 Kennedy Street
Cambridge, MA 02138
(617) 495-5863

Peter J. Parks
Center for Resource and
Environment Policy Research
214 Biological Sciences Building
Duke University
Durham, North Carolina 27706
(919) 684-6090

Stephen J. Pyne
15221 N. 61st Avenue
Glendale, AZ 85306
(602) 938-8572

Steve Rayner
Global Environmental Studies Center
Oak Ridge National Laboratory
Oak Ridge, TN 37381-6206
(615) 574-5348

John Richards
Department of History
Duke University
Durham, NC 27701
(919) 688-8828

Jennifer M. Robinson
Separtment of Geography
Pennsylvania State University
302 Walker Building
University Park, PA 16802
(814) 865-2493 or 3433

Richard Rockwell
Social Science Research Coundil
605 Third Avenue
New York, NY 10158
(212) 661-0280

V.W. Ruttan
Department of Agriculture and
Applied Economics
231 Classroom Office Building
University of Minnesota
1994 Buford Avenue
Sanford, MN 55108
(612) 376-3560

Robert Stavins
Kennedy School of Government
Harvard University
79 JFK Street
Cambridge, MA 02138
(617) 495-1820

Sam H. Schurr
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303
(415) 855-2909

B. L. Turner II
Graduate School of Geography
Clark University
950 Main Street
Worcester, MA 01610
(508) 793-7325

Anne Whyte
International Development Research
Centre
P.O. Box 8500
Ottawa, Ontario, Canada K1G 3H9
(613) 598-0558

STAFF

Ruth DeFries
CPSMR, HA-594
National Research Council
2101 Constitution Avenue, N.W.
Washington, DC 20418
(202) 334-3518

John S. Perry
CPSMR, HA-594
National Research Council
2101 Constitution Avenue, N.W.
Washington, DC 20418
(202) 334-3517

Samuel Rod
Program Office
National Academy of Engineering
NAS 310
2101 Constitution Avenue, N.W.
Washington, DC 20418
(202) 334-1679

Hedy Sladovich
Program Office
National Academy of Engineering
NAS 309
2101 Constitution Avenue, N.W.
Washington, DC 20418
(202) 334-1691

Paul Stern
Study Director
National Research Council
Commission on Behavioral and
Social Sciences and Education, HA 184
2101 Constitution Avenue, N.W.
Washington, DC 20418
(202) 334-334-005

*On sabbatical until June 1990, Harold Mooney, c/o Professor Dr. E.D. Schulze, Lehrstuhl fur Pflanzenokologie, Universitat Bayreuth, Universitats strasse 30, Postfach 10-12-51, 8580 Bayreuth, West Germany (FRG), Tel: 49-921-55.25.70, Telex: (17) 9211824, Fax: (49) 921-64889- (c/o D. Schulze), Bitnet: BTB =402@DBTHRZ5

**APPENDIX D**
**A Selective Literature Review on the Human Sources of Global Environmental Change**
**written by Vicki Norberg-Bohm**

This appendix was written in preperation for a workshop on the Human Interactions of Global Change. It provides a brief review of scholarship in the two areas identified by the U.S. Committee on Global Change as initial priorities for research into the human interactions with global change: land use changes and industrial metabolism. While there is an enormous amount of scholarship that is relevant to the "human dimensions of global environmental change", it is not within the scope of this document to provide a thorough review of all of this work. This work strives to be illustrative rather than exhaustive. In general, only more recent works are discussed. This appendix is also aimed at being descriptive rather than critical. The goal of this review is to provide a starting point for determining where an extension of current research directions and methods will provide usable knowledge for global change studies, and where (and what) new directions or methods are needed.

As was the case in the main body of this report, this literature review uses the categories of data, process, and synthesis as an organizing framework. Section 1 describes integrative modeling studies. The studies highlighted in this section are examples of research which has developed a synthetic framework or model capable of generating consistent scenarios of global environmental change. Section 2 describes studies on industrial transformations of material and energy while section 3 describes studies on land use transformations. The main focus in these two sections is on process studies. Section 4 provides a discussion of several data bases that have been developed for global change studies. Finally, because many of the models depend on population estimates, Section 5 provides a review of global population models.

This review is organized around illustrative major studies, or groups of studies of a similar nature. Because most studies do not singularly contribute only to data, process, or synthesis, each study (or group of studies) is reviewed for the contribution it makes in each of these three general areas. In some cases, the category "synthesis" is not included because the study being reviewed makes no major contribution to synthesis, as narrowly defined for the purposes of this document.

## 1. INTEGRATIVE MODELING

The studies highlighted in this section are the most ambitious examples of research which has developed a synthetic framework or model capable of generating scenarios of the human activities driving global environmental change. The output from these models describes the changes in emissions or in physical and biological variables (i.e. environmental transformations) caused by alternative development paths.

### 1.1 Impacts of World Development on Selected Characteristics of the Atmosphere: An Integrative Approach (Darmstadter, et. al., 1987)

This study focuses on "development, atmospheric emissions associated with development, and atmospheric impacts caused by emissions." It was an interdisciplinary collaborative effort that grew out of discussions at a conference sponsored by the Sustainable Development of the Biosphere Program at the International Institute for Applied System Analysis (IIASA). In addition to its synthetic approach, its major contribution is further development and implementation of a qualitative methodology for ranking the relative contribution from various sources, and for historical assessments of fluxes of key chemicals. The categories of atmospheric impact that it examines are: photochemical smog, precipitation acidity, atmospheric corrosion, and stratospheric ozone depletion.

Data: The study constructed a data base of emissions of $CH_4$, $NO_x$, $SO_x$, HCl and sea salt on a regional basis, and $CH_4$, CO, $NO_x$, $N_2O$ and CFCs on a global basis. Data is for the years 1800 to 1980, every 30 years, excluding 1830. In some instance no data was available for the 19th century. Sources of emission are:

metallurgical and certain other industrial emissions, coal production and use, petroleum production and use, biomass combustion, and emissions from vegetation and soils. Regions are: the Northeastern U.S., Europe, and the Gangetic Plain of India, and the Amazonian basin of Brazil.

The study contributes new data in: historical estimates of land in wet rice cultivation, and historical emissions from combustion, the flaring of natural gas, smelters, cokers, and other industrial processes.

Process: This study performs a historical reconstruction of industrial practices and technologies to determine emissions from industry and energy sources. See section 3.1 for a description of this materials balance approach. Future demand is based on IIASA "conventional wisdom" reference scenarios (Anderberg 1986). Two scenarios were examined: one assumed constant emission coefficients, the other a 1 percent yearly rate of decline in emission coefficients (i.e., no technological change and constant rates of change).

Synthesis: This study is synthetic in three respects: (1) It combines an analysis of historical emission coefficients with data on levels of human activity to develop a historical data base of emissions. (2) It combines information on emission factors with scenarios of future development to develop qualitative assessments of future environmental flows and thus the degree of environmental degradation. (3) It includes emissions from both industry and land-use in its analysis.

### 1.2 The IEA/ORAU Model (Edmonds-Reilly, 1983)

This model was developed at Oak Ridge Associated Universities for the U.S. Department of Energy to examine future scenarios of $CO_2$ emissions. "The long-term, global energy-$CO_2$ model was developed to provide a consistent and conditional representation of economic, demographic and energy interactions (Edmonds and Reilly, 1983)."

Although this model looks only at emissions from fossil fuel use, it is a prime example of synthesis in that it combines energy supply and demand scenarios (driving forces include economic and demographic factors) with $CO_2$ emission factors derived from an understanding of various combustion processes to produce estimates of $CO_2$ emissions. The end product is a model which can be used to analyze future scenarios of $CO_2$ emissions.

This model has been used extensively in the analysis of future $CO_2$ emissions. Edmonds and Reilly (1983) and Mintzer (1987) used this model for evaluating global emissions for various types of policy intervention. Chandler (1988) used the model for evaluating policy options for reducing $CO_2$ emissions and achieving economic development goals for China. The EPA study, "Policy Options for Stabilizing Global Climate" (Tirpak and Lashoff, 1989), used this model as a starting point from which they made significant modifications.

A discussion of the strengths and weaknesses of using this model is found in an interchange between Keepin (1988) and Edmonds (1988).

Data: This study uses emission coefficients and elasticities calculated elsewhere.

Process: This is a partial equilibrium model. Critical demand assumptions include: population, labor productivity, GNP growth rates, an energy technology parameter which specifies the rate of change in energy productivity, price and income elasticities. Critical supply assumptions include resource constraints and breakthrough costs of new technologies.

Demand in the OECD is disaggregated into 3 economic sectors: residential/commercial, transport, and industrial. All other regions are modeled as a single sector. The model makes projections to the year 2100 in 25 year intervals. The globe is divided into 9 regions. The model includes 6 primary fuel sources, 4

secondary fuel sources, plus biomass, shale oil and synfuels. The outputs of the model include primary and secondary fuel mixes, a variety of trade, price and development indicators, and $CO_2$ emissions.

Synthesis: This model combines energy supply and demand (driving force include economic and demographic factors) with $CO_2$ emission factors derived from an understanding of various combustion processes to produce estimates of $CO_2$ emissions. The model is constructed to facilitate the examination of alternative future energy paths based on different assumptions about prices, population, economic growth, technological change, and supply constraints.

**1.3 Policy Options for Stabilizing Global Climate, U.S. Environmental Protection Agency** (Tirpak and Lashof, 1989)

This report was written in response to a Congressional request to examine "policy options that if implemented would stabilize current levels of atmospheric greenhouse gas concentrations." One of the major goals of the study was "to develop an integrated analytical framework to study how different assumptions about the global economy and the climate system could influence future greenhouse gas concentrations and global temperatures."

Data: This study has compiled the best available estimates of current emissions of all greenhouse gases. In a few cases, new databases were developed, such as an energy end-use data base (Mintzer, 1988, for industrialized countries, Sathaye, et al., 1988, for developing countries).

Process: This study has compiled the best available estimates of emission coefficients for all greenhouse gases. Future activity levels are determined by population growth, economic development, and technological change.

The study develops four scenarios of the future. These are based on two different patterns of economic development and technological change, each examined with and without policy intervention to stabilize climate change. A sensitivity analysis is performed on values for the key variables in these scenarios.

Assumptions regarding population growth rates, economic growth rates, and oil prices are developed as follows: Population estimates were developed from Zachariah and Vu (1988) of the World Bank and the U.S. Bureau of the Census (1987). The primary source for economic growth rates was the World Bank (1987). Oil prices were taken from the U.S. DOE (1988).

Synthesis: The study combines models of activity levels with information on emission coefficients to develop an analytical framework which relates the underlying forces of population, economic development and technological change to the emissions of all the important greenhouse gases. The study uses several detailed models of individual components to inform this general framework.

There are four modules used to calculate emissions. Attention was paid to developing consistent scenarios, but there are no explicit feedbacks between modules. The four modules are briefly described below. A more detailed description can be found in the Appendix of the EPA report.

(1) The energy module is based on a considerably modified Edmonds-Reilly model (developed by ICF) and two end use studies (Mintzer, 1988, for industrialized countries, Sathaye, et al., 1988, for developing countries). The end use studies are used to project demand in the year 2025. This in turn is used to anchor the demand estimates which are calculated for other years using the modified E-R model.
(2) The Industry Module is based largely on the EPA's CFC model (U.S. EPA, 1988). Non-CFC industry emissions (from landfills and cement manufacture) are calculated as simple estimates of population and per capita income.

(3) The Agriculture Module uses the IIASA/IOWA Basic Linked System to calculate agricultural production and fertilizer use. This model was first developed at IIASA's Food and Agriculture Program (see section 4.4.3). It was modified by the Center for Agriculture and Rural Development at Iowa State University to extend the time horizon to the year 2050 (Frohberg and Vande Kamp, 1988 and Fisher, et al., 1988). Emission coefficients are derived from the literature.
(4) The Land-Use and Natural Source Module uses the Terrestrial Carbon Model developed at the Woods Hole Marine Biological Laboratory to calculate $CO_2$ emission factors for land use changes. CO and $N_2O$ emissions are scaled based on $CO_2$ emissions. Natural emissions (from forest fires, wetlands, soils, oceans and fresh water) are based on values from the literature and generally held constant.

The study uses two concentration modules to calculate atmospheric concentrations and temperature rise based on scenarios of emissions.

**1.4 Future Environments for Europe: Some Implications of Alternative Development Paths** (Stigliani, et al., 1989)

This study is a regional case study sponsored by the Sustainable Development of the Biosphere Program at IIASA. "The purpose of this study is to provide new insights into the long-term management of the European environment during an era of fundamental transitions in technologies, climate, and scale of effects." The specific objectives of the study include developing a method for examining regional environmental problems 40 years into the future, learning about the major environmental problems that would be facing Europe in this time frame, and developing tools to improve the management of the environment in the long term. The study considers land use transformations and industry/energy transformations in its assessment.

Data: The study uses current data (1980) on activity levels for population, energy, industry and transportation, agriculture, and forestry. These provide the starting point for scenario development.

Process: The study constructs several socio-economic development paths (scenarios of the future) for Europe. These paths describe future trends in population, energy, industry and transportation, agriculture, and forestry. These trends in turn cause changes in the environment. The environmental components analyzed include: climate, hydrology, atmospheric pollution and regional acidification, soil quality, water quality, biota, and land use. This study develops a scenario based on "conventional wisdom" and several based on not impossible alternatives to the most likely scenario. These alternatives are based on surprises, or turning points from the conventional wisdom scenario. The study uses a qualitative framework similar to that used in the Darmstadter et al. (1987) study for presenting the seriousness of the environmental consequences of four different development paths.

Synthesis: The socio-economic scenarios are used to drive development. The study describes changes in the environment based on these scenarios.

**1.5 Strategies for Environmentally Sound Development: An Input-Output Analysis.** (Duchin, 1989)

This describes a project that has recently begun at the Institute for Economic Analysis at New York University. "The objective of the proposed study is to identify and evaluate concrete, consistent, economically feasible strategies for environmentally sound development, that is, to examine alternative approaches to reducing poverty over the next 50 years while also reducing global pollution." This analysis will be based on a world input-output model.

The analysis will incorporate detailed technical process information and provide quantities and geographic distribution of pollutant emissions under various scenarios as one of its outputs.

## 2. INDUSTRIAL METABOLISM: TRANSFORMATION OF MATERIALS AND ENERGY

Industrial metabolism can be defined as the production and consumption processes of industrial society. These processes include extraction, processing, refining, use, and dispersion of fossil fuels and minerals. These processes transform materials and energy into emissions to the environment, and are thus a major source of global environmental change in industrialized societies. One of our goals is to define research initiatives that will improve our understanding of how the historical and current industrial metabolism have and are causing environmental change. Equally important, is gaining an understanding of the dynamics of industrial metabolisms: what are the factors causing changes, how have they changed over time, and what are possible future industrial metabolisms.

This section is divided into four subsections: materials balance studies, trends in material and energy intensity, long wave studies, and global energy modeling.

### 2.1 MATERIALS BALANCE STUDIES

The materials balance approach is based on the concept of conservation of mass (i.e. the first law of thermodynamics). It tracks the use of materials and energy from "cradle to grave". In other words, it follows them from extraction through various transformation processes to disposal and their final environmental destination. It is a tool which allows economic data to be used in conjunction with technical information on industrial processes to describe chemical flows to the environment. For a discussion of this methodology see Ayres (1988) and Ayres et al. (1989).

Some important conclusions that have been drawn from applying this type of analysis are: (1) Major sources of environmental pollutants have been shifting from production to consumption processes. (2) Large numbers of materials uses are inherently dissipative spreading widely in the environment.

#### 2.1.1 The Hudson-Raritan Study (Ayres, et. al., 1988, Ayres and Rod, 1987)

This is the most far reaching study of this type. It provided a historical reconstruction of major pollutant levels in the Hudson-Raritan Basin from 1880-1980. The methodology was a materials balance approach. The major contribution of this work is in the framework it provides for developing data of pollutant loadings using process information and economic data.

Data: This study provides current and historical (1880-1980) pollutant loading data for the Hudson-Raritan river basin for heavy metals (silver, arsenic, cadmium, chromium, copper, mercury, lead, zinc, petroleum, and coal) and for chemicals and other wastes (chlorinated pesticides, chlorinated herbicides, chlorinated phenols, polynuclear aromatic hydrocarbons, oil and grease, carbon, nitrogen, and phosphorus).

Process: This study developed process-product flows for heavy metals which describe the location and form from extraction through consumer end-use to the disposal of these materials. It used historical data of how processes changed over time to determine the level of different types of production activities. It used emission coefficients from the literature on production emissions. There is little information in the literature on consumption emissions; thus the study used an "ad hoc" choice of consumption emission coefficients. The runoff estimation model is a modified version of that developed by Heany (Heany et al, 1976).

Synthesis: This study implements the materials balance framework for one region. It serves as an example of how data on pollutant loadings can be developed using process information and economic data.

### 2.1.2 Other Studies

Several other studies which have examined the processes of transformation of materials and energy and developed data on emissions are listed below.

(1) Impacts of World Development on Selected Characteristics of the Atmosphere: An integrative Approach (Darmstadter, et al., 1985). This study provides a historical reconstruction of emissions of CO, $SO_x$, $N_2O$ and $NO_x$, $CH_4$ for the years 1880 - 1980 for four regions. For a more detailed discussion of this study, see section 2.1.

(2) "Carbon Dioxide from Fossil Fuel Combustion: Trends, Resources, and Technological Implications" (Rotty and Masters, 1985). This study develops global emissions of $CO_2$ from fossil fuel combustion for the years 1860 to 1982.

(3) The Study of Chemical Pollution and Its Sources in Dutch Estuaries and Coastal Regions will be using a materials balance framework. It is just beginning as a collaborative project between The Netherlands' Ministry of Public Housing, Physical Planning and Environment, The Netherlands' National Institute of Public Health and the International Institute for Applied Systems Analysis (Shaw, 1989). An interesting feature of this study is the use of the RAINS model (developed at IIASA to trace regional pollution for acid rain) to determine heavy metal loadings from atmospheric releases.

## 2.2 TRENDS IN MATERIAL AND ENERGY INTENSITY

Materials intensity is defined as the mass of a material per unit of GNP or per capita. Similarly, energy intensity is defined as the energy per unit GNP or per capita. Energy intensity is also defined as the primary energy per unit of useful energy or end-use service. In sum, material and energy intensity are defined as the quantity of material or energy consumed per unit of value created. Trends in material and energy intensity are determined by changes in the amount and types of goods and services that are produced and consumed, the efficiency of energy and material use in the production and consumption process, and by the substitution of materials within the same good (e.g. plastic instead of steel in automobiles). In other words, these trends are determined by the structure of the economy, the income level, and technology. The topic of whether the industrialized countries are experiencing a decline in material and energy intensity, a trend called "dematerialization", is relevant to scenarios of future environmental effects from industrialization.

This sections reviews studies of material and energy intensity, and studies of substitution of one material for another.

### 2.2.1 Materials, Affluence, and Industrial Energy Use (Williams, Larson, and Ross, 1987).

This study focuses on the trends in the use of materials in the U.S. It concludes that there is indeed a trend toward dematerialization in the U.S.

Data: About 100 years of data on prices and consumption of steel, cement, paper, ammonia, chlorine, aluminum, and ethylene in the U.S., in units of kilograms. Also for low and intermediate volume metals, including copper, lead, zinc, manganese, chromium, nickel, tin, molybdenum, titanium, tungsten.

Process: This study concludes that "the U.S. is passing the era of materials-intensive production and beginning a new era of economic growth dominated by high-technology products having low materials content." Dematerialization is the result of a structural shift in U.S. which is based on the level of income. Analysis of data show that reduced energy use per unit GNP in the U.S. is half from structural changes and half from energy efficiency improvements. The authors postulate three stages and a bell curve for the materials use cycle. This has implications not only for materials flows, but also for energy use. The result is that industrial demand for energy may be zero growth or negative.

The maturing of basic materials use in the U.S. is attributed to: improvements in efficiency of materials use, substitution of cheaper materials or materials with more desirable characteristics for traditional materials, saturation of bulk markets for materials, and shifts in consumer preferences at high income levels to less materials intensive goods and services. Recycling can achieve greater market share as demand growth for a material decreases.

This study examines in detail the trends in materials use for steel, ethylene/plastics, aluminum, pulp and paper, minor metals, and "new age" materials.

**2.2.2 Dematerialization** (Herman, Ardekani, and Ausubel, 1989)

This essay examines the question of whether we are experiencing dematerialization, and what is a meaningful definition of dematerialization with regards to the environment. They suggest defining dematerialization as " the amount of waste generated per unit industrial product". Their goal is to look at forces "beyond the obviously very powerful forces of economic and population growth".

Data: They provide data which shows that consumer solid waste streams have been growing.

Process: They identify product life as a key factor in dematerialization, and identify several product traits which are important in determining product life, including: quality, ease of manufacture, production cost, size and complexity of product, repair or replace, and size of waste stream. They draw a distinction between the dematerialization of production and consumption.

**2.2.3 Energy Use, Technological Change, and Productive Efficiency: An Economic-Historical Interpretation** (Schurr, 1984)

The goal of this paper is to explain the simultaneous occurrence of rising total productivity, low energy prices, and declining intensity of energy use. This work builds upon, and updates, research originally reported in the 1960 Resources for the Future book, Energy in the American Economy, by the author and associates.

Data: This analysis is based on data of energy use, capital and labor inputs, and productivity for the past century.

Process: The intensity of energy use has risen in relation to labor and capital inputs, but has dropped in relationship to total output since 1920. The explanation for this apparent paradox is based on an energy-technology-productivity connection thesis. The characteristics of energy supply - low cost, abundance, and enhanced flexibility in use - sets the stage for discovery which quickens the pace of technical advance. This is reflected in labor and multifactor productivity increases which lead to increases in total output.

**2.2.4 Energy for a Sustainable World** (Goldemburg, et al., 1987, 1988)

This work presents the findings of the End-Use Global Energy Project, a study by an international team of researchers. It analyzes energy demand from an end-use perspective, with a focus on energy efficiency improvements that are technically possible using commercially available or near-commercial technologies. The results of this study are presented in two forms: a report containing the major findings (Goldemburg, et al., 1987) and a book presenting the models and data in greater detail (Goldemburg, et al., 1988).

Data: This study presents data on trends in energy and material intensity. It includes data on energy consumption disaggregated by sector, i.e. commercial, residential, transportation, and industry. Within these sectors, there is great detail on specific end uses. The study also presents large amounts of technical

information on the energy efficiency of equipment, appliances, automobiles and other modes of transportation, and industrial processes. This work includes detailed case studies of the U.S., Sweden, India and Brazil.

Process: An examination of energy use in the industrialized countries leads to the conclusion that there are structural economic shifts toward less energy-intensive activities, and that there is great potential for more efficient energy use. Future scenarios of energy use in the U.S. and Sweden are presented. These scenarios are based on the saturation of the most energy efficient technologies that are commercially available or near commercial.

For developing countries, they examine the energy requirements for meeting basic human needs. Again, the most efficient commercially available technologies are applied.

Synthesis: The study uses technical data on energy efficient technologies in conjunction with assumptions about population and economic growth to develop scenarios of future energy consumption. The result is a normative model which shows that human needs can be satisfied (including improved standards of living) with much lower energy consumption than projected by "conventional wisdom" scenarios.

**2.2.5 Toward a New Iron Age** (Gordon et al.,1987)

This book is about quantitative modeling of resource exhaustion. Its goal is to analyze future patterns of resource exhaustion, substitution, and associated price paths. The key contribution of this book is its integration of geology, substitution, and recycling; i.e. combining science, economics and engineering.

Data: Copper resources of 48 continental U.S. states, by ore grade. Data on production and price of copper products and copper substitutes.

Process: The framework of analysis is based on general equilibrium principles. This framework is represented by a linear programming optimization model. The study estimates a supply function for copper based on a detailed assessment of U.S. copper deposits. The costs of alternative sources of copper and copper services relative to the cost of new copper determines the amount of substitution and recycling.

Estimates of demand: This study divided the use of copper into demand categories based on common engineering functions (ruling properties). It determined a switch price when a substitute material was less expensive. It used a logistic curve and a 30 year time for switching (based on Fisher and Pry, 1971). Two methods of cost estimation were used: expert opinion and use of product census data. The recycling module is weak, as there was little data available. For demand, they assumed a unitary income elasticity and zero price elasticity. Elasticity estimates are based on reasoning, as there were no data for empirical estimation. The study assumes GNP growth of 3% per annum for first 100 years, and 1% thereafter.

The model does not include currently unknown technologies. A sensitivity analysis found that the uncertainty about future technical advances is the most important single uncertainty in the study.

They conclude that in the year 2072, copper will be obtained from common rock, even after allowing for recycling. A major reservation in their study results is the assumption that the large scale mining of low-grade resources will be acceptable (i.e. concern that they may have mistakenly represented environmental impacts).

Synthesis: Although this model does not extend to the environmental impacts, it is synthetic in its combination of assessments of resource availability, use of engineering/technical data, and an economic framework of demand in examining the future supply and consumption of a resource.

## 2.3 STUDIES OF LONG WAVES (Marchetti and Nakicenovic, 1979, Marchetti, 1983, Nakicenovic, 1988 and Marchetti, 1988.

There have been numerous studies which conclude that there are long-term regularities in the evolution, diffusion, and replacement of socio-technical systems. A review of these results is found in Ausubel, 1989.

Data: These studies are basically empirical in nature. They have used data on technical substitution in the areas of energy (Marchetti and Nakicenovic, December 1979), and transportation (Marchetti, July 1983, Nakicenovic, 1988 and Marchetti, 1988).

Process: The process model used is one of logistic substitution. In the case of two competing technologies, the historical data is fit to a logistic function to determine the characteristic time constant to go from 10% to 90% of market saturation (Fisher and Pry, 1971). For more than two competing technologies, the model is more complex, but similar in that historical data is used to determine the time constant (for a given technology to go from 10% to 90% of its eventual maximum market penetration). In terms of forecasting, the parameters derived from data on a given system are applied to forecast future behavior of that system. For a concise explanation of logistic substitution modeling, see Nakicenovic (1988).

Causal explanation is related to capital replacement, and substitution possibilities which have a total cost advantage over existing technologies (Starr, 1989), although this has not been rigorously discussed in the literature.

Theoretical economic frameworks have been specified by Peterka (1977) for centrally planned economies and Spinrad (1980) for market economies. Both models can be understood as strategic principles. For the Peterka model, the attractiveness of investment is proportional to the degree to which a technology is in use, and to a measure of economic merit. For the Spinrad model, the economic attractiveness of a technology is proportional to the inverse of the price that would have to be charged for its product.

Synthesis: Ausubel, et al. (1988) used logistic substitution models to examine future emissions of $CO_2$. The logistic substitution model predicts that natural gas will be the dominant energy source for the next 50 years, peaking at 70% of world energy supply. This paper examined the emission levels based on this scenario of energy supply. It concludes that $CO_2$ emissions will be a problem, even in a methane economy.

## 2.4 GLOBAL ENERGY MODELING

Modeling of development - environment interactions on a global scale is probably best understood in the area of energy. Two global energy models, the IEA/ORAU model (Edmonds-Reilly) and the Nordhaus-Yohe model, have been developed specifically to explore the $CO_2$ emissions related to different future energy paths. Both of these models are based on a neo-classical economic framework. In addition to these two models, the IIASA energy model, which is based on an end-use approach, is also discussed in this section. Global energy models are reviewed for their applicability to global change in Toth, Hizsynyik and Clark (1989). A review of models of carbon dioxide emissions from fossil fuel use is found in Edmonds and Reilly (1985). Another recent review of energy models is found in Goldemburg, et al., (1985).

### 2.4.1 The IEA/ORAU Model (Edmonds and Reilly, 1983)

This model is discussed in more detail in section 2.2.

Data: Uses emission coefficients and elasticities calculated elsewhere.

Process: This is a partial equilibrium model. Critical demand assumptions include: population, labor productivity, and GNP growth rates, an energy technology parameter which specifies the rate of change in energy productivity, price and income elasticities. Critical supply assumptions include resource constraints and breakthrough costs of new technologies.

Demand in the OECD is disaggregated into 3 economic sectors: residential/commercial, transport, and industrial. All other regions are modeled as a single sector. The model makes projections to the year 2100 in 25 year intervals. The globe is divided into 9 regions. The model includes 6 primary fuel sources, 4 secondary fuel sources, plus biomass, shale oil and synfuels. The outputs of the model include primary and secondary fuel mixes, a variety of trade, price and development indicators, and $CO_2$ emissions.

Synthesis: This model combines energy supply and demand (driving force includes economic and demographic factors) with $CO_2$ emission factors derived from an understanding of various combustion processes to produce estimates of $CO_2$ emissions. Model is constructed to facilitate the examination of alternative future energy paths based on different assumptions about prices, population, economic growth, technological change, and supply constraints.

**2.4.2 Paths of Energy and Carbon Dioxide Emissions** (Nordhaus and Yohe, 1983)

Data: Uses emission coefficients and elasticities calculated elsewhere.

Process: This model is based on a generalized Cobb-Douglas production function. The world is treated as one region. There are two aggregated fuel types: fossil fuels and non-fossil fuels. The model makes projections to the year 2100 in 25 year intervals. The exogenously specified input variables are: population growth rate, labor productivity, rates of technological change in the energy industry, and the fossil fuel mix. The outputs of the model are: consumption and prices of fossil and nonfossil fuels, GNP, carbon emissions, and $CO_2$ concentration.

Synthesis: This model combines a neo-classical economic framework to determine future energy use with information on $CO_2$ emission coefficients to produce estimates of $CO_2$ emissions. This model can be used to perform a simple probabilistic scenario analysis.

**2.4.3 Energy in a Finite World, IIASA** (Heafele et al., 1981)

Data: Large amounts of data on energy technologies and energy resources.

Process: Energy demand is disaggregated into three sectors: industry, transport and commercial/residential. Population and GDP rates determine the activity levels in each of these sectors. Energy demand is determined based on these activity levels and a set of parameters for economic structure (industrial products), demographic structure (lifestyles) and technological structure (energy intensities). This set of parameters can be varied to examine alternative futures.

End-use energy is translated into primary energy by use of a linear programing optimization model whose key variables are: costs of capital, operating, maintenance, and fuels; costs, availability and quality of resources; build-up rates; and energy production capacities.

The study looks at scenarios from 1975 to the year 2030, at five year iterations. The world is divided into 7 regions. There are 7 fuel types.

This is a loop of models, one for final energy demand, one for energy supply, one for impacts (economic and other) of energy use, and one for macroeconomic issues. While the models are not directly linked, they are designed to be run iteratively until a consistent scenario of supply and demand is reached. The macroeconomic model was not applied.

Synthesis: This model works toward integrating an end-use model (containing microeconomic, technological and demographic detail) with a macroeconomic model. This model does not take the step of calculating $CO_2$ emissions, although they could be straightforwardly calculated from the energy projections provided by the model.

## 3. LAND USE TRANSFORMATIONS

Anthropogenic land transformations occur in the processes of agricultural production, mineral extraction and human settlement. Land transformations associated with agriculture occur either through more intensive use of currently productive land, or by expanding into land which was either previously uncultivated, or used for other purposes. In other words, this includes both intensive and extensive changes in land use. Land transformation processes contribute to global environmental change by affecting the flow of chemicals such as $CO_2$, $CH_4$, and N20, by changing physical properties such as albedo and roughness, and by changing biological properties such as biodiversity.

This section is divided into four subsections: land conversion and transformation; technical and institutional change in agriculture; regional dynamic land-use models; and global agriculture and forestry production models.

### 3.1 LAND CONVERSION AND TRANSFORMATION

This section first highlights two ambitious studies which survey land transformation; the first looking at land transformation in agriculture, the second taking a comprehensive historical look at land transformation over the past 300 years. The section then turns to studies of three land transformation processes of particular concern for global environmental change: wetland transformation, deforestation, and biomass burning. Other land transformation processes that are important to global environmental change, but which have not been reviewed below due to time constraints include: desertification, irrigation, soil erosion, and urbanization. The first of these are discussed in Wolman and Fournier (1987), which is reviewed in section 4.1.2.

This section examines only direct human impacts on land. It does not look at second order effects, where humans have caused changes in other environmental components, such as climate, which in turn cause land transformations.

#### 3.1.1 Land Transformation in Agriculture, SCOPE 32 (Wolman and Fournier, 1987)

This book is the result of almost a decade long SCOPE project. The project was undertaken because of concern over the environmental effects of land transformations on land resources, and therefore on the ability to produce adequate food and fiber in the future.

Data: The first three chapters present historical data on trends in land use and agricultural production. The chapters on specific processes present data significant to the process under study. The book contains many detailed case studies. The book also contains a chapter on "Criteria for Observing and Measuring changes Associated with Land Transformations." This discussion focuses on measures at the local level. It does not discus what types of measures might be useful on a regional or global scale, or how to aggregate these local measures.

Process: This book begins with an overview of the types of land transformation and the ability for the land base to support population. It then has a chapter on "transformation of land in pre-industrial times" and one on "the industrial revolution and land transformation." The latter identifies the key forces causing change in agriculture over time as: population growth, urbanization, industrialization, transport changes, and the role of science and the state. It then discusses three major types of farming and their evolution: Western European farming, the rice economies of Asia, and shifting cultivation and bush fallowing in the tropics.

The book contains chapters on several agricultural processes which transform the land, including: wetland conversion, irrigation, mechanization, use of fertilizer, use of pesticides and insecticides, and practices which cause soil erosion. The main focus of these chapters is how these agricultural practices transform the land, and how the resulting transformations affect agricultural productivity. There is some discussion of other environmental problems related to these land transformations.

Several case studies are presented:

(1) Land transformation in Israel
(2) Influence of Large-scale Farming Methods on Soil Exploitation in Czechoslovakia
(3) Effects of Intensification of Agriculture on Nature and Landscape in the Netherlands
(4) Saline Seeps in Northern Great Plains, USA and Canada
(5) Soil Erosion and Degradation in Southern Piedmont of USA
(6) USA Soil Depletion Study of the Southern iowa River Basin
(7) Reclamation of Areas Affected by Open-cast Mining in Czechoslovakia
(8) Transformation of Small Villages into Rural Cities in Czechoslovakia

**3.1.2 The Earth as Transformed by Human Action** (Turner II, et al. 1989)

This book is a compilation of papers presented at the "Earth as Transformed by Human Action" symposium held at Clark University in 1987 as part of Clark's centennial-year celebration. The book and symposium were the results of an ambitious effort whose goals were to document changes in the biosphere over the past 300 years, to contrast the global patterns of change with those experienced at the regional level, and to explore the major human forces that have driven changes in the biosphere.

A thorough review of this book was not undertaken in this document due to time constraints. A summary of the book, quoted from its preface, is given below.

> The text is composed of an introduction and four principal sections. The introductory chapter of the volume establishes the intellectual ancestry of the subject of The Earth as Transformed by Human Action and briefly traces some of the basic views of the human-nature relationships of the last 300 years. It then summarizes the major findings of the volume as a whole, assessing the major trends in the transformation variables and the major patterns found in the regional case studies.
>
> Section I, Changes in Population and Society, examines five major human forces of change over the past 300 years: population, technology, institutions/organization/culture, location of production and consumption, and urbanization. The stage for these five studies is set by the lead chapter of the section, which examines long-term, regional population changes, and the section is set in intellectual context by a concluding chapter on the history of beliefs regarding transformation, which themselves may also be seen as real or potential human forces of environmental change.

Section II, Transformations of the Global Environment, consists of 18 papers that address the principal objective of the volume, a stocktaking of the major transformations of the biosphere wrought by human action over the past 300 years. Again, the first chapter of the section establishes the context by assessing long-term changes in the biosphere of natural origin. The other papers attempt to track the changes in the components of the biosphere, either a single variable of a set of variable. These are arranged in subsections: land, water, oceans and atmosphere, biota, and chemicals and radiation.

Section III, Regional Studies of Transformations, is comprised of 12 case studies that document the multiple-variable interactions of environmental change over a 300-year period for specific areas, serving as spatial and conceptual comparisons for the global papers.

Section IV, Understanding Transformations, briefly examines a range of perspectives and theories that purport to explain human actions in regard to the biosphere. Three papers address such themes as they emanate from the realms of meaning, social relations, and ecology.

### 3.1.3 Studies of Deforestation/Reforestation

#### 3.1.3.1 Deforestation (Arnold, 1987)

This article was prepared for the Dahlem Workshop on Resources and World Development It provides a short overview on deforestation.

Data: Deforestation estimates are based on data from the 1980 FAO/UNEP study of tropical forest resources (Lanly, 1982).

Process: The principle causes of deforestation in the tropics are rapid population growth coinciding with poverty, unequal distribution of land, and low agricultural productivity. In closed tree formations, shifting cultivation is the principle cause of deforestation for all regions. Grazing is the second most important cause. Timber harvesting is an important cause in Asia and Africa. This is because logging roads open the area for agriculture. In open tree formations, shifting cultivation and grazing are the major causes of deforestation. Fuelwood harvesting is another important cause.

This article also discusses the consequences of deforestation (ecological, social, and economic) and policies for reducing deforestation.

#### 3.1.3.2 Global Deforestation and the Nineteenth Century World Economy (Tucker and Richards, 1983) and World Deforestation in the Twentieth Century (Richards and Tucker, 1988)

These books are based on case studies presented at two separate symposia. The goal of both meetings was to draw generalizations and themes from a diverse set of studies from around the globe. The essays in these books document, describe and analyze aspects of the world trend toward deforestation.

Data: Both books are mainly a compilation of case studies. Several of the authors in the book on the 20th century address the problem of collecting adequately detailed, accurate, comparable data across time and space.

Process: The dominant cause of deforestation in the 19th century was "the steeply rising demand for production of agricultural commodities exerted by the core or metropolitan societies of Europe, North America, and Japan."(p. xi) A dominant theme in these essays was the increasing unification of the global economy under the leadership of British capital, technology and imperial institutions.

The global economy continues to be a significant factor in the 20th century. Thus, in addition to rural population growth as a factor in deforestation (through demands on timber and land resources for agriculture), the impact of industrial economies remains a critical contributing factor.

We see more clearly the impact of outside capital: industrial economies tapping the developing economies' timber resources to meet their consumption demand and private investors (in some cases in alliance with local commercial interests) cashing in on the high short-term profitability of timber exports from capital-starved countries. The consequences of this imbalance of power between industrialized and developing nations are the main concern of this volume. (p. 4)

In the volume on the 20th century, the themes explored in case studies include: the ability of some industrialized countries to reverse trend of deforestation; the relationship between timber as a commodity and deforestation; interactions between Western capital and regional markets controlled by local entrepreneurs responding to regional opportunities for profit (control of timber by international interests); the role of development policies; the role of the timber lobby; the disruption of traditional production and social systems; and the effect of modern forest management on land and indigenous people.

The case studies demonstrate that until very recently an awareness of environmental costs has occurred only in industrialized, high literacy, high income countries.

**3.1.3.3 Conversion of Tropical Moist Forests** (Myers, 1980) and **The Primary Source** (Myers, 1984)

The report, Conversion of Tropical Moist Forests was commissioned by the National Research Council's Committee on Research Priorities in Tropical Biology. The goal was to document the forms and degree of tropical forest destruction. The Primary Source is an update of that survey.

Data: This document makes clear the shortcomings in data on the amount of deforestation. It provides a review of forest resources and the rates of forest depletion (deforestation and degradation) for tropical countries. It classifies areas as undergoing rapid rates of conversion, moderate rates, or experiencing little change.

Process: This examines the role of the following factors in deforestation: forest farmers, the timber trade, cattle raising, and firewood cutting. Population pressure, particularly from forest farmers, is indentified as the greatest factor in deforestation.

**3.1.3.4 Quantifying Changes in Forest Cover in the Humid Tropics: Overcoming Current Limitations** (Grainger, 1984)

This work develops a model of deforestation based on population, food consumption per capita and average yield per hectare. The model is used to forecast deforestation for 43 tropical countries. A major assumption it that once forest area has fallen to a critical level in a given country, the government will take action to prevent further deforestation. This work is cited in World Resources 1988 - 1989 (World Resources Institute and International Institute for Environment and Development, 1988). It has not been reviewed by this author.

**3.1.3.5 Deforestation Perspectives for the Tropics: A Provisional Theory with Pilot Applications** (M. Palo, 1987)

This is a chapter in The Global Forest Sector, an IIASA study which is reviewed in section 4.4.5.

Data: Although actual case studies are not presented in this chapter, the model is primarily based on observations from field work in 4 countries.

Process: This paper develops a theory of the causes of deforestation in the tropics. This is a systematic, interdisciplinary, global theory consisting of 20 hypothesis. The theory takes into account natural factors, accessibility, population pressures, public ownership (public goods), government policies, colonialism, and positive feedback loops which increase the rate of deforestation.

**3.1.3.6 Other Case Studies**

There are many case studies on deforestation. In addition to those mentioned above:

"Borneo and Peninsular Malaysia" in The Earth Transformed by Human Action, Turner II, et al., eds. (Brookfield, H.C. et al., 1990)

**3.1.4 Studies of Wetland Conversion**

**3.1.4.1 Forested Wetland Depletion in the United States: An Analysis of Unintended Consequences of Federal Policy and Programs** (Stavins and Jaffe, 1988), and **Alternative Renewable Resource Strategies: A Simulation of Optimal Use** (Stavins, 1989).

These two papers develop an economically driven model of the conversion between forested wetlands and farmland in the Lower Mississippi Alluvial Plain. They are reviewed in section 4.3.1.

**3.1.4.2 Case Studies**

There are many case studies of wetland conversion, including:

- "Sweden" in The Earth Transformed by Human Action (Hagerstrand and Lohm).
- "The Impact of Wetland Reclamation" in Land Transformation in Agriculture, case studies of Indonesia and China (Ruddle, K.).
- The Changing Fenlands (Darby, H.C.).
- "Drainage and Economic Development of Poles'ye, USSR" (French, R.A.).
- "The Reclamation of Swamp in Pre-Revolutionary Russia" (in Transactions and Papers of the Institute of British Geographers 34).
- "Draining the Swamps" in The Making of the South Australian Landscape (Williams, M.).

**3.1.5 Studies of Burning**

**3.1.5.1 The Role of Fire** (Robinson, 1987)

This dissertation provides an in depth overview of fire as a force in transforming the landscape and as a contributor to the chemical and radiative behavior of the atmosphere. A large portion of this work is devoted to evaluating the prospects for using remote sensing and related information systems for assessing the role of fire on earth.

Data: This study provides a critical review of current estimates of emissions from burning. It suggests where and why these estimates are most in error (see also Robinson, 1986). It provides a detailed review of aerosol and trace gas emission from burning, with a compilation of emission coefficients and global estimates. It presents data on calculated global surface type and albedo changes. Five case studies of burning are presented: Lago Calado; Altamira-Itiatuba Stretch, Transamazon Highway; Chiapas, Mexico; Minas Gerais; and Hengchun, Taiwan.

This study notes that while agricultural and cooking fires are responsible for a large fraction of total biomass burned, data on these activities are quite poor. Satellite remote sensing is unlikely to improve these estimates. Robinson suggests that social indices may be the most useful approach for inferring the magnitude of burning (Robinson, 1988, p. 285 - 293).

Process: Agricultural and cooking fire regimes are closely related to many social factors, including population pressures, surplus labor, poverty, and agricultural practices. This work discusses the relationship between anthropogenic fire regimes and population density (p.285 - 293).

**3.1.5.2 Fire in America, A Cultural History of Wildland and Rural Fire** (Pyne, 1982)

This book provides a chronological history of fire in America, as well as detailed regional histories. It discusses fire as a cultural phenomenon, as an environmental modifier, and in relationship to social organization. "The relationship between mankind and fire is reciprocal: fire has made possible most technological and agricultural developments and has provoked fundamental intellectual discourse; yet fire itself takes on many particular characteristics because of the cultural environment in which it occurs, just as it does in response to the natural environment of fuels, topography and weather. ... And it is the culture of fire - as distinct from its physics, chemistry, biology, and meteorology - that forms the subject of this study (p. 5)."

**3.1.5.3 Estimation of Gross and Net Fluxes of Carbon between the Biosphere and the Atmosphere from Biomass Burning** (Seiler and Crutzen, 1980)

This paper estimates global $CO_2$ releases from biomass burning. There is a large range in the estimates of carbon flux from burning. Other studies which estimate current emissions from all land use changes include: Houghton et al. (1987), Detwiler and Hall (1988), and Bolin (1986). Estimates of cumulative rates of $CO_2$ release from deforestation have been made by Woodwell et al. (1983) and Bolin et al. (1986).

Data: The following activities which lead to burning were included in the calculations: tropical shifting agriculture, deforestation due to population increase and development programs, industrialization and colonization, natural or agricultural fires in savanna areas, wild-fires in temperate forests, prescribed fires, wildfires in boreal forests, burning of industrial wood and fuel wood, and burning of agricultural wastes. Estimates on the level of these activities are made from a variety of data sources. The authors recognize the large uncertainty in their estimates due to limitations in the data on which the estimates were made.

Process: Estimates of biomass burned were made using the following model:

$$M = A * B * C * D$$

where:

A = total land area burned annually
B = average organic matter per unit area
C = fraction of the average above-ground biomass relative to total average biomass
D = burning efficiency of above ground biomass.

The parameters A through D were generally estimated by a critical review of values cited in the literature.

Synthesis: This study used measures of the level of human activities in combination with technical information about emissions from burning to determine the carbon flux.

## 3.2 TECHNOLOGICAL (AND INSTITUTIONAL) CHANGE IN AGRICULTURE

### 3.2.1 Agricultural Development (Hayami and Ruttan, 1985)

This book develops the theory of induced innovation as a explanation of alternative paths and rates of agricultural development.

Data: Cross section data on levels of production, productivity and inputs in agriculture for the years 1960 and 1980 (44 countries). Time series data on U.S. and Japan for the years 1880 to 1980. Data at the village level for the Philippines and Indonesia.

Process: A brief summary of the theory of induced innovation in agriculture is: Technological change is mostly endogenous, induced by changes in relative resource endowments (factor supply) and the growth of demand (product demand). In this scheme, improvements in mechanization provide substitutes for labor; biological and chemical innovations provide substitutes for land. Institutional innovation is induced both by changes in relative resource endowments and by technical change. The theory and analysis concentrate on resource endowments, technological change and institutional change.

The econometric analysis presented in this book supports the theory of induced innovation. For an abbreviated discussion of this analysis, see Ruttan (Feb. 1985). Further development of the ideas of induced innovation can be found in Binswanger and Ruttan (1978) and Ahmed and Ruttan (1988).

## 3.3 DYNAMIC LAND USE MODELING

Dynamic land use modeling describes how land is allocated over time between competing uses. This paper reviews a model of land use conversion at the regional level. There are no dynamic models of land use on the global scale.

A review article by Parks and Alig (1988) presents a taxonomy of land use modeling approaches:

> "(1) inventory and descriptive studies that classify the physical amount and characteristics of land or its subclasses; (2) normative, optimizing models that explain how land should be used in relation to various objectives; (3) positive studies that explain the use of land as it relates to economic, social, policy, climatic, and other variables."

Positive and normative models are generally based on neoclassical economic theory.

### 3.3.1 Forested Wetland Depletion in the United States: An Analysis of Unintended Consequences of Federal Policy and Programs (Stavins and Jaffe, 1988), and Alternative Renewable Resource Strategies: A Simulation of Optimal Use (Stavins, 1989)

These two papers examine the conversion between forested wetlands and farmland in the Lower Mississippi Alluvial Plain. The major contribution of this work is the development of a model based on the heterogeneity of the land base with parameters estimated from land-use data.

Data: This work used data for the years 1935 - 1984. Data on forested land was based on U.S. Forest Service aerial photographs. The study also employed data on agricultural revenue, agricultural costs of production, forestry revenue, flood and drainage conditions, flood and drainage protection, weather conditions, and costs of conversion.

Process: This study develops a model of land-use based on individual firms making rational economic decisions. Land-use decisions are modeled as a function of the relative expected economic returns from alternative land uses. The study examines the effect of Federal flood control strategies and price changes. The study also develops a model for the socially optimal time-path of resource use which is analogous to the model for the individual firm, but includes the cost of externalities in the conversion of wetlands to cropland.

Synthesis: A model of the heterogeneity of the land base was estimated from land-use data. This model was integrated with an econometrically estimatable model of the effect of economic and policy variables.

## 3.4 AGRICULTURAL AND FORESTRY PRODUCTION MODELING

This section reviews several global models of agriculture production. Some of the agricultural models assess the productive capacity of the world's land base, while others look at the supply and demand for agricultural products. These models only project scenarios to the year 2000 or 2010. There are currently no agricultural models which provide an agro-ecological assessment, incorporate economic processes, and look at a time horizon of 80 to 100 years into the future. In addition, the existing models are not dynamic with regard to changes in the land base.

The situation for forestry is not much different. The global forestry model reviewed in this section was developed to understand supply and demand of wood products, and does not illuminate land use changes or other environmental effects of forest use.

The above discussion points to the fact that by the definition used for this study, these models do not provide a "synthetic" component. It is for this reason that the reviews of this section do not include the category "synthesis". This does not imply that these complex models did not require the synthesis of a significant range of concepts, analytical techniques and data.

A detailed review of agriculture models, with a focus on the ability of these models to illuminate relationships between development and environment, is found in Scenarios of Socioeconomic Development for Studies of Global Environmental Change: A Critical Review (Toth, Hizsnyik and Clark, 1989). Another comprehensive review of these models, with a focus on the relationship between population growth and food, is found in Srinivasan (1988). A review focused on the LDC food balance is found in Fox and Ruttan (1983).

### 3.4.1 Agro-ecological Zones Project (AEZ). (Food and Agriculture Organization of the United Nations, 1978-1981 and Shah et al., 1985)

The goal of this study was to assess the rainfed production potential and the population supporting capacity of the world land resources.

Data: The study develops a data base of climate and soil characteristics for the developing world, with spatial disaggregation of 50,000 land units and 14 major climates. The model results provide data on the land base by region and possible losses to the land base due to erosion if conservation practices are not used. The study also calculates per capita calorie and protein requirements for present and future populations. It includes a detailed case study of Kenya.

Process: The study incorporates the developing world only. The model assesses climate and soil characteristics. Based on climate and soil suitability, the land suitability by crop for three levels of technology is determined. From this, the potential crop yield is calculated. The level of irrigated production and demand for food per capita are exogenous variables. The land loss due to erosion when no conservation practices are employed is assessed. Except for soil loss and productivity loss, the model is static.

### 3.4.2 Model of International Relations in Agriculture (MOIRA). (Linnemann et al., 1979)

This study evaluates the production potential for food and policy options for ameliorating world hunger. It contains both a food production potential model and an economic model.

Data: For soil assessment, the world is divided into 222 land units. For economic assessment, the world is divided into 106 geographical units. Country level data for the year 1965 includes: ratio of non-food to food agricultural production, ratio of non-agriculture to agriculture per capita incomes, sectoral income distribution, fish catch and distribution, and technological parameters in agriculture.

Process: In the food production model, this study determines the availability of agricultural land and applies a theoretical maximum rate of photosynthesis. The food production potential model is static. The economic model is based on an economic equilibrium model with international trade in food. Consumption and production are dependent on the domestic food price, which is subject to government intervention. Regression analysis, based on 1965 country level data, is used to determine parameters in the model . These structural parameters do not change. The model assumes values at the country level for 3 exogenous variables: population growth, non-agricultural GDP growth, and regional fertilizer prices. Projections are made for one-year time periods to the year 2010.

### 3.4.3 Basic Linked System, Food and Agricultural Program (FAP), IIASA (Parikh, 1981)

The goals of the Food and Agricultural Program at IIASA were to evaluate the world food situation, to identify underlying factors and to suggest policy alternatives at the national, regional and global levels. The basic linked system was one of the products of this effort.

Data: Model parameters are calibrated based on the FAO's supply utilization accounts for the years 1970 - 1976.

Process: This is a dynamic general equilibrium model. It includes 18 country models, 2 country group models, and 14 regional group models which are linked together in trade, aid and capital flows. Projections are made to the year 2000. The model is structured to evaluate the effect of policy alternatives on output. The policies examined include domestic price policies, quantity rationing, trade restrictions, strategic reserves, normative consumption and import, plan target realization, self-sufficiency, and free market on output. A major shortcoming of this model for long-term studies is that available land is treated as a time trend.

This model has been modified to extend the time horizon to the year 2050 for use in the EPA Stabilization Study (See section 2.3).

### 3.4.4 Other Agriculture Models

There are several economic models which simulate supply, demand, distribution and hunger. These include:

**Agriculture - Toward 2000** (Food and Agriculture Organization of the U.N., 1981). This is a normative model which forecasts to the year 2000.

**Resources and Environmental Effects of U.S. Agriculture, Resources for the Future** (Crosson and Sterling, 1982) and **Global 2000** (Council on Environmental Quality and the Department of State, 1980). These two studies provide good information on the effect of agriculture on the environment. They are not useful on a global scale for production/consumption questions. The Crosson and Sterling study looks at U.S. production only.

### 3.4.5 The Global Forest Sector (Kallio, Dykstra and Binkley, eds., 1987)

This is the final report of the Forest Sector Project at the International Institute for Applied Systems Analysis (IIASA). The goals of this project were to study long-term developments in the production, consumption, and world trade of forest products, and to develop a policy analysis tool. The study focuses on the use of wood, and not other benefits of forests. It presents a detailed discussion of the global forest sector model developed at IIASA. This volume also provides a thorough critical review of modeling approaches for supply, demand and trade in the forest sector.

Data: Many different contributors to this volume noted the lack of consistent comparable data on forest resources as a major obstacle to improved modeling in this sector. Improvement in data is more important than improvement in estimation techniques. Better data is needed on stumpage prices, harvest qualities, forest characteristics, and ownership variables.

This modeling effort relied heavily on existing data which is referenced throughout the work.

Process: The global forest sector model is a partial equilibrium model, using a nonlinear programming framework. The model has four modules: timber supply, forest products industry, product demand, and international trade. The world is divided into 18 regions. There are 16 forest products. The planning horizon is 50 years. The model is designed for evaluating future scenarios with differing assumptions about socioeconomic and environmental factors.

The forest resource is modeled by a simple growth function with parameters estimated from historical data where feasible. The changes in the land area used for forests (afforestation and deforestation) were estimated exogenously.

Chapter 3 develops a theory of the causes of deforestation in the tropics. This is reviewed in section 4.1.3.5.

## 4. DATA AND MONITORING

There are significant data requirements for developing a better understanding of human interactions with global change. A thorough review of existing data sources is beyond the scope of this paper.[1] Instead, this section strives to be illustrative by highlighting several examples of data bases which were explicitly developed to improve our understanding of global environmental change.[2] Although limited in scope, the goal of this section is to act as a catalyst for thinking about what new data are most needed to develop a better understanding of the processes of change in the two areas of concern to this committee: land use transformations and industrial transformations of materials and energy.

The data bases listed below are of two kinds: (1) data on levels of human activity (e.g. deforestation), and (2) quantitative data on emissions which are calculated based on the level of human activity and information on emission factors (e.g. $CO_2$ emissions from deforestation). A general knowledge of a broad class of economic/social data bases is assumed, and not reviewed here.

### Data Bases

- Emissions of $CH_4$, $NO_x$, $SO_x$, HCl and sea salt on a regional basis, and $CH_4$, CO, $NO_x$, $N_2O$ and CFCs on a global basis for the years 1800 to 1980, in thirty year intervals, excluding 1830. The study contributes new data in: historical estimates of land in wet rice cultivation, and for emissions from combustion, the flaring of natural gas, smelters, cokers, and other industrial processes. Darmstadter, et al. (1987). For a more in depth review, see section 2.1.

- Current (mean value for 1980 - 1986) and cumulative (for years 1860 - 1986) releases of $CO_2$ from fossil fuel combustion and biota for most countries of the world. Estimates for biota are "fairly crude" because data on deforestation and biomass burning are not yet well documented. Subak (1989).

- Annual $CO_2$ emissions from fossil fuels, by country, for the years 1949 to 1986. Based on U.N. Energy Statistics. Marland, et al. (1988).

- Annual global emissions of $CO_2$ from fossil fuel combustion for the years 1860 to 1982. (Rotty and Masters, 1985).

- $CO_2$ releases from land clearing for agricultural purposes, for the years 1860 - 1986. Richards et al (1983).

- Energy consumption by end-use sector for all countries. Mintzer (1988) for industrialized countries and Sathaye, et. al. (1988) for developing countries.

- Forest resources, and amount and rates of deforestation for the 1980s, by country. Data are based on the U.N. Food and Agriculture Organization, the U.N. Economic Commission for Europe and country data sources. IIED and WRI (1987).

- Forest resources and the rates of deforestation and forest degradation for tropical countries. Myers (1980, 1984) For a review of this work, see section 4.1.3.3.

- Data on production of halocarbons from 1960 to 1985. U.S. EPA (1987) and Hammit et al., 1986.

- Global anthropogenic emissions of trace metals to the atmosphere, water, and soil. Data on emission factors for key anthropogenic processes. (Nriagu and Pacyna, 1988).

- Natural emissions of trace metals to the atmosphere and comparison of natural and anthropogenic emissions to atmosphere. (Nriagu, 1989)

## 6. GLOBAL POPULATION MODELS

In the models reviewed in the body of this report, population is always specified exogenously. Population estimates are generally derived from one of a few models, which will be described below. These models tend to have similar estimates to the year 2025, with some divergence when projecting further into the future. For a review of population models with a focus on the ability of these models to illuminate relationships between development and environment, see (Toth, Hizsnyik and Clark, 1989). For a critical review of global population modeling, see Keyfitz (1983) and Lee (1989).

The most widely used models for forecasting and scenario development have much in common. The key parameters in population models are initial population size and age-sex structure, fertility rates, mortality rates, and net migration rates. Estimates of fertility rates are the greatest source of uncertainty in these models. Determination of the values for key parameters in population models are based on one of two approaches: (1) trend extrapolation, modified by expert judgement, or (2) assuming a date in the future when replacement level fertility will be reached, and using linear interpolation to determine intervening rates. Both of these methods are based on expert judgement. There is no clear theoretical explanation upon which population models are built.

In concluding his review, Lee (1989) emphasized the lack of consistent theory behind long-term global population forecasts.

"Current longrun population forecasts ignore economic, natural resource and environmental constraints. Yet they assume that populations are even now converging to stationarity at a global level about twice the current population. If the assumption derives from a Malthusian orientation, it must be based on unexpressed and, in this context, unexamined views about future growth prospects and reproductive response to economic or environmental change. ...

"If, instead, population convergence to stationarity has been inferred from some version of transition theory, such as modern socio-economic fertility models, then again the forecasts rest on unexamined assumptions. They must assume that growth and development will proceed along global trend patterns without encountering serious Malthusian constraints ... The assumption that the end point of the transition is at replacement level fertility is supported neither by history nor by the logic of relevant social theory."

A review of global population models (Toth, Hizsnyik and Clark, 1989) recommended three models as most suitable for use in long-term, large-scale development-environment studies.

1. **World Population Prospects Estimates and Projections as Assessed in 1982.** (United Nations, 1985)
2. **Global Population (1975-2075) and Labor Force (1975-2050).** (Keyfitz et al., 1983)
3. **World Development Report 1984, World Population Projections 1984.** (World Bank, 1984).

Another critical appraisal of global population models is found in Lee (1989).

## REFERENCES


Ahmed, I. and V.W. Ruttan, eds. 1988. Generation and Diffusion of Agricultural Innovations: The Role of Institutional Factors. Aldershot, England: Gower Publishing Company Limited.

Anderberg, S. 1989. A Conventional Wisdom Scenario for Global Population, Energy, and Agriculture 1975 - 2075, and Surprise-Rich Scenarios for Global Population, Energy and Agriculture 1975 - 2075. In Scenarios of Socioeconomic Development for Studies of Global Environmental Change: A Critical Review, Toth et al., eds. RR-89-4. Laxenburg, Austria: IIASA.

Arnold, J.E.M. 1987. Deforestation. In Resources and World Development, D.J. McLaren and B.J. Skinner, eds. Chichester, England: J.Wiley and Sons.

Ausubel, J.H. and Herman, R., eds. 1988. Cities and Their Vital Systems, Infrastructure Past, Present and Future. Washington, D.C.: National Academy Press.

Ausubel, J.H. 1989. Regularities in Technological Development: An Environmental View in Technology and Environment, Ausubel, J. H. and Hedy E. Sladovich, eds. Washington D.C.: National Academy Press.

Ausubel, J.H., A. Grubler, N. Nakecenovic. Carbon Dioxide Emissions in a Methane Economy. Climatic Change.

Ayres, R.U. 1989. Technological Transformations and Long Waves. Laxenberg: Austria, International Institute for Applied Systems Analysis. Research Report, 89-1.

Ayres, R.U. 1989. Industrial Metabolism in Technology and Environment, Ausubel, J.H. and H.E. Sladovich, eds. Washington D.C.: National Academy Press.

Ayres, R.U., L.W. Ayres, J.A. Tarr, and R.C. Widgery. 1988. An Historical Reconstruction of Major Pollutant Levels in the Hudson-Raritan Basin: 1880-1980. NOAA Technical Memorandum NOS OMA 42. Washington, D.C.: United States Department of Commerce, National Oceanic and Atmospheric Administration.

Ayres, R.U., Norberg-Bohm, V., Prince, J., Stigliani, W.M., Yanowitz, J. 1989. Industrial Metabolism, the Environment, and Application of Materials-Balance Principles for Selected Chemicals. Laxenburg, Austria: IIASA Research Report.

Ayres, R.U., and S.R. Rod 1986. Reconstructing an environmental history: patterns of pollution in the Hudson-Raritan Basin. Environment 28(4):14-20, 39-43.

Binswanger, H.P., V.W. Ruttan, and Others. 1978. Induced Innovation. Baltimore, Maryland: John Hopkins University Press.

Bolin, B., B.R. Doos, J. Jager, R.A. Warrick, eds. 1986. The Greenhouse Effect, Climatic Change, and Ecosystems. Scope 29. Chichester: John Wiley & Sons.

Brookfield, H.C., F. Lian, L. Kwai-Sim, and L. Potter. 1990. "Borneo and Peninsular Malaysia"." In The Earth as Transformed by Human Action, B.L. Turner, et al., eds.. Cambridge: Cambridge University Press.

Brower, F.M. and M.J. Chadwick. Future Land Use Patterns in Europe. IIASA WP-88-040. Laxenburg, Austria: IIASA.

Burke, L. M. and D.A. Lashof. 1989. Greenhouse Gas Emissions Related to Agriculture and Land - Use Practices. Prepared for the Annual Meeting Proceedings of the Agronomy Society of America, Anaheim, California, Nov 27 to Dec 2, 1988 (Supported by U.S. Environmental Protection Agency).

Chandler, W.U. 1988. Assessing the Carbon Emission Control Strategies: The Case of China. Climatic Change.

Committee on Earth Sciences. 1989. Our Changing Planet: The FY 1990 Research Plan. Washington, D.C.: Office of Science and Technology Policy, Federal Coordinating Council on Science, Engineering, and Technology.

Committee on Global Change (U.S. National Committee for the IGBP). 1988. Toward an Undersatnding of Global Change, Initial Priorities for U.S. Contributions to the International Geosphere-Biosphere Program. Washington, D.C.: National Academy Press.

Council on Environmental Quality and Department of State. 1980. Global 2000 Report to the President: Entering the Twenty-first Century. Washington, D.C,: U.S. Government Printing Office. (Three Volumes).

Crosson, P.R. and B. Sterling. 1982. Resource and environmental effects of U.S. agriculture. Research paper from Resources for the Future. Washington, D.C.

Crutzen, P.J. 1987. Role of the tropics in atmospheric chemistry. In Geophysiology of Amazonia, Dickinson, R., ed. New York: J. Wiley & Sons.

Darby, H.C. 1983. The Changing Fenlands. Cambridge: Cambridge University Press.

Darmstadter, J., L.W. Ayres, R.U. Ayres, W.C. Clark, P. Crosson, P.J. Crutzen, T.E. Graedel, R. McGill, J.F. Richards, J.A. Tarr. 1987. Impacts of World Development on Selected Characteristics of the Atmosphere: An Integrative Approach, Vol 1 and Vol 2. ORNL/Sub/86-22033/1/V1. Oak Ridge, Tennessee : Oak Ridge National Laboratory.

Detwiler, R.P. and Hall, C.A. 1988. Tropical forests and the global carbon cycle. Science. Vol. 239.

Duchin, F. 1989. Framework for the Evaluation of Scenarios for the Conversion of Biological Materials and Wastes to Useful Products: An Input-Output Approach. Presented at the joint session of the American Economics Association/American Association for the Advancement of Science, "Prospects and Strategies for the American Economy," ASSA Meetings, New York, December 29, 1988.

Duchin, F. 1989. Project Proposal: Strategies for Environmentally Sound Development: An Input-Output Analysis. Institute for Economic Analysis, New York University.

Duchin, F. 1988. Analyzing Technological Change: An Engineering Data Base for Input-Output Models of the Economy. Engineering with Computers 4, 99-105.
Duchin, F. 1988. Analyzing structural change in the economy. In Input- Output Analysis: Current Developments (Ed. M. Ciaschini). London: Chapman Hall.

Duchin, F. 1989. An Input-Output Approach to Analyzing the Future Economic Implications of Technological Change. In Frontiers of Input-Output Analysis, Edited by R. Miller, K. Polenske, and A. Rose. New York: Oxford University Press, 1989.

Edmonds, J. 1989. A Second Generation Greenhouse Gas Emissions Model. Outline of Design and Approach.

Edmonds, J. 1988. "Editorial Response to Bill Keepin" Climatic Change.

Edmonds, J. and J. Reilly. 1985. Future Global Energy and Carbon Dioxide Eissions in Atmospheric Carbon Dioxide and the Global Carbon Cycle, J.R. Trabalka, ed. DOE/ER-0239. Washington, D.C.: U.S. Department of Energy.

Edmonds, J. and J. Reilly. 1985. Global energy: assessing the future. New York: Oxford University Press.

Edmonds, J. and Reilly, J. 1983. Global Energy and CO2 to the Year 2050. The Energy Journal, Vol. 4, No. 3.

Fisher, G., K. Frohberg, M.A. Keyzer, and K.S. Parikh. 1988. Linked National Models: A Tool For International Food Policy Analysis. Dordrecht: Kluwer Academic Publishers.

Fisher, J.C., and R.H. Pry. 1970. A Simple Substitution Model of Technological Change. Technological Forecasting and Social Change 3:75-88.

Food and Agriculture Organization of the United Nations. 1978-1981. Reports of the Agro-ecological Zones Project. World Soil Resources Report 48. Vol.1 - Vol.4 Rome: FAO.

Food and Agriculture Organization of the United Nations. 1981. Agriculture toward 2000. Economic and Social Development Series, 23. Rome: FAO.

Fox, G. and V.W. Ruttan. 1983. A guide to LDC food balance Projections. European Review of Agricultural Economics, Volume 10-4.

French, R.A. 1959. Drainage and Economic Development of Poles'ye, USSR. In Economic Geography 25, pp. 172-80.

Frohberg, K.K, and P.R. Bende Kamp. Results of Eight Agricultural Policy Scenarios for Reducing Agricultural Sources of Trace Gas Emissions. Center for Agricultural and Rural Development, Iowa State University.

Frosch, r. J.H. Ausubel, and R. Herman. 1989. Technology and Environment: An Overview. In Technology and Environment, J.H. Ausubel and H. E. Sladovich. Washington, D.C.: National Academy Press.

Goldemburg, J., T.B. Johansson, A.K.N. Reddy, and R.H. Williams. 1985. An End-Use Oriented Global Energy Strategy. In Annual Review of Energy 1985. Palo Alto, CA: Annual Reviews Press.

Goldemburg, J., T.B. Johansson, A.K.N. Reddy, and R.H. Williams. 1987. Energy for a Sustainable World. Washington, D.C.: World Resources Institute.

Goldemburg, J., T.B. Johansson, A.K.N. Reddy, and R.H. Williams. 1988. Energy for a Sustainable World. New Delhi, India: Wiley Eastern Limited.

Gordon, R.B., T.C. Koopmans, W.D. Nordhaus, and B.J. Skinner. 1987. Toward a New Iron Age. Cambridge, MA: Harvard University Press.

Grainger, Alan. 1987. A Land Use Simulation Model for the Humid Tropics in Proceedings of International Conference on Land and Resource Evaluation for National Planning in the Tropics, Chetumal, Mexico, January 25 - 31. Washington, D.C.: USDA Forest Service.

Grainger, Alan. 1984. Quantifying Changes in Forest Cover in the Humid Tropics: Overcoming Current Limitations. Journal of World Forest Resource Management, Vol. 1, No. 1. :

Haefele, W. and P. Basile. 1979. Modelling of long range energy strategies with a global perspective. In K.B. Haley, ed. Operation Research '78. pp. 493-529. North Holland, Amsterdam.

Haefele, W., J. Anderer, A. McDonald, and N. Nakicenovic. 1981. Energy in a finite world. Vol 1: Paths to a sustainable future. Vol 2: A global system analysis. Report by the Energy Systems Program Group. Cambridge, Massachusetts: Ballinger.

Hagerstrand, T. and U. Lohm. 1990. Sweden. The Earth as Transformed by Human Action. B.L. Turner II et al., eds. Cambridge: Cambridge University Press.

Hammit, J.K., K.A. Wolf, F. Camm, W.E. Mooz, T.h. Quin, and A. Bamezai. 1986. Product Uses and Market Trends for Potential Ozone-Depleting Substances. U.S. Environmental Protection Agency and RAND, Santa Monica.

Hayami, Y. and Ruttan, V.W. 1985. Agricultural Development. Baltimore, Maryland: The Johns Hopkins University Press.

Herman, R., S.A. Ardekani, and J.H. Ausubel. 1989. Dematerialization. In Technology and Environment, Ausubel, Jesse H. and Hedy E. Sladovich, eds. Washington D.C.: National Academy Press.

Houghton, R.A., R.D. Boone, J.E. Fruci, J.E. Hobbie, J.M. Melillo, C.A. Palm, B.J. Peterson, G.R. Shaver, G.M. Woodwell, B. Moore, D.L. Skole, N. Myers. 1987. The flux of carbon from terrestiral ecosystems to the atmosphere in 1980 due to changes in land use: Geographic distribution of the global flux. Tellus. 39B. :

International Istitute for Environment and Development and World Resources Institute. 1987. World Resources 1987. New York, N.Y.: Basic Books, Inc.

Kallio, M., D.P. Dykstra and C.S. Binkley. 1987. The Global Forest Sector. Chichester, England: J. Wiley and Sons.

Keepin, B. 1988. Caveats in Global Energy/CO2 Modeling. In Climatic Change.

Keyfitz, N. 1982. Can Knowledge Improve Forecasts? Population and Development Review 8, No. 4.

Keyfitz, N. 1981. The Limits of Population Forecasting. Population and Development Review, Vol 7, No. 4.

Lanly, Jean Paul. 1982. Tropical Forest Resources. Rome, Italy: United Nations Food and Agriculture Organization.

Lashof, D.A. and D.A. Tirpak. 1989. Policy Options for Stabilizing Global Climate. Draft Report to Congress. Washington, D.C.: U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation.

Lee, Ronald. 1989. The Second Tragedy of the Commons. Berkeley, CA: Graduate Group in Demography, University of California.
Lee, Ronald. Longrun Global Population Forecasts: A Critical Appraisal. Demography and Economics, University of California, Berkeley.

Lee, T.H. and Nakicenovic, N. 1988. Technology Life-Cycles and Business Decisions, International Journal of Technology Management, Vol. 3, No. 4.

Linnemann, H., J. De Hoogh, M.A. Kayzer, H.D.J. Van Heemst. 1979. MOIRA model of International Relations in Agriculture. Amsterdam: North-Holland Publishing Company.

Manning, Edward W. 1988. The Analysis of Land Use Determinants in Support of Sustainable Development. Laxenburg, Austria: IIASA Research Report.

Marchetti, C. November, 1981. Society as a Learning System: Discovery, Invention, and Innovation Cycles Revisited. RR-81-29. Laxenburg, Austria: IIASA Research Report.

Marchetti, C. July 1983. The Automobile in a System Context: The Past 80 Years and the Next 20 Years. RR-83-18. Laxenburg, Austria: IIASA Research Report.

Marchetti, C. 1988. Infrastructures for Movement: Past and Future. In Cities and Their Vital Systems; Infrastructure Past, Present, and Future, J.H. Ausubel and R. Herman, eds. Washington, D.C.: National Academy Press.

Marchetti, C. and Nakicenovic, N. 1979. The Dynamics of Energy Systems and the Logistic Substitution Model. RR-79-13. Laxenburg, Austria: IIASA Research Report.

Marland, G. 1982. The impact of synthetic fuels on carbon dioxide emissions in Clark, W.C., ed. Carbon Dioxide Review. New York: Oxford University Press.

Marland, G., T.A. Boden, R.C. Griffin, S.F. Huang, P. Kanciruk, and T.R. Nelson. 1988. Estimates of CO2 Emissions from Fopssil Fuel Burning and Cement Manufacturing Using the United Nations Energy Statistics and the U.S. Bureau of Mines Cement Manufacturing Data. Oak Ridge: Oak Ridge National Laboratory.

Mintzer, I.M. 1987. A Matter of Degrees: The Potential for Controlling the Greenhouse Effect. Washington, D.C.: World Resources Institute.

Mintzer, I.M. 1988. Projecting Future Energy Demand in Industrialized Countries: An End-Use Oriented Approach. Washington, D.C.: U.S. Environmental Protection Agency.

Myers, Norman. 1980. Conversion of Tropcal Moist Forests. Washington, D.C.: National Academy of Sciences.

Myers, N. 1986. Tropical Forests: Patterns of Depletion. Tropical Rain Forests and the World Atmosphere. AAAS Select Symposium 101. Westview Press, Inc., Boulder CO.

Nakicenovic, N. 1988. Dynamics and Replacement of U.S. Transport Infrastructures. In Cities and Their Vital Systems; Infrastructure Past, Present, and Future, J.H. Ausubel and R. Herman, eds. Washington, D.C.: National Academy Press.

Nordhaus, W.D., and G.W. Yohe. 1983. Paths of Energy and Carbon Dioxide Emissions in Changing Climate. Washington, D.C.: National Academy Press.

Nriagu, J.O. 1989. A global assessment of natural sources of atmospheric trace metals. Nature Vol. 338.
Nriagu, J.O. and J.M. Pacyna. 1988. Quantitative assessment of worldwide contamination of air, water and solid by trace metals. Nature vol. 333.

Palo, M. 1987. Deforestation Perspectives for the Tropics: A Provisional Theory with Pilot Applications. In The Global Forest Sector, Kallio, M., D.P. Dykstra and C.S. Binkley, eds. Chichester, England: J. Wiley and Sons.

Parks, P.J. and Alig, R.J. 1988. Land Base Models for Forest Resource Supply Analysis: A Critical Review". Canadian Journal of Forest Research, Vol. 18.

Parikh, K.S. 1981. Exploring national food policies in an international setting. Publication number WP-81-12. Laxenburg, Austria: IIASA>

Parks, P.J., ed. 1988. Land Area Modeling and Its Use in Policy: A workshop on Current Research. Duke University, Durham, NC

Peterka, V. November 1977. Macrodynamics of Technological Change: Market Penetration by New Technologies. RR-77-22. Laxenburg, Austria: IIASA Research Report.

Phipps, T.T., P.R. Crosson, and K.A. Price, eds. 1986. Agriculture and the Environment. Washington, D.C.: Resources for the Future, Inc.

Pyne, Stephen J. 1982. Fire in America, A Cultural History of Wildland and Rural Fire. Princeton, N.J.: Princeton University Press.

Radian Corporation. 1988. Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of NOx, N20, CH4, CO and CO2. Triangle Park: U.S. Environmental Protection Agency.

Richards, J.F. 1986. World Environmental History and Econmic Development. In Sustainable Development of the Biosphere, W.C. Clark and R.E. Munn, eds. Cambridge, England: Cambridge University Press.

Richards, J.F., J.S. Olson, R.M. Rotty. 1983. Development of a Data Base for Carbon Dioside Releases Resulting from Conversion of Land to Agricultural Uses. Oak Ridge: Institute for Energy Analysis.

Richards, J.R and Richard P. Tucker. 1988. World Deforestation in the Twentieth Century. Durham, North Carolina: Duke University Press.

Robinson, J.M. 1987. The Role of Fire on Earth: A review of the State of Knowledge and a Systems Framework for Satellite and Ground-Based Observations, PhD Dissertation, Dept of Geography, U. of California, Santa Barbara, Ca.

Robinson, J.M. 1989. On Uncertainty in the Computation of Global Emissions from Biomass Burning. Climatic Change.

Rotty, R.M. and Masters, C.D. 1985. Carbon dioxide from fossil fuel combustion: Trends, resources and technological implications. In Atmospheric Carbon Dioxide and the Global Carbon Cycle, J.R. Trabalka, ed. Washington, D.C.: U.S. DOE.

Ruddle, K. 1987. The Impact of Wetland Reclamation. In Land Transformation in Agriculture (SCOPE 32), M.G. Wolman and F.G.A. Fournier, eds. Chichester: John Wiley & Sons.

Ruttan, V.W. 1985. Technical and Institutional Change in Agricultural Development: Two Lectures. Economic Development Center, Department of Agricultural and Applied Economics, University of Minnesota.

Sathaye, J.A.; Ketoff, A.N.; Schipper, L.J.; and Lele S.M. 1988. An End-Use Approach to Development of Long-Term Energy Demand Scenarios for Developing Countries. Washington, D.C.: U.S. Environmental Protection Agency.

Schurr, S.H. 1984. Energy Use, Technological Change, and Productive Efficiency: An Economic-Historical Interpretation in Annual Review of Energy 1984. Palo Alto, CA: Annual Reviews Press.

Seiler, W. and Crutzen, P.J. 1980. Estimation of Gross and Net Fluxes of Carbon between the Biosphere and the Atmosphere from Biomass Burning. Climatic Change 2, 207-247.

Shah, M.M., G.M. Higgins, A.H. Dassam and G. Fischer. 1985. Land resources and productivity potential - agro-ecological methodology for agricultural development planning. Publication number CP-85-14. Laxenburg, Austria: IIASA.

Shaw, R. 1989. The Study of Chemical Pollution and Its Sources in Dutch Estuaries and Coastal Regions, a Proposal for a Collaborative Agreement. IIASA, Laxenburg, Austria.

Spinrad, Bernard I. July 1980. Market substitution Models and Economic Parameters. RR-80-28. Laxenburg, Austria: IIASA Research Report.

Srinivasan, T.N. 1988. Population Growth and Food, An Assessment of Issues, Models, and Projections in Population, Food and Rural Development, ed. Lee, R. et al. Oxford, England: Clarendon Press.

Starr, Chauncy. 1989. Comments at meeting of the Working Group on Human Interactions with Global Change.

Stavins, R. N. 1989. Alternative Renewable Resource Strategies: A Simulation of Optimal Use. Discussion Paper Number E-89-10. Cambridge, Massachusetts: Harvard University, Energy and Environmental Policy Center.

Stavins, R. N. and Adam B. Jaffe. 1988. Forested Wetland Depletion in the United States: An Analysis of Unintended Consequences of Federal Policy and Programs. Discussion Paper Number 1391. Cambridge, Massachusetts: Harvard Institute of Economic Research.

Stigliani, W.M., F.M. Brouwer, R.E. Munn, R.W. Shaw, and M. Antonovsky. 1989. Future Environments for Europe: Some Implications of Alternative Development Paths, Executive Summary. IIASA Executive Report 15. IIASA.

Stigliani, W.M., F.M. Brouwer, R.E. Munn, R.W. Shaw, and M. Antonovsky. 1989. Future Environments for Europe: Some Implications of Alternative Development Paths. RR-89-5. Laxenburg, Austria: IIASA.

Subak, Susan. 1989. Accountability for Climate Change. Cambridge, Massachusetts: Kennedy School of Government Discussion Paper (in press).

Svedin, U. and B. Aniansson, eds. 1987. Surprising Futures, Notes from an International Workshop on Long-term World Development. Stockholm: Swedish Council for Planning and Coordination of Research.

Toth, F.L., E. Hizsnyik, and W.C. Clark, eds. 1989. Scenarios of Socioeconomic Development for studies of Global Environmental Change: A Critical Review. RR-89-4. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Tucker, R.P. and J.F. Richards. 1983. Global Deforestation and the Nineteenth Century World Economy. Durham, N.C.: Duke University Press.

Turner II, B., W.C. Clark, R.W. Kates, J.T. Mathews, J.R. Richards, and W. Mayer, eds. 1990. The Earth as Transformed by Human Action. Proceedings of an international symposium held at the Graduate School of Geography, Clark University, Worcester, Mass., October 25-30, 1987. Cambridge: Cambridge University Press.

U.S. Bureau of the Census. 1987. World Population PRofile: 1987. Washington, D.C.: U.S. Department of Commerce.

U.S. Department of Energy. 1988. An Assessment of the Naturyal Gas Resource Base of the United States. Washington, D.C.: U.S. DOE

U.S. Environmental Protection Agency, Office of Air and Radiation. 1987. Assessing the Risks of Trace Gases That Can Modify the Stratosphere. Washington, D.C.: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. 1988. Regulatory Impact Analysis: Protection of Stratospheric Ozone. Washington, D.C.: Office of Air and Radiation, Environmental Protection Agency.

U.S. Environmental Protection Agency. February 1988. Office of Policy, Planning, and Evaluation. "Policy Options for Stabilizing Global Climate." DRAFT.

Williams, M. 1974. The Making of the South Australian Landscape, a study in the historical geography of Australia. New York: Academic Press.

Williams, R. H., Eric D. Larson, and Marc H. Ross. 1987. Materials, Affluence, and Industrial Energy Use in Annual Review of Energy 1987. Palo Alto, CA: Annual Reviews Press.

Wolman, M.G. and Fournier, F.G.A., eds. 1987. Land Transformation in Agriculture, SCOPE 32. J.Wiley and Sons.

Woodwell, G.M., J.E. Hobbie, R.A. Houghton, J.M. Melillo, B. Moore, B.J. Peterson, and G.R. Shaver. 1983. Global Deforestation: Contribution to Atmospheric Carbon Dioxide. Science 222, 1081-1086.

World Bank. 1987. World Development Report 1987. New York: Oxford University Press.

World Resources Institute and International Institute for Environment and Development. 1988. World Resources 1988-89. New York: Basic Books Inc.

Zachariah, K.C. and M.T. Vu. 1988. World Population Projections: 1987-88 Edition. Baltimore, MD: Johns Hopkins University Press.

## NOTES

1. For current information on data sources of greenhouse gas emission levels, and of human activities which cause greenhouse gas emissions, see Lashof and Tirpak (1989). For a discussion of the strengths and weaknesses of current observational programs in the area of human interactions with global environmental change, see Committee on Earth Sciences (1989).

2. The examples given are based on the author's knowledge and do not represent a thorough review of all data. Lack of a listing does not necessarily indicate there are no appropriate data bases. Likewise, inclusion does not indicate reliability of the data.

## THE GLOBAL ENVIRONMENTAL POLICY PROJECT

The Global Environmental Policy Project (GEPP) began in 1989 as a joint effort of the Kennedy School of Government's Energy and Environmental Policy Center (EEPC) and its Science, Technology and Public Policy Program (STPP), and the Harvard Business School Negotiations Project. The Global Environmental Policy Project focuses on four subjects:

- *Options for Negotiations*

  In recent history, regional agreements have emerged bringing together countries who share a common resource. There are lessons to be learned from the formulation and implementation of these environmental negotiations. The Project explores various global negotiations issues, including technology transfer from developed to developing countries, funding mechanisms to cover the cost of reforestation, and $CO_2$ emissions and reductions.

- *Analytic Tools*

  The analytical tools that we use to evaluate environmental impact and mitigation options were developed to combat problems with local impact and short time frames. These tools are not adequate for the examination of issues, such as global climate change, which are characterized by long-time horizons, tremendous factors of uncertainty, and a broad spectrum of perceptions among nations. The Project is developing a range of analytical techniques for the evaluation of policy options to provide governments with decision rules to assist in their selection among these options.

- *Social Learning*

  GEPP researchers are looking at how nations have responded to issues of global environmental change over the past forty years. What lessons can we draw from these experiences? Are societies improving their responses to issues of environmental change? What impedes more rapid progress? Given that different countries react differently, what can we learn from these different responses and how can we use these lessons in developing future programs and policies?

- *Training*

  Global environmental issues will require nations to look at energy, environment, security and economic policy in a more integrated fashion. Furthermore, they will force countries to absorb more scientific and technical information than they can currently evaluate. Many nations do not have the internal capability independently to assess information being generated on global environmental problems.

  The Project is attempting to develop an executive program to teach senior government officials how to assess and manage global and regional environmental problems.