COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK
VICE PROVOST

Domestic Studies

'98 MAY 19 AM9:21

May 7, 1998

The Honorable Todd D. Stern
Assistant to the President and Staff Secretary
The White House
1600 Independence Avenue
Washington, D.C. 20500

Dear Todd:

Attached is a summary analysis that was prepared regarding our efforts with the development of Biosphere 2 Center in Arizona. This report was prepared at our request by Frank Press (former President of the National Academy of Sciences), Bob White (former President of the National Academy of Engineering), Frank Rhodes (former President of Cornell University), and Eric Bloch (former Director of the National Science Foundation). We asked these individuals to analyze the intellectual and programmatic objectives of the Biosphere 2 Center strategy and the emerging content of the educational, research and outreach programs. I think that you will find their comments of interest.

Sincerely,

Michael

Michael M. Crow
Vice Provost

Attachment

Todd -
Jerry Melillo at OSTP was on the review panel and thinks this asset should be used as a post Kyoto research tool.

Low Memorial Library, Room 205 Mail Code 4312 535 W. 116th Street New York, NY 10027 212-854-2761 Fax 212-932-0418 mc71@columbia.edu

The Washington
Advisory
Group LLC

Biosphere 2 Center

Prepared for
Columbia University

by
The Washington Advisory Group

March 31, 1998

Acknowledgments

This project was carried out by a team from the Washington Advisory Group: Erich Bloch, Bruce Guile, Frank Press, Frank H.T. Rhodes, and Robert M. White. All of the members of the team made at least one site visit to B2C and several members made additional visits to Oracle to meet with the B2C administration or members of the Earth Learning Center Advisory Committee. In addition, the team spent a day in New York City with faculty and administrators of Columbia's Earth Institute. We'd like to thank William Harris, President and Executive Director of B2C, and Michael Crow, Vice Provost at Columbia, for their excellent support in executing this project. In addition, we would like to thank the members of the Earth Learning Center Advisory Committee who spent considerable time and effort educating the Advisory Group team about B2C and the apparatus. In particular, Joseph Berry, Harold Mooney, Boyd Strain and Phillip Dougherty gave generously of their time.

The Washington Advisory Group retained, and the team was joined during one visit to the facility, by three additional specialists: Jerry Melillo of the Ecosystem Center at the Marine Biological Laboratory at Woods Hole; Peter Raven of the Missouri Botanical Garden, and Joseph Yavitt from the Department of Natural Resources of Cornell University. We would like to thank these individuals for their substantial contributions, though it is important to note that they bear no responsibility for the final content of the report. Errors and omissions are the responsibility of The Washington Advisory Group, LLC.

Table of Contents

Executive Summary 1
Report to Columbia University on Biosphere 2 Center 3
The Unique Potential of the B2 Apparatus. 4
The Value of Learning From Experience with the B2 Apparatus 8
The Value of Columbia's Organizational Experiment. 9
Pressing Current Challenges and Questions for the B2C Enterprise 12
Research Management Challenges for B2C. 12
Building a Research Consortium 14
Graduate and Undergraduate Education at B2C. 16
Public Education. 18
Columbia's Immediate Management Challenges 19
Integrating B2C and the Earth Institute. 19
Additional Immediate Management Challenges. 20
Critical Next Steps for B2C 21
APPENDIX 1 23
APPENDIX 2 25
APPENDIX 3 28

Executive Summary

Large-scale, closed, and controlled facilities[1] offer unusual opportunities for the conduct of certain kinds of environmental research. In particular, a large-scale, closed-system facility like the Biosphere 2 apparatus represents a promising experimental device for studying problems in ecosystem dynamics. Only in a large-scale closed-system facility can significant aspects of ecosystems and their dynamics be studied under controlled conditions. The precise measurements that fully and accurately characterize ecosystems in terms of mass flows, chemical circulation of elements, and response to multiple stresses are amenable to study in systems such as the Biosphere 2 apparatus.

The Biosphere 2 apparatus--operated as an accessible, large-scale, closed facility--has great promise. There, however, are a host of non-trivial technical and engineering challenges that need to be addressed. These include effective control over the internal environment, the accuracy of measurement systems, and the degree to which the processes in the facility are representative of natural systems and processes.

Columbia and B2C--with the help of the Earth Learning Center Advisory Committee--are demonstrating that valuable work can be done in the apparatus with relatively small additional investments in re-engineering the apparatus. They have made important facilities modifications and are starting to see the results of their investment in published research results. As a result, the B2C apparatus has begun to attract important intellectual interest.

Columbia's role in B2C challenges the ecoscience research community to learn how to design, build, use, and re-engineer large-scale closed facilities. An important feature of the Biosphere 2 apparatus is the role it can play as a first generation research tool from which the research community can learn a) a great deal about what needs to be designed into the next generation and b) the kinds of environmental issues that are amenable to studies in large-scale closed facilities.

Biosphere 2 Center has the potential--with significant but marginal additional investment--to be the distinctive and important element of Columbia's university-wide initiative to become a leading academic center in Earth System research, education, and policy formulation. The 250 acres of Sonoran desert that surround the Center are a wonderful natural site, providing an ideal ecological setting for long-term studies and instruction. The site in Arizona is, however, isolated and remote from

---

[1] A closed facility and a controlled facility are not the same thing, but they are treated here as one category of "closed" facilities that are fully controlled and may also be closed if the research demands it.

Columbia. This raises issues of effective communication with Lamont-Doherty, B2C, Columbia and other locations. It also requires continuing attention to increasing and maintaining Columbia faculty participation in the work of B2C. Further, Columbia University lacks depth in areas of ecological science, agriculture, forestry and relevant engineering that are important to B2C's success. This suggests both that Columbia may need to strengthen those areas and that they look to establish one or more strategic partnerships with other institutions.

The success of the Biosphere 2 apparatus as a research facility may depend on Columbia's ability to create and lead an effective research consortium. Facilities on the scale of the Biosphere 2 apparatus are often operated by a consortium--or by a single institution on behalf of a consortium--that shares in governance, fund raising, and participation of its staff and students in its research and training programs. Columbia has already taken the first steps in opening discussions with other institutions. An attempt should be made to bring together a small group of institutions with a deep interest in ecoscience to experiment with the ways in which a larger consortium of institutions might govern the closed facility which would be operated by Columbia University.

The viability of graduate education at B2C depends entirely on involvement of first rank research faculty, which in turn depends on the viability and quality of the research programs which as yet are unproven.

Biosphere 2 Center has successfully launched an undergraduate "earth semester" program that could form the core of a substantially expanded undergraduate program at the Center. The present undergraduate student group at B2C is heterogenous in terms of background and interests. To strengthen B2C's potential as a center for research and graduate education increased effort should be placed on programs which attract science majors into the undergraduate student body.

The public education and outreach programs of B2C are already having a favorable impact and, with additional investments and new concepts, this program can be greatly strengthened.

REPORT TO COLUMBIA UNIVERSITY ON BIOSPHERE 2 CENTER

The Biosphere 2 apparatus is an imposing steel and glass structure set in the Arizona desert. It is the world's largest closed ecological laboratory. Beyond its sheer size (3.15 acres), Biosphere 2 apparatus is unique among such facilities in its complexity, both biologically and technically. Within the apparatus as designed and built there are five distinct but contiguous biomes--ocean, rainforest, desert, thorn scrub, and agricultural (a.k.a. the intensive agricultural biome or IAB). Appendix 1 provides several figures and a brief introduction to the apparatus.

The apparatus was developed originally by the private sector to support missions with people living inside to determine whether it was possible to sustain life as we know it for up to 2 years without material transfer from the outside. In January 1996, Columbia University assumed responsibility for the development of the apparatus, along with functional control over an extensive (250 acre) "campus" that surrounds the apparatus. This enterprise--the apparatus, the supporting infrastructure, housing for staff and students, a small conference hotel, the facilities for and operation of a public tour of the apparatus--is known as Biosphere 2 Center or B2C. Columbia's challenge has been to determine the best possible use for the apparatus and the center with respect to teaching, research, and learning in the broad area of ecoscience.

During 1996 and 1997, Columbia systematically invested in the development of the apparatus and the enterprise by hiring on-site leadership and staff, creating management structures, launching an "Earth Semester" program for qualified undergraduates from any college or university, and both laying the foundation for, and initiating research, in the apparatus. Two years ago B2C as an integrated teaching, research and outreach campus was mostly an idea. It is now a functioning multi-purpose enterprise with the promise of durable success in several activities.

In the fall of 1997, Columbia University asked the Washington Advisory Group to assess the potential of the apparatus and B2C to become an internationally recognized center for ecoscience research, education, and public outreach. The specific request was that the Advisory Group address three sets of questions (see Appendix 2). The first two sets of questions focus on the value of large-scale closed facilities for use in research, education, and public outreach. The final set of questions deal with the potential contributions of B2C--in the context of Columbia's Earth Institute--to the development of integrated ecoscience research, teaching and public outreach.

The questions are addressed in the first three major sections of this report. A fourth section defines a set of challenges that Columbia and B2C face in transforming B2C into a viable high-quality enterprise and recommends a series of actions. A brief appendix (Appendix 3) addresses some of challenges presented in converting the B2 apparatus into a useful research tool.

The Unique Potential of the B2 Apparatus

There is now a universal realization, not quite yet a commitment, that responsible Earth stewardship on the part of humanity is required to assure the continuing health of the planet. At the core of humankind's ability to exercise responsible Earth stewardship is the understanding of the processes of the biosphere and its ecosystems--industrial, natural, and managed.

Crucial among Earth system processes are those that involve the interactions between the biosphere--the living world--and the geosphere--the oceans, the atmosphere, and the solid earth. How do ecosystems respond to changes in the physical conditions surrounding them? In what ways do they in turn affect the geosphere? How do the biosphere and geosphere maintain the life support systems of the planet? What roles do the biosphere and geosphere play in the growing concentration of greenhouse gases, such as carbon dioxide in the atmosphere, that directly affect the climate? Our knowledge of biosphere/geosphere interactions has improved greatly over the years, but it still deficient. Many questions are difficult to investigate in the open environment; the Biosphere 2 apparatus can be useful in addressing some of these questions.

Scientific studies of the biosphere, atmosphere, hydrosphere or oceans face the imposing dilemma that the processes to be studied occur on such large scales that research on them has traditionally required approaches that: a) deduce their characteristics from the historical record (data often collected for other purposes) or from limited observations; or b) model the processes by extrapolation of physical and biological processes studied at smaller scales. Special observing and measurement campaigns address particular questions (e.g., NSF's long-term environmental research sites [LTER's], the DOE's atmospheric radiation measurement [ARM] program, and the IRIS mobile seismic array) and provide data from which earth systems dynamics are deduced. Small-scale laboratory work has also made substantial contributions to understanding key global processes. An excellent example is the research that explained the chemical processes responsible for the decrease of stratospheric ozone. It is, however, clear that a host of important research questions about ecosystem dynamics and biogeochemical processes are not amenable to small-scale laboratory experimentation or easily comprehended in the open environment. Therefore, large-scale, closed, and

controlled facilities[2] offer unusual opportunities for the conduct of certain kinds of research and related educational activities.

In particular, a large-scale, closed-system facility represents a useful experimental device for studying problems in ecosystem dynamics. The response of individual plants, or small groups of plants, have been and can be more easily studied in small-scale facilities or within the laboratory. Only in a large-scale closed-system facility can the broader scale working ecosystem and its dynamics be studied under controlled conditions. The ability to trace exchanges of water, carbon, nitrogen, and other elements within a closed system give it unique advantages. In a closed facility, perturbation experiments--which drive an ecosystem from one state to another--can be a tool for exploring problems of ecosystem dynamics that are relevant to ecosystem management and restoration.

While there should be no presumption that an experimental ecosystem in a closed facility will mimic natural ecosystems outside the facility, there is much useful information on ecosystem dynamics that can be generated using a physical model of an ecosystem in a controlled facility. In particular, managed ecosystems, such as plantation forests or agro-ecosystems, may be modeled relatively effectively in a large closed facility and, therefore, present good opportunities for study. There are opportunities to try a variety of "treatments" or "insults" on such a closed ecosystem and to observe the ecosystem's response. Results from such work can add to the probability that hypotheses about real world dynamics are right or wrong. Such work can provide information that will be useful both in formulating actions to manage or repair ecosystems, and in understanding the response of ecosystems to external forces.

Further, in research in the fields of biogeochemistry, ecology, and industrial ecology the ability to fully and accurately characterize the system under scrutiny in terms of the mass flows and chemical circulation of elements can improve understanding of the biospheric dynamics. In this context, large-scale closed facilities that are designed and managed to assess mass balance create opportunities to do important research in science and engineering. For example, uncertainties arise from a lack of knowledge of the global carbon cycle, a biogeochemical cycle that involves the transfer and storage of carbon between and among the biosphere, the atmosphere, the oceans and the solid earth. A knowledge of this cycle is essential to predicting the concentration of atmospheric carbon dioxide, which has been systematically increasing over the past century, raising the threat of significant climate warming, a sea level rise and shifting ecosystems. In this biogeochemical cycle, the biosphere plays a central role and important insights can be obtained in a carefully controlled large-scale closed facility.

---

[2] A closed facility and a controlled facility are not the same thing, but they are treated here as one category of "closed" facilities that are fully controlled and may also be closed if the research demands it.

Therefore, large-scale closed systems such as B2C offer possibilities for addressing major knowledge gaps such as the following:

- There is a growing recognition of the need for and the difficulty of understanding multiple stresses on ecosystems as a key aspect of changing climate. The responses of ecosystems to multiple stresses--CO_2 enhancement, precipitation intensity and frequency, and elevated temperatures-- are poorly understood and difficult to assess in other than controlled conditions available in closed environments.

- Among the key problems that arise as a result of the interaction of the biosphere and geosphere are those that involve biogeochemical cycling of elements through terrestrial and marine biospheres, the atmosphere, oceans and the solid earth. The circulation of nutrients and carbon among plants, soils, and atmosphere requires a means of assessing mass balances with precision that is only possible in a closed system. Sequestration of carbon, an important factor in understanding the process of global climate warming, is an example of a scientific issue that can be illuminated in a closed system by examination of plant responses to CO_2 enhancement.

- An understanding of ecosystem dynamics is necessary not only for the light that can be shed on issues related to global change and ecosystem deterioration, but on broader issues of the management and restoration of ecosystems. Detailed information about ecosystem response to environmental and other external forces can be documented in a closed system.

The B2 apparatus was not designed specifically for ecosystem science and was not, in its initial configuration, well suited for the types of experimental studies now envisioned (see Appendix 3). There are, however, important and unique opportunities; the near-term value of an accessible, well-managed, large-scale, closed facility could be substantial. For the facility to be truly valuable for research, there are a variety of technical and engineering challenges--such as the degree of effective control over the internal environment, the accuracy of measurement systems, and the degree to which the processes in the facility are representative of natural systems and processes--that need to be addressed.

Despite design limitations, relatively marginal levels of investment will make it possible to do some valuable mass balance and ecosystem dynamic work, especially in the Ocean Biome and the IAB. Indeed, Columbia and B2C--with the help of the Earth Learning Center Advisory Committee[3] (ELCAC)--are already demonstrating that valuable work can be done with relatively marginal investments. B2C is engaged in a baseline facility assessment (to determine exactly what the apparatus can do); has systematically

---

[3]An advisory committee to B2C composed of plant scientists, ecologists, marine biologists, soil scientists, and forestry researchers from a wide variety of institutions.

studied and begun to fully cost the upgrades necessary to re-engineering the facility; has made important facilities modifications to enable some research to be performed; and is starting to see the results of its investment in published work. As a result of these efforts, there are a host of current, credible and intriguing proposals for work in the apparatus, ranging from projects to study crop periodicity in trees to the long-term effects of global change on a typical tropical agroforestry system. In short, building on the involvement of Columbia faculty and the ELCAC, the B2 apparatus has begun to attract the serious intellectual interest of a wide range of first rank researchers and educators.

Most of the proposed work, however, requires some re-engineering and, by implication, some choices about long-term directions in the use of the facility. While the cost of re-engineering can be substantial relative to the direct costs of the research proposed, the re-engineering costs are minimal when compared to the cost of building a new facility. Further, the apparatus presents two unique opportunities: a) for the community to learn how to design and use large-scale facilities big enough for trees and ecosystem studies; and b) to pioneer the integration of work between those in different disciplines (biologists, chemists, hydrologists, climatologists, mathematical modelers) in the use of large-scale closed facilities for ecoscience.

Even though Columbia has received long-term control of the apparatus as a gift, the fundamental design of the apparatus raises the issue of upgrade and operating costs. This is, from the perspective of Columbia and the community that supports research, a critical issue. First, a number of key performance characteristics will largely determine the value of the apparatus for research. Upgrades to assure the ability to control conditions in a biome (environmental controls and degree of closure) and the ability to collect and analyze data (sensor network) will be part of the cost of launching most research projects in the facility. These, as well as other design-determined costs--e.g. the costs of changing between one experimental path and another, or the costs and time to replace the soils--are unlikely to be one-time costs, but more in the nature of virtually continuous re-engineering.

Second, operating costs of the facility are substantial--on the order of $3 million per year. Indirect costs on research projects must be competitive with prevailing rates. This implies that operating costs must be borne not only by research but also by educational, public outreach, and philanthropic sources. Columbia may have to seek philanthropic support to "keep the doors open" for research and learning about large-scale, closed, and controlled environments until these programs become credible and a consortium has been established.

B2C--with the apparatus at its core--is also demonstrably valuable with regard to educational goals for undergraduates, graduates, professional groups, policy-makers, and the public. The educational value of B2C as a public outreach device to increase the understanding of the general public on the nature of research and the important

environmental problems that humanity confronts is great, and is already demonstrated. It can become an attractive facility, around which a community of students and scholars can be assembled. The educational contribution of B2C at the graduate level, and the ability of B2C to make a substantial contribution in undergraduate education for science majors, depends on the viability and attractiveness of the large-scale, closed facility for conducting front-line research. The value of B2C as an educational enterprise is discussed in more depth in a later section of this report.

The Value of Learning From Experience with the B2 Apparatus

Biosphere 2 Center is an experiment in learning how to operate a facility in a way to make it institutionally attractive to other universities, to funding agencies, and to communities of scholars. In many fields of science, large facilities are too expensive for single investigators or even single institutions. As a result, it has become commonplace for shared facilities to be operated by single institutions or a consortium for the benefit of a broad national or international user community. No closed-system facility of the magnitude and complexity of Biosphere 2 Center exists that enables the study of whole working ecosystems and their interaction with the surrounding environment. Most scientists who might seek research opportunities inherent in a large-scale, closed ecoscience facility such as the B2 apparatus have little or no experience with them. Therein lie challenges and opportunities for learning from experience with the B2 apparatus.

First, the ecoscience research community is challenged to learn how to design, build, use, and re-engineer large-scale closed facilities. With the B2 apparatus this common cycle of research tool development begins in the middle: the first challenge is how to use the B2 apparatus, which raises questions about how it should be re-engineered, which, in turn, should lead the community to think differently about how the next apparatus to be built should be designed. This is a truly unique feature of the B2 apparatus and one that may create an enduring contribution--as a first generation research tool where the research community learns what needs to be designed into the next generation and the kinds of environmental issues that are amenable to studies in large-scale closed facilities.

Because of the very large size of the B2 apparatus, much of what has been proposed as valuable science takes advantage of its large scale. Many of the projects proposed can be done in just one of the five biomes. This means there is room to experiment with different approaches to re-engineering the B2 apparatus to suit the demands of ecoscience research in large-scale closed facilities. While the facility was not designed to do ecosystem research, there is a tremendous amount to be learned from careful analysis of the facility's construction and operation to date.

The experimental demands with regard to sunlight, heat, and soil (discussed in Appendix 3) are a small part of what can be learned from the experience with the B2 apparatus. The difficulties of sealing a large structure, managing a large salt water biome that is not open to the ocean, and the ecosystem dynamics of the original plants and animals introduced in the B2C are equally instructive for those who would design and build the next generation of large-scale, closed research facilities for ecoscience. It is critically important to document carefully what is known and has been recorded about past experience with this unique structure.

Second, a large-scale closed facility is like a research vessel, accelerator, or seismic array only in the broadest sense. It has its own special characteristics. A facility dedicated to studying the biogeochemistry and dynamics of an ecosystem over several growing cycles is not available for other work until the project is complete. In an accelerator, time at a detector can be productively allocated in short bursts. In a research vessel, time may be allocated in months or a year with some experiments running simultaneously. The prospect for large-scale, closed systems for ecoscience research is that time will need to be allocated in blocks of several years and it will require some very creative thinking and coordination to allow experiments to run in parallel. This research management challenge is non-trivial, but poses an opportunity for B2C to make a durable contribution to the structure of ecoscience research in closed facilities.

Third, almost anything significant proposed for the B2 apparatus will demand an approach that draws on historically distinct disciplines. Not only are ecologists trained in biology, botany, zoology, or microbiology needed, but also geophysicists, biogeochemists, engineers, and others. There is a real necessity for interdisciplinary approaches to research problems in a large-scale closed facility. Although interdisciplinary research is common in ecoscience, building a research community--by involving credible scientists willing to bridge traditional fields and work in a pioneering facility--is a fundamental challenge for B2C's research program. To date, almost everything significant proposed for the B2 apparatus is untried. If successful, B2C could help nucleate a community of scientists who, over the course of their careers, develop new capabilities for experimental approaches to ecoscience that can fully exploit the potential contributions of large-scale closed facilities.

The Value of Columbia's Organizational Experiment

A multiplicity of attributes in Oracle give an upgraded B2C the potential to be the distinctive element of Columbia's university-wide initiative to become a leading academic center in Earth System research, education, and policy formulation. These include B2C as:

- a magnet for attracting scholars engaged in laboratory or field research;
- a site for graduate students and their advisers, providing many opportunities for dissertation research on a number of important, accessible, ecological systems, such as those found in the Sonora desert, the Basin and Range Province, and the Cordillera;
- an attractive center in an extraordinary setting for undergraduate education in the environmental sciences;
- a one-of-a kind, large-scale closed system research facility at a time of heightened interest in the interplay between ecological systems and global climate change;
- a site with proximity to an international border, presenting opportunities for bi-national collaboration in training, research, and policy formulation;
- a focus for public outreach on environmental issues that will dominate domestic and international policy-making in future decades;
- a significant land area (250 acres with room to expand to 2000 acres).

The advantages offered by the Biosphere 2 for undergraduate education are substantial. The facility itself is unique, representing an exciting architectural and scientific facility on a massive scale. The 250 acres of high Sonoran desert that surround the Center are themselves a wonderful natural site, providing an ideal ecological setting for long-term studies and instruction. The elevation, the surrounding scenery and the local geology all contribute to a setting of breathtaking beauty and scientific significance. Furthermore, the accommodation available for up to 75 students is of very high quality.

The Oracle site has some disadvantages. It is isolated and its remoteness from Columbia makes it difficult to maintain meaningful communication. The site at present also lacks facilities which are important for a balanced and satisfying undergraduate experience there, especially adequate library, study space, and recreational facilities. Many of these issues related to the distance between Oracle and Columbia University's New York campus can be addressed, in part, through the use of modern telecommunications links between Lamont-Doherty, B2C, Columbia and other locations.

With regard to graduate education, if the Biosphere 2 apparatus proves to be an appropriate research tool, then there would be substantial opportunities for integrated agricultural and ecological research at the site. Such use would reinforce the Columbia presence, it would serve to link the Columbia faculty to B2C, and it would prove invaluable in complementing undergraduate education. Such research can be expanded to include related studies outdoors, or in additional closed facilities that might be constructed on the site as the need for them becomes apparent. The campus site, comprising as it does some 250 acres, would also provide splendid opportunities for

continuing studies at the graduate-professional level in everything from range management to micro climatic and successional studies. We believe that the Oracle site can also serve as a center for graduate thesis research involving field studies in a range of biomes accessible to it.

Because of its physical attractiveness, Biosphere 2 affords a substantial opportunity for demonstrations of basic environmental principles and of sustainability, especially if facilities and exhibits specifically designed to interpret the man-built and natural environment in these terms are developed in the area. Such activities could allow the development of a significant resource not only for the region, but also for similar ecologically fragile areas of semi-arid climate around the world.

In spite of the summer climate, the Center lends itself to a variety of summer programs, all of which could have educational interest. These include at least the following:

- A third semester undergraduate program of the kind now offered through the earth semester.
- A junior college/high school based program of one, two, four, or six weeks' duration.
- A public interest, special focus-type program of short, perhaps one week's, duration.
- A base for university-run field camps in the earth and life sciences, including also, perhaps, archaeology, forestry and agriculture.

There is a possibility that, with some upgrading of existing accommodation, Biosphere 2 could become an "environmental Aspen." With the involvement of recognized senior faculty from Columbia and other institutions, a truly meaningful program could be developed for the site. If it chose to focus both on policy and science, it could, we believe, attract corporate and other leaders to conferences of limited duration--either weekend, or week-long--which would address some fundamental social issues. In doing this, it could provide common ground for those of different interests--environmentalists, public policy experts, political leaders, public figures, captains of industry, and so on-- who would come together seeking common solutions. This could be profitable, both financially and socially.

Biosphere 2 offers unusual opportunities to extend the reach of the Earth Institute into a new range of environmental research, education, and public outreach. It also offers an unusual opportunity for integrating the ecological sciences into the other broad efforts of the university. It is a creative concept that, if well managed, properly engineered, and innovatively planned and executed, can also serve as a prototype for a new generation of large-scale, closed systems for ecological research.

Once the likelihood of a successful outcome is demonstrated, Columbia, as the initial "venture investor," will be the natural leader in building consortia of institutions for the management, financing, and use of B2C for education. Columbia's B2C efforts are being watched closely by universities and funding-agencies and it is sensible to make the investment necessary to entrain universities and funding agencies into long-term partnerships. Forging regional alliances, such as that with the University of Arizona, but also with many other educational, environmental, and civic institutions in the area, will be of fundamental importance in securing the future of the facility as a whole. With a strong regional base, it can expand naturally to national and international alliances that can strengthen and deepen the program.

Ecological science must rest on a foundation of field research and large-scale experiments. B2C provides such an essential and distinctive element for the Earth Institute. It anchors the program in a unique and highly visible large-scale laboratory. B2C, together with the Lamont-Doherty Earth System Observatory and the many other strong elements in Columbia's Earth Institute, has the potential of enhancing greatly the University's overall program and influence in the environmental sciences.

Pressing Current Challenges and Questions for the B2C Enterprise

Biosphere 2 Center is a unique resource. The apparatus is an architectural gem, an icon of substantial significance and an instructional site of remarkable opportunity. It is also clear that with appropriate re-engineering some very valuable and unique first-rank research can be done in at least part of the apparatus. There is, however, a substantial list of critical issues that could have a material impact upon the success of B2C as an enterprise:

Research Management Challenges for B2C

The commitment of Columbia University, now two years old, has attracted much attention. The progress of B2C is being followed closely. The initial momentum generated by Columbia's involvement and the value of early successes with outreach and education will not last indefinitely. It is urgent that decisions be made, facilities upgraded, and experiments identified and initiated lest the history of Biosphere tarnish B2C. Columbia needs to make and demonstrate the case within a fairly limited time that at least part of the apparatus can be re-engineered to do valuable research. Some of the actions required are outlined below:

- Establish a strong management process that is decisive and encompasses:

  a) approval of budgets;
  b) preparation of budgets and the allocation of funds;
  c) decision making on upgrading facilities;
  d) issuing RFPs;
  e) using the science advisory mechanism to recommend priorities and evaluate proposals;
  f) philanthropic fund raising (application for grants);
  g) building a consortium of interested and participating institutions;
  h) evaluation of quality of program;
  i) staff appointments;
  j) faculty appointments.

  It is important to set clear guidelines of authority between those delegated to the resident B2C management and those retained by the Columbia campus authorities. Where the B2C Board fits in the hierarchy of authority between Columbia and B2C requires definition. The Advisory Group recommends that items a, g, h, and j be reserved by the Columbia authorities. Appointments at the level of President and Chief scientist should be reserved by Columbia and meet the standards of Columbia administrative officers and faculty. All other items would be delegated to the B2C President with the advice of the Chief Scientist and Science Advisory Committee.

- Upgrade the facilities in The Intensive Agricultural Biome and the Ocean Biome, as recommended by the ELCAC, at an early date. Select and initiate within this time frame experiments to be carried out in these biomes, after proposals have been submitted and evaluated. These two biomes are the easiest to prepare for meaningful experiments that will both combine facility testing/development with meaningful experiments and establish the uniqueness of B2C for large-scale projects. Most of this has already been accomplished for the Ocean Biome. So far as the world scientific community and government funding agencies are concerned, these steps are the most important indicator of progress. It may be necessary for Columbia to fund these actions out of its own resources to show results and build support. The overhead required to keep the entire facility operating when only two biomes are involved in unique experiments presents a funding problem that may have to be absorbed in the initial years.

- Ecological engineering--which encompasses both the design of utilitarian facilities and of facilities for controlled experiments that address global ecological problems--is a field that will undoubtedly assume importance in the years ahead. For this reason, B2C should be advanced as an innovative concept for research in both ecological engineering and ecological science, in fund raising and in attracting the intellectual interest of both the technological and scientific communities. For example, the

re-engineering of a B2 apparatus biome with the dual purpose of preparing it for a particular set of experimental contributions and learning about the challenges of design and construction of closed facilities could be an attractive proposal for a foundation or federal agency.

In pursuing these opportunities, B2C authorities should be sensitive to possible responses of the scientific community at large. It has been the case that major new enterprises often trigger concerns about competition for government funds. A small, informal survey by The Advisory Group indicated that this is a fear in the case of B2C. The history of such initiatives as Deep Ocean Drilling, the National Center for Atmospheric Research, and IRIS indicate that early positive contributions not only generate support but often lead to overall increases for the fields involved.

Building a Research Consortium

Biosphere 2 Center is not only a facility for the conduct of research; it is also in a real sense, an experiment in learning how to operate the facility in a way that would make it institutionally attractive to other universities, to funding agencies, and to communities of scholars.

B2C is a concept too grand in scope for a single institution to fully exploit. It will attract the interests of scientists and engineers from many disciplines drawn from many regions of the United States and other countries and from academia, government, and industry laboratories. A facility of this scale, expense, and range of interest is often operated by a consortium--or by a single institution on behalf of a consortium--that shares in governance, fund raising, and participation of its staff and students in its research and training programs.

The operation of large-scale scientific facilities on behalf of communities of interested scholars, consortia of institutions, and funding agencies is a common practice. Many fields of science provide examples. In the environmental arena, these range from the operation of deep-sea drilling vessels, as part of the Ocean Drilling Program on behalf of the U.S. and international community, to the National Center for Atmospheric Research, serving a consortium of some 60 universities with computer, aircraft and field facilities. In other fields of science, such as physics, it is common to operate accelerators and reactors on behalf of consortia.

Many lessons have been learned from other areas of science where large facilities became important tools to researchers. Perhaps foremost has been the need for consensus. Only with such a consensus can the support, both financial and intellectual, be generated to support large facilities. The atmospheric, oceanic and hydrologic communities recognized the need for large facilities early and support was obtained over

the years. Facilities such as those at the National Center for Atmospheric Research, at astronomy observatories, at high energy physics reactors and accelerators, all have indicated the fundamental need for support in the scientific community, the need for experimental review bodies, and the need for continuous upgrading in response to new scientific needs.

B2C bears the additional burden of the apparatus not having been developed by the relevant research community. There is a long history of conversion of facilities to research, largely having to do with facilities developed by the Department of Defense. Oceanographic facilities such as underwater sound systems and ships, atmospheric facilities such as powerful radars, have all found themselves converted to research use by the scholarly community. These redirections of Defense-supported facilities not originally designed for research purposes do not have much to offer in the way of lessons in the use of Biosphere 2, other than to show that it is not unusual to convert a facility if an adequately persuasive case can be made for the science it will support.

Facilities that become viable shared research facilities are based on a core of long-term financial and intellectual support, a clear scientific plan, strong scientific leadership, committed research teams, periodic external evaluations, and frequent publication of results in peer reviewed literature. Therefore, especially during the initial years, B2C must be managed in such a way that it is attractive to scientists and engineers by making it easily accessible and easy to undertake research. A central feature of the management must be creative approaches to supporting scientists bringing research to be conducted in facility. Staff must be available for organizing sensor and data processing systems necessary for specific research projects, for assuring the adequate control and hence the accuracy of the environmental variables. Arrangements must be made for remote interaction with the staff at the facility and for remote readout of facility and ecosystem conditions as specified by the participating scientists. Additionally, the analytical laboratories at B2C will need to be systematically upgraded to adequately support the research proposed and carried out. The "Guidelines for Visiting Scientists" issued in September 1997 are an important step in facilitating the use of the facility by outside scientists.

To operate a genuine shared facility, some form of experiment review and recommendation board will be necessary. The group must have credibility and broad interests in advancing ecoscience to determine which experiments will be selected for implementation. Some of this function is now performed by the Earth Learning Center Advisory Committee, but a smaller group with clear authority will be necessary as the facility moves into routine operations. An experiment review board will be pressed to select sets of experiments that can be compatible during the periods of time they are conducted in the closed facility.

Columbia has already taken the first steps in opening discussions with other institutions. To build a user-consortium of dedicated partners will take some time. But

visible progress as described earlier should make it easier for the university to engage university partners and connect with potential government and industrial sponsors. Workshops, symposia, briefings, published and oral papers are all tools that can be used. The transformation of B2C into a national facility with meaningful research and training in fields of high intellectual interest and with high national priority is a realizable goal. It should qualify for research support in ecological engineering and science from several federal departments and from industry, especially after a consortium has been formed.

An attempt should be made initially to bring together a small group of institutions with a deep interest in ecoscience to experiment with the ways in which a larger consortium of institutions might govern the closed facility which would be operated by Columbia University. An additional opportunity for Columbia arises from the interests of a diverse and R&D-sophisticated community of companies focused on agricultural, forestry, and environmental services and instrumentation markets. Although basic science facilities have historically been operated by universities or government, industry can play a critical role in multiparty research enterprises when those enterprises bring unique facilities to bear on problems with both commercial and scientific aspects. The National Science Foundation's supercomputing centers--based at a single university but with full and active collaboration both with other universities and companies--are excellent examples of nationally important research activities with very substantial industry participation. B2C already has some industrial participation through the industrial members of the ELCAC but Columbia and B2C should consider the value of substantial industry participation in any consortium that is assembled.

Graduate and Undergraduate Education at B2C

The exposure of the Washington Advisory Group team to the educational program was limited. Its views follow:

- Although there may be some opportunities to use the site of B2C as a field station or base for graduate research, the viability of graduate education at B2C depends entirely on involvement of first rank research faculty, which in turn depends on the viability and quality of the research programs. Serious consideration of the role of B2C in graduate education needs to follow decisions and real progress in utilizing the B2 apparatus.

- The description of the earth semester is based on a persuasive rationale and is broadly representative in its range of topics covered. The courses are well conceived, though inevitably, given the size of the faculty, rather limited in scope. The fact that there are only 4 ½ fte faculty members creates an unavoidable lack of depth in the curriculum. The three basic courses on earth systems science, conservation biology, and law, politics, and economics of global change are particularly wide in their emphasis. The

curriculum and readings assigned for each of the courses are thorough, comprehensive and appropriate. Three teaching assistants are available to assist in these courses and undergraduates expressed general satisfaction with their experience. There is a strong group identity among students and a sense of partnership. Field trips are popular activities and their content and style are praised.

- Progress has been made in recruiting a Director of Recruitment, Dean of Student Affairs, and Director of Educational and Research Programs.

- Faculty members were uniformly impressive, enthusiastic, and committed. They represent a talented group of young individuals, eager to succeed in their task. They are, however, very thinly stretched and several complained that the schedule was becoming increasingly demanding. They do not enjoy appointments on the Columbia tenure track and expressed concerns about their future, including a concern as to the criteria on which they will be judged when their contracts are reconsidered. They are frustrated that they have little or no time for research and that they have little opportunity for contacts with colleagues on the Columbia campus.

- Visiting faculty members are highly praised by students. The list of visiting faculty members includes a wide range of interests and high-quality individuals, coming as they do not only from Columbia, but also from half-a-dozen other substantial universities and colleges, as well as from the U.S. Geological Survey. The presentations made by these visiting faculty are seen as both interesting and relevant to the program they are pursuing. A wish was expressed that it might be possible to assemble the visiting faculty to take part in some form of integrative symposium to be held at the end of the course. In thinking about the future of the educational program, serious thought will need to be given to the role of full-time and visiting faculty and the conditions of appointment of both.

- The Advisory Group team was told that it had proved more difficult to recruit students from Columbia than to recruit those from other institutions, although enrollment represents a satisfactory mix of Columbia and non-Columbia students. Attention clearly needs to be given to a facilitation of recruiting on the Columbia campus. There are also concerns about the difficulty of recruiting students from public institutions, where tuition levels are substantially lower than those in private universities and colleges. Perhaps the earth semester program needs to be thought of in the same terms as a study abroad semester, and financial aid provisions allocated accordingly.

- Enrollment during the first semester of 1997-98 was 50 students. The target for the second semester, 1997-98 is 75 students. With suitable inexpensive additions to residential accommodation, the western campus could handle up to 250. This would alter the character of the program, but it would allow for more depth and breadth in the range of educational offerings. Several faculty members believe that the program would be improved by expanding in this way. The financial implications of this will

be an important consideration, as well as the impact upon the style of the offerings and the quality of the educational experience. Such expansion is worth serious review by Columbia.

- One area that provides both advantages and disadvantages is the heterogeneity of the undergraduate student group. This is an advantage in terms of the educational environment. It provides some significant challenges, however, in the differing degrees of preparation of those involved. We believe that greater efforts should be placed on attracting science majors into the student body. These efforts will depend, in part, on making B2C a site for the type of high-quality research that can draw first rank researchers.

We were asked to consider whether Biosphere 2 programs could be used as model programs for other institutions. The impression of The Advisory Group team is that substantially more development would be required to provide such a demonstration or template for other institutions.

Public Education

The role of B2C in public outreach and education about ecoscience has been, to date, largely a result of the public attention to the facility's original mission. B2C leadership is appropriately focused on converting the stream of visitors created by that notoriety into a opportunity for a quality, public educational experience. The Advisory Group applauds the improvement in the educational experience of visitors, but much remains to be accomplished.

Some ways to improve overall attendance are to add to the educational content of the tours and to provide some formal link with other institutions in the area which welcome visitors, such as Kitt Peak Observatory, and/or the Desert Museum. In addition to such existing walk-on visits, arrangements should continue to be pursued for alliances with local, statewide and regional school districts. These provide the benefit not only of numbers, but also of access to educational programs which may be developed on an ongoing basis.

It also seems appropriate to raise the question of whether or not a group who might be called "The Friends of Biosphere 2" should now be established. Videotapes, publications, newsletters, and PBS-type programs all fall within the range of public education and are attractive possibilities, given the unique nature of the facility.

Columbia's Immediate Management Challenges

Many of the challenges to the success of B2C are beyond the appropriate scope of the on-site leadership of B2C and fall on the shoulders of the Columbia University administration and the management of the Earth Institute.

Integrating B2C and the Earth Institute

The intention of Columbia University is to integrate the Biosphere 2 Center as part of the Columbia Earth Institute and to make the Biosphere 2 Center the western campus of the Institute, serving as a focus for an integrated approach to environmental education, research, and public outreach.

The goal of integration into the Earth Institute is ambitious and presents a variety of obstacles. For example:

- The success of the Biosphere 2 Center will depend to a large extent on the success of the Columbia Earth Institute. The quality of leadership of the Institute, and the degree of attention and priority it provides for the work of Biosphere 2, will be crucial to the success of the Biosphere's programs.

- The remoteness of the Biosphere 2 Center from the Columbia campus at Morningside Heights makes it difficult to have continuing, meaningful communication between members of the faculty on the eastern and the western campuses.

- Columbia, at present, lacks depth in several areas of crucial significance to the work of Biosphere 2 Center, especially ecosystem agriculture, forestry and relevant engineering. This lack of balance must be addressed. However, the development of these fields appears to be important to the overall intellectual balance of the Earth Institute program in any event, and is therefore recommended, independently of the future of B2C.

- The success of Biosphere 2 Center as a higher-education and demonstration facility depends significantly upon the success of the apparatus as an experimental facility. This is the fundamental rationale for Columbia's involvement. Until it has established itself as a major facility for research, with clear demonstration of the degree of sophistication and control that it is able to provide, its use as an educational tool will be hampered.

- If this linkage of quality research and education is to be fulfilled, leading researchers on the faculty of Columbia and consortium members must be involved in the undergraduate programs at B2C.

The Columbia initiative proposes to bring together, not only an integrated approach to biological and physical processes on and within the planet, but also to link these to a

sustained program in socio-economic and policy planning, in both research and education. This type of integration can be pursued through a variety of mechanisms:

- Integration can be achieved through research projects. It may require a continuing availability of seed money from Columbia to bring researchers from different areas together in common ventures.

- Integration around policy development is also a strategic possibility. Leadership in defining policy areas is needed.

- Integration can occur in educational programs and this is already beginning to take place.

To achieve these kinds of integration, the support and commitment of the deans and the faculty, as well as the central administration and the officers of the Earth Institute are needed. Once the strategic approaches to integration have been determined, it will be important to create tactical means of pursuing them. This will involve the provision of incentives, appointments, research funding, space, partnerships and investment, as well as constant encouragement from the central administration. It is clear that some major steps have already been made in this direction, but it is now almost two years since Biosphere 2 was taken over by Columbia. The university could usefully review the extent to which progress suggests the need to strengthen management at all levels, make sure the right incentives are in place, modify appointments, and review both investments and accountability.

Additional Immediate Management Challenges

- **The degree of identification and interaction of the educational program with Columbia University requires strengthening.** Although the earth semester program is a Columbia University program, the activity is most closely identified with the Biosphere 2 Center itself. One clear need is to improve the degree of interaction between the two campuses, both by having a more significant presence of Columbia faculty members, and having a significant number of Columbia students. We were advised, for example, during our visit to Columbia that six additional appointments will be made over the next year or two to the Columbia Earth Institute. Perhaps an understanding could be reached with individuals appointed to these positions that part of their responsibility would be to serve in residence at the western campus. Perhaps visits from existing faculty members could be facilitated in useful ways and a degree of interchangeableness in teaching assignments developed.

- **In education, engineering, and research, the people on the ground at Biosphere 2 are very thinly spread.** There is little or no backup in any area and this presents problems for all aspects of the program. How to address this is a topic of importance and urgency. Here again, a relationship with a nearby land grant university would be immensely helpful.

- **Administration, organization, and management of B2C could profit from additional support.** The Washington Advisory Group was not asked to address these issues directly, but we are unable to give a comprehensive report on the research, educational and outreach opportunities without paying some modest attention to these other items. The management team under Dr. Harris has done an outstanding job. Despite the recent additions to the management team, however, the on-site leadership of B2C is seriously overextended.

Critical Next Steps for B2C

- **Columbia's involvement should be intensified and made more visible.** The involvement of Columbia University is at present rather modest in terms of day-to-day life on the western campus. The deans and faculty of Columbia University need to be more directly involved. Strengthening the linkage is a major concern and it involves both financial commitment and personal engagement. The B2C leadership could benefit from more access to the faculty at Columbia.

- **The lack of depth in ecological science, agriculture, forestry, and relevant engineering on the Columbia campus and therefore in the earth semester program is a matter of some concern and needs to be addressed**. In the absence of substantial expertise in these program areas it is difficult to develop a rounded education and research program. It is not clear to us that visiting appointments, as they now stand, can make up these deficiencies. We note little or no expertise in these areas among the list of visiting and contributing faculty and visiting appointments are not a satisfactory solution to the longer-term challenge.

  This leads us to suggest that Columbia University would be well served by developing a strategic partnership at a high level with a land grant type institution. The University of Arizona would appear to us to be one strong candidate, especially now that some past tensions between Columbia's role and the interests of the University of Arizona have been lessened due to Dr. Harris' activity and diplomacy. The strong and visible partnership of such a local university would add not only expertise in understaffed areas, but would also provide the possibilities of shared management, services and oversight, the benefits of which could be substantial. It could also facilitate a State role in supporting the Biosphere 2 Center under appropriate conditions.

- **The governance structure of B2C would benefit from being broadened.** The present governing board consists entirely of senior members of the Columbia administration. We believe that it might be helpful to consider making this group a management board and appointing, in addition, a governing or advisory board which would be made up of independent external individuals and some Columbia representatives. Such a board, with clearly defined and prescribed powers, could give

valuable local support, partnership and counsel to the enterprise and could do much to encourage long-term support.

- **B2C needs a strategic plan and an ongoing management process to reach Columbia University's aspirations for the enterprise.** As discussed earlier in the report, the commitment of Columbia University to B2C, now three years old, has attracted both applause and skeptical attention. The progress of B2C is being followed closely and it is urgent that decisions be made, facilities upgraded, and experiments identified and initiated so that progress is evident to potential grantors and the science community. In reviewing the activity at B2C, it became apparent that fundamental questions about the direction and type of activity at B2C are not yet settled.

  The ELCAC has done an excellent job of developing a comprehensive research plan, but it suffers--in moving from plan to action--from the lack of a focused enterprise plan as context. The science plan needs to be supported by a multi-year management, financing and operating plan for all aspects of B2C (science, education, outreach, conferences, etc) and both of those operational plans need to be supported by an articulated vision or plan that describes Columbia and B2C's goals for the enterprise and places the responsibility for pursuing those goals on a robust governance structure for the enterprise.

  It is especially critical that the goals, ways and means for the educational aspects of B2C be fully articulated. Although the educational aspects of the plan will be influenced by the scientific viability and experimental suitability of the B2 apparatus, they are not entirely dependent on the apparatus. The educational plan should include--in addition to the critical issues of finance and operations mentioned above--a) an articulation of the choices available for educational offerings; b) an evaluation of the linkages and partnerships that would be required to pursue each of the various options; c) an identification of the educational-social and other benefits and liabilities of each of the options; and d) a statement of the priorities among competing opportunities. A plan of implementation is also, of course, critical.

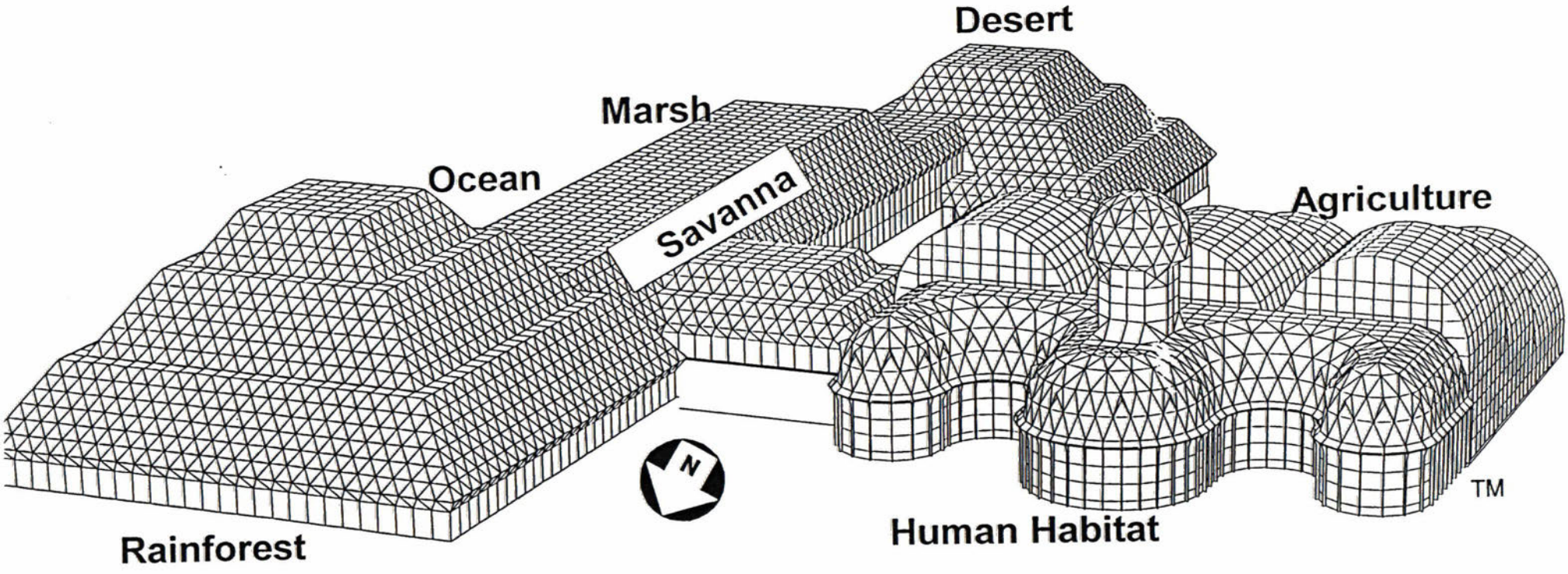
  Only in the context of fully articulated vision of the future of the enterprise does it become possible to value and evaluate proposals about how to expand, contract, or re-direct activities at B2C.

APPENDIX 1

Overview of the B2 Apparatus

Biosphere 2 Apparatus is comprised of medium-scale synthetic communities of plants and soils encased in a glass and metal shell. It includes rainforest, desert, savanna, marsh, ocean, wilderness area, and a separate agriculture area known as the Intensive Agriculture Biome (IAB) (see attached figure). The structure covers 3.15 acres and can be operated in a variety of configurations including 'flow-through' and 'closed system' modes. When operated as a 'closed system' the apparatus is sealed to all external materials and gas exchange with the outside. Leakage is estimated at a rate of 1.5 % per day (as measured on 12 May 97). Operation as a 'flow-through' system means that the apparatus has external air flowing through it. In the wilderness area, air can either be brought into the desert and exhausted through the rainforest with a TESCO fan at a rate of up to 280 cubic meters/min (10,000 cubic feet/min) or by passive air movement in and out of the apparatus. In the agricultural area, air can be blown through the west lung and exhausted through exit windows in the north side.

The enclosure contains approximately 170,000 cubic meters (6,000,000 cubic feet) of atmosphere, 1,500,000 liters (390,000 gallons) of freshwater, 3,800,000 liters (988,000 gallons) of saltwater, and 17,000 cubic meters (600,000 cubic feet) of soil. Located at an elevation of 1,200 meters (3,960 feet) above sea level at 32.50 north latitude in southern Arizona, Biosphere 2 Apparatus is subject to the light regimes of a temperate desert region. The designers of Biosphere 2 Apparatus used artificial soils with high organic matter in the agricultural zone and the rainforest, resulting in a system that intrinsically experiences higher than ambient concentrations of CO_2. Internal climate is controlled to reflect typical conditions for each distinct ecosystem. Heating, cooling, and electricity are supplied from an energy center external to the structure. Water is conserved inside Biosphere 2 Apparatus. The major internal water cycling components are condensation (mainly in cooling coils of airhandlers), artificial rain or irrigation (by sprinkler systems), evapotranspiration, and soil sub-drainage. The internal pressure is maintained close to external pressures by using two domes, or 'lungs', to avoid pressure-induced damage to the glass structure. The lungs are used only when the structure is operated as a closed system. An array of sensors (CO_2 analyzers, temperature, relative humidity, and light) are housed inside the facility to provide continuous monitoring of changes in the atmospheric composition and climate. Data acquisition and communication are fully automated.


Desert
Marsh
Ocean
Savanna
Agriculture
N
Rainforest
Human Habitat
TM

Appendix 2

Statement of Work

Columbia's Earth Institute is designed to change both the content of research and education and the role of a major research university in the life of the nation and the world. The Biosphere 2 Center is perhaps the most radical, and therefore risky, aspect of Columbia's initiative. Columbia is making a serious attempt to turn an expensive facility designed and built for one purpose into the hub of a multi-institutional environmental research, education, and outreach campus.

The Washington Advisory Group will assess the concepts driving B2C and will prepare a report addressing the questions below.

Organizing Question 1: What would be the near-term value of an accessible, well-managed, large-scale, closed-system facility to the research and education community concerned with global change? With ecosystem dynamics? With biogeochemical dynamics? With industrial ecology? Does such a facility have significant value when compared with other investments in research tools for the same communities?

Specific Questions:

a. Within the context of the development of global climate change science, what is the need for and potential value of large-scale closed-cycle research facilities? Are they a potentially useful tool?

b. In terms of tool development overall, has the time come to consider the use of larger-scale experimental devices to study ecosystem management, biogeochemical cycles, environmental systems and other related areas?

c. What are the key science questions that might be better addressed through closed-system facilities of the general class of Biosphere 2? What unique problems might be pursued in such facilities? How might such facilities be also used as tools for teaching and learning on a local and national scale?

d. What is the merit of taking the Biosphere 2 research facility through baseline studies and technical assessments to determine its utility as a potential research tool?

e. In what ways might research facilities like Biosphere 2 serve as research learning tools in the sense of allowing broad disciplines to learn to work together in critical areas?

Organizing Question 2: What is the long-term value to the relevant research and education communities of gaining some well-documented experience working in a large-scale closed facility? Does such learning have significant value when compared to investments in other research tools for the same communities?

Specific Questions:

f. What is the projected development of research tools over the next 20-30 years on ecosystems management and global climate change? What are the long term needs for closed cycle systems R&D?

g. What might be the barriers and issues in the evolution of large-scale user facilities in the ecosystem, environmental, and global change areas? How should major user facilities be designed in the future in these areas of science?

h. What criteria should be used to evaluate the research potential of a tool like Biosphere 2 as a very early generation research device? As an early generation learning and development tool?

I. What outcomes from the use of Biosphere 2 as an early generation research and learning tool would help in the design and development of future tools and future closed-systems?

j. What lessons have we learned from other areas of science where large facilities became important tools to researchers? From situations where potential research tools not developed by the research community become available for redirection and use?

Organizing Question 3: The "green field" nature of B2C gives Columbia a degree of flexibility to experiment with integrated approaches to environmental education, research and public outreach that is not normally available to major research universities. What is this worth to Columbia, both alone and in the context of the goals of the Earth Institute? To other universities or to funding sources that might learn from Columbia's experiment?

Specific Questions:

k. In the context of Columbia's efforts to build it's new integrated, systems-oriented Earth Institute, what might be the role of large-scale tool development (like Biosphere 2) in the development of such a new intellectual enterprise? What is the value of more closely linking biogeochemistry and ecology as fields? How do you do that?

l. From a conceptual level, what is the value of considering the use of Biosphere 2 as a

potential science tool and as an educational tool?

m. From the perspective of the earth sciences, how are the educational and outreach programs underway and planned at Biosphere 2 useful as organizational learning tools? What is the value of integrating teaching and learning with research in a highly visible way at B2C?

n. What are the potential benefits of making Biosphere 2 work as an educational tool? As a research tool? As a national learning tool about global climate change and/or as a national learning tool about ecosystem management?

Appendix 3

Challenges in Converting the B2 Apparatus into a Useful Research Tool

The B2 apparatus was not designed by scientists to undertake research that meets the standards of modern peer reviewed science. Nevertheless approximately $200 million was expended in building the world's largest scale (in all three dimensions) glass enclosed structure engineered in principle to control the atmosphere, its temperature and composition, the flow of fluids, nutrients, and other biogeochemical components, and temperature. It is separated into 5 biomes with distinct ecological systems that include trees, plants, crops, ocean reefs, microfauna and flora. Unfortunately, Biosphere as originally conceived, designed, and constructed was deeply flawed for the types of scientific research. The biogeochemical and physical components could not be controlled and stabilized in all dimensions in all biomes. The biomes were not adequately isolated from each other. The soils may not be appropriate for certain kinds of experiments. The light levels are inhomogeneously distributed. The network of monitoring sensors are inadequate.

There is such intense competition for research funds that 'good science' is not good enough. Fundable research needs important research questions, innovative methods, and elegant ways to analyze the data. Peer reviewers of B2C projects are likely to be concerned about conceptual flaws such as inadequate replication in experimental design, and a supposed inability of B2C biomes to mimic natural ecological systems in meaningful ways. To address these and other questions B2C established a national advisory committee (the Earth Learning Center Advisory Committee or ELCAC) of plant scientists, ecologists, marine biologists and soil scientists. That group saw that with the proper management, oversight, and faculty involvement by a credible research university, the overall structure had a scientific and educational potential that could not be matched elsewhere. They recognized the possibilities for upgrading the facility and transforming it into a unique tool for ecological research under controlled, monitored, closed system conditions at a cost of a few percent of the original investment. They provided a list of the required engineering changes. They proposed a number of significant, publishable experiments that could be carried out in an upgraded Biosphere. A few are already underway. In this manner, limitations could be transformed into unique research opportunities by the fortuitous earlier large private investment augmented by new public/private funding at the margin, new management and oversight by respected scientists.

The ELCAC has throughly discussed the weaknesses of B2C and is satisfied that it is possible to incorporate such concerns in the design of experiments so that useful results can be expected that could not be obtained elsewhere. In drafting proposals for support, these likely concerns--at both the level of the details of the science and at the level of the

bridges between the science and the operation of B2C--should be anticipated and addressed.

The Advisory Group team, following the path of the ELCAC, identified some concerns that need close attention. All of these issues are manageable if B2C/Columbia spends the necessary time, money, and attention on them.

Baseline Studies. In the competition for funding, B2C bears the additional burden of the simultaneous process of learning about and proving that the facilities can make important scientific contributions. Baseline studies and technical assessments are necessary for any experiments to be meaningful, especially in this unique facility. Baseline studies are a "make or break" issue for the use of the facility for the conduct of research. B2C leadership is sensitive to this issue.

Ecoscience Representation. The relevant community of researchers (including both funders and peer reviewers) have very little or no experience with large-scale, closed, and controlled environments for experiments. In designing and presenting research for peer review, almost anything significant proposed for the B2 apparatus demands an approach that draws on historically distinct disciplines. Not only are ecologists trained in biology, botany, zoology, or microbiology needed, but also geophysicists, biogeochemists, engineers, and others. Building a research community--by involving credible scientists who can bridge these gaps and work in a pioneering but unusual facility--is a fundamental challenge for B2C's research program.

Light Levels. Light transmission in the B2 apparatus in wavelengths used by plants for photosynthesis (i.e., photosynthetic photon fluence rate or PPFR) is only 60% of full sunlight. This is low: commercial greenhouses transmit 85 to 92% of full sunlight in the photosynthetic wavelengths. There are two reasons for the low PPFR levels in the B2C: 1) the grid structure of the roof reflects about 20% of the sunlight, and 2) the covering glass reflects another 20% of the sunlight. The low PPFR argues for studies with trees, especially those that have evolved in cloudy regions, since most of the leaves on trees 'see' low light levels.

Soil. The soil is very unusual. It is extremely rich in base cations (e.g., potassium), phosphorus (about 20-times greater than levels in a fertile soil), nitrogen, and organic matter. Very fertile, well-watered soil is not common in nature.

Heat. Plants simply do not grow well at 40° C, or greater. Some of the enzymes in plant leaves begin to change their shape at temperatures above 45° C. There needs to be a strong effort to reduce air temperature.

Utility of Biomes. The Advisory Group team questions the efficiency of maintaining some of the present biomes in the B2C, such as the desert biome. Plants in this biome grow very slowly and use insects to pollinate. Since the native insects are not present,

there is a high maintenance cost. A better use of the space might be to establish and maintain a managed ecosystem such as a plantation forest or an agroforestry system.

Replication. It is difficult to replicate experiments in the B2C. Studies in the B2C need to be designed in order to create different treatments that might overcome the need for replication. It is possible to address these concerns by appropriate experimental design and facilities upgrades over time. For example, it might be possible to use curtains to divide the IAB to create: 1) a high temperature-low CO_2 treatment, 2) a high temperature-high CO_2 treatment, and 3) a very low light level treatment.

Brief Biographical Information on the Washington Advisory Group Team Members

Principals:

Erich Bloch
IBM Corporate Vice President, 1981-84; Director, National Science Foundation, 1984-90; National Medal of Technology, 1985; IEEE Founders Medal, 1990; IEEE Computer Pioneer Award, 1995; Member, U.S. National Academy of Engineering.

Bruce Guile
Managing Director, The Washington Advisory Group; Director, Program Office, U.S. National Academy of Engineering, 1989-96; Staff Officer, U.S. National Academy of Engineering, 1984-89; Economic and Management Consultant, 1978-84.

Frank Press
President, U.S. National Academy of Sciences and Chairman, National Research Council, 1981-93; Science Advisor to the President of the United States, 1977-80; Chairman, Earth and Planetary Sciences, MIT, 1965-77; Awarded the Japan Prize, 1993.

Frank H.T. Rhodes
President and Professor of Geological Sciences, Cornell University, 1977-95; Vice President for Academic Affairs, University of Michigan, 1974-77; Dean, College of Literature Science and the Arts, University of Michigan, 1971-74; Chair, National Science Board, 1994-96; former Chair of Board of American Council on Education and Association of American Universities.

Robert M. White
President, The Washington Advisory Group; Senior Fellow, H. John Heinz III Center for Science, Economics and the Environment and the University Corporation for Atmospheric Research, 1996 to present, 1995 to present; President, U.S. National Academy of Engineering and Vice Chairman, National Research Council, 1983-95; Administrator, National Oceanic and Atmospheric Administration, 1970-77.

Associates:

Jerry M. Melillo
Research scientist at the Ecosystems Center of the Marine Biological Laboratory in Woods Hole, Massachusetts. Co-Director of the Center, a scientific research organization dedicated to the study of ecological systems and to the application of knowledge thus gained to the problems of sustaining and managing natural resources. Dr. Melillo's research on biogeochemistry includes work on global change, the ecological consequences of tropical deforestation, and sustainable management of forest ecosystems.

Peter H. Raven
Director, Missouri Botanical Garden and Engelmann Professor of Botany at Washington University. The research programs of the Garden now range throughout the world, with particular concentration on Latin America and Africa, as well as important programs in North America, China, and other parts of the world. Dr. Raven is also a member of President Clinton's Committee of Advisors on Science and Technology, and is a long-time member of the National Geographic Society's Committee for Research and Exploration.

Joseph B. Yavitt
Assistant Professor of Agriculture and Life Sciences, Cornell University, 1992-present; Research Associate, Cornell University 1988-1991, Research Associate, West Virginia University, 1983-88. Dr. Yavitt's research focuses on the biogeochemistry of terrestrial, aquatic, and wetland ecosystems. His current research program involves a comparative study of methane cycling in boreal and temperate wetlands.

Domestic studies

IPCC Working Group II:
Special Report on the Regional Impacts of Climate Change

Table of Contents

Chapters

Summary for Policymakers
1. Introduction
2. Africa
3. Arctic/Antarctic
4. Australasia
5. Europe
6. Latin America
7. Middle East and Arid Asia
8. North America
9. Small Island States
10. Temperate Asia
11. Tropical Asia

Annexes

A. Regional Trends and Variations of Temperature and Precipitation
B. Simulation of Regional Climate Change with Global Coupled Climate Models and Regional Modeling Techniques
C. Simulated Changes in Vegetation Distribution under Global Warming
D. Socio-Economic Baseline Data
E. Color Plates—N/A
F. Glossary of Terms—TBD
G. Acronyms, Chemical Symbols, and Units—TBD
H. Authors, Contributors, and Expert Reviewers of the Regional Impacts Special Report—TBD
I. List of Major IPCC Reports—TBD

SUMMARY FOR POLICYMAKERS

1. Scope of the Assessment

This report has been prepared at the request of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and its subsidiary bodies (specifically the Subsidiary Body for Scientific and Technological Advice–SBSTA). The special report provides, on a regional basis, a review of state-of-the-art information on the vulnerability to potential changes in climate of ecological systems, socio-economic sectors (including agriculture, fisheries, water resources, and human settlements), and human health. The report reviews the sensitivity of these systems as well as options for adaptation. Though drawing heavily upon the sectoral impact assessments of the Second Assessment Report (SAR), the report also draws upon more recent peer-reviewed literature (*inter alia*, country studies programs).

2. Nature of the Problem

Human activities, primarily the burning of fossil fuels and changes in land-use and land-cover, are increasing the atmospheric concentrations of greenhouse gases, which alter radiative balances and tend to warm the atmosphere; and, in some regions, aerosols, which have an opposite effect on radiative balances and tend to cool the atmosphere. At present, in some locations primarily in the Northern Hemisphere, the cooling effects of aerosols can be large enough to more than offset the warming due to greenhouse gases, although aerosols do not remain in the atmosphere for long periods, and thus will not offset the long-term effects of greenhouse gases, which are long-lived. Aerosols can have important consequences for continental-scale patterns of climate change.

These changes in greenhouse gases and aerosols, taken together, are projected to lead to regional and global changes in temperature, precipitation, and other climate variables, resulting in global changes in soil moisture, an increase in global mean sea level, and the prospects for more severe extreme high temperature events, floods, and droughts in some places. Based on the range of sensitivities of climate to changes in the atmospheric concentrations of greenhouse gases (SAR, WG I) and plausible changes in emissions (IS 92a-f), climate models project that the mean annual global surface temperature will increase by between 1.0 and 3.5 degrees Centigrade by 2100, and that global mean sea level will rise by between 15 and 95 cm. The average rate of warming would probably be greater than any seen in the last 10,000 years, although the actual annual to decadal rate would include considerable natural variability, and regional changes could differ substantially from the global mean value. These long-term, large-scale, human-induced changes will interact with higher-frequency natural variability on timescales of days to decades (e.g., the El Nino Southern Oscillation – ENSO), and thus influence social and economic well-being.

Scientific studies show that human health, ecological systems, and socio-economic sectors (e.g., agriculture, water resources, forestry, industry, and financial services such as insurance), which are all vital to sustainable development, are sensitive to changes in climate, including both the magnitude and rate of climate change, as well as to changes in climate variability. Hence, climate change represents an important additional stress on systems already affected by increasing resource demands, unsustainable management practices, and pollution. These stresses will interact in different ways across the regions but can be expected to reduce the ability of environmental systems to provide, on a sustained basis, key goods and services needed for successful economic and social development, including adequate food, clean air and water, energy, safe shelter, low levels of disease, and employment opportunities. Climate change also will take place in the context of economic development, which may make some groups or countries less vulnerable to climate change, for example by increasing the resources available for adaptation; while those that experience low rates of growth, rapid increases in population, and ecological degradation may become increasingly vulnerable to potential changes.

3. Approach of the Assessment

A quantitative assessment of the implications of changes in climate by sector and by region requires accurate projections of baseline socio-economic conditions and the regional patterns of climate change. Unfortunately, there

coping mechanisms is needed and will offer lessons for the design of effective adaptation options to potential future changes in climate.

5. Vulnerability to Climate Change

Article 2 of the UNFCCC explicitly acknowledges the importance of natural ecosystems, food production, and sustainable economic development (see Box 1). This report's assessment of regional vulnerability to climate change focuses on ecosystems, water resources, food and fiber production, coastal systems, human settlements, human health, and other sectors or systems important to ten regions that encompass the Earth's land surface. Wide variation in the vulnerability of similar sectors or systems is to be expected across the regions, due to regional differences in local environmental conditions, pre-existing stresses to ecosystems, current resource use patterns, and the framework of factors affecting decision-making, including government policies, prices, preferences, and values. Nonetheless, some general observations, based on information contained in the Second Assessment Report and synthesized from the regional analyses in this assessment, provide a global context for the assessment of each region's vulnerability.

Box 1. Article 2 of the UNFCCC: Objective

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

Ecosystems

Ecosystems provide many goods and services critical to individuals and societies. These goods and services include: (i) providing food, fiber, medicines, and energy; (ii) processing and storing carbon and nutrients; (iii) assimilating wastes; (iv) purifying water, regulating water runoff, and controlling floods; (v) building soils and controlling soil degradation; (vi) providing opportunities for recreation and tourism; and (vii) housing the Earth's entire reservoir of genetic and species diversity. In addition, natural ecosystems have cultural, religious, aesthetic, and intrinsic existence values. Changes in climate have the potential to affect the geographic location of ecological systems, the mix of species which they contain, and their ability to provide the wide range of benefits on which societies rely for their continued existence. Ecological systems are intrinsically dynamic and are constantly influenced by climate variability. The primary influence of anthropogenic climate change on ecosystems is expected to be through the rate and magnitude of change in climate means and extremes – climate change is expected to occur at a rapid rate relative to the speed at which ecosystems can adapt and reestablish themselves – and through the direct effects of increased atmospheric CO_2 concentrations, which increase the productivity and efficiency of water use in some plant species. Secondary effects of climate change involve changes in soil characteristics and disturbance regimes (e.g., fires, pests, and diseases), which would favor some species over others and thus change the species composition of ecosystems.

Based on model simulations of vegetation distribution, which use GCM-based climate scenarios, large shifts of vegetation boundaries into higher latitudes and elevations can be expected. The mix of species within a given vegetation class will likely change. Under equilibrium GCM climate scenarios, large regions show drought-induced declines in vegetation, even when the direct effects of CO_2 fertilization are included. By comparison, under transient climate scenarios, in which trace gases increase slowly over a period of years, the full effects of changes in temperature and precipitation lag behind the effects of a change in atmospheric composition by a number of decades; hence the positive effects of CO_2 precede the full effects of changes in climate.

Climate change is projected to occur at a rapid rate, relative to the speed at which forest species grow, reproduce, and reestablish themselves (past tree species migration rates are believed to be on the order of 4–200 km per century). For mid-latitude regions, an average warming of 1-3.5° C over the next 100 years would be equivalent to a poleward

and the considerable time and expense required to implement many adaptation measures, the water resources sector in many regions and countries is vulnerable to potential changes in climate.

Food and Fiber Production

Currently, 800 million people are malnourished and, as the world's population increases and incomes in some countries rise, food consumption is expected to double over the next three to four decades. The last doubling in food production occurred over a 25-year period, using irrigation, chemical inputs, and high-yielding crop varieties. Whether a new "green revolution" will be able to repeat the remarkable gains of the last 25 years is uncertain, as problems associated with intensifying production on land already in use (e.g., chemical and biological runoff, waterlogging and salinization of soils, soil erosion and compaction) are becoming increasingly evident. Expanding the amount of land under cultivation (including by reducing land deliberately taken out of production to reduce agricultural output) is also an option for increasing total crop production, but it could lead to increases in competition for land and pressure on natural ecosystems, increased agricultural emissions of greenhouse gases, a reduction in natural sinks of carbon, and expansion of agriculture to marginal lands, all of which could undermine the ability to sustainably support increased agricultural production.

Changes in climate will interact with the stresses which result from actions to increase agricultural production, affecting crop yields and productivity in different ways, depending on the types of agricultural practices and systems in place. The main direct effects will be through changes in such factors as temperature, precipitation, length of growing season, and the timing of extreme or critical threshold events relative to crop development, as well as through changes in atmospheric CO_2 concentration (which has a beneficial effect on the growth of many crop types). Indirect effects will include potentially detrimental changes in diseases, pests, and weeds, the effects of which have not yet been quantified in most available studies. Evidence continues to support the findings of the IPCC Second Assessment Report that "global agricultural production could be maintained relative to baseline production" for a growing population under $2xCO_2$ equilibrium climate conditions. In addition, the regional findings of this special report lend strong support to concerns over the "potential serious consequences" of increased risk of hunger and famine in some regions, particularly the tropics and sub-tropics. Generally, mid-to-high latitudes may experience increases in productivity, depending on crop type, growing season, changes in temperature regimes, and the seasonality of precipitation. In the tropics and sub-tropics, where some crops are near their maximum temperature tolerance and where dryland, non-irrigated agriculture predominates, yields are likely to decrease. The livelihood of subsistence farmers and pastoral peoples, who make up a large portion of rural populations in some regions, also could be negatively affected. In regions where there is a likelihood of decreased rainfall, agriculture could be significantly affected.

Fisheries and fish production are sensitive to changes in climate and are currently at risk from pervasive overfishing, diminishing nursery areas, and extensive inshore and coastal pollution. Globally, marine fisheries production is expected to remain about the same in response to changes in climate; high-latitude freshwater and aquaculture production is likely to increase, assuming that natural climate variability and the structure and strength of ocean currents remain about the same. The principal impacts will be felt at the national and local levels as centers of production shift. The positive effects of climate change—such as longer growing seasons, lower natural winter mortality, and faster growth rates in higher latitudes—may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships.

Given the many forces bringing profound changes to the agricultural sector, adaptation options that enhance resilience to today's natural climate variability and potential changes in means and extremes, and which address other concerns (e.g., soil erosion, salinization), offer no- or low-regret options. For example, linking agricultural management to seasonal climate predictions can assist in incremental adaptation, particularly in regions where climate is strongly affected by El Niño-Southern Oscillation (ENSO) conditions. The suitability of these options for different regions varies, in part due to differences in the financial and institutional ability of the private sector and governments in different regions to implement them. The options include changes in crops and crop varieties, changes in planting schedules and tillage practices, the introduction of new bio-technologies, and improved water-management and irrigation systems, which have high capital costs and are limited by availability of water resources.

if accompanied by increased access to services such as sanitation and supply of potable water, but also can lead to serious urban environmental problems, including air pollution (e.g., particulates, surface ozone, and lead), poor sanitation, and associated problems in water quality and potability, if access to services is not improved.

Climate change could affect human health through increases in heat-stress mortality, tropical vector-borne diseases, urban air pollution problems, and decreases in cold-related illnesses. Compared to the total burden of ill-health, these problems are not likely to be large. However, in the aggregate, the direct and indirect impacts of climate change on human health do constitute a hazard to human population health, especially in developing countries in the tropics and sub-tropics, with considerable potential to lead to significant loss of life, and to affect communities and increase costs. Projections by models (that entail necessary simplifying assumptions) indicate that the geographical zone of potential malaria transmission in response to world temperature increases at the upper part of the IPCC-projected range (3-5°C by 2100) would expand, increasing the affected percent of the world's population from approximately 45% to approximately 60% by the latter half of the next century. This could lead to increases in malaria incidence (on the order of 50–80 million additional annual cases, relative to an estimated global background total of 500 million cases), primarily in tropical, subtropical, and less well-protected temperate-zone populations. Some increases in non-vector-borne infectious diseases—such as salmonellosis, cholera, and giardiasis—also could occur as a result of elevated temperatures and increased flooding. However, quantifying the projected impacts is uncertain because the extent of climate-induced health disorders depends on other factors, such as migration, provision of clean urban environments, improved nutrition, increased availability of potable water, improvements in sanitation, the extent of disease vector-control measures, changes in resistance of vector organisms to insecticides, and more wide-spread availability of health care. For example, modernization of the energy system in urban environments—including improvements in efficiency and increases in the use of electricity and other modern energy carriers—could reduce levels of indoor and outdoor air pollution. Human population health is vulnerable to changes in climate, particularly in urban areas, where access to space conditioning may be limited; and in areas where exposure to vector-borne and communicable diseases may increase and health-care delivery and basic services, such as sanitation, are poor.

6. Regional Perspectives

Africa

Several climate regimes characterize the African continent, with the wet tropical, dry tropical, and alternating wet and dry climates being the most common. Many countries on the continent are prone to recurrent droughts, with some of the drought episodes, particularly in southeast Africa, being associated with the occurrence of the El Niño-Southern Oscillation (ENSO) phenomena. Deterioration in terms of trade, inappropriate policies, high population growth rates, and lack of significant investment, coupled with a highly variable climate, have made it difficult for several countries to develop patterns of livelihood that would reduce pressure on the natural resource base. Although Africa has contributed the least to the threat of climate change, it is the continent most vulnerable to the risks of projected changes because widespread poverty limits capabilities for adaptation.

Ecosystems: In Africa today, tropical forests and rangelands are under threat from population pressures and systems of land use. The generally apparent effects of these threats has been the loss of biodiversity, rapid deterioration in land cover, and depletion of water availability through destruction of catchments and aquifers. Changes in climate projected by GCMs will interact with these baseline trends. A sustained increase in mean ambient temperatures beyond 1°C would cause significant changes in forest and rangeland cover, and species distribution, composition, and migration patterns, as well as biome distribution. Many organisms in the deserts are already near their tolerance limits and some may not be able to adapt further under hotter conditions. Arid to semi-arid sub-regions and the grassland areas of eastern and southern Africa, as well as areas currently under threat from land degradation and desertification, are particularly vulnerable. Were rainfall to increase as projected by some GCMs in the highlands of East Africa and equatorial Central Africa, marginal lands would become more productive than they are at the moment. However, these effects are likely to be negated by population pressure on the marginal forests and rangelands. Adaptive options include control of deforestation, improved rangeland management, expansion of protected areas, and sustainable management of forests.

would have far-reaching economic consequences. In view of the poor economic status of most African nations, global efforts will be necessary to tackle the potential health effects.

Tourism and Wildlife: Tourism, one of Africa's fastest-growing industries, is based on wildlife, nature reserves, and an abundant water supply for recreation. The projected droughts and/or reduction in precipitation in the Sahel, eastern and southern Africa, would devastate wildlife and reduce the attractiveness of some nature reserves, thereby reducing income from current vast investments in tourism.

Conclusions: Widespread poverty, inherent proneness to drought, imbalances in land distribution, and over-dependence on rain-fed agriculture are some of the factors that make the African continent particularly vulnerable to climate change. While adaptation options are theoretically available, in practice they could be well beyond the economic means of some countries.

Arctic/Antarctica

The Arctic is defined as the area within the Arctic Circle. It is a frozen ocean surrounded by land. By contrast, Antarctica is a frozen continent surrounded by ocean, including the area within the Antarctic Circle and the Southern Ocean and the sub-Antarctic islands. Projected warming is greater for many parts of these polar regions than for any other region of the world.

Ecosystems: Major physical and ecological changes are expected in the Arctic. Frozen areas close to freezing point will thaw and undergo substantial changes with warming. Substantial loss of sea ice is expected in the Arctic ocean. If warming occurs, there will be considerable thawing of permafrost leading to changes in drainage, increased slumping, and altered landscapes over large areas. Polar warming will probably increase biological production, but may lead to different species composition on land and in the sea. On land, there will be a tendency for polar shifts in major biomes such as tundra and boreal forest and associated animals. However, the Arctic Ocean geographically limits northward movement. Much smaller changes are likely for the Antarctic, but there may be species shifts. In the sea, marine ecosystems will move poleward. Animals dependent on ice may be disadvantaged in both polar areas.

Hydrology and water resources: Increasing temperature will thaw permafrost and melt more snow and ice. There will be more running and standing water. Drainage systems in the Arctic are likely to change at the local scale. River and lake ice will break-up earlier and freeze later.

Food and fiber production: Agriculture is severely limited by the harsh climate. Many of these limitations will remain in the future, but some small northern extension of farming may be possible into the Arctic. In general, marine ecological productivity should rise. Warming should increase growth and development rates of non-mammals; however, UV-B is still increasing, which may constrain primary productivity as well as fish productivity.

Coastal systems: If there is warming, the Arctic could experience a thinner and reduced ice cover. Coastal and river navigation will increase, with new opportunities for water transport, tourism, and trade. The Arctic Ocean could become a major global trade route. Less ice will benefit offshore oil production. Increased erosion of Arctic shorelines is expected from a combination of rising sea level, thaw of permafrost, and increased wave action due to increased open water. Further breakup of ice shelves in the Antarctic Peninsula is likely. Elsewhere in Antarctica, little change is expected in coastlines and probably in its large ice shelves.

Human settlements: Human communities in the Arctic will be substantially affected by these physical and ecological changes. Effects will be particularly important for indigenous peoples leading traditional lifestyles.

Human health: Climate change is expected to have little impact on human health, except for increasing UV-B radiation at high latitudes.

Integration: Climate change will bring economic benefits and costs. Benefits include new opportunities for shipping through Arctic waters, lower operational costs for the oil and gas industry, lower heating costs, and easier access for both Arctic and Antarctic tourism. Increased costs can be expected from disruptions caused by thawing of permafrost

Coastal Systems: Parts of the region's coasts and rapidly-growing coastal settlements and infrastructure are very vulnerable to any increase in coastal flooding and erosion arising from sea level rise and meteorological changes. Indigenous coastal and island communities in the Torres Strait and in New Zealand's Pacific island territories are especially vulnerable. Many adaptation options exist, although these are not easily implemented on low-lying islands. Moreover, climate change and sea level rise are generally not well accommodated in current coastal management planning frameworks.

Human Settlements: In addition to hydrological and coastal risks, moderate vulnerability is present from a variety of impacts on air quality, drainage, waste disposal, mining, transport, insurance and tourism. Overall, these effects are likely to be small relative to other economic influences, but may still represent significant costs for large industries.

Human Health: Some degree of vulnerability is apparent. Indigenous communities and the economically disadvantaged may be more at risk. Increases are expected in heat stress mortality, vector-borne diseases such as dengue, water and sewage-related diseases, and urban pollution-related respiratory problems. While small compared to the total burden of ill-health, these have the potential to cause considerable community impact and cost.

Integration: Integrated or multi-sector studies are at an early stage of development. Those currently available generally do not consider multi-national interactions or the ameliorating effects of potential adaptations.

Conclusion: Australia's relatively low latitude makes it particularly vulnerable to impacts on its scarce water resources and on crops growing near or above their optimum temperatures, while New Zealand's cooler, wetter mid-latitude location may provide some benefit through the ready availability of suitable crops and likely increases in agricultural production. However, in both countries there is a wide range of situations where vulnerability is thought to be moderate to high, particularly in ecosystems, hydrology, coastal zones, human settlements, and human health.

Europe

This regions consist of the western fifth of the Eurasian land mass.

Ecosystems: Natural ecosystems are generally fragmented, disturbed and confined to poor soils. This makes them sensitive to climate change. Mediterranean and boreal grasslands would shift in response to changes in the amount and the seasonal distribution of precipitation. The northern boundaries of forests in Fennoscandia and northern Russia would expand into tundra regions, reducing the extent of tundra, mires, and permafrost areas. Survival of some species and forest types may be endangered by the projected movement of climate zones at rates faster than migration speeds. Alpine ecosystems and species are particularly vulnerable, as these have nowhere to migrate. An increase in temperature, accompanied by decreases in soil moisture, would lead to a substantial reduction in peat formation in Fennoscandian and northern Russian peatlands. Thawing of the permafrost layer would lead to lowered water tables in some areas and flood thaw lakes in others, altering current wetland ecosystem types. While it is possible that the diversity of freshwater species may increase in a warmer climate, particularly in middle and high latitudes, there may be an initial reduction in species diversity in cool temperate and boreal regions.

Hydrology and Water Resources: Water supply may be affected by possible increases in floods in northern and northwest Europe, and droughts in southern portions of the continent. Many flood plains in western Europe are already overpopulated, which hampers effective additional flood protection. Pollution is a major problem for many rivers; a warmer climate could lead to reduced water quality, particularly if accompanied by reduced runoff. Warmer summers would lead to increased water demand; increased demand for irrigation would be at least partly offset by increased water-use efficiency of many crops associated with CO_2 fertilization. Water management is partly determined by legislation and cooperation among government entities, both within countries and internationally. Altered water supply and demand would call for a reconsideration of existing legal and cooperative arrangements.

Food and Fiber Production: Risks of frost would be reduced in a warmer climate, allowing winter cereals and other winter crops to expand to areas such as southern Fennoscandia and western Russia. Potential yields of winter crops are expected to increase, especially in central and southern Europe, assuming that neither precipitation nor irrigation

South. The impacts on the water resources could be sufficient to lead to conflicts among users, regions, and countries.

Food and Fiber Production: Decreases in agricultural production, even after allowing for the positive effects of elevated CO_2 on crop growth and moderate levels of adaptation at the farm level, are projected for several major crops in Mexico, countries of the Central American Isthmus, Brazil, Chile, Argentina, and Uruguay. In addition, livestock production would decrease if temperate grasslands have to face substantial decreases in water availability. Extreme events (e.g., floods, droughts, frosts, storms) have the potential to adversely affect rangelands and agricultural production (e.g., banana crops in Central America). The livelihoods of traditional peoples, such as many Andean communities, would be threatened if the productivity or surface area of rangelands or traditional crops are reduced.

Coastal Systems: Losses of coastal land and biodiversity (including coral reefs, mangrove ecosystems, estuarine wetlands, and marine mammals and birds), damage to infrastructure, and saltwater intrusion due to sea level rise could occur in low-lying coasts and estuaries in countries such as those of the Central American Isthmus, Venezuela, Argentina, and Uruguay. Sea level rise blocking the runoff of flatland rivers into the ocean could increase the risks of floods in their basins (e.g., the Argentine Pampas).

Human Health: Projected changes in climate could increase the impacts of already serious chronic malnutrition and diseases for some Latin American populations. The geographical distribution of vector-borne diseases (e.g., malaria, dengue, chagas) and infectious diseases (e.g., cholera) would expand southward and to higher altitudes if temperature and precipitation increase. Pollution and high concentrations of ground-level ozone, exacerbated by increasing surface temperature and increased penetration of UV-B radiation, would have the potential to negatively affect human health and welfare, especially in urban areas.

Integration: Increasing environmental deterioration arising from climate variability, climate change, and land-use practices, such as changes in water availability and loses of agricultural lands as a result of coastal, riverine, and flatland flooding, would aggravate socio-economic and health problems, furthering migrations of rural and coastal populations, and deepening national and international conflicts.

Additional efforts in monitoring, research, and sensitivity analyses are needed in order to allow decision makers and other stakeholders to assess the risks associated with changes in climate and climate variability, to prepare to take advantage of potential benefits, to minimize negative impacts, and to identify promising adaptation options. Some specific priorities include: organization and/or updating of bio-geo-physical observation networks and monitoring systems, development of regional climate models, sensitivity studies of the most vulnerable sectors -from ecosystems to infrastructure, and the development of suitable adaptation options. These efforts include both the creation of new technologies or the adaptation of existing technologies generated within or beyond the region. Initiatives to encourage cooperation within countries of the region or with other regions of the world (e.g., Valdivia Group), appear promising.

Middle East/Arid Asia

This region includes 21 countries of the predominantly arid and semi-arid areas of the Middle East and central Asia. The region extends from Turkey in the west to Kazakstan in the east, and from Yemen in the south to Kazakstan in the north.

Ecosystems: Little change is expected in the location of the grassland, rangeland, woodland and desert vegetation types that dominate the region. Small increases in precipitation are projected but these are likely to be countered by increased temperature and evaporation. Improved water use efficiency by some plants under elevated CO_2 may lead to some improvement in plant productivity and changes in ecosystem composition. Grasslands, livestock, and water resources are likely to be the most vulnerable to climate change in this region because they are located mostly in marginal areas. Management options, such as better stock management and more integrated agro-ecosystems, could improve land conditions and counteract pressures arising from climate change. The region is an important refuge for wild relatives of many important crop species, and with appropriate conservation measures may continue to provide a source of genetic material for future climatic conditions.

Coastal Systems: In the next century, rising sea level could inundate coastal wetlands and dry land areas currently below 50 cm above sea level. The projected changes in sea level would also put at risk human settlements, infrastructure, natural ecosystems, and marine mammals in these vulnerable coastal areas. Salt water intrusion, both upstream and inland, is likely to occur due to sea-level rise. This, in turn, could affect drinking water quality and coastal ground water.

Human Settlements: Projected changes in climate could have both positive and negative impacts on the operation and maintenance costs of North American land and water transportation. They could also increase the risks to property and human health/life as a result of possible increased exposure to natural hazards (e.g., wildfire, landslides, and extreme weather events) and result in increased demand for cooling and decreased demand for heating energy, with the overall net effect varying with geographic regions.

Human Health: Climate can have wide ranging and potentially adverse effects on human health via both direct (e.g., thermal stress and extreme weather/climate events) and indirect (e.g., disease vectors and infectious agents, environmental and occupational exposures to toxic substances, and food production) pathways.

Integration: Taken individually, any one of the impacts discussed here may be within the capabilities of a sub-region or sector to respond. The fact that they are projected to occur simultaneously and in concert with changes in population, technology, economics, and other environmental and social changes, adds to the complexity of the impacts assessment and to the choice of appropriate responses. The characteristics of the sub-regions and sectors of North America suggest that neither the impacts of climate change nor response options will be uniform. The technological capacity to adapt to climate change and many of its impacts is likely to be readily available in North America, but its application will be realized only if the necessary information is available in a timely manner (i.e., sufficiently far in advance in relation to the planning horizons and lifetimes of investments) and if the institutional and financial capacity to manage change exists.

Conclusion: While many sectors/regions are sensitive to climate change, the technological capability to adapt to climate change is, for the most part, readily available, although uncertainties exist about the feasibility of certain options, especially those for natural ecosystems. Once current adaptive capability has been factored in, the most vulnerable sectors and regions include: long-lived natural forest ecosystems in the east and interior west, water resources in the southern plains, agriculture in the southeast and southern plains, human health in areas currently experiencing diminished urban air quality, northern ecosystems and habitats, estuarine beaches in developed areas, and low latitude cool and cold-water fisheries. Other sectors and sub-regions may benefit from opportunities associated with warmer temperatures or potentially, from CO_2 fertilization, including: west coast coniferous forests, some western rangelands, reduced energy costs for heating in the northern latitudes, salting and snow clearance costs, open water season in northern channels and ports, and agriculture in the northern latitudes, the interior west, and west coast.

Small Island States

With the exception of Malta and Cyprus in the Mediterranean, all of the Small Island States considered in this report are located within the tropics. About one-third of the states comprise a single main island; the others are made up of several or many islands. While some states are experiencing relative sea-level fall, others, primarily low-lying island states and atolls, are especially vulnerable to climate change and associated sea-level rise because in many cases (e.g. the Bahamas, Kiribati, Maldives, Marshall Islands) much of the land area rarely exceeds 3-4 m above present mean sea level. Many islands at higher elevation are also vulnerable to climate change effects, particularly in their coastal zones, where the main settlements and vital economic infrastructure are almost invariably concentrated.

Ecosystems: While projected temperature rise is not anticipated to have widespread adverse consequences, some critical ecosystems, such as coral reefs, are highly sensitive to temperature changes. Although some reefs have the ability to keep pace with the projected rate of sea-level rise, in many parts of the Tropics (e.g. the Caribbean, Pacific) some species of corals live near their limits of tolerance to temperature. Elevated sea water temperatures (above seasonal maxima) can impair the reproductive functions of corals, and lead to increased mortality. The adaptive capacity of mangroves to climate change is expected to vary by species and according to local site conditions

respond effectively to changing conditions such as climate change, would be beneficial to the Small Islands States, even if climate change did not occur. Integrated coastal management is an example of one such policy initiative, whose implementation the Small Islands States might wish to consider.

Temperate Asia

Temperate Asia includes countries in Asia between 18°N and the Arctic Circle, including the Japanese Islands, Korean Peninsula, Mongolia, most parts of China, and Russian Siberia. The east-west distance of the area is about 8000km and its north-south extent is about 5000 km. Distinct sub-regions include arid/semi-arid, monsoonal, and Siberian regions.

Ecosystems: Although the area of potential distribution of temperate forests in Temperate Asia is to a large extent cleared and used for intensive agriculture, global warming can be considered sufficient to trigger structural changes in the remaining temperate forests. However, the nature and magnitude of these changes depends on the associated changes in water availability, as well as in water use efficiency. Shifts in temperature and precipitation in temperate rangelands may result in altered growing seasons and boundary shifts between grasslands, forests and shrublands. Under $2xCO_2$ equilibrium conditions (UKMO-H3, GFDL-A2), there would be a large reduction in the area (up to 50%) and productivity of boreal forests, primarily in the Russian Federation, accompanied by a significant expansion of grasslands and shrub lands. There would be also a decrease in the area of the tundra zone by up to 50%, accompanied by the release of CH_4 from deep peat deposits, and a modest increase, less than 25%, of present emission of CO_2.

Hydrology and Water Resources: Overall, most $2\times CO_2$ equilibrium scenario simulations show a decrease in water supply, except for a few river basins. Warmer winters may affect water balances since water demands are higher in spring and summer. Equilibrium climate conditions for doubled CO2 concentrations indicate a decrease of up to 25% in present mountain glacier mass is possible by 2050. Initially, runoff from glaciers in Central Asia is projected to increase threefold by 2050, but by 2100 would taper off to two-thirds of its present value. Model results suggest that runoff in the northern part of China is quite vulnerable to climate change, mainly due to changes in precipitation in spring, summer and autumn, especially during the floods. To balance water supply with water demand, increasingly efficient water management is likely the approach for Japan. In other parts of Temperate Asia, water resource development will remain important, and the central adaptation issue is how the design of new water resource infrastructure should be adjusted to account for uncertainties resulting from climate change. The most critical uncertainties are the lack of credible projections of the effects of global change on either the Asia monsoon or ENSO, which have great influence on river runoffs. Multiple-stress impact studies on water resources in international river basins are needed in the future.

Food and Fiber Production: Changes in crop yields from different GCMs vary widely in range. For example, in China, across different scenarios and different sites, the changes for several crop yields by 2050 are found to be: rice (-78% to +15%); wheat (-21% to +55%); and maize (-9% to +5%). An increase in productivity may occur if the positive effects of CO_2 on crop growth are considered, but its magnitudes remain uncertain. A northward shift of crop zones is expected to increase agricultural productivity in northern Siberia, but to decrease (about 25%) grain production in southwestern Siberia because of a more arid climate. Aquaculture is particularly important to Temperate Asia. Climate change impacts generally will be positive through faster growth, lower winter mortality rates, less ice-cover and reduced energy costs, with expanded regions of warmer water. Greater cultivation of warm water species could develop. Warming will require greater attention to possible oxygen depletion, fish diseases, and introduction of unwanted species, as well as to potential negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships.

Coastal Systems: An increase in sea level will exacerbate the current severe problems of tectonically - and anthropogenically - induced land subsidence in delta areas of China. Saltwater intrusion would also become more serious. A sea level rise of one meter would threaten the Japanese coastal zone on which 50% of Japan's industrial production is located (Tokyo, Osaka and Nagoya). In addition, about 80% of the remaining sandy beaches in Japan would be in danger of disappearing.

Food and Fiber Production: The sensitivity of the major cereal and tree crops to changes in temperature, moisture, and CO_2 concentration of the magnitudes projected for the region has been demonstrated in many studies. For instance, impacts on rice yield, wheat yield, and sorgham yield suggest that any increase in production associated with CO_2 fertilization is more than offset by reductions in yield from temperature and/or moisture changes. Although it is evident that climate change impacts could result in significant changes in crop yields, production, storage, and distribution, the net effect of the changes region-wide is uncertain because of (i) varietal differences; (ii) local differences in growing season, crop management, etc.; (iii) the lack of inclusion of possible diseases, pests, and micro-organisms in crop model simulations; and (iv) the vulnerability of agricultural areas to episodic environmental hazards, including floods, droughts, and cyclones. Low-income rural populations dependent on traditional agricultural systems or on marginal lands are particularly vulnerable.

Coastal Systems: The coastal lands are particularly vulnerable, with sea-level rise being the most obvious climate-related impact. The densely-settled and intensively-used low-lying coastal plains and deltas are especially vulnerable to coastal erosion and land loss, inundation and sea flooding, upstream movement of the saline/fresh water front, and sea-water intrusion into freshwater lenses. Especially at risk are the large delta regions of Bangladesh, Myanmar, Vietnam, and Thailand. Socio-economic impacts could be felt in the major cities and ports, tourist resorts, artisinal and commercial fishing, coastal agriculture, and infrastructure developments. International studies have projected the displacement of several millions of people from the region's coastal zone, assuming a 1 m rise in sea level. The costs of response measures to reduce the impact of sea-level rise in the region could be immense.

Human Health: The incidence and extent of vector-borne diseases are expected to increase with global warming. Malaria, schistosomiasis, and dengue, which are a significant cause of mortality and morbidity in Tropical Asia, are highly sensitive to climate change and are likely to spread into new regions on the margins of the presently endemic areas. Newly-affected populations would initially experience higher fatality rates. In presently-vulnerable regions, an increase in epidemic potential of 12-27% for malaria and 31-47% for dengue and decrease of schistosomiasis of between 11 to 17% are anticipated under a range of GCM scenarios. Water-borne and water-related infectious diseases, which already account for the majority of epidemic emergencies in the region, are also expected to increase when higher temperatures and higher humidity are superimposed on existing conditions and projected increases in population, urbanization, declining water quality, etc.

Adaptation and Integration: Individual countries, regions, resources, sectors, and systems will not be affected by climate change in isolation, but rather in interaction with one another. The potential direct effects of climate change assessed here, such as changes in rice crop yields and inundation of coastal areas, will all have further indirect effects. Suitability of adaptation strategies to a different climatic environment will vary across the diverse sub-regions and land-uses of the region. Options include: new temperature and pest resistant crop varieties, new technologies to reduce crop yield loss, improvements in irrigation efficiency from current levels in order to reduce the total water requirements, integrated approaches to river basin management, and integrated approaches to coastal zone management taking account of both current and longer-term issues, including climate change and sea-level rise.

Clinton Presidential Records
Digital Records Marker

This is not a presidential record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

This marker identifies the place of a publication.

Publications have not been scanned in their entirety for the purpose of digitization. To see the full publication please search online or visit the Clinton Presidential Library's Research Room.

Fall 1997 No. 4

REPORTS TO THE NATION

On Our Changing Planet

Our Changing Climate

Domestic Cabinet Energy Studies

'97 NOV 12 PM12:05

Energy Information Administration
Washington, DC

FACSIMILE TRANSMISSION SHEET

Date: 11/12/97

To: Jonathan Adashek
White House

Phone: 202 456 2702

FAX: 202 456 2215

From: Jonathan Cogan
National Energy Information Center

Phone: (202) 586-8719

FAX: (202) 586-0727

COMMENTS:

This document has 10 pages including this cover sheet.

INTERNET E-MAIL: infoctr@eia.doe.gov
HOME PAGE: HTTP://WWW.EIA.DOE.GOV

On-line and off-the shelf, EIA is the first place to go for the last word in energy information.

EIA's analysis includes the transition to competitive prices in regions (California, New York, and New England) where plans to implement restructuring are currently in place. Restructuring actions in States without formal plans are omitted, so the projections do not represent the full impact of moving to competitive pricing. (The complete *Annual Energy Outlook 1998*, to be released next month, analyzes a fully competitive electricity market.)

Other forecast highlights

- The average minemouth price of coal is projected to decline from $18.50 a ton in 1996 to $13.27 a ton in 2020. By 2015, the price is expected to be 12 percent lower than EIA forecast a year ago, contributing to the lower electricity price projections. Recent data show a greater impact of productivity on mining cost and price than projected last year. Productivity improvements are also expected to reduce costs for Western surface mines, shifting more production to lower-cost Western mines.

- Natural gas wellhead prices are projected to be $2.54 per thousand cubic feet in 2020, up from $2.24 per thousand cubic feet in 1996. Prices are about 9 percent higher in 2015 than last year's projection, because of a lower assessment of the expansion of the resource base, higher drilling costs as indicated by more recent data, and higher projected demand for natural gas.

- The average world price of crude oil is projected to rise from $20.48 a barrel in 1996 to $22.32 a barrel in 2020. EIA projections for worldwide oil demand are higher than in last year's forecast because of higher assumed economic growth; however, the 2015 price is the same in both forecasts because of expanded production particularly from countries outside the Organization of Petroleum Exporting Countries (OPEC).

- Net oil imports are expected to provide 66 percent of oil consumption in 2020, compared with 46 percent in 1996, as a result of increasing oil consumption and declining domestic production. Crude oil production declines from 6.5 million barrels a day in 1996 to 4.9 million barrels a day in 2020. Although projected oil production in 2015 is the same as in last year's forecast, oil consumption is higher, leading to net petroleum imports that are 11 percent higher in 2015 than projected a year ago.

- Renewable sources of energy are expected to penetrate energy markets at a slower pace than previously forecast, due to electricity restructuring and increased competition with fossil fuel technologies. The assumptions for increased competition in the electricity industry tend to favor the less-capital intensive technologies over coal and baseload renewables. As a result, electricity generation from renewable resources remains relatively stable between 1996 and 2020. The slower penetration of renewable energy sources contributes to the higher carbon emissions in the current forecast.

(MORE)

Reference case projections from the *Annual Energy Outlook 1998* and an overview of the results can be accessed immediately on EIA's World Wide Web Site (http://www.eia.doe.gov). The direct Internet address is: www.eia.doe.gov/oiaf/aeo98/earlyrel.html. The overview is also available from EIA's press contact. The figures referenced above may be viewed, together with this press release, on EIA's Web Site, or they may be obtained from EIA's press contact.

The full *Annual Energy Outlook 1998* will be released on December 18, 1997. The *Outlook* includes cases that analyze the changes caused by different technology and productivity assumptions. Additional cases assume higher or lower economic growth rates and higher or lower world oil prices than those in the reference case. The forecasts in the *Outlook* assume that current legislation and regulations remain in effect.

At the time of its release, copies of the *Annual Energy Outlook 1998* will be available from the U.S. Government Printing Office 202/512-1800 or through EIA's National Energy Information Center, Forrestal Building, Washington, DC 20585, 202/586-8800. The full *Outlook*, its underlying assumptions, and more detailed, regional projections will be available on EIA's Web Site by December 19, 1997.

The report described in this press release was prepared by the Energy Information Administration, the independent statistical and analytical agency within the U.S. Department of Energy. The information contained in the report and the press release should be attributed to the Energy Information Administration and should not be construed as advocating or reflecting any policy position of the Department of Energy or any other organization.

- EIA -

EIA Program Contact: Mary J. Hutzler, 202/586-2222
EIA Press Contact: Thomas Welch, 202/586-1178

EIA-97-34

Figure 1. Carbon Emissions from Energy Use, AEO98 vs. AEO97, 1990-2020 (million metric tons)

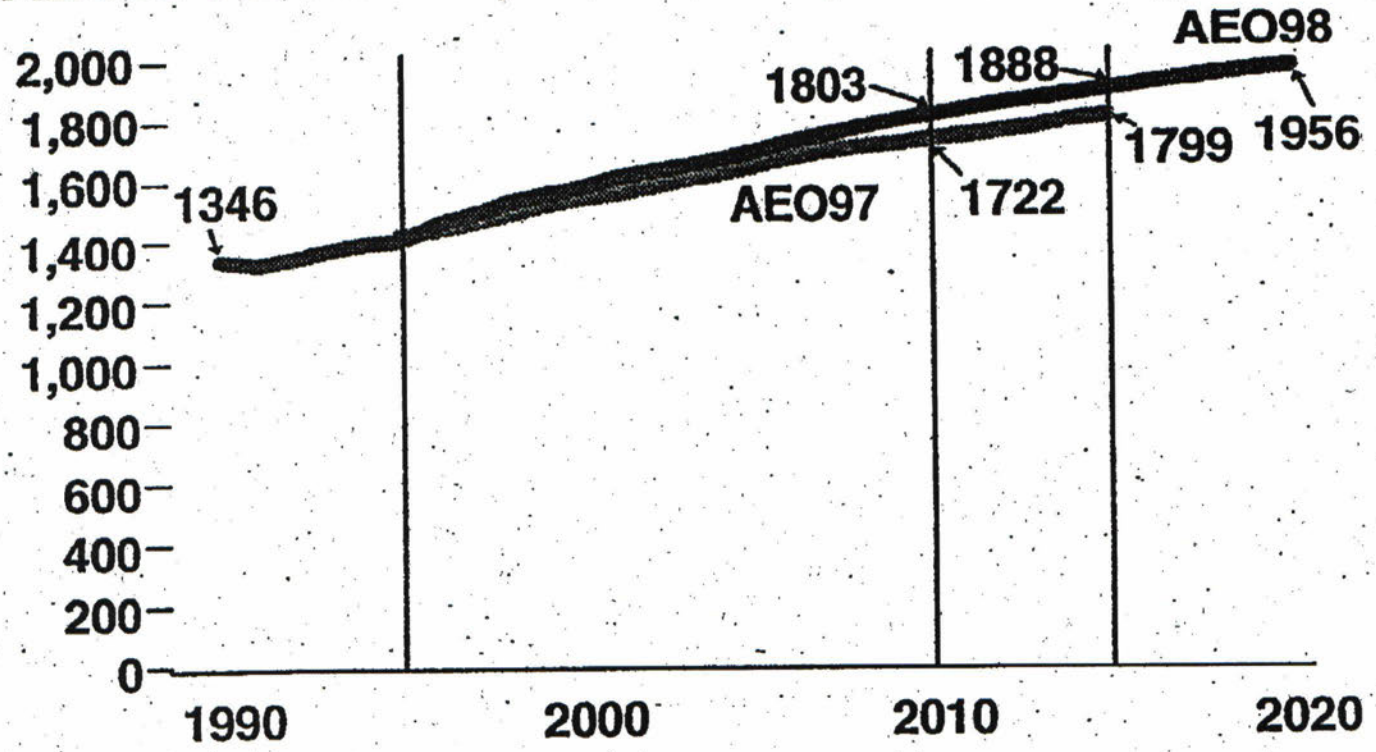
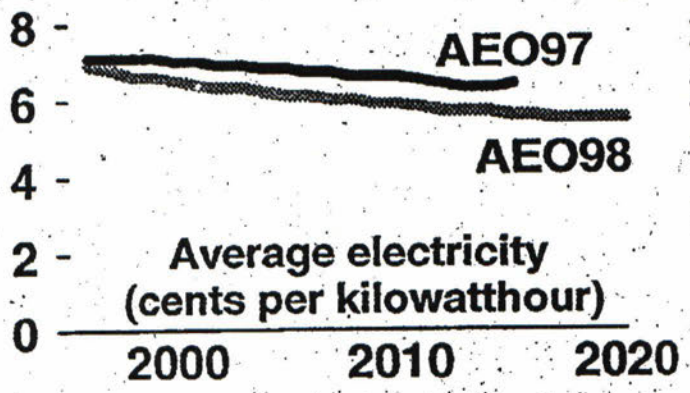
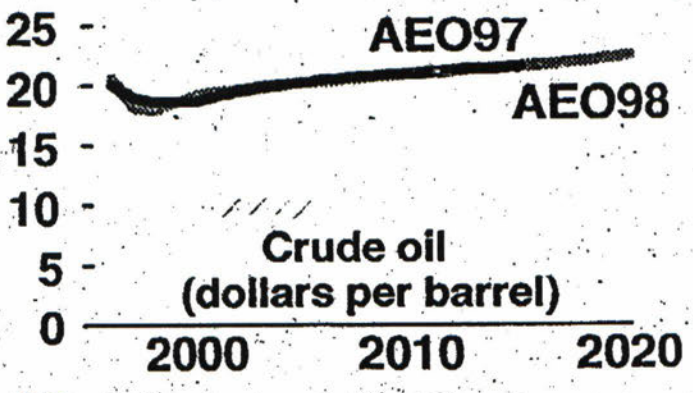
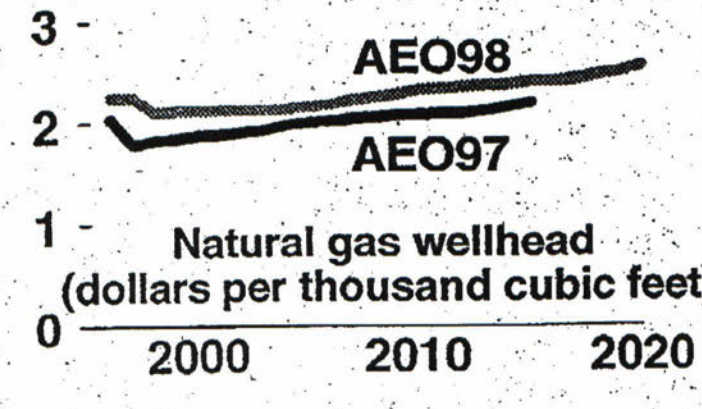
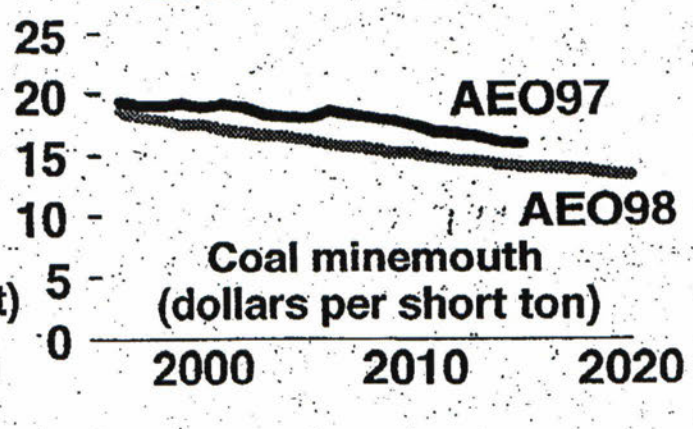


Figure 2. Fuel Prices, AEO98 vs. AEO97, 1996-2020 (1996 dollars)









EMBARGOED UNTIL 12:00 NOON EASTERN TIME NOVEMBER 12, 1997

Overview

Key Issues

The *Annual Energy Outlook 1998* (*AEO98*) is the first *AEO* with projections to 2020. Key issues for the forecast extension are trends in energy efficiency improvements, the effects of increasing production and productivity improvements on energy prices, and the reduction in nuclear generating capacity.

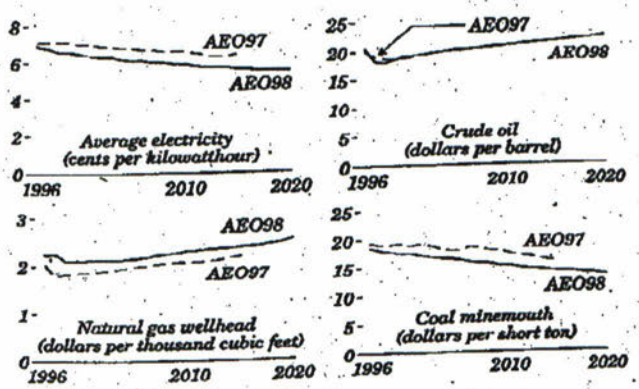
Projections in *AEO98* also reflect a greater shift to electricity market restructuring. Restructuring is addressed through several changes that are assumed to occur in the industry, including a shorter capital recovery period for capacity expansion decisions and a revised financial structure that features a higher cost of capital as the result of higher competitive risk. Both assumptions tend to favor less capital-intensive generation technologies, such as natural gas, over coal or baseload renewable technologies.

The forecasts include specific restructuring plans in those regions that have announced plans. California, New York, and New England are assumed to begin competitive pricing in 1998. The provisions of the California legislation for stranded cost recovery and price caps are incorporated. In New York and New England, stranded cost recovery is assumed to be phased out by 2008.

Prices

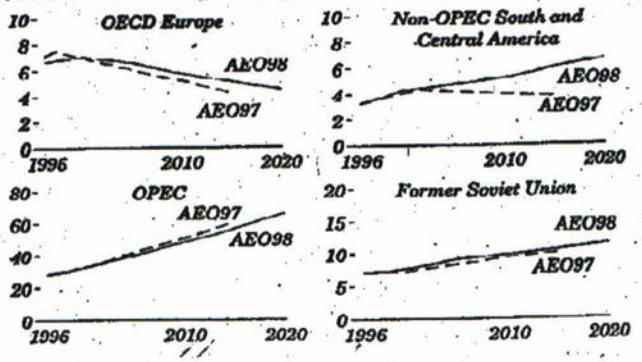
Average world crude oil prices in *AEO98* are projected to be similar to those in *AEO97* (Figure 1), $21.48 a barrel (all prices are in 1996 dollars) in 2015, rising to $22.32 a barrel in 2020. Worldwide demand for oil is expected to reach 116.6 million barrels per day in 2020. Because of higher assumed economic growth, the *AEO98* projection of world oil demand in 2015 is 3 percent higher than the *AEO97* projection—106.2 million barrels per day compared with 102.8 million barrels per day.

Figure 1. Fuel price projections, 1996-2020: AEO97 and AEO98 compared (1996 dollars)



Oil production in the Organization of Petroleum Exporting Countries (OPEC) continues to expand to 2020 in the *AEO98* projections, but OPEC production in 2015 is 7 percent lower than was projected in *AEO97* (Figure 2). Partially offsetting a lower outlook for Persian Gulf production are recent offshore discoveries in Nigeria and Algeria and capacity expansion in Venezuela. It is assumed that Iraqi oil production will not exceed sanction-approved levels until after 1998 and then will increase to full capacity within a decade. OPEC production capacity expansion in the Persian Gulf is lower than in *AEO97* because of a more optimistic assessment of oil production potential and technological advances in non-OPEC countries.

Figure 2. Sources of world oil supply, 1996-2020: AEO97 and AEO98 compared (million barrels per day)



Higher expectations for non-OPEC oil production in *AEO98*, as compared with *AEO97*, maintain world oil prices at *AEO97* levels even with higher world demand. New fields in the North Sea slow the projected production decline in that area. Production in Central and South America increases, particularly in Mexico, Brazil, Colombia, and Argentina. In the oil-producing areas of the Former Soviet Union, current production increases through 2020, mostly due to the development of the Caspian Sea oil fields. Expectations for oil production in Canada and in the offshore areas of West Africa are also higher in *AEO98* than they were in *AEO97*.

The average wellhead price of natural gas in *AEO98* is projected to increase to $2.38 per thousand cubic

Overview

feet in 2015 (9 percent higher than the $2.18 in *AEO97*), increasing to $2.54 in 2020. Higher price projections are the result of a lower assessment of the expansion of the oil and gas resource base, higher drilling costs as indicated in more recent data, and higher projected demand for natural gas.

In *AEO98*, the average minemouth price of coal is projected to be $13.99 per ton in 2015, 12 percent lower than the $15.84 in *AEO97*. Prices are lower in *AEO98* due to analysis of more recent data showing a greater impact of productivity on mining costs and price, regional analysis of productivity improvements that reduce costs for western surface mines, and a higher share for western coal. By 2020, the price declines to $13.27 per ton as a result of increasing productivity, a continued shift to lower-cost western production, and competitive pressures on labor costs.

AEO97 represented increased competition in electricity markets by incorporating the Federal Energy Regulatory Commission actions on open access, lower costs for gas-fired technologies, and early retirements of higher cost coal-fired plants. In addition, *AEO98* assumes lower operating and maintenance costs as indicated by recent data, lower capital costs and improved efficiency for coal- and gas-fired generation technologies, lower general and administrative costs, early retirement of higher cost nuclear units, changes in financial structure, and transition to competitive prices in California, New York, and New England (as noted above). Average electricity prices decline to 5.5 cents per kilowatthour in 2020. Because of these assumptions and lower coal prices, electricity prices are 13 percent lower than in *AEO97*—5.6 cents per kilowatthour in 2015 in *AEO98*, compared to 6.4 cents in *AEO97*.

Currently evolving legislative actions that could shape the future of the electricity industry are discussed in the "Legislation and Regulations" section of this report. An analysis of the potential impacts of competitive pricing nationwide is included in the "Issues in Focus" section.

Consumption

Total U.S. energy consumption is projected to increase from 94.0 to 118.6 quadrillion British thermal units (Btu) between 1996 and 2020. In 2015 the *AEO98* projection is 4.7 quadrillion Btu (4 percent) higher than in *AEO97*, reflecting higher projected consumption levels in all end-use sectors.

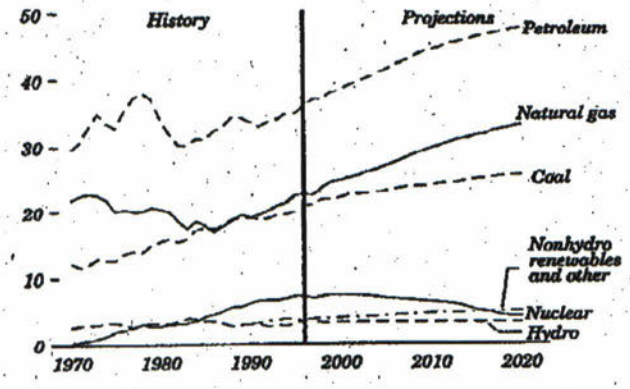
Transportation demand grows at an average annual rate of 1.6 percent through 2020 and is 2.6 quadrillion Btu (8 percent) higher in 2015 compared with *AEO97*. Recent data indicate increased light-duty vehicle travel, particularly by the older age groups and women, and slower growth in efficiency of light-duty vehicles because of continuing consumer preference for improved performance and larger vehicles over efficiency. In 2015, motor gasoline demand is 10 percent (0.9 million barrels per day) higher than was projected in *AEO97*. In *AEO98*, jet fuel demand is 17 percent higher in 2015, reflecting an ongoing trend of more air travel, combined with slower sales of the more efficient wide-body aircraft.

In *AEO98*, residential and commercial demand is higher than in *AEO97* by a total of 1.5 quadrillion Btu (4 percent) in 2015, partly as the result of lower projected electricity prices. In the absence of additional efficiency standards beyond the new refrigerator and room air conditioner standards that were issued in 1997, penetration of more efficient technologies is assumed to occur more slowly than in *AEO97*. In the residential sector, there are also more mobile homes, a more disaggregated representation of end uses, and greater use of the more traditional heating technologies (as indicated by recent data), all contributing to higher projected demand in *AEO98*. Commercial floorspace increases at a faster rate than in *AEO97* early in the projection period, contributing to higher demand in *AEO98*. Industrial sector demand is 2 percent (0.6 quadrillion Btu) higher in 2015, with higher expected growth in some of the more energy-intensive industries partially offset by more rapid efficiency improvements.

AEO98 incorporates the efficiency standards for new energy-using equipment in buildings and for motors mandated through 1994 by the National Appliance Energy Conservation Act of 1987 and the Energy Policy Act of 1992. Several alternative cases in *AEO98* examine the impacts of technology on the projections by assuming the penetration of more energy-efficient technologies in the end-use sectors beyond that projected in the reference case and, conversely, assuming slower penetration of technology improvements. Modifications to residential equipment standards are discussed in "Legislation and Regulations."

Natural gas consumption increases by an average of 1.6 percent a year (Figure 3), with increased demand in all sectors. The most rapid growth is in consumption by electricity generators (excluding cogenerators), which is projected to increase from 3.0 to 10.1 quadrillion Btu between 1996 and 2020. Total gas consumption in 2015 is 0.5 quadrillion Btu (2 percent) higher than in *AEO97*, due to higher projected consumption in the residential, commercial, and industrial sectors.

Figure 3. Energy consumption by fuel, 1970-2020 (quadrillion Btu)



Although coal-fired generation loses market share over the projection period, it accounts for more than one-half of electricity generation (excluding cogeneration). Total coal consumption increases from 20.9 to 25.6 quadrillion Btu between 1996 and 2020, an average annual rate of 0.9 percent. About 90 percent of U.S. coal consumption is used for electricity generation. Coal consumption is 5 percent (1.2 quadrillion Btu) higher than in *AEO97* in 2015, due to an increase in projected consumption for generation.

Demand for petroleum products is projected to grow by an average of 1.2 percent a year through 2020. In 2020, 72 percent of petroleum use is in the transportation sector, up from 66 percent in 1996. Increases in light-duty vehicle miles traveled more than offset the increases in vehicle efficiency throughout the projection period. Continued economic growth also increases petroleum use for air and freight travel and shipping over the forecast horizon. In 2015, total petroleum demand is 7 percent higher than in *AEO97*, due primarily to higher travel and slower efficiency improvements in the transportation sector.

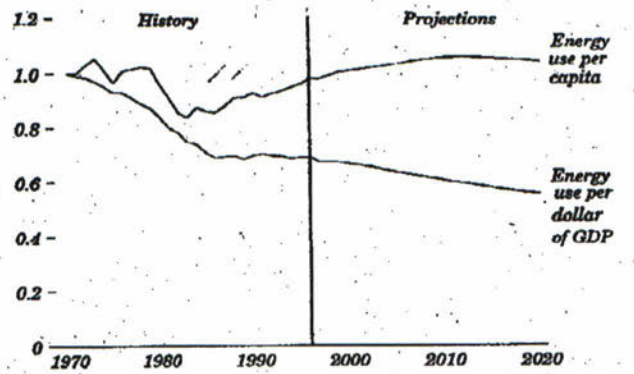
Renewable fuel use increases by an average of 0.5 percent a year. In 2020, 59 percent of the total is for electricity generation and the rest for dispersed heating and cooling, industrial uses, and blending in vehicle fuels. In 2015, renewables consumption is lower than in *AEO97* by 0.2 quadrillion Btu (3 percent) due to lower demand for renewables for electricity generation and for industrial sector cogeneration, as indicated by recent data.

Electricity consumption is projected to grow by 1.4 percent a year through 2020. Efficiency gains in the use of electricity partially offset the continued trend of electrification and the penetration of new electricity-using equipment. Compared to *AEO97*, electricity demand is higher by 0.2 quadrillion Btu (2 percent) in 2015, due to slower efficiency improvements in the residential and commercial sectors and a more disaggregated treatment of residential end uses.

Energy Efficiency

Energy intensity, measured as energy use per dollar of GDP, has generally declined since 1970, particularly during periods of rapid increases in energy prices (Figure 4). From 1970 to 1986, it declined on average by 2.3 percent a year, as the economy shifted to less energy-intensive industries and more efficient technologies. Energy intensity was relatively stable from 1986 to 1996 due to moderate price increases and the growth of more energy-intensive industries. From 1996 to 2020, intensity is projected to decline at an average annual rate of 0.9 percent.

Figure 4. Energy use per capita and per dollar of gross domestic product, 1970-2020 (index, 1970 = 1)



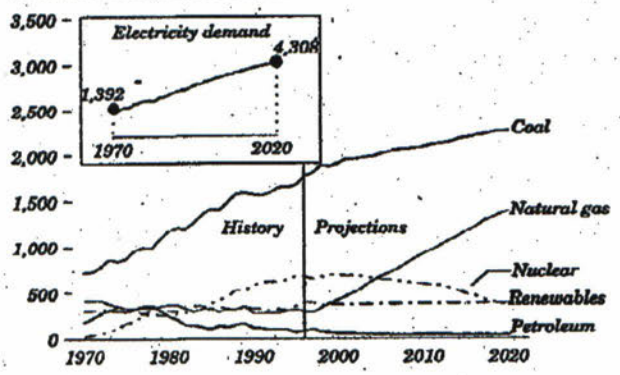
Energy use per capita, which also declined from 1970 through the early 1980s, rose in the mid-1980s as energy prices declined. Per capita energy use is expected to remain relatively stable through 2020 and below the high in the early 1970s, as efficiency gains offset higher demand for energy services.

Overview

Electricity Generation

Electricity generation from nuclear power declines significantly over the projection period (Figure 5). Of the 101 gigawatts of nuclear capacity available in 1996, 52 gigawatts (65 units) are assumed to be retired by 2020, with no new plants constructed by 2020. In *AEO97*, it was assumed that nuclear plants would be retired at the end of their 40-year operating licenses; however, *AEO98* assumes that 24 units will be retired as early as 10 years before their licenses expire. The early retirement assumptions are based on utility announcements and on analysis of the ages and operating costs of the units.

Figure 5. Energy generation by fuel, 1970-2020 (billion kilowatthours)



Generation from both natural gas and coal is projected to increase significantly through 2020 to meet increased demand for electricity and offset the decline in nuclear power. With lower coal prices, lower capital costs for coal-fired generating technologies, and higher electricity demand, the projection for coal-fired generation is higher than the *AEO97* projection. The share of coal generation declines in the *AEO98* forecast to 2020, because the assumptions concerning the restructuring of the electricity industry favor the less capital-intensive gas technologies for new capacity additions. *AEO98* also incorporates a more optimistic assessment of ultimately recoverable natural gas resources, which affects capacity expansion decisions in favor of natural gas technologies. The natural-gas-fired share of electricity generation (excluding cogenerators) more than triples, from 9 percent to 31 percent, between 1996 and 2020.

Generation from renewable energy sources remains nearly stable between 1996 and 2020. Compared with *AEO97*, renewable generation is 2 percent (6 billion kilowatthours) lower in 2015. Renewables penetrate more slowly than they did in *AEO97* due to competition with fossil fuel technologies. In addition, the shorter assumed capital recovery period for new projects weighs against more capital-intensive projects, such as coal and baseload renewables. Biomass generation is significantly lower than in *AEO97* because of lower coal prices and reduced costs for coal technologies, which compete with biomass.

In *AEO98*, hydropower, the main renewable source of electricity generation, is lower in 2020 than in 1996, primarily because regulatory actions limit capacity at existing sites and no large new sites are available for development. Generation from all other renewables increases to 2020, although at slower rates than in *AEO97*.

Production and Imports

U.S. crude oil production declines at an average rate of 1.1 percent a year between 1996 and 2020 to a projected level of 4.9 million barrels a day. Advances in oil exploration and production technologies are insufficient to offset declining resources. In 2015, projected world oil prices are the same in *AEO98* as those in *AEO97*, and domestic crude oil production is also the same at 5.2 million barrels a day. In projections of total petroleum production (Figure 6), increases in the production of natural gas plant liquids partially offset the decline in crude oil production.

Declining production and rising consumption lead to increasing petroleum imports through 2020 (Figure 7). The share of petroleum consumption met by net imports rises from 46 percent in 1996 (measured in barrels per day) to 66 percent in 2020. Comparing *AEO97* to *AEO98*, the 2015 share increases from 61 to 63 percent as a result of higher demand and stable production.

In *AEO98*, dry natural gas production is projected to increase from 19.0 trillion cubic feet in 1996 to 27.4 trillion cubic feet in 2020, an average annual rate of 1.5 percent, to meet most of the growing demand for gas. Net imports of natural gas, primarily from Canada, increase from 2.7 to 4.9 trillion cubic feet between 1996 and 2020. It is assumed that pipeline

Figure 6. Energy production by fuel, 1970-2020 (quadrillion Btu)

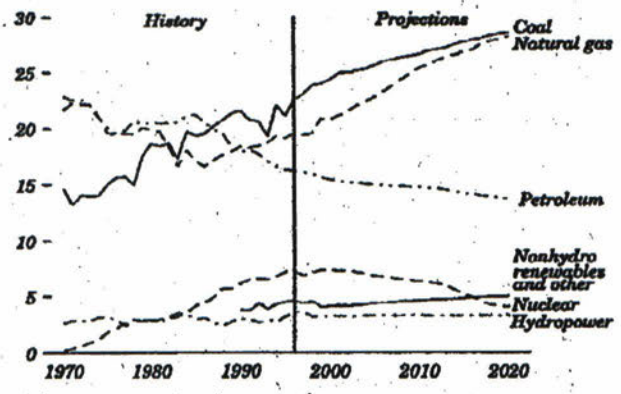
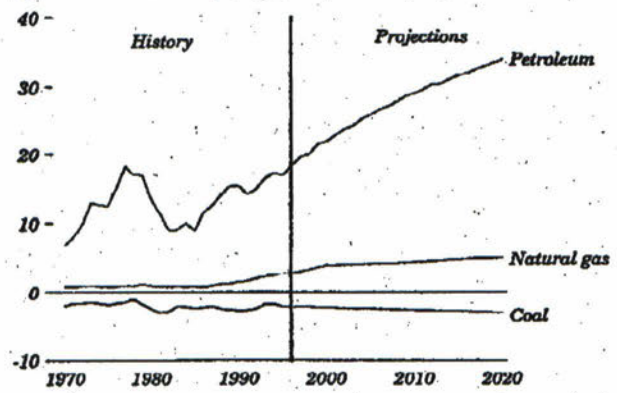


Figure 7. Net energy imports by fuel, 1970-2020 (quadrillion Btu)



capacity from Canada and pipeline utilization rates increase to encourage imports of competitively priced Canadian gas. Net imports of liquefied natural gas increase to 0.3 trillion cubic feet in 2020.

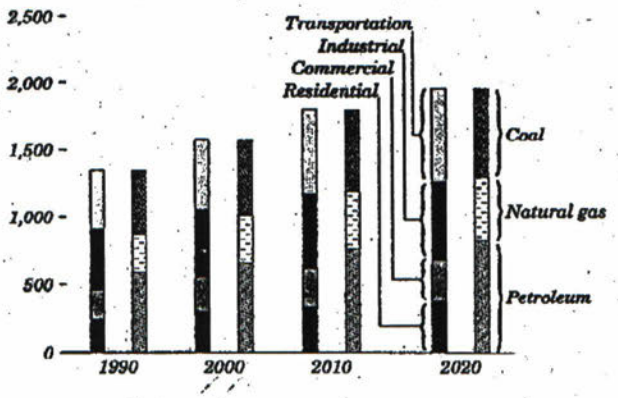
Coal production increases by an average of 1.1 percent a year, from 1,064 million tons in 1996 to 1,376 million tons in 2020, with increasing demand for domestic use and for exports. Exports of steam coal will primarily serve expanding markets for electricity generation in Asia, although exports to Europe and the Americas also increase. Total metallurgical coal exports are essentially unchanged from 1996 to 2020. In 2015, coal production in the *AEO98* projections is higher than in *AEO97* by 58 million tons (5 percent) due to increased consumption by electricity generators, which is offset slightly by a reduction in industrial demand.

Renewable energy production, including hydropower, is projected to increase from 6.9 to 7.7 quadrillion Btu between 1996 and 2020, primarily from industrial biomass, along with municipal solid waste, geothermal, wind, and biomass for electricity generation. With lower consumption in the industrial and generation sectors, the *AEO98* projection for renewable energy production is 0.2 quadrillion Btu (3 percent) lower in 2015 than in *AEO97*.

Carbon Emissions

Carbon emissions from energy use are projected to increase by 1.2 percent a year, to 1,956 million metric tons in 2020 (Figure 8). Projected emissions in 2015 are 5 percent higher than in *AEO97*—1,888 million metric tons compared with 1,799 million metric tons—due to higher energy consumption and lower penetration of renewables. About one-third of the increase from *AEO97* is attributable to increased electricity demand and the resulting increase in consumption of natural gas and coal for generation. Increased use of petroleum in the transportation sector contributes more than 50 percent of the increased emissions in *AEO98* compared to *AEO97*.

Figure 8. U.S. carbon emissions by sector and fuel, 1990-2020 (million metric tons)



The Climate Change Action Plan (CCAP) is a collection of 44 actions developed by the Clinton Administration in 1993 to stabilize greenhouse gas emissions at 1990 levels in 2000. In 1990, carbon emissions from energy use were estimated to be about 1,346 million metric tons. *AEO98* incorporates the impacts of those CCAP provisions related to carbon emissions from energy use, including the Climate Challenge and Climate Wise programs, which foster voluntary reductions in emissions by electric utilities and industry; however, projected emissions exceed 1990 levels in 2000 by 17 percent and in 2020 by 45 percent. Further discussion of carbon emissions is presented in the "Issues in Focus" and "Market Trends" sections.

Energy Information Administration
Washington, DC

FACSIMILE TRANSMISSION SHEET

'97 NOV 12 PM12:

Date: 11/12/97

To: Jonathan Adashek
White House

Phone: 202 456 2702

FAX: 202 456 2215

From: Jonathan Cogan

National Energy Information Center

Phone: (202) 586-8719

FAX: (202) 586-0727

COMMENTS:

This document has 29 pages including this cover sheet.

INTERNET E-MAIL: infoctr@eia.doe.gov
HOME PAGE: HTTP://WWW.EIA.DOE.GOV

On-line and off-the shelf, EIA is the first place to go for the last word in energy information.

Table A1. Total Energy Supply and Disposition Summary
(Quadrillion Btu per Year, Unless Otherwise Noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Production								
Crude Oil and Lease Condensate	13.69	13.71	13.06	12.52	11.79	11.09	10.43	-1.1%
Natural Gas Plant Liquids	2.37	2.46	2.39	2.69	2.95	3.12	3.29	1.2%
Dry Natural Gas	19.12	19.55	20.84	22.88	25.39	26.85	28.21	1.5%
Coal	21.99	22.64	24.34	25.62	26.62	27.73	28.59	1.0%
Nuclear Power	7.19	7.20	7.36	6.87	6.36	5.12	4.09	-2.3%
Renewable Energy[1]	6.40	6.91	6.82	7.12	7.41	7.59	7.71	0.5%
Other[2]	1.36	1.33	0.56	0.55	0.48	0.47	0.47	-4.2%
Total	72.31	73.80	75.37	77.98	81.00	81.97	82.77	0.5%
Imports								
Crude Oil[3]	15.70	16.30	19.16	22.01	23.17	24.36	25.30	1.8%
Petroleum Products[4]	3.19	3.98	4.25	5.47	7.61	9.01	10.09	3.9%
Natural Gas	2.90	2.93	4.20	4.39	4.66	5.04	5.34	2.5%
Other Imports[5]	0.59	0.57	0.62	0.58	0.57	0.54	0.56	-0.1%
Total	22.38	23.78	28.25	32.45	36.02	38.96	41.28	2.3%
Exports								
Petroleum[6]	2.02	2.04	1.71	1.73	1.80	1.89	1.67	-0.8%
Natural Gas	0.16	0.16	0.28	0.28	0.29	0.30	0.32	3.0%
Coal	2.32	2.37	2.41	2.64	2.84	3.03	3.23	1.3%
Total	4.50	4.57	4.39	4.65	4.93	5.21	5.23	0.6%
Discrepancy[7]	0.65	0.99	0.58	0.04	0.08	0.00	-0.25	N/A
Consumption								
Petroleum Products[8]	34.74	36.01	38.35	41.32	44.33	46.20	47.64	1.2%
Natural Gas	22.18	22.60	24.74	26.93	29.63	31.44	33.06	1.6%
Coal	19.96	20.90	22.14	23.21	24.03	24.95	25.61	0.9%
Nuclear Power	7.19	7.20	7.36	6.87	6.36	5.12	4.09	-2.3%
Renewable Energy[1]	6.40	6.91	6.82	7.12	7.42	7.62	7.74	0.5%
Other[9]	0.39	0.39	0.41	0.37	0.40	0.40	0.43	0.4%
Total	90.86	94.01	99.82	105.82	112.17	115.72	118.58	1.0%
Net Imports - Petroleum	16.87	16.25	21.72	25.75	28.99	31.48	33.71	2.6%
Prices (1996 dollars per unit)								
World Oil Price (dollars per barrel)[10]	17.58	20.48	19.11	20.19	20.81	21.48	22.32	0.4%
Gas Wellhead Price (dollars per Mcf)[11]	1.61	2.24	2.11	2.15	2.31	2.38	2.54	0.5%
Coal Minemouth Price (dollars per ton)	19.25	18.50	17.46	16.18	15.05	13.99	13.27	-1.4%
Average Electric Price (cents per kilowatthour)	7.0	6.9	6.5	6.1	5.9	5.6	5.5	-1.0%

[1]Includes grid-connected electricity from conventional hydroelectric; wood and wood waste; landfill gas; municipal solid waste; other biomass; wind; photovoltaic and solar thermal sources; non-electric energy from renewable sources, such as active and passive solar systems, and wood; and both the ethanol and gasoline components of E85, but not the ethanol components of blends less than 85 percent. Excludes electricity imports using renewable sources and nonmarketed renewable energy. See Table A18 for selected nonmarketed residential and commercial renewable energy.
[2]Includes liquid hydrogen, methanol, supplemental natural gas, and some domestic inputs to refineries.
[3]Includes imports of crude oil for the Strategic Petroleum Reserve.
[4]Includes imports of finished petroleum products, imports of unfinished oils, alcohols, ethers, and blending components.
[5]Includes coal, coal coke (net), and electricity (net).
[6]Includes crude oil and petroleum products.
[7]Balancing item. Includes unaccounted for supply, losses, gains, and net storage withdrawals.
[8]Includes natural gas plant liquids, crude oil consumed as a fuel, and nonpetroleum based liquids for blending, such as ethanol.
[9]Includes net electricity imports, methanol, and liquid hydrogen.
[10]Average refiner acquisition cost for imported crude oil.
[11]Represents lower 48 onshore and offshore supplies.
Btu = British thermal unit.
Mcf = Thousand cubic feet.
N/A = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Figures for 1995 and 1996 may differ from published data due to internal conversion factors.
Sources: 1995 natural gas values: Energy Information Administration (EIA), *Natural Gas Annual 1995*, DOE/EIA-0131(95) (Washington, DC, November 1996). 1995 coal minemouth prices: EIA, *Coal Industry Annual 1995*, DOE/EIA-0584(95) (Washington, DC, October 1996). Other 1995 values: EIA, *Annual Energy Review 1995*, DOE/EIA-0384(95) (Washington, DC, July 1996). 1996 natural gas values: EIA, *Natural Gas Monthly*, DOE/EIA-0130(97/06) (Washington, DC, June 1997). 1996 coal minemouth price: *Coal Industry Annual 1996* DOE/EIA-0584(96) (Washington, DC, November 1997). Coal production and exports derived from: EIA, *Monthly Energy Review*, DOE/EIA-0035(97/09) (Washington, DC, August 1997). Other 1996 values: EIA, *Annual Energy Review 1996*, DOE/EIA-0384(06) (Washington, DC, July 1997). Projections: EIA, AEO96 National Energy Modeling System run AEO96B.D100197A.

Reference Case Forecast

Table A2. Energy Consumption by Sector and Source
(Quadrillion Btu per Year, Unless Otherwise Noted)

Sector and Source	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Energy Consumption								
Residential								
Distillate Fuel	0.69	0.89	0.85	0.79	0.77	0.74	0.72	-0.9%
Kerosene	0.07	0.08	0.08	0.07	0.07	0.07	0.07	-0.6%
Liquefied Petroleum Gas	0.40	0.42	0.45	0.47	0.49	0.50	0.51	0.8%
Petroleum Subtotal	1.36	1.40	1.38	1.34	1.33	1.32	1.30	-0.3%
Natural Gas	4.98	5.39	5.35	5.47	5.63	5.82	5.97	0.4%
Coal	0.05	0.05	0.06	0.05	0.05	0.05	0.05	-0.2%
Renewable Energy[1]	0.59	0.61	0.61	0.62	0.63	0.64	0.64	0.2%
Electricity	3.56	3.68	3.97	4.29	4.61	4.94	5.28	1.5%
Delivered Energy	10.54	11.13	11.36	11.77	12.25	12.77	13.25	0.7%
Electricity Related Losses	7.88	8.23	8.75	9.05	9.39	9.58	9.93	0.8%
Total	18.42	19.36	20.11	20.81	21.64	22.35	23.17	0.8%
Commercial								
Distillate Fuel	0.47	0.44	0.41	0.40	0.40	0.39	0.37	-0.7%
Residual Fuel	0.17	0.15	0.12	0.12	0.12	0.12	0.12	-0.9%
Kerosene	0.02	0.03	0.02	0.02	0.02	0.02	0.02	-0.2%
Liquefied Petroleum Gas	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.8%
Motor Gasoline[2]	0.07	0.03	0.03	0.03	0.03	0.02	0.02	-0.3%
Petroleum Subtotal	0.81	0.71	0.65	0.65	0.65	0.65	0.63	-0.5%
Natural Gas	3.11	3.30	3.47	3.62	3.75	3.85	3.85	0.7%
Coal	0.08	0.08	0.09	0.09	0.09	0.10	0.10	0.8%
Renewable Energy[3]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1%
Electricity	3.26	3.37	3.59	3.84	4.09	4.33	4.45	1.2%
Delivered Energy	7.26	7.47	7.80	8.21	8.60	8.92	9.04	0.8%
Electricity Related Losses	7.21	7.54	7.91	8.09	8.35	8.39	8.37	0.4%
Total	14.46	15.01	15.72	16.30	16.94	17.31	17.41	0.6%
Industrial[4]								
Distillate Fuel	1.13	1.17	1.21	1.35	1.45	1.51	1.56	1.2%
Liquefied Petroleum Gas	2.00	2.12	2.14	2.25	2.40	2.45	2.47	0.6%
Petrochemical Feedstock	1.23	1.28	1.31	1.38	1.47	1.49	1.51	0.7%
Residual Fuel	0.37	0.34	0.35	0.35	0.35	0.34	0.35	0.1%
Motor Gasoline[2]	0.19	0.19	0.20	0.23	0.25	0.26	0.27	1.4%
Other Petroleum[5]	3.77	4.12	4.35	4.60	4.84	5.05	5.10	0.9%
Petroleum Subtotal	8.69	9.23	9.55	10.15	10.75	11.10	11.25	0.8%
Natural Gas[6]	9.91	10.14	10.94	11.16	11.67	11.77	11.80	0.6%
Metallurgical Coal	0.89	0.85	0.83	0.76	0.71	0.65	0.61	-1.4%
Steam Coal	1.60	1.55	1.56	1.70	1.77	1.78	1.79	0.6%
Net Coal Coke Imports	0.03	0.00	0.03	0.05	0.06	0.07	0.08	N/A
Coal Subtotal	2.51	2.40	2.42	2.51	2.54	2.51	2.48	0.1%
Renewable Energy[7]	1.74	1.82	1.96	2.11	2.25	2.31	2.34	1.0%
Electricity	3.46	3.46	3.69	4.05	4.37	4.58	4.75	1.3%
Delivered Energy	26.30	27.05	28.57	29.97	31.58	32.27	32.62	0.8%
Electricity Related Losses	7.65	7.74	8.14	8.53	8.92	8.88	8.93	0.6%
Total	33.95	34.79	36.71	38.50	40.50	41.15	41.55	0.7%

Table A2. Energy Consumption by Sector and Source (Continued)
(Quadrillion Btu per Year, Unless Otherwise Noted)

Sector and Source	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Transportation								
Distillate Fuel[6]	4.24	4.48	5.14	5.63	6.02	6.19	6.31	1.4%
Jet Fuel[7]	3.13	3.27	3.83	4.47	5.23	5.79	6.28	2.8%
Motor Gasoline[8]	14.65	14.94	15.96	17.17	18.22	18.84	19.38	1.1%
Residual Fuel	0.87	0.90	0.94	1.10	1.27	1.42	1.56	2.3%
Liquefied Petroleum Gas	0.03	0.03	0.04	0.10	0.16	0.20	0.24	8.7%
Other Petroleum[9]	0.28	0.29	0.31	0.33	0.35	0.37	0.37	1.1%
Petroleum Subtotal	23.21	23.91	26.22	28.81	31.25	32.80	34.14	1.5%
Pipeline Fuel Natural Gas	0.72	0.73	0.80	0.85	0.95	0.99	1.03	1.4%
Compressed Natural Gas	0.01	0.01	0.05	0.15	0.24	0.30	0.34	15.8%
Renewable Energy (E85)[11]	0.00	0.00	0.00	0.03	0.09	0.13	0.16	20.5%
Methanol[12]	0.00	0.00	0.00	0.03	0.08	0.13	0.15	20.6%
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.7%
Electricity	0.06	0.06	0.06	0.11	0.16	0.19	0.22	5.6%
Delivered Energy	24.00	24.72	27.14	29.97	32.77	34.54	36.04	1.6%
Electricity Related Losses	0.13	0.13	0.14	0.23	0.32	0.37	0.41	4.9%
Total	24.12	24.85	27.28	30.20	33.09	34.91	36.45	1.6%
Delivered Energy Consumption for All Sectors								
Distillate Fuel	6.73	6.98	7.61	8.18	8.63	8.83	8.96	1.0%
Kerosene	0.11	0.13	0.12	0.11	0.11	0.11	0.11	-0.5%
Jet Fuel[7]	3.13	3.27	3.83	4.47	5.23	5.79	6.28	2.8%
Liquefied Petroleum Gas	2.50	2.65	2.71	2.90	3.13	3.24	3.31	0.9%
Motor Gasoline[8]	14.92	15.16	16.19	17.43	18.49	19.12	19.67	1.1%
Petrochemical Feedstock	1.23	1.28	1.31	1.38	1.47	1.49	1.51	0.7%
Residual Fuel	1.41	1.39	1.40	1.56	1.74	1.88	2.03	1.6%
Other Petroleum[13]	4.03	4.39	4.64	4.91	5.18	5.40	5.45	0.9%
Petroleum Subtotal	34.06	35.25	37.80	40.95	43.98	45.87	47.33	1.2%
Natural Gas[5]	18.73	19.56	20.61	21.24	22.25	22.72	22.99	0.7%
Metallurgical Coal	0.89	0.85	0.83	0.76	0.71	0.65	0.61	-1.4%
Steam Coal	1.73	1.68	1.70	1.84	1.92	1.93	1.94	0.6%
Net Coal Coke Imports	0.03	0.00	0.03	0.05	0.06	0.07	0.08	N/A
Coal Subtotal	2.64	2.53	2.56	2.65	2.69	2.66	2.63	0.2%
Renewable Energy[14]	2.33	2.44	2.58	2.76	2.96	3.08	3.15	1.1%
Methanol[12]	0.00	0.00	0.00	0.03	0.08	0.13	0.15	20.6%
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.7%
Electricity	10.32	10.57	11.32	12.29	13.23	14.04	14.70	1.4%
Delivered Energy	68.09	70.36	74.88	78.92	85.19	88.50	90.95	1.1%
Electricity Related Losses	22.86	23.64	24.94	25.90	26.97	27.22	27.63	0.7%
Total	90.95	94.01	99.82	105.82	112.17	115.72	118.58	1.0%
Electric Generators[15]								
Distillate Fuel	0.13	0.09	0.08	0.07	0.07	0.07	0.07	-0.6%
Residual Fuel	0.55	0.66	0.47	0.30	0.28	0.25	0.24	-4.2%
Petroleum Subtotal	0.68	0.75	0.54	0.37	0.35	0.32	0.31	-3.6%
Natural Gas	3.44	3.04	4.14	5.69	7.38	8.71	10.07	5.1%
Steam Coal	17.31	18.36	19.57	20.55	21.34	22.29	22.99	0.9%
Nuclear Power	7.19	7.20	7.36	6.87	6.36	5.12	4.09	-2.3%
Renewable Energy[16]	4.08	4.47	4.24	4.37	4.46	4.53	4.59	0.1%
Electricity Imports[17]	0.39	0.39	0.41	0.34	0.31	0.28	0.28	-1.4%
Total	33.09	34.21	36.26	38.19	40.20	41.26	42.33	0.9%

Reference Case Forecast

Table A2. Energy Consumption by Sector and Source (Continued)
(Quadrillion Btu per Year, Unless Otherwise Noted)

Sector and Source	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Total Energy Consumption								
Distillate Fuel	6.66	7.07	7.68	8.25	8.70	8.90	9.04	1.0%
Kerosene	0.11	0.13	0.12	0.11	0.11	0.11	0.11	-0.5%
Jet Fuel[5]	3.13	3.27	3.83	4.47	5.23	5.79	6.28	2.8%
Liquefied Petroleum Gas	2.50	2.65	2.71	2.90	3.13	3.24	3.31	0.9%
Motor Gasoline[6]	14.92	15.16	16.19	17.43	18.49	19.19	19.67	1.1%
Petrochemical Feedstock	1.23	1.26	1.31	1.38	1.47	1.49	1.51	0.7%
Residual Fuel	1.96	2.05	1.87	1.86	2.02	2.14	2.27	0.4%
Other Petroleum[13]	4.03	4.39	4.64	4.91	5.18	5.40	5.45	0.9%
Petroleum Subtotal	34.74	36.01	38.35	41.32	44.33	46.20	47.64	1.2%
Natural Gas	22.18	22.50	24.74	26.83	29.63	31.44	33.06	1.6%
Metallurgical Coal	0.89	0.85	0.83	0.76	0.71	0.65	0.61	-1.4%
Steam Coal	19.05	20.05	21.28	22.40	23.26	24.22	24.92	0.9%
Net Coal Coke Imports	0.03	0.00	0.03	0.05	0.06	0.07	0.08	N/A
Coal Subtotal	19.96	20.90	22.14	23.21	24.03	24.95	25.61	0.9%
Nuclear Power	7.19	7.20	7.36	6.87	6.36	5.12	4.00	-2.3%
Renewable Energy[16]	6.40	6.91	6.82	7.12	7.42	7.62	7.74	0.5%
Methanol[12]	0.00	0.00	0.00	0.03	0.08	0.13	0.15	20.6%
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.7%
Electricity Imports[17]	0.39	0.39	0.41	0.34	0.31	0.28	0.28	-1.4%
Total	90.86	94.01	99.82	105.82	112.17	115.72	118.58	1.0%
Energy Use and Related Statistics								
Delivered Energy Use	68.09	70.36	74.88	79.92	85.19	88.50	90.95	1.1%
Total Energy Use	90.86	94.01	99.82	105.82	112.16	115.71	118.55	1.0%
Population (millions)	263.58	266.07	275.62	287.12	298.92	311.19	323.47	0.8%
Gross Domestic Product (billion 1992 dollars)	6742.08	6928.40	7652.77	8503.48	9431.22	10210.71	10899.70	1.9%
Total Carbon Emissions (million metric tons)	1411.40	1462.90	1577.32	1688.76	1803.22	1888.33	1956.19	1.2%

[1]Includes wood used for residential heating. See Table A18 estimates of nonmarketed renewable energy consumption for geothermal heat pumps & solar thermal hot water heating.

[2]Includes ethanol (blends of 10 percent or less) and others blended into gasoline.

[3]Includes commercial sector electricity cogenerated by using wood and wood waste, landfill gas, municipal solid waste, and other biomass. See Table A18 for estimates of nonmarketed renewable energy consumption for solar thermal hot water heating.

[4]Fuel consumption includes consumption for cogeneration.

[5]Includes petroleum coke, asphalt, road oil, lubricants, still gas, and miscellaneous petroleum products.

[6]Includes lease and plant fuel and consumption by cogenerators, excludes consumption by nonutility generators.

[7]Includes consumption of energy from hydroelectric, wood and wood waste, municipal solid waste, and other biomass; including for cogeneration, both for sale to the grid and for own use.

[8]Low sulfur diesel fuel.

[9]Includes naphtha and kerosene type.

[10]Includes aviation gas and lubricants.

[11]E85 is 85 percent ethanol (renewable) and 15 percent motor gasoline(nonrenewable).

[12]Only M85 (85 percent methanol and 15 percent motor gasoline).

[13]Includes unfinished oils, natural gasoline, motor gasoline blending compounds, aviation gasoline, lubricants, still gas, asphalt, road oil, petroleum coke, and miscellaneous petroleum products.

[14]Includes electricity generated for sale to the grid and for own use from renewable sources, and non-electric energy from renewable sources. Excludes nonmarketed renewable energy consumption for geothermal heat pumps and solar thermal hot water heaters.

[15]Includes consumption of energy by all electric power generators for grid-connected power except cogenerators, which produce electricity and other useful thermal energy.

[16]Includes conventional hydroelectric, geothermal, wood and wood waste, municipal solid waste, other biomass, E85, wind, photovoltaic and solar thermal sources. Excludes cogeneration. Excludes net electricity imports.

[17]In 1996 approximately two-thirds of the U.S. electricity imports were provided by renewable sources (hydroelectricity); EIA does not project future proportions.

[18]Includes hydroelectric, geothermal, wood and wood waste, municipal solid waste, other biomass, wind, photovoltaic and solar thermal sources. Includes ethanol components of E85; excludes ethanol blends (10 percent or less) in motor gasoline. Excludes net electricity imports and nonmarketed renewable energy consumption for geothermal heat pumps and solar thermal hot water heaters.

Btu = British thermal unit.

N/A = Not applicable.

Note: Totals may not equal sum of components due to independent rounding. Figures for 1995 and 1996 may differ from published data due to internal conversion factors. Consumption values of 0.00 are values that round to 0.00, because they are less than 0.005.

Sources: 1995 natural gas lease, plant, and pipeline fuel values: Energy Information Administration (EIA), *Natural Gas Annual 1995*, DOE/EIA-0131(95) (Washington, DC, November 1996). 1996 natural gas lease, plant, and pipeline fuel values: EIA, *Short-Term Energy Outlook, August 1997*. Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). 1996 transportation sector compressed natural gas consumption: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A. 1995 and 1996 electric utility fuel consumption: EIA, *Electric Power Annual 1996, Volume I*, DOE/EIA-0348(96)/1 (Washington, DC, August 1997). 1995 and 1996 nonutility consumption estimates: EIA Form 867, "Annual Nonutility Power Producer Report." Other 1995 values derived from: EIA, *State Energy Data Report 1994*. ftp://ftp.eia.doe.gov/pub/state.data/021494.pdf (August 26, 1997), and Office of Coal, Nuclear, Electric, and Alternative Fuels estimates. Other 1996 values: EIA, *Short-Term Energy Outlook August 1997*. Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Table A3. Energy Prices by Sector and Source
(1996 Dollars per Million Btu, Unless Otherwise Noted)

Sector and Source	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Residential	13.02	12.94	12.45	12.31	12.21	11.91	11.97	-0.3%
Primary Energy[1]	6.37	6.63	6.32	6.23	6.15	6.07	6.17	-0.3%
Petroleum Products[2]	7.69	8.51	8.67	9.20	9.42	9.54	9.70	0.5%
Distillate Fuel	5.39	7.09	7.15	7.47	7.55	7.64	7.71	0.3%
Liquefied Petroleum Gas	10.45	11.59	11.56	12.21	12.45	12.43	12.57	0.3%
Natural Gas	6.07	6.19	5.77	5.55	5.42	5.32	5.44	-0.5%
Electricity	25.00	24.85	22.93	22.04	21.43	20.40	20.01	-0.9%
Commercial	12.77	12.92	12.33	11.84	11.63	11.19	11.15	-0.5%
Primary Energy[1]	5.01	5.26	4.91	4.82	4.79	4.77	4.91	-0.3%
Petroleum Products[2]	5.11	5.56	5.54	5.67	5.82	5.12	6.25	0.5%
Distillate Fuel	4.49	5.27	5.23	5.53	5.65	5.75	5.86	0.4%
Residual Fuel	3.22	3.24	2.97	3.06	3.16	3.28	3.40	0.2%
Natural Gas[3]	5.07	5.28	4.88	4.71	4.66	4.62	4.77	-0.4%
Electricity	22.30	22.24	21.02	19.81	19.16	18.02	17.58	-1.0%
Industrial[4]	4.97	5.40	4.92	5.04	5.15	5.10	5.21	-0.1%
Primary Energy	3.41	4.03	3.59	3.79	3.97	4.04	4.20	0.2%
Petroleum Products[5]	4.97	5.68	4.96	5.92	5.53	5.55	5.70	0.0%
Distillate Fuel	4.72	5.50	5.24	5.56	5.74	5.88	6.07	0.4%
Liquefied Petroleum Gas	6.63	7.60	5.96	6.60	6.76	6.64	6.81	-0.6%
Residual Fuel	2.64	3.00	2.70	2.83	3.02	3.15	3.36	0.5%
Natural Gas[6]	2.37	2.96	2.73	2.77	2.93	3.00	3.17	0.3%
Metallurgical Coal	1.81	1.77	1.76	1.71	1.68	1.67	1.66	-0.3%
Steam Coal	1.50	1.46	1.41	1.36	1.33	1.31	1.30	-0.5%
Electricity	14.00	13.54	12.68	11.93	11.41	10.59	10.26	-1.1%
Transportation	8.20	8.77	8.53	8.78	8.83	8.86	8.87	0.0%
Primary Energy	8.18	8.76	8.52	8.76	8.81	8.84	8.85	0.0%
Petroleum Products[2]	8.18	8.76	8.52	8.77	8.80	8.82	8.82	0.0%
Distillate Fuel[8]	8.22	8.90	8.53	8.74	8.81	8.60	8.52	-0.2%
Jet Fuel[7]	4.18	5.52	5.12	5.58	5.85	6.05	6.27	0.5%
Motor Gasoline[9]	9.48	9.89	9.78	10.06	10.18	10.22	10.24	0.1%
Residual Fuel	2.33	2.55	2.61	2.85	3.07	3.14	3.32	1.1%
Liquid Petroleum Gas[9]	12.44	12.62	12.80	13.27	13.30	13.07	13.01	0.1%
Natural Gas[10]	5.41	5.41	5.46	5.72	6.60	7.06	7.39	1.3%
E85[11]	15.25	15.85	15.81	16.30	16.71	17.04	17.79	0.5%
Electricity	15.39	15.31	14.66	13.69	13.25	12.54	12.26	-0.9%
Average End-Use Energy	8.29	8.68	8.26	8.33	8.35	8.28	8.35	-0.2%
Primary Energy	7.91	8.35	7.94	8.05	8.09	8.04	8.11	-0.1%
Electricity	20.41	20.19	18.93	17.94	17.32	16.36	16.01	-1.0%
Electric Generators[12]								
Fossil Fuel Average	1.51	1.54	1.46	1.49	1.57	1.60	1.66	0.3%
Petroleum Products	2.94	3.26	3.21	3.57	3.84	4.00	4.21	1.1%
Distillate Fuel	4.01	4.90	4.84	5.16	5.33	5.47	5.64	0.6%
Residual Fuel	2.68	3.07	2.95	3.20	3.46	3.60	3.77	0.9%
Natural Gas	2.03	2.64	2.48	2.63	2.84	2.98	3.15	0.7%
Steam Coal	1.35	1.29	1.20	1.14	1.09	1.03	0.97	-1.2%

Table A3. Energy Prices by Sector and Source (Continued)
(1996 Dollars per Million Btu, Unless Otherwise Noted)

Sector and Source	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Average Price to All Users[1]								
Petroleum Products[2]	7.26	7.86	7.59	7.92	8.02	8.06	8.12	0.1%
Distillate Fuel	7.06	7.84	7.65	7.92	7.88	7.91	7.90	0.0%
Jet Fuel	4.18	5.52	5.12	5.58	5.85	6.05	6.27	0.5%
Liquefied Petroleum Gas	7.38	8.53	7.12	7.84	8.09	8.05	8.24	-0.1%
Motor Gasoline[3]	9.46	9.69	9.76	10.05	10.16	10.21	10.23	0.1%
Residual Fuel	2.56	2.84	2.73	2.92	3.19	3.21	3.38	0.7%
Natural Gas	3.63	4.13	3.74	3.66	3.70	3.72	3.86	-0.3%
Coal	1.38	1.32	1.22	1.16	1.11	1.05	1.00	-1.2%
E85[11]	15.25	15.85	15.81	16.30	16.71	17.04	17.79	0.5%
Electricity	20.41	20.19	18.93	17.94	17.32	16.36	16.01	-1.0%
Non-Renewable Energy Expenditures by Sector (Billion 1996 dollars)								
Residential	113.43	117.09	118.89	124.21	130.36	134.72	143.05	0.8%
Commercial	92.62	96.47	96.19	97.11	99.96	99.87	100.74	0.2%
Industrial	122.76	136.22	130.95	140.45	151.07	152.63	157.75	0.6%
Transportation	190.86	210.35	224.71	254.98	278.70	293.73	306.35	1.6%
Total Non-Renewable Expenditures	519.68	560.12	570.54	616.74	660.09	681.15	707.89	1.0%
Transportation Renewable Expenditures	0.02	0.03	0.05	0.45	1.47	2.25	2.79	21.1%
Total Expenditures	519.70	560.15	570.59	617.19	661.57	683.40	710.68	1.0%

[1]Weighted average price includes fuels below as well as coal.
[2]This quantity is the weighted average for all petroleum products, not just those listed below.
[3]Excludes independent power producers.
[4]Includes cogenerators.
[5]Excludes uses for lease and plant fuel.
[6]Low sulfur diesel fuel. Price includes Federal and State taxes while excluding county and local taxes.
[7]Kerosene-type jet fuel. Price includes Federal and State taxes while excluding county and local taxes.
[8]Sales weighted-average price for all grades. Includes Federal and State taxes and excludes county and local taxes.
[9]Includes Federal and State taxes while excluding county and local taxes.
[10]Compressed natural gas used as a vehicle fuel. Price includes estimated motor vehicle fuel taxes.
[11]E85 is 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable).
[12]Includes all electric power generators except cogenerators, which produce electricity and other useful thermal energy.
[13]Weighted averages of end-use fuel prices are derived from the prices shown in each sector and the corresponding sectoral consumption.
Btu = British thermal unit.
Note: 1995 and 1996 figures may differ from published data due to internal rounding.
Sources: 1995 prices for gasoline, distillate, and jet fuel are based on prices in the Energy Information Administration (EIA), *Petroleum Marketing Annual 1995*. Online. http://www.eia.doe.gov/oil_gas/pmal/pmaframe.html (May 30, 1997). 1996 prices for gasoline, distillate, and jet fuel are based on prices in various issues of EIA, *Petroleum Marketing Monthly*, DOE/EIA-0380(96/13-97/4) (Washington, DC, 1996-97). 1995 and 1996 prices for all other petroleum products are derived from the EIA, *State Energy Price and Expenditure Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997). 1995 residential, commercial, and transportation natural gas delivered prices: EIA, *Natural Gas Annual 1995*, DOE/EIA-0131(95) (Washington, DC, November 1996). 1995 electric generators natural gas delivered prices: Form FERC-423, "Monthly Report of Cost and Quality of Fuels for Electric Plants." 1995 and 1996 industrial gas delivered prices are based on EIA, *Manufacturing Energy Consumption Survey 1991*. 1995 residential and commercial natural gas delivered prices: EIA, *Natural Gas Monthly*, DOE/EIA-0130(97/6) (Washington, DC, June 1997). Other 1996 natural gas delivered prices: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A. Values for 1995 and 1996 coal prices have been estimated from EIA, *State Energy Price and Expenditure Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997) by use of consumption quantities aggregated from EIA, *State Energy Data Report 1994*. Online. ftp://ftp.eia.doe.gov/pub/state.data/021494.pdf (August 26, 1997) and the *Coal Industry Annual 1996*, DOE/EIA-0584(96) (Washington, DC, November 1997). 1995 residential electricity prices derived from EIA, *Short Term Energy Outlook, August 1997*. Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). 1995 and 1996 electricity prices for commercial, industrial, and transportation: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A. **Projections:** EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Table A4. Residential Sector Key Indicators and Consumption
(Quadrillion Btu per Year, Unless Otherwise Noted)

Key Indicators and Consumption	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Key Indicators								
Households (millions)								
Single-Family	68.66	69.61	73.26	77.46	81.54	85.60	89.52	1.1%
Multifamily	24.56	24.76	25.54	26.54	27.92	29.44	30.84	0.9%
Mobile Homes	5.84	6.00	6.54	7.08	7.56	8.01	8.35	1.4%
Total	99.06	100.37	105.34	111.08	117.04	123.05	128.71	1.0%
Average House Square Footage	1643	1649	1669	1689	1704	1716	1726	0.2%
Energy Intensity								
(million Btu consumed per household)								
Delivered Energy Consumption	106.41	110.90	107.87	105.95	104.63	103.79	102.91	-0.3%
Electricity Related Losses	80.78	83.37	83.92	82.23	80.73	78.15	77.20	-0.3%
Total Energy Consumption	187.19	194.27	191.79	188.18	185.37	181.95	180.11	-0.3%
Delivered Energy Consumption by Fuel								
Electricity								
Space Heating	0.44	0.47	0.46	0.46	0.50	0.51	0.53	0.5%
Space Cooling	0.49	0.46	0.48	0.51	0.54	0.58	0.60	1.1%
Water Heating	0.36	0.36	0.36	0.36	0.36	0.39	0.40	0.5%
Refrigeration	0.41	0.41	0.36	0.31	0.28	0.27	0.27	-1.6%
Cooking	0.13	0.13	0.13	0.14	0.15	0.16	0.17	1.0%
Clothes Dryers	0.19	0.19	0.20	0.21	0.22	0.24	0.25	1.1%
Freezers	0.13	0.13	0.11	0.09	0.08	0.07	0.07	-2.4%
Lighting	0.33	0.34	0.35	0.36	0.39	0.42	0.45	1.2%
Clothes Washers[1]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.8%
Dishwashers[1]	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.6%
Color Televisions	0.19	0.21	0.25	0.30	0.32	0.35	0.37	2.5%
Personal Computers	0.01	0.01	0.01	0.02	0.02	0.02	0.03	5.3%
Furnace Fans	0.11	0.12	0.13	0.14	0.15	0.16	0.18	1.7%
Other Uses[2]	0.71	0.78	1.06	1.29	1.49	1.68	1.86	3.7%
Delivered Energy	3.56	3.68	3.97	4.29	4.61	4.94	5.28	1.5%
Natural Gas								
Space Heating	3.45	3.76	3.72	3.76	3.87	3.97	4.04	0.3%
Space Cooling	0.00	0.00	0.00	0.00	0.00	0.01	0.01	8.1%
Water Heating	1.24	1.32	1.32	1.37	1.43	1.49	1.55	0.7%
Cooking	0.15	0.16	0.16	0.17	0.17	0.18	0.19	0.6%
Clothes Dryers	0.05	0.05	0.05	0.05	0.06	0.06	0.06	1.0%
Other Uses[3]	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.8%
Delivered Energy	4.98	5.39	5.35	5.47	5.63	5.82	5.97	0.4%
Distillate								
Space Heating	0.80	0.80	0.75	0.70	0.67	0.64	0.62	-1.0%
Water Heating	0.09	0.09	0.10	0.09	0.10	0.10	0.10	0.1%
Other Uses[4]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.6%
Delivered Energy	0.89	0.89	0.85	0.79	0.77	0.74	0.72	-0.9%
Liquefied Petroleum Gas								
Space Heating	0.29	0.31	0.33	0.33	0.34	0.35	0.35	0.5%
Water Heating	0.07	0.07	0.08	0.09	0.10	0.10	0.11	1.8%
Cooking	0.03	0.03	0.04	0.04	0.04	0.04	0.04	1.1%
Other Uses[5]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	1.5%
Delivered Energy	0.40	0.42	0.45	0.47	0.49	0.50	0.51	0.8%

Reference Case Forecast

Table A4. Residential Sector Key Indicators and Consumption (Continued)
(Quadrillion Btu per Year, Unless Otherwise Noted)

Key Indicators and Consumption	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Delivered Energy Consumption by End-Use								
Space Heating	5.69	6.09	6.00	6.04	6.13	6.24	6.31	0.1%
Space Cooling	0.49	0.46	0.48	0.52	0.55	0.58	0.61	1.2%
Water Heating	1.76	1.84	1.86	1.91	1.99	2.08	2.17	0.7%
Refrigeration	0.41	0.41	0.36	0.31	0.28	0.27	0.27	-1.6%
Cooking	0.31	0.33	0.33	0.35	0.36	0.38	0.40	0.8%
Clothes Dryers	0.23	0.24	0.25	0.28	0.28	0.30	0.32	1.1%
Freezers	0.13	0.13	0.11	0.09	0.08	0.07	0.07	-2.4%
Lighting	0.33	0.34	0.35	0.36	0.39	0.42	0.45	1.2%
Clothes Washers	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.6%
Dishwashers	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.6%
Color Televisions	0.19	0.21	0.25	0.30	0.32	0.35	0.37	2.5%
Personal Computers	0.01	0.01	0.01	0.02	0.02	0.02	0.03	5.3%
Furnace Fans	0.11	0.12	0.13	0.14	0.15	0.16	0.18	1.7%
Other Uses[1]	0.80	0.89	1.17	1.40	1.61	1.80	1.99	3.4%
Delivered Energy	**10.54**	**11.13**	**11.36**	**11.77**	**12.25**	**12.77**	**13.25**	**0.7%**
Electricity Related Losses	**7.88**	**8.23**	**8.75**	**9.05**	**9.39**	**9.58**	**9.93**	**0.8%**
Total Energy Consumption by End-Use								
Space Heating	6.85	7.13	7.03	7.06	7.15	7.24	7.30	0.1%
Space Cooling	1.57	1.50	1.54	1.60	1.66	1.70	1.74	0.6%
Water Heating	2.55	2.66	2.64	2.68	2.76	2.84	2.93	0.4%
Refrigeration	1.32	1.32	1.15	0.97	0.86	0.80	0.79	-2.1%
Cooking	0.59	0.62	0.63	0.65	0.67	0.69	0.72	0.6%
Clothes Dryers	0.84	0.87	0.88	0.70	0.73	0.76	0.79	0.7%
Freezers	0.43	0.42	0.34	0.27	0.23	0.21	0.21	-2.9%
Lighting	1.05	1.09	1.12	1.12	1.20	1.24	1.30	0.7%
Clothes Washers	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.3%
Dishwashers	0.15	0.15	0.14	0.14	0.14	0.15	0.16	0.2%
Color Televisions	0.62	0.67	0.81	0.93	0.98	1.02	1.08	2.0%
Personal Computers	0.02	0.03	0.04	0.05	0.06	0.07	0.08	4.8%
Furnace Fans	0.36	0.38	0.41	0.43	0.46	0.48	0.51	1.2%
Other Uses[1]	2.37	2.64	3.50	4.13	4.64	5.06	5.48	3.1%
Total	**18.42**	**19.36**	**20.11**	**20.81**	**21.64**	**22.35**	**23.17**	**0.8%**
Non-Marketed Renewables								
Geothermal[2]	0.01	0.01	0.02	0.03	0.04	0.05	0.06	7.1%
Solar[3]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-0.3%
Total	**0.02**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**5.0%**

[1]Does not include water heating or load.
[2]Includes small electric devices, heating elements and motors.
[3]Includes such appliances as swimming pool heaters, outdoor grills, and outdoor lighting (natural gas).
[4]Includes such appliances as swimming pool and hot tub heaters.
[5]Includes wood used for primary and secondary heating in wood stoves or fireplaces as reported in the *Residential Energy Consumption Survey 1993*.
[6]Includes kerosene and coal.
[7]Includes all other uses listed above.
[8]Includes primary energy displaced by geothermal heat pumps in space heating and cooling applications.
[9]Includes primary energy displaced by solar thermal water heaters.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding.
Sources: 1995 and 1996: EIA, *Short-Term Energy Outlook, August 1997*. Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Table A5. Commercial Sector Key Indicators and Consumption
(Quadrillion Btu per Year, Unless Otherwise Noted)

Key Indicators and Consumption	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Key Indicators								
Total Floor Space (billion square feet)								
Surviving	68.5	69.2	73.1	77.3	81.1	84.3	85.7	0.9%
New Additions	1.6	1.7	1.8	1.7	1.7	1.5	1.1	-1.7%
Total	70.1	70.9	74.9	79.0	82.8	85.8	86.8	0.8%
Energy Consumption Intensity (thousand Btu per square foot)								
Delivered Energy Consumption	103.6	105.3	104.2	103.8	103.8	104.0	104.2	-0.0%
Electricity Related Losses	102.9	106.3	105.7	102.4	100.8	97.7	96.4	-0.4%
Total Energy Consumption	206.5	211.5	209.9	206.2	204.5	201.7	200.5	-0.2%
Delivered Energy Consumption by Fuel								
Electricity								
Space Heating	0.12	0.12	0.12	0.13	0.14	0.15	0.15	0.9%
Space Cooling	0.57	0.51	0.53	0.54	0.55	0.56	0.56	0.4%
Water Heating	0.17	0.17	0.17	0.16	0.15	0.15	0.14	-0.8%
Ventilation	0.17	0.17	0.17	0.18	0.18	0.19	0.18	0.4%
Cooking	0.03	0.03	0.03	0.03	0.03	0.03	0.03	-1.0%
Lighting	1.14	1.15	1.20	1.22	1.24	1.27	1.28	0.4%
Refrigeration	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.7%
Office Equipment (PC)	0.07	0.07	0.07	0.08	0.09	0.09	0.10	1.6%
Office Equipment (non-PC)	0.19	0.19	0.21	0.24	0.27	0.30	0.33	2.2%
Other Uses[1]	0.66	0.82	0.95	1.12	1.29	1.43	1.53	2.6%
Delivered Energy	3.26	3.37	3.59	3.84	4.09	4.33	4.45	1.2%
Natural Gas[2]								
Space Heating	1.29	1.34	1.33	1.37	1.40	1.42	1.40	0.2%
Space Cooling	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.6%
Water Heating	0.46	0.45	0.47	0.50	0.52	0.54	0.55	0.8%
Cooking	0.18	0.18	0.20	0.21	0.22	0.23	0.23	1.1%
Other Uses[3]	1.17	1.31	1.44	1.52	1.59	1.64	1.65	1.0%
Delivered Energy	3.11	3.30	3.47	3.62	3.75	3.85	3.85	0.7%
Distillate								
Space Heating	0.20	0.20	0.19	0.18	0.18	0.17	0.15	-1.0%
Water Heating	0.05	0.05	0.05	0.05	0.05	0.04	0.04	-1.1%
Other Uses[4]	0.22	0.19	0.17	0.17	0.18	0.18	0.18	-0.3%
Delivered Energy	0.47	0.44	0.41	0.40	0.40	0.39	0.37	-0.7%
Other Fuels[5]	0.42	0.36	0.33	0.34	0.35	0.36	0.36	0.0%
Marketed Renewable Fuels								
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1%
Delivered Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1%
Delivered Energy Consumption by End-Use								
Space Heating	1.80	1.85	1.85	1.88	1.71	1.73	1.70	0.1%
Space Cooling	0.60	0.53	0.55	0.56	0.57	0.58	0.58	0.4%
Water Heating	0.68	0.68	0.69	0.70	0.72	0.73	0.73	0.3%
Ventilation	0.17	0.17	0.17	0.18	0.18	0.19	0.18	0.4%
Cooking	0.21	0.21	0.23	0.24	0.25	0.26	0.26	0.8%
Lighting	1.14	1.15	1.20	1.22	1.24	1.27	1.28	0.4%
Refrigeration	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.7%
Office Equipment (PC)	0.07	0.07	0.07	0.08	0.09	0.09	0.10	1.6%
Office Equipment (non-PC)	0.19	0.19	0.21	0.24	0.27	0.30	0.33	2.2%
Other Uses[6]	2.47	2.68	2.89	3.16	3.41	3.61	3.71	1.4%
Delivered Energy	7.26	7.47	7.80	8.21	8.60	8.92	9.04	0.8%

Reference Case Forecast

Table A5. Commercial Sector Key Indicators and Consumption (Continued)
(Quadrillion Btu per Year, Unless Otherwise Noted)

Key Indicators and Consumption	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Electricity Related Losses	7.21	7.54	7.91	8.09	8.35	8.39	8.37	0.4%
Total Energy Consumption by End-Use								
Space Heating	1.85	1.92	1.92	1.96	1.99	2.01	1.98	0.1%
Space Cooling	1.87	1.66	1.71	1.69	1.69	1.67	1.63	-0.1%
Water Heating	1.07	1.06	1.05	1.04	1.04	1.02	1.00	-0.2%
Ventilation	0.54	0.54	0.55	0.55	0.56	0.54	0.53	-0.1%
Cooking	0.28	0.28	0.29	0.30	0.31	0.31	0.31	0.3%
Lighting	3.67	3.73	3.83	3.76	3.77	3.74	3.67	-0.1%
Refrigeration	0.45	0.45	0.47	0.47	0.48	0.48	0.48	0.2%
Office Equipment (PC)	0.22	0.22	0.23	0.24	0.26	0.27	0.29	1.2%
Office Equipment (non-PC)	0.60	0.62	0.68	0.74	0.82	0.88	0.94	1.7%
Other Uses[6]	3.82	4.51	4.96	5.52	6.03	6.39	6.58	1.6%
Total	14.46	15.01	15.72	16.30	16.94	17.31	17.41	0.6%
Non-Marketed Renewable Fuels								
Solar[7]	0.01	0.01	0.02	0.03	0.03	0.04	0.04	4.2%
Total	0.01	0.01	0.02	0.03	0.03	0.04	0.04	4.2%

[1]Includes miscellaneous uses, such as service station equipment, district services, automated teller machines, telecommunications equipment, and medical equipment.
[2]Excludes estimated consumption from independent power producers.
[3]Includes miscellaneous uses, such as district services, pumps, lighting, emergency electric generators, and manufacturing performed in commercial buildings.
[4]Includes miscellaneous uses, such as cooking, district services, and emergency electric generators.
[5]Includes residual fuel oil, liquefied petroleum gas, coal, motor gasoline, and kerosene.
[6]Includes miscellaneous uses, such as service station equipment, district services, automated teller machines, telecommunications equipment, medical equipment, pumps, lighting, emergency electric generators, manufacturing performed in commercial buildings, and cooking (distillate), plus residual fuel oil, liquefied petroleum gas, coal, motor gasoline, and kerosene.
[7]Includes primary energy displaced by solar thermal water heaters.
Btu = British thermal unit.
PC = Personal computer.
Note: Totals may not equal sum of components due to independent rounding. Consumption values of 0.00 are values that round to 0.00, because they are less than 0.005.
Sources: 1995 and 1996 Energy Information Administration (EIA), *Short-Term Energy Outlook*, *August 1997*, Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Table A6. Industrial Sector Key Indicators and Consumption
(Quadrillion Btu per Year, Unless Otherwise Noted)

Key Indicators and Consumption	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Key Indicators								
Value of Gross Output (billion 1987 dollars)								
Manufacturing	2950	3030	3324	3801	4318	4646	4957	2.1%
Nonmanufacturing	759	774	835	897	969	1019	1062	1.3%
Total	3709	3805	4159	4698	5287	5665	6019	1.9%
Energy Prices (1996 dollars per million Btu)								
Electricity	14.00	13.54	12.68	11.93	11.41	10.59	10.26	-1.1%
Natural Gas	2.37	2.96	2.73	2.77	2.93	3.00	3.17	0.3%
Steam Coal	1.50	1.46	1.41	1.36	1.33	1.31	1.30	-0.5%
Residual Oil	2.64	3.00	2.70	2.83	3.02	3.15	3.35	0.5%
Distillate Oil	4.72	5.50	5.24	5.56	5.74	5.88	6.07	0.4%
Liquefied Petroleum Gas	6.63	7.80	5.98	6.60	6.76	6.64	6.81	-0.6%
Motor Gasoline	9.40	9.86	8.46	8.91	9.17	9.40	9.56	-0.1%
Metallurgical Coal	1.81	1.77	1.76	1.71	1.66	1.67	1.66	-0.3%
Energy Consumption								
Consumption[1]								
Purchased Electricity	3.48	3.46	3.69	4.05	4.37	4.58	4.75	1.3%
Natural Gas[2]	9.91	10.14	10.94	11.16	11.67	11.77	11.80	0.6%
Steam Coal	1.60	1.55	1.56	1.70	1.77	1.78	1.79	0.6%
Metallurgical Coal and Coke[3]	0.91	0.85	0.86	0.81	0.77	0.73	0.69	-0.9%
Residual Fuel	0.37	0.34	0.35	0.35	0.35	0.34	0.35	0.1%
Distillate	1.13	1.17	1.21	1.35	1.45	1.51	1.56	1.2%
Liquefied Petroleum Gas	2.00	2.12	2.14	2.25	2.40	2.45	2.47	0.6%
Petrochemical Feedstocks	1.23	1.28	1.31	1.38	1.47	1.49	1.51	0.7%
Other Petroleum[4]	3.96	4.31	4.55	4.83	5.09	5.31	5.36	0.9%
Renewables[5]	1.74	1.82	1.96	2.11	2.25	2.31	2.34	1.0%
Delivered Energy	26.30	27.05	28.57	29.97	31.58	32.27	32.82	0.8%
Electricity Related Losses	7.65	7.74	8.14	8.53	8.92	8.88	8.93	0.6%
Total	33.95	34.79	36.71	38.50	40.50	41.15	41.55	0.7%
Consumption per Unit of Output[1] (thousand Btu per 1987 dollars)								
Purchased Electricity	0.93	0.91	0.89	0.86	0.83	0.81	0.79	-0.6%
Natural Gas[2]	2.67	2.66	2.63	2.37	2.21	2.06	1.96	-1.3%
Steam Coal	0.43	0.41	0.38	0.36	0.34	0.31	0.30	-1.3%
Metallurgical Coal and Coke[3]	0.25	0.22	0.21	0.17	0.15	0.13	0.11	-2.7%
Residual Fuel	0.10	0.09	0.08	0.07	0.07	0.06	0.06	-1.8%
Distillate	0.30	0.31	0.29	0.29	0.27	0.27	0.26	-0.7%
Liquefied Petroleum Gas	0.54	0.56	0.51	0.48	0.45	0.43	0.41	-1.3%
Petrochemical Feedstocks	0.33	0.34	0.31	0.29	0.28	0.26	0.25	-1.2%
Other Petroleum[4]	1.07	1.13	1.09	1.03	0.96	0.94	0.89	-1.0%
Renewables[5]	0.47	0.48	0.47	0.45	0.42	0.41	0.39	-0.9%
Delivered Energy	7.09	7.11	6.87	6.38	5.97	5.70	5.42	-1.1%
Electricity Related Losses	2.06	2.04	1.96	1.82	1.69	1.57	1.48	-1.3%
Total	9.15	9.14	8.83	8.20	7.66	7.26	6.90	-1.2%

[1]Fuel consumption includes consumption for cogeneration.
[2]Includes lease and plant fuel and consumption by cogenerators, excludes consumption by nonutility generators.
[3]Includes net coke coal imports.
[4]Includes petroleum coke, asphalt, road oil, lubricants, motor gasoline, still gas, and miscellaneous petroleum products.
[5]Includes consumption of energy from hydroelectric, wood and wood waste, municipal solid waste, and other biomass.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding.
Sources: 1995 prices for gasoline and distillate are based on prices in the Energy Information Administration (EIA), *Petroleum Marketing Annual 1995*, DOE/EIA-0487(95) (Washington, DC, September 1996). 1996 prices for gasoline and distillate are based on prices in various issues of EIA, *Petroleum Marketing Monthly*, DOE/EIA-0380(96/03-97/04) (Washington, DC, 1996 - 97). 1995 and 1996 coal prices: EIA, *Monthly Energy Review*, DOE/EIA-0035(97/08) (Washington, DC, August 1997). 1995 and 1996 electricity prices: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A. Other 1996 values and 1996 prices derived from EIA, *State Energy Data Report 1994*. Online, ftp://ftp.eia.doe.gov/pub/state.data/021494.pdf (August 26, 1997). Other 1996 values: EIA, *Short-Term Energy Outlook, August 1997*. Online, http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A

Reference Case Forecast

Table A7. Transportation Sector Key Indicators and Delivered Energy Consumption

Key Indicators and Consumption	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Key Indicators								
Level of Travel (billions)								
Light-Duty Vehicles <8,500 lbs. (VMT)	2150	2275	2454	2665	2892	3077	3242	1.5%
Commercial Light Trucks (VMT)[1]	66	67	72	80	87	93	98	1.6%
Freight Trucks >10,000 lbs. (VMT)	152	161	188	212	232	243	250	1.8%
Air (seat miles available)	937	999	1230	1518	1855	2139	2416	3.7%
Rail (ton miles traveled)	1275	1204	1334	1432	1533	1584	1623	1.3%
Marine (ton miles traveled)	774	777	815	868	923	949	967	0.9%
Energy Efficiency Indicators								
New Car (miles per gallon)[2]	27.7	27.9	28.0	29.5	30.2	30.5	30.7	0.4%
New Light Truck (miles per gallon)[2]	20.4	20.7	19.3	19.8	20.1	20.5	21.1	0.1%
Light-Duty Fleet (miles per gallon)[3]	20.0	20.2	20.3	20.2	20.3	20.7	21.2	0.2%
New Commercial Light Truck (MPG)[1]	19.9	20.2	18.9	19.4	19.6	20.0	20.6	0.1%
Stock Commercial Light Truck (MPG)[1]	14.3	14.5	14.7	14.9	15.0	15.2	15.4	0.3%
Aircraft Efficiency (seat miles per gallon)	50.2	50.6	52.1	53.9	55.7	57.4	59.0	0.6%
Freight Truck Efficiency (miles per gallon)	5.6	5.6	5.7	5.9	6.0	6.0	6.1	0.4%
Rail Efficiency (ton miles per thousand Btu)	2.7	2.7	2.8	2.8	2.9	3.0	3.0	0.5%
Domestic Shipping Efficiency (ton miles per thousand Btu)	2.7	2.7	2.7	2.8	2.9	3.0	3.0	0.5%
Energy Use by Mode (quadrillion Btu)								
Light-Duty Vehicles	13.63	13.96	15.04	16.48	17.76	18.55	19.20	1.3%
Commercial Light Trucks[1]	0.58	0.58	0.62	0.67	0.73	0.76	0.79	1.3%
Freight Trucks	3.84	4.02	4.54	4.99	5.32	5.47	5.58	1.4%
Air	3.18	3.32	3.87	4.52	5.27	5.84	6.35	2.7%
Rail	0.55	0.52	0.57	0.59	0.62	0.63	0.63	0.8%
Marine	1.39	1.43	1.51	1.71	1.91	2.09	2.25	1.9%
Pipeline Fuel	0.72	0.73	0.80	0.85	0.95	0.99	1.03	1.4%
Other[4]	0.24	0.25	0.27	0.29	0.31	0.32	0.33	1.3%
Total	**24.00**	**24.72**	**27.14**	**29.97**	**32.77**	**34.54**	**36.04**	**1.6%**

[1]Commercial trucks 8,500 to 10,000 pounds.
[2]Environmental Protection Agency rated miles per gallon.
[3]Combined car and light truck "on-the-road" estimate.
[4]Includes lubricants and aviation gasoline.
Btu = British thermal unit.
VMT=Vehicle miles traveled.
MPG = Miles per gallon.
Lbs. = Pounds.
Note: Totals may not equal sum of components due to independent rounding.

Sources: 1995 pipeline fuel consumption: Energy Information Administration (EIA), *Natural Gas Annual 1995*, DOE/EIA-0131(95) (Washington, DC, November 1996). Other 1995 values: Federal Highway Administration, *Highway Statistics 1995* (Washington, DC, 1995); Oak Ridge National Laboratory, *Transportation Energy Data Book: 12, 13, 14, 15, and 16*, (Oak Ridge, TN, July 1996); Federal Aviation Administration (FAA), *FAA Aviation Forecasts Fiscal Years 1994-2007*; National Highway Traffic and Safety Administration, *Summary of Fuel Economy Performance*, (Washington, DC, February 1996); EIA, *Residential Transportation Energy Consumption Survey 1991*, DOE/EIA-0464(91) (Washington, DC, December 1993); U.S. Dept. of Commerce, Bureau of the Census, "Truck Inventory and Use Survey", TC92-T-52, (Washington D.C., May 1995); EIA, *Describing Current and Potential Markets for Alternative-Fuel Vehicles*, DOE/EIA-0604(96) (Washington, D.C., March 1996); EIA, *Alternatives To Traditional Transportation Fuels 1994*, DOE/EIA-0585(94) (Washington, DC, February 1996); and EIA, *State Energy Data Report 1994*. Online. ftp://ftp.eia.doe.gov/pub/state.data/021494.pdf (August 26, 1997). 1996: FAA, *FAA Aviation Forecasts Fiscal Years 1996-2007*, (Washington, DC, February 1996); EIA, *Short-Term Energy Outlook, August 1997*, Online. http://ww.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997); EIA, *Fuel Oil and Kerosene Sales 1996*, DOE/EIA-0535(96) (Washington, DC, September 1997); and United States Department of Defense, Defense Fuel Supply Center. Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Table A8. Electricity Supply, Disposition, and Prices
(Billion Kilowatthours, Unless Otherwise Noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Generation by Fuel Type								
Electric Generators[1]								
Coal	1671	1758	1903	2007	2085	2190	2265	1.1%
Petroleum	64	60	54	37	35	33	32	-3.6%
Natural Gas	322	288	419	671	920	1171	1389	6.8%
Nuclear Power	673	675	689	643	590	460	383	-2.3%
Pumped Storage	-2	-2	-3	-3	-3	-3	-3	1.3%
Renewable Sources[2]	354	392	370	377	382	388	393	0.0%
Total	3083	3181	3432	3732	4015	4258	4459	1.4%
Non-Utility Generation for Own Use	26	26	26	26	26	26	26	0.0%
Cogenerators[3]								
Coal	37	39	37	38	39	39	39	-0.1%
Petroleum	5	6	6	6	6	6	6	0.2%
Natural Gas	170	174	184	192	201	200	194	0.5%
Other Gaseous Fuels[4]	7	7	7	7	7	7	7	0.0%
Renewable Sources[2]	37	41	42	43	43	43	42	0.1%
Other[5]	3	3	3	3	4	4	3	0.2%
Total	259	270	278	289	299	299	291	0.3%
Sales to Utilities	119	121	124	125	127	127	126	0.2%
Generation for Own Use	140	149	155	163	172	172	165	0.4%
Net Imports[6]	38	38	39	33	30	27	27	-1.4%
Electricity Sales by Sector								
Residential	1042	1079	1164	1258	1350	1449	1548	1.5%
Commercial	954	988	1053	1125	1200	1266	1304	1.2%
Industrial	1013	1014	1083	1186	1282	1343	1392	1.3%
Transportation	17	17	19	32	45	55	64	5.6%
Total	3026	3098	3318	3601	3877	4115	4308	1.4%
End-Use Prices (1996 cents per kilowatthour)[7]								
Residential	8.5	8.4	7.8	7.5	7.3	7.0	6.8	-0.9%
Commercial	7.6	7.6	7.2	6.8	6.5	6.1	6.0	-1.0%
Industrial	4.8	4.6	4.3	4.1	3.9	3.6	3.5	-1.1%
Transportation	5.2	5.2	5.0	4.7	4.5	4.3	4.2	-0.9%
All Sectors Average	7.0	6.9	6.5	6.1	5.9	5.8	5.5	-1.0%

[1]Includes grid-connected generation at all utilities and nonutilities except for cogenerators. Includes small power producers, exempt wholesale generators, and generators at industrial and commercial facilities which provide electricity for on-site use and for sales to utilities.
[2]Includes conventional hydroelectric, geothermal, wood, wood waste, municipal solid waste, landfill gas, other biomass, solar, and wind power.
[3]Cogenerators produce electricity and other useful thermal energy. Includes sales to utilities and generation for own use.
[4]Other gaseous fuels include refinery and still gas.
[5]Other includes hydrogen, sulfur, batteries, chemicals, fish oil, and spent sulfite liquor.
[6]In 1996 approximately two-thirds of the U.S. electricity imports were provided by renewable sources (hydroelectricity); EIA does not project future proportions.
[7]Prices represent average revenue per kilowatthour.
Note: Totals may not equal sum of components due to independent rounding.
Sources: 1995 and 1996 commercial and transportation sales derived from: Total transportation plus commercial sales come from Energy Information Administration (EIA), *State Energy Data Report 1994*. Online. ftp://ftp.eia.doe.gov/pub/state.data/021494.pdf (August 26, 1997), but individual sectors do not match because sales taken from commercial and placed in transportation, according to Oak Ridge National Laboratories, *Transportation Energy Data Book 16* (July 1996) which indicates the transportation value should be higher. 1995 and 1996 generation by electric utilities, nonutilities, and cogenerators, net electricity imports, residential sales, and industrial sales: EIA, *Annual Energy Review 1996*, DOE/EIA-0384(96) (Washington, DC, July 1997). 1995 and 1996 residential electricity prices derived from EIA, *Short Term Energy Outlook, August 1997*. Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). 1995 and 1996 electricity prices for commercial, industrial, and transportation; price components; and projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A9. Electricity Generating Capability
(Thousand Megawatts)

Net Summer Capability[1]	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Electric Generators[2]								
Capability								
Coal Steam	305.5	305.3	296.8	302.1	304.6	316.0	323.6	0.2%
Other Fossil Steam[3]	139.3	138.1	121.3	103.6	101.0	97.1	96.0	-1.5%
Combined Cycle	14.7	15.3	27.7	71.3	106.5	154.9	186.5	11.0%
Combustion Turbine/Diesel	55.4	80.0	140.4	176.2	191.4	210.1	221.9	4.3%
Nuclear Power	99.6	100.6	95.6	95.6	80.4	63.9	49.2	-2.9%
Pumped Storage	19.9	19.9	19.9	19.9	19.9	19.9	19.9	N/A
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Renewable Sources[4]	88.5	88.6	91.3	92.9	93.6	94.7	95.7	0.3%
Total	**722.9**	**748.0**	**792.8**	**852.7**	**897.3**	**956.7**	**992.8**	**1.2%**
Cumulative Planned Additions[5]								
Coal Steam	1.2	2.4	3.2	3.2	4.7	4.7	4.7	3.0%
Other Fossil Steam[3]	0.0	0.0	0.1	0.1	0.1	0.1	0.1	2.2%
Combined Cycle	1.4	2.0	2.7	2.7	3.0	3.0	3.0	1.5%
Combustion Turbine/Diesel	2.8	3.8	5.2	5.2	5.2	5.2	5.2	1.3%
Nuclear Power	0.0	1.2	1.2	1.2	1.2	1.2	1.2	N/A
Pumped Storage	1.1	1.1	1.1	1.1	1.1	1.1	1.1	N/A
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Renewable Sources[4]	0.7	0.7	2.9	3.1	3.2	3.2	3.2	6.3%
Total	**7.4**	**11.3**	**16.3**	**16.5**	**18.5**	**18.5**	**18.5**	**2.1%**
Cumulative Unplanned Additions[6]								
Coal Steam	0.0	0.0	0.0	13.3	16.9	32.1	45.4	N/A
Other Fossil Steam[3]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Combined Cycle	0.0	0.0	11.1	54.7	89.7	138.1	169.7	N/A
Combustion Turbine/Diesel	0.0	23.6	82.7	119.1	134.6	154.5	166.3	6.5%
Nuclear Power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Pumped Storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Renewable Sources[4]	0.4	0.5	0.7	2.0	2.8	4.2	5.4	10.8%
Total	**0.4**	**24.1**	**94.4**	**189.1**	**244.0**	**328.9**	**386.7**	**12.3%**
Cumulative Total Additions	**7.9**	**35.4**	**110.6**	**205.6**	**262.5**	**347.4**	**405.2**	**10.7%**
Cumulative Retirements[6]	**11.9**	**14.4**	**45.9**	**80.1**	**92.4**	**117.1**	**138.8**	**9.9%**

Reference Case Forecast

Table A9. Electricity Generating Capability (Continued)
(Thousand Megawatts)

Net Summer Capability[1]	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Cogenerators[2]								
Capability								
Coal	7.1	7.1	7.3	7.5	7.7	7.7	7.7	0.3%
Petroleum	1.0	1.0	1.1	1.1	1.2	1.2	1.2	0.6%
Natural Gas	27.4	28.0	30.5	31.6	32.7	32.7	31.9	0.5%
Other Gaseous Fuels	1.1	1.2	1.1	1.1	1.1	1.1	1.1	-0.1%
Renewable Sources[4]	5.8	5.8	6.4	6.5	6.6	6.6	6.4	0.4%
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Total	42.4	43.0	46.4	47.9	49.3	49.3	48.3	0.5%
Cumulative Additions[5]	7.4	8.1	11.4	12.9	14.4	14.3	13.4	2.1%

[1]Net summer capability is the steady hourly output that generating equipment is expected to supply to system load (exclusive of auxiliary power), as demonstrated by tests during summer peak demand.

[2]Includes grid-connected utilities and nonutilities except for cogenerators. Includes small power producers, exempt wholesale generators, and generators at industrial and commercial facilities which produce electricity for on-site use and sales to utilities.

[3]Includes oil-, gas-, and dual-fired capability.

[4]Includes conventional hydroelectric, geothermal, wood, wood waste, municipal solid waste, landfill gas, other biomass, solar and wind power.

[5]Cumulative additions after December 31, 1995. Non-zero utility planned additions in 1995 indicate units operational in 1995 but not supplying power to the grid.

[6]Cumulative total retirements from 1990.

[7]Nameplate capacity is reported for nonutilities on Form EIA-867, "Annual Power Producer Report." Nameplate capacity is designated by the manufacturer. The nameplate capacity has been converted to the net summer capability based on historic relationships.

N/A = Not applicable.

Notes: Totals may not equal sum of components due to independent rounding. Net summer capability has been estimated for nonutility generators for AEO98. Net summer capacity is used to be consistent with electric utility capacity estimates. Data for electric utility capacity are the most recent data available as of August 25, 1997. Therefore, capacity estimates may differ from other Energy Information Administration sources.

Sources: 1995 and 1996 net summer capability at electric utilities and planned additions: Energy Information Administration (EIA), Form EIA-860, "Annual Electric Generator Report." Net summer capability for nonutilities and cogeneration in 1995 and 1996 and planned additions estimated based on EIA, Form EIA-867, "Annual Nonutility Power Producer Report." Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A10. Electricity Trade
(Billion Kilowatthours, Unless Otherwise Noted)

Electricity Trade	Reference Case							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Interregional Electricity Trade								
Gross Domestic Firm Power Sales	155.0	173.4	149.3	139.2	139.2	139.2	139.2	-0.9%
Gross Domestic Economy Sales	93.2	79.5	74.5	67.7	78.3	79.7	86.6	0.4%
Gross Domestic Trade	248.2	252.9	223.9	207.0	217.5	218.9	225.8	-0.5%
Gross Domestic Firm Power Sales (million 1996 dollars)	7194.8	8050.2	6932.3	6462.9	6462.9	6462.9	6462.9	-0.9%
Gross Domestic Economy Sales (million 1996 dollars)	2483.8	1812.7	1514.1	1446.9	1747.9	1712.8	1905.6	0.2%
Gross Domestic Sales (million 1996 dollars)	9678.5	9862.9	8446.4	7909.8	8210.8	8175.6	8368.5	-0.7%
International Electricity Trade								
Firm Power Imports From Canada and Mexico[1]	30.3	26.1	32.0	17.8	17.8	17.8	17.8	-1.6%
Economy Imports From Canada and Mexico[1]	18.0	20.7	22.2	35.7	33.6	30.1	30.1	1.6%
Gross Imports From Canada and Mexico[1]	48.3	46.8	54.2	53.4	51.4	47.9	47.9	0.1%
Firm Power Exports To Canada and Mexico	3.4	2.8	8.3	13.4	13.4	13.4	13.4	6.7%
Economy Exports To Canada and Mexico	7.2	6.4	6.4	7.0	7.7	7.7	7.7	0.7%
Gross Exports To Canada and Mexico	10.7	9.3	14.7	20.3	21.0	21.0	21.0	3.5%

[1]Historically electric imports were primarily from renewable resources, principally hydroelectric.

Note: Totals may not equal sum of components due to independent rounding. Firm Power Sales are capacity sales, meaning the delivery of the power is scheduled as part of the normal operating conditions of the affected electric systems. Economy Sales are subject to curtailment or cessation of delivery by the supplier in accordance with prior agreements or under specified conditions.

Sources: 1995 and 1996 interregional electricity trade data: Energy Information Administration (EIA), Bulk Power Data System. 1995 and 1996 international electricity trade data: DOE Form FE-781R, "Annual Report of International Electrical Export/Import Data." Firm/economy share: National Energy Board, *Annual Report 1993*. Planned interregional and international firm power sales: DOE Form IE-411, "Coordinated Bulk Power Supply Program Report," April 1995. Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A11. Petroleum Supply and Disposition Balance
(Million Barrels per Day, Unless Otherwise Noted)

Supply and Disposition	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Crude Oil								
Domestic Crude Production[1]	6.56	6.46	6.17	5.82	5.57	5.24	4.92	-1.1%
Alaska	1.48	1.40	1.13	0.93	0.75	0.60	0.48	-4.3%
Lower 48 States	5.08	5.06	5.04	4.89	4.82	4.64	4.44	-0.6%
Net Imports	7.14	7.40	8.75	10.14	10.67	11.22	11.65	1.9%
Other Crude Supply[2]	0.28	0.33	0.00	0.00	0.00	0.00	0.00	N/A
Total Crude Supply	13.98	14.21	14.92	15.96	16.24	16.46	16.58	0.6%
Natural Gas Plant Liquids	1.76	1.83	1.87	2.02	2.24	2.35	2.47	1.3%
Other Inputs[3]	0.49	0.39	0.32	0.29	0.25	0.22	0.20	-2.7%
Refinery Processing Gain[4]	0.77	0.84	0.86	0.89	0.89	0.87	0.82	-0.1%
Net Product Imports[5]	0.75	1.10	1.42	1.96	3.00	3.70	4.33	5.9%
Total Primary Supply[6]	17.75	18.37	19.39	21.12	22.63	23.60	24.40	1.2%
Refined Petroleum Products Supplied								
Motor Gasoline[7]	7.83	7.99	8.52	9.18	9.75	10.10	10.39	1.1%
Jet Fuel[8]	1.51	1.56	1.65	2.16	2.53	2.80	3.03	2.8%
Distillate Fuel[9]	3.23	3.32	3.61	3.88	4.09	4.19	4.25	1.0%
Residual Fuel	0.85	0.90	0.81	0.81	0.88	0.93	0.99	0.4%
Other[10]	4.34	4.66	4.82	5.11	5.45	5.64	5.72	0.9%
Total	17.73	18.44	19.62	21.15	22.70	23.65	24.39	1.2%
Refined Petroleum Products Supplied								
Residential and Commercial	1.15	1.13	1.11	1.09	1.09	1.09	1.08	-0.2%
Industrial[11]	4.58	4.87	5.02	5.33	5.65	5.82	5.89	0.8%
Transportation	11.79	12.11	13.26	14.57	15.81	16.60	17.27	1.5%
Electric Generators[12]	0.30	0.33	0.24	0.16	0.16	0.14	0.14	-3.5%
Total	17.73	18.44	19.62	21.15	22.70	23.65	24.39	1.2%
Discrepancy[13]	-0.01	-0.08	-0.23	-0.03	-0.08	-0.05	0.01	N/A
World Oil Price (1996 dollars per barrel)[14]	17.58	20.48	19.11	20.19	20.81	21.48	22.32	0.4%
Import Share of Product Supplied	0.44	0.48	0.52	0.57	0.60	0.63	0.66	1.8%
Net Expenditures for Imported Crude Oil and Products (billion 1996 dollars)	50.34	62.27	71.35	90.49	106.39	120.20	133.54	3.2%
Domestic Refinery Distillation Capacity	15.4	15.4	15.9	16.8	17.1	17.4	17.5	0.5%
Capacity Utilization Rate (percent)	92.0	94.0	94.1	95.1	95.2	95.2	95.2	0.1%

[1]Includes lease condensate.
[2]Strategic petroleum reserve stock additions plus unaccounted for crude oil and crude stock withdrawals minus crude products supplied.
[3]Includes alcohols, ethers, petroleum product stock withdrawals, domestic sources of blending components, and other hydrocarbons.
[4]Represents volumetric gain in refinery distillation and cracking processes.
[5]Includes net imports of finished petroleum products, unfinished oils, other hydrocarbons, alcohols, ethers, and blending components.
[6]Total crude supply plus natural gas plant liquids, other inputs, refinery processing gain, and net petroleum imports.
[7]Includes ethanol and ethers blended into gasoline.
[8]Includes naphtha and kerosene types.
[9]Includes distillate and kerosene.
[10]Includes aviation gasoline, liquefied petroleum gas, petrochemical feedstocks, lubricants, waxes, asphalt, road oil, still gas, special naphthas, petroleum coke, crude oil product supplied, and miscellaneous petroleum products.
[11]Includes consumption by cogenerators.
[12]Includes all electric power generators except cogenerators, which produce electricity and other useful thermal energy.
[13]Balancing item. Includes unaccounted for supply, losses and gains.
[14]Average refiner acquisition cost for imported crude oil.
N/A = Not applicable.
Note: Totals may not equal sum of components due to independent rounding.
Sources: 1995 and 1996 expenditures for imported crude oil and petroleum products based on internal calculations. 1995 and 1996 product supplied data from Table A2. Other 1995 data: Energy Information Administration (EIA), *Petroleum Supply Annual 1995*, DOE/EIA-0340(95) (Washington, DC, May 1996). Other 1996 data: EIA, *Petroleum Supply Annual 1996*, DOE/EIA-0340(96) (Washington, DC, June 1997). Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A12. Petroleum Product Prices
(1996 Cents per Gallon, Unless Otherwise Noted)

Sector and Fuel	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
World Oil Price (1996 dollars per barrel)	17.58	20.46	19.11	20.19	20.81	21.48	22.32	0.4%
Delivered Sector Product Prices								
Residential								
Distillate Fuel	88.6	98.4	99.2	103.5	104.8	106.0	107.0	0.3%
Liquefied Petroleum Gas	90.3	100.0	99.8	105.4	107.5	107.3	108.5	0.3%
Commercial								
Distillate Fuel	62.3	73.1	72.5	76.8	78.3	79.7	81.0	0.4%
Residual Fuel	46.2	48.4	44.5	45.7	47.3	49.2	50.9	0.2%
Residual Fuel (1996 dollars per barrel)	20.26	20.35	18.69	19.21	19.85	20.65	21.36	0.2%
Industrial[1]								
Distillate Fuel	65.5	76.3	72.7	77.2	79.6	81.5	84.2	0.4%
Liquefied Petroleum Gas	57.3	67.3	51.6	57.0	58.4	57.3	58.8	-0.6%
Residual Fuel	39.6	45.0	40.4	42.9	45.2	47.2	50.1	0.5%
Residual Fuel (1996 dollars per barrel)	16.63	18.88	16.98	17.79	18.97	19.80	21.04	0.5%
Transportation								
Diesel Fuel (distillate)[2]	114.1	123.5	118.4	121.3	119.4	119.3	118.2	-0.2%
Jet Fuel[3]	56.5	74.6	69.1	75.3	79.0	81.7	84.6	0.5%
Motor Gasoline[4]	117.6	122.5	121.2	124.7	126.0	126.6	126.8	0.1%
Residual Fuel	34.8	38.2	39.1	42.7	46.0	47.0	49.7	1.1%
Residual Fuel (1996 dollars per barrel)	14.63	16.04	16.41	17.95	19.32	19.75	20.86	1.1%
Electric Generators[5]								
Distillate Fuel	55.6	68.0	67.1	71.6	73.9	75.9	78.2	0.6%
Residual Fuel	40.2	45.9	44.2	48.0	51.9	53.9	56.4	0.9%
Residual Fuel (1996 dollars per barrel)	16.87	19.27	18.55	20.15	21.78	22.64	23.70	0.9%
Refined Petroleum Product Prices[6]								
Distillate Fuel	98.1	108.7	106.1	109.8	109.2	109.7	109.6	0.0%
Jet Fuel[3]	56.5	74.6	69.1	75.3	79.0	81.7	84.6	0.5%
Liquefied Petroleum Gas	53.7	73.6	61.5	67.7	69.8	69.4	71.1	-0.1%
Motor Gasoline[4]	117.6	122.5	121.0	124.5	125.9	126.4	126.7	0.1%
Residual Fuel	36.4	42.5	40.9	43.7	45.7	48.0	50.5	0.7%
Residual Fuel (1996 dollars per barrel)	16.12	17.87	17.19	18.35	19.63	20.15	21.23	0.7%
Average	85.0	102.8	99.8	103.8	104.9	105.4	106.0	0.1%

[1] Includes cogenerators. Includes Federal and State taxes while excluding county and state taxes.
[2] Low sulfur diesel fuel. Includes Federal and State taxes while excluding county and local taxes.
[3] Kerosene-type jet fuel.
[4] Sales weighted-average price for all grades. Includes Federal and State taxes while excluding county and local taxes.
[5] Includes all electric power generators except cogenerators, which produce electricity and other useful thermal energy.
[6] Weighted averages of end-use fuel prices are derived from the prices in each sector and the corresponding sectoral consumption.

Sources: 1995 prices for gasoline, distillate, and jet fuel are based on prices in the Energy Information Administration (EIA), *Petroleum Marketing Annual 1995*. Online, http://www.eia.doe.gov/oil-gas/pmai/pmaframe.html (May 30, 1997). 1996 prices for gasoline, distillate, and jet fuel are based on prices in various issues of EIA, *Petroleum Marketing Monthly*, DOE/EIA-0380(96/08-97/04) (Washington, DC, 1996-97). 1995 and 1996 prices for all other petroleum products are derived from EIA, *State Energy Price and Expenditures Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997). Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A13. Natural Gas Supply and Disposition
(Trillion Cubic Feet per Year)

Supply and Disposition	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Production								
Dry Gas Production[1]	18.60	19.02	20.27	22.25	24.70	26.12	27.44	1.5%
Supplemental Natural Gas[2]	0.11	0.12	0.11	0.11	0.05	0.05	0.05	-3.6%
Net Imports	2.69	2.72	3.84	4.02	4.28	4.64	4.91	2.5%
Canada	2.79	2.76	3.66	3.89	4.13	4.50	4.80	2.3%
Mexico	-0.05	-0.02	-0.13	-0.14	-0.15	-0.15	-0.17	9.5%
Liquefied Natural Gas	-0.05	-0.03	0.12	0.27	0.29	0.29	0.29	N/A
Total Supply	21.40	21.86	24.23	26.39	29.03	30.81	32.41	1.7%
Consumption by Sector								
Residential	4.84	5.23	5.20	5.31	5.47	5.66	5.80	0.4%
Commercial	3.03	3.20	3.37	3.52	3.65	3.74	3.75	0.7%
Industrial[3]	8.41	8.60	9.29	9.39	9.75	9.75	9.70	0.5%
Electric Generators[4]	3.37	2.98	4.05	5.57	7.22	8.52	9.85	5.1%
Lease and Plant Fuel[5]	1.22	1.25	1.35	1.45	1.59	1.68	1.76	1.5%
Pipeline Fuel	0.70	0.71	0.78	0.82	0.83	0.96	1.00	1.4%
Transportation[6]	0.01	0.01	0.05	0.15	0.23	0.29	0.33	15.8%
Total	21.58	21.99	24.08	26.22	28.84	30.61	32.20	1.6%
Discrepancy[7]	-0.18	-0.12	0.15	0.17	0.19	0.20	0.21	N/A

[1]Marketed production (wet) minus extraction losses.
[2]Synthetic natural gas, propane air, coke oven gas, refinery gas, biomass gas, air injected for Btu stabilization, and manufactured gas commingled and distributed with natural gas.
[3]Includes consumption by cogenerators.
[4]Includes all electric power generators except cogenerators, which produce electricity and other useful thermal energy.
[5]Represents natural gas used in the field gathering and processing plant machinery.
[6]Compressed natural gas used as vehicle fuel.
[7]Balancing item. Natural gas lost as a result of converting flow data measured at varying temperatures and pressures to a standard temperature and pressure and the merger of different data reporting systems which vary in scope, format, definition, and respondent type. In addition, 1995 and 1996 values include net storage injections.
Btu = British thermal unit.
N/A = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Figures for 1995 and 1996 may differ from published data due to internal conversion factors.
Sources: 1995 supply values and consumption as lease, plant, and pipeline fuel: Energy Information Administration (EIA), *Natural Gas Annual 1995*, DOE/EIA-0131(95) (Washington, DC, November 1996). Other 1995 consumption derived from: EIA, *State Energy Data Report 1994*, Online. ftp://ftp.eia.doe.gov/pub/state.data/021497.pdf (August 26, 1997). 1996 supplemental natural gas: EIA, *Natural Gas Monthly*, DOE/EIA-0130(97/8) (Washington, DC, June 1997). 1996 imports and dry gas production derived from: EIA, *Natural Gas Annual 1996*, DOE/EIA-0131(96) (Washington, DC, November 1997). 1996 transportation sector consumption: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A. Other 1996 consumption: EIA, *Short-Term Energy Outlook August 1997*. Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997) with adjustments to end-use sector consumption levels for consumption of natural gas by electric wholesale generators based on EIA, AEO98 National Energy Modeling System run AEO98B.D100197A. Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A14. Natural Gas Prices, Margins, and Revenues
(1996 Dollars per Thousand Cubic Feet, Unless Otherwise Noted)

Prices, Margins, and Revenue	Reference							Annual Growth 1996-2020 (percent)
	1996	1998	2000	2005	2010	2015	2020	
Source Price								
Average Lower 48 Wellhead Price[1]	1.61	2.24	2.11	2.15	2.31	2.38	2.54	0.5%
Average Import Price	1.53	1.98	1.96	2.14	2.32	2.40	2.56	1.1%
Average[2]	**1.60**	**2.21**	**2.08**	**2.15**	**2.31**	**2.38**	**2.54**	**0.6%**
Delivered Prices								
Residential	6.25	6.37	5.93	5.71	5.58	5.47	5.60	-0.5%
Commercial	5.22	5.43	5.02	4.85	4.79	4.76	4.81	-0.4%
Industrial[3]	2.43	3.05	2.81	2.85	3.01	3.09	3.26	0.3%
Electric Generators[4]	2.08	2.70	2.54	2.69	2.91	3.04	3.22	0.7%
Transportation[5]	5.57	5.57	5.82	5.89	6.79	7.26	7.61	1.3%
Average[6]	**3.73**	**4.25**	**3.85**	**3.76**	**3.80**	**3.83**	**3.97**	**-0.3%**
Transmission and Distribution Margins[7]								
Residential	4.65	4.17	3.85	3.56	3.27	3.09	3.05	-1.3%
Commercial	3.62	3.23	2.93	2.70	2.48	2.38	2.37	-1.3%
Industrial[3]	0.89	0.84	0.73	0.70	0.71	0.70	0.71	-0.7%
Electric Generators[4]	0.48	0.49	0.45	0.54	0.60	0.66	0.68	1.3%
Transportation[5]	3.97	3.36	3.54	3.74	4.48	4.88	5.06	1.7%
Average[6]	**2.13**	**2.04**	**1.76**	**1.61**	**1.49**	**1.44**	**1.43**	**-1.5%**
Transmission and Distribution Revenue (billion 1996 dollars)								
Residential	22.51	21.81	20.00	18.93	17.91	17.48	17.70	-0.9%
Commercial	10.94	10.34	9.86	9.50	9.05	8.88	8.87	-0.6%
Industrial[3]	7.02	7.23	6.75	6.60	6.89	6.87	6.92	-0.2%
Electric Generators[4]	1.62	1.47	1.83	3.00	4.32	5.63	6.69	6.5%
Transportation[5]	0.04	0.03	0.16	0.56	1.04	1.43	1.68	17.8%
Total	**42.13**	**40.88**	**38.64**	**38.60**	**39.21**	**40.29**	**41.87**	**0.1%**

[1]Represents lower 48 onshore and offshore supplies.
[2]Quantity-weighted average of the average lower 48 wellhead price and the average price of imports at the U.S. border.
[3]Includes consumption by cogenerators.
[4]Includes all electric power generators except cogenerators, which produce electricity and other useful thermal energy.
[5]Compressed natural gas used as a vehicle fuel. Price includes estimated motor vehicle fuel taxes.
[6]Weighted average prices and margins. Weights used are the sectoral consumption values excluding lease, plant, and pipeline fuel.
[7]Within the table, "transmission and distribution" margins equal the difference between the delivered price and the source price (average of the wellhead price and the price of imports at the U.S. border) of natural gas and, thus, reflect the total cost of bringing natural gas to market. When the term "transmission and distribution" margins is used in today's natural gas market, it generally does not include the cost of independent natural gas marketers or costs associated with aggregation of supplies, provisions of storage, and other services. As used here, the term includes the cost of all services and the cost of pipeline fuel used in compressor stations.

Note: Totals may not equal sum of components due to independent rounding.

Sources: 1995 residential, commercial, and transportation delivered prices: average lower 48 wellhead price; and average import price: Energy Information Administration (EIA), *Natural Gas Annual 1995*, DOE/EIA-0131(95) (Washington, DC, November 1996). 1995 electric generators delivered price: Form FERC-423, "Monthly Report of Cost and Quality of Fuels for Electric Plants". 1995 and 1996 industrial delivered prices based on EIA, *Manufacturing Energy Consumption Survey 1991*. 1996 residential and commercial delivered prices, average lower 48 wellhead price, and average import price: EIA, *Natural Gas Monthly*, DOE/EIA-0130(97/06) (Washington, DC, June 1997). Other 1995 values, other 1996 values, and projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A15. Oil and Gas Supply

Production and Supply	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Crude Oil								
Lower 48 Average Wellhead Price[1] (1996 dollars per barrel)	15.96	19.41	19.12	20.52	21.08	21.01	21.58	0.4%
Production (million barrels per day)[2]								
U.S. Total	6.56	6.48	6.17	5.82	5.57	5.24	4.92	-1.1%
Lower 48 Onshore	3.82	3.76	3.39	3.13	3.15	3.13	3.09	-0.9%
Conventional	3.16	3.15	2.81	2.47	2.36	2.35	2.41	-1.1%
Enhanced Oil Recovery	0.66	0.61	0.58	0.66	0.79	0.78	0.68	0.5%
Lower 48 Offshore	1.26	1.32	1.65	1.75	1.67	1.52	1.35	0.1%
Alaska	1.48	1.40	1.13	0.93	0.75	0.60	0.48	-4.3%
Lower 48 End of Year Reserves (billion barrels)	17.03	16.82	15.25	14.68	14.87	14.67	14.33	-0.7%
Natural Gas								
Lower 48 Average Wellhead Price[1] (1996 dollars per thousand cubic feet)	1.61	2.24	2.11	2.15	2.31	2.38	2.54	0.5%
Production (trillion cubic feet)[3]								
U.S. Total	18.60	19.01	20.27	22.25	24.70	26.12	27.44	1.5%
Lower 48 Onshore	12.82	13.07	13.90	15.30	17.33	18.72	18.99	1.6%
Associated-Dissolved[4]	1.80	1.84	1.69	1.39	1.27	1.21	1.19	-1.8%
Non-Associated	11.02	11.23	12.21	13.91	16.06	17.51	17.81	1.9%
Conventional	7.97	7.96	8.74	10.18	11.77	12.44	12.32	1.8%
Unconventional	3.05	3.27	3.47	3.73	4.30	5.06	5.49	2.2%
Lower 48 Offshore	5.35	5.50	5.88	6.43	6.81	6.81	7.83	1.5%
Associated-Dissolved[4]	0.77	0.80	0.89	0.93	0.92	0.89	0.85	0.3%
Non-Associated	4.58	4.70	4.99	5.49	5.89	5.92	6.98	1.7%
Alaska	0.43	0.43	0.49	0.53	0.56	0.59	0.62	1.5%
Lower 48 End of Year Reserves (trillion cubic feet)	155.65	157.23	172.04	187.25	196.33	196.28	185.11	0.7%
Supplemental Gas Supplies (trillion cubic ft.)[5]	0.11	0.12	0.11	0.11	0.05	0.05	0.05	-3.6%
Total Lower 48 Wells (thousands)	18.66	21.75	22.18	25.30	28.19	29.39	32.04	1.6%

Ft. = feet.
[1]Represents lower 48 onshore and offshore supplies.
[2]Includes lease condensate.
[3]Market production (wet) minus extraction losses.
[4]Gas which occurs in crude oil reserves either as free gas (associated) or as gas in solution with crude oil (dissolved).
[5]Synthetic natural gas, propane air, coke oven gas, refinery gas, biomass gas, air injected for Btu stabilization, and manufactured gas commingled and distributed with natural gas.

Note: Totals may not equal sum of components due to independent rounding. Figures for 1995 and 1996 may differ from published data due to internal conversion factors.

Sources: 1995 lower 48 onshore, lower 48 offshore, Alaska crude oil production: Energy Information Administration (EIA), *Petroleum Supply Annual 1995*, DOE/EIA-0340(95)/1 (Washington, DC, May 1996). 1995 U.S. crude oil and natural gas reserves: EIA, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves*, DOE/EIA-0216(95) (Washington, DC, November 1996). 1995 natural gas lower 48 average wellhead price: EIA, *Natural Gas Annual 1995*, DOE/EIA-0131(95) (Washington, DC, November 1996). 1995 and 1996 crude oil lower 48 average wellhead price: EIA, Office of Integrated Analysis and Forecasting. 1995 and 1996 total wells completed: EIA, Office of Integrated Analysis and Forecasting. 1996 lower 48 onshore, lower 48 offshore, Alaska crude oil production: EIA, *Petroleum Supply Annual 1996*, DOE/EIA-0340(96) (Washington, DC, June 1997). 1996 natural gas lower 48 average wellhead price, Alaska and total natural gas production, and supplemental gas supplies. EIA, *Natural Gas Monthly*, DOE/EIA-0130(97/06) (Washington, DC, June 1997). Other 1995 and 1996 values: EIA, Office of Integrated Analysis and Forecasting. Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A16. Coal Supply, Disposition, and Prices
(Million Short Tons per Year, Unless Otherwise Noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 1996-2020 (percent)
	1996	1998	2000	2005	2010	2015	2020	
Production[1]								
Appalachia	435	452	491	506	505	505	513	0.5%
Interior	169	173	183	176	177	167	166	-0.2%
West	430	439	471	525	583	654	697	1.9%
East of the Mississippi	544	564	603	608	602	609	623	0.4%
West of the Mississippi	488	500	541	599	663	717	754	1.7%
Total	1033	1064	1145	1207	1265	1326	1376	1.1%
Net Imports								
Imports	7	7	7	8	8	8	8	0.4%
Exports	88	90	94	104	112	119	128	1.4%
Total	-81	-83	-87	-96	-104	-112	-120	1.5%
Total Supply[2]	952	981	1058	1111	1161	1215	1256	1.0%
Consumption by Sector								
Residential and Commercial	6	6	6	6	6	7	6	0.4%
Industrial[3]	72	70	71	77	81	81	81	0.6%
Coke Plants	33	32	31	28	26	24	23	-1.4%
Electric Generators[4]	847	896	950	1000	1049	1103	1147	1.0%
Total	958	1003	1058	1112	1162	1215	1257	0.9%
Discrepancy and Stock Change[5]	-6	-23	-1	-1	-1	-0	-1	N/A
Average Minemouth Price								
(1996 dollars per short ton)	19.25	18.50	17.45	16.18	15.05	13.99	13.27	-1.4%
(1996 dollars per million Btu)	0.90	0.87	0.82	0.76	0.72	0.67	0.64	-1.3%
Delivered Prices (1996 dollars per short ton)[6]								
Industrial	33.14	32.28	31.03	29.92	29.29	28.90	28.57	-0.5%
Coke Plants	48.39	47.33	47.16	45.90	45.10	44.79	44.61	-0.2%
Electric Generators								
(1996 dollars per short ton)	27.61	26.45	24.71	23.37	22.09	20.72	19.52	-1.3%
(1996 dollars per million Btu)	1.35	1.29	1.20	1.14	1.08	1.03	0.97	-1.2%
Average	28.75	27.52	25.80	24.40	23.12	21.78	20.56	-1.2%
Exports[7]	41.17	40.77	38.37	36.40	35.02	33.75	32.47	-0.9%

[1]Includes anthracite, bituminous coal, and lignite.
[2]Production plus net imports and net storage withdrawals.
[3]Includes consumption by cogenerators.
[4]Includes all electric power generators except cogenerators, which produce electricity and other useful thermal energy.
[5]Balancing item: the sum of production, net imports, and net storage minus total consumption.
[6]Sectoral prices weighted by consumption tonnage; weighted average excludes residential/ commercial prices and export free-alongside-ship (f.a.s.) prices.
[7]F.a.s. price at U.S. port of exit.
N/A = Not applicable.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding.
Sources: 1995: Energy Information Administration (EIA), *Coal Industry Annual 1995*, DOE/EIA-0584(95) (Washington, DC, October 1996). 1996 data derived from: EIA, *Coal Industry Annual 1996*, DOE/EIA-0584(96) (Washington, DC, November 1997). **Projections:** EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A17. Renewable Energy Generating Capability and Generation
(Thousand Megawatts, Unless Otherwise Noted)

Capacity and Generation	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Electric Generators[1] (excluding cogenerators)								
Net Summer Capability								
Conventional Hydropower	78.48	78.58	80.32	80.65	80.71	80.71	80.71	0.1%
Geothermal[2]	3.02	3.02	3.02	2.93	2.92	2.87	2.94	-0.1%
Municipal Solid Waste[3]	2.87	2.91	3.11	3.46	3.92	4.26	4.38	1.7%
Wood and Other Biomass[4]	1.91	1.91	1.91	2.02	2.07	2.28	2.50	1.1%
Solar Thermal	0.36	0.36	0.36	0.40	0.46	0.51	0.56	1.8%
Solar Photovoltaic	0.01	0.01	0.02	0.08	0.22	0.38	0.56	18.0%
Wind	1.84	1.85	2.55	3.31	3.33	3.68	4.06	3.3%
Total	88.49	88.64	91.29	92.86	93.64	94.69	95.70	0.3%
Generation (billion kilowatthours)								
Conventional Hydropower	309.82	346.28	316.00	318.16	318.67	318.75	318.82	-0.3%
Geothermal[2]	14.66	15.70	17.24	17.34	17.64	17.92	19.26	0.9%
Municipal Solid Waste[3]	18.89	18.85	20.76	23.14	26.32	28.68	29.52	1.9%
Wood and Other Biomass[4]	7.12	7.27	8.96	9.48	9.79	11.24	12.81	2.4%
Solar Thermal	0.82	0.82	0.92	1.04	1.24	1.39	1.56	2.7%
Solar Photovoltaic	0.00	0.00	0.05	0.20	0.60	1.00	1.45	29.4%
Wind	3.17	3.17	5.67	7.70	7.76	8.86	10.08	4.9%
Total	354.28	392.09	369.60	377.05	382.03	387.84	393.50	0.0%
Cogenerators[5]								
Net Summer Capability								
Municipal Solid Waste	0.41	0.41	0.43	0.45	0.46	0.47	0.48	0.7%
Biomass	5.35	5.41	5.93	6.06	6.14	6.08	5.95	0.4%
Total	5.75	5.81	6.36	6.50	6.61	6.56	6.43	0.4%
Generation (billion kilowatthours)								
Municipal Solid Waste	2.00	2.09	2.14	2.22	2.30	2.34	2.36	0.5%
Biomass	34.85	39.17	39.67	40.48	41.00	40.55	39.65	0.1%
Total	36.85	41.25	41.81	42.70	43.29	42.89	42.01	0.1%

[1]Includes grid-connected utilities and nonutilities other than cogenerators. These nonutility facilities include small power producers, exempt wholesale generators and generators at industrial and commercial facilities which do not produce steam for other uses.
[2]Includes hydrothermal resources only (hot water and steam).
[3]Includes landfill gas.
[4]Includes projections for energy crops after 2010.
[5]Cogenerators produce electricity and other useful thermal energy.

Notes: Totals may not equal sum of components due to independent rounding. Net summer capability has been estimated for nonutility generators for AEO98. Net summer capability is used to be consistent with electric utility capacity estimates. Data for electric utility capacity are the most recently available as of August 25, 1997. Additional retirements are also determined on the basis of the size and age of the units. Therefore, capacity estimates may differ from other Energy Information Administration sources.

Sources: 1995 and 1996 electric utility capability: Energy Information Administration (EIA), Form EIA-860 "Annual Electric Utility Report." 1995 and 1996 nonutility and cogenerator capability: Form EIA-867, "Annual Nonutility Power Producer Report." 1995 and 1996 generation: EIA, *Annual Energy Review 1996*, DOE/EIA-0384(96) (Washington, DC, July 1997).
Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A18. Renewable Energy, Consumption by Sector and Source[1] (Quadrillion Btu per Year)

Sector and Source	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Marketed Renewable Energy[2]								
Residential	0.59	0.61	0.61	0.62	0.63	0.64	0.64	0.2%
Wood	0.59	0.61	0.61	0.62	0.63	0.64	0.64	0.2%
Commercial[3]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1%
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1%
Industrial[4]	1.73	1.82	1.96	2.10	2.24	2.31	2.34	1.0%
Conventional Hydroelectric	0.03	0.03	0.03	0.03	0.03	0.03	0.03	N/A
Municipal Solid Waste	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.8%
Biomass	1.70	1.78	1.92	2.07	2.20	2.27	2.30	1.1%
Transportation	0.11	0.10	0.17	0.17	0.17	0.14	0.15	1.5%
Ethanol used in E85[5]	0.00	0.00	0.00	0.02	0.07	0.11	0.13	20.5%
Ethanol used in Gasoline Blending	0.11	0.10	0.16	0.14	0.09	0.03	0.01	-8.3%
Electric Generators[6]	3.97	4.40	4.21	4.31	4.40	4.48	4.56	0.2%
Conventional Hydroelectric	3.18	3.56	3.25	3.27	3.28	3.28	3.28	-0.3%
Geothermal	0.39	0.43	0.48	0.50	0.52	0.53	0.58	1.2%
Municipal Solid Waste	0.30	0.30	0.33	0.37	0.42	0.46	0.47	1.9%
Biomass	0.06	0.06	0.06	0.06	0.09	0.10	0.11	2.4%
Solar Thermal	0.01	0.01	0.01	0.01	0.01	0.01	0.00	N/A
Solar Photovoltaic	0.00	0.00	0.00	0.00	0.01	0.01	0.01	29.4%
Wind	0.03	0.03	0.06	0.06	0.06	0.09	0.10	4.9%
Total Marketed Renewable Energy	6.41	6.93	6.95	7.21	7.44	7.58	7.69	0.4%
Non-Marketed Renewable Energy[7] Selected Consumption								
Residential	0.02	0.02	0.03	0.04	0.05	0.06	0.07	5.0%
Solar Hot Water Heating	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-0.3%
Geothermal Heat Pumps	0.01	0.01	0.02	0.03	0.04	0.05	0.06	7.1%
Commercial	0.01	0.01	0.02	0.03	0.03	0.04	0.04	4.2%
Solar Thermal	0.01	0.01	0.02	0.03	0.03	0.04	0.04	4.2%

[1]Actual heat rates used to determine fuel consumption for all renewable fuels except hydropower, solar, and wind. Consumption at hydroelectric, solar, and wind facilities determined by using the fossil fuel equivalent of 10,280 Btu per kilowatthour.

[2]Includes nonelectric renewable energy groups for which the energy source is bought and sold in the marketplace, although all transactions may not necessarily be marketed, and marketed renewable energy inputs for electricity entering the marketplace on the electric power grid. Excludes electricity imports; see Table A8.

[3]Value is less than 0.005 quadrillion Btu per year and rounds to zero.

[4]Includes all electricity production by industrial and other cogenerators for the grid and for own use.

[5]Excludes motor gasoline component of E85.

[6]Includes renewable energy delivered to the grid from electric utilities and nonutilities. Renewable energy used in generating electricity for own use is included in the individual sectoral electricity energy consumption values.

[7]Includes selected renewable energy consumption data for which the energy is not bought or sold, either directly or indirectly as an input to marketed energy. The Energy Information Administration does not estimate or project total consumption of nonmarketed renewable energy.

N/A = Not applicable.

Btu = British thermal unit.

Notes: Totals may not equal sum of components due to independent rounding.

Sources: 1995 ethanol: Energy Information Administration (EIA), *Annual Energy Review 1995*, DOE/EIA-0384(95) (Washington, DC, July 1996). 1995 and 1996 electric generators: EIA, Form EIA-860, "Annual Electric Utility Report" and EIA, Form EIA-867, "Annual Nonutility Power Producer Report." Other 1995: EIA, Office of Integrated Analysis and Forecasting. 1996 ethanol: EIA, *Petroleum Supply Annual 1996*, DOE/EIA-0340(96/1) (Washington, DC, June 1997). Other 1996: EIA, Office of Integrated Analysis and Forecasting. Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Table A19. Carbon Emissions by Sector and Source
(Million Metric Tons per Year)

Sector and Source	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Residential								
Petroleum	25.6	27.3	25.8	25.0	24.8	24.5	24.2	-0.5%
Natural Gas	71.7	77.4	77.0	79.7	81.1	83.6	85.9	0.4%
Coal	1.4	1.4	1.4	1.4	1.3	1.3	1.3	-0.3%
Electricity	170.1	179.9	201.3	215.9	230.9	248.8	267.5	1.7%
Total	268.0	286.0	305.6	321.0	338.1	358.5	378.0	1.2%
Commercial								
Petroleum	15.0	15.3	12.8	12.8	12.8	12.7	12.4	-0.9%
Natural Gas	44.8	47.4	49.9	52.1	54.0	55.4	55.5	0.7%
Coal	2.1	2.1	2.2	2.3	2.4	2.5	2.5	0.8%
Electricity	155.7	164.8	182.2	193.1	205.1	217.8	225.5	1.3%
Total	217.6	229.6	247.1	260.4	274.4	288.4	296.0	1.1%
Industrial[1]								
Petroleum	97.4	104.6	103.3	109.7	115.6	119.3	120.3	0.6%
Natural Gas[2]	139.5	142.8	155.5	158.5	165.8	167.1	167.5	0.7%
Coal	62.1	59.3	60.7	62.3	62.8	61.7	60.7	0.1%
Electricity	165.2	169.2	187.3	203.6	219.1	230.6	240.6	1.5%
Total	464.2	476.1	506.7	534.1	563.3	578.7	589.2	0.9%
Transportation								
Petroleum	447.5	457.9	502.4	552.8	601.0	632.3	658.6	1.5%
Natural Gas[3]	10.4	10.5	12.2	14.4	17.2	18.6	19.8	2.7%
Other[4]	0.0	0.0	0.1	0.5	1.5	2.2	2.7	N/A
Electricity	2.7	2.8	3.2	5.5	7.8	9.5	11.0	5.8%
Total	460.6	471.2	517.9	573.3	627.5	662.7	692.1	1.6%
Total Carbon Emissions[5]								
Petroleum	585.7	605.3	644.4	700.4	754.2	788.9	815.5	1.2%
Natural Gas	266.4	278.1	294.6	303.7	318.1	324.9	328.7	0.7%
Coal	65.6	62.8	64.3	66.0	66.6	65.6	64.5	0.1%
Other[4]	0.0	0.0	0.1	0.5	1.5	2.2	2.7	N/A
Electricity	493.7	516.7	574.0	618.1	662.9	706.8	744.7	1.5%
Total	1411.4	1462.9	1577.3	1688.8	1803.2	1888.3	1956.2	1.2%
Electric Generators[6]								
Petroleum	13.8	15.5	11.4	7.7	7.4	6.8	6.6	-3.5%
Natural Gas	47.2	40.3	59.6	82.0	106.3	125.4	145.0	5.5%
Coal	432.7	460.9	503.0	528.4	549.3	574.5	593.1	1.1%
Total	493.7	516.7	574.0	618.1	662.9	706.8	744.7	1.5%
Total Carbon Emissions[7]								
Petroleum	599.5	620.8	655.8	708.1	761.5	795.7	822.1	1.2%
Natural Gas	313.6	318.4	354.2	385.7	424.4	450.3	473.7	1.7%
Coal	498.3	523.7	567.3	594.4	615.9	640.1	657.7	1.0%
Other[4]	0.0	0.0	0.1	0.5	1.5	2.2	2.7	N/A
Total	1411.4	1462.9	1577.3	1688.8	1803.2	1888.3	1956.2	1.2%
Carbon Emissions (tons per person)	5.4	5.5	5.7	5.9	6.0	6.1	6.0	0.4%

[1]Includes consumption by cogenerators.
[2]Includes lease and plant fuel.
[3]Includes pipeline fuel natural gas and compressed natural gas used as vehicle fuel.
[4]Includes methanol and liquid hydrogen.
[5]Measured for delivered energy consumption.
[6]Includes all electric power generators except cogenerators, which produce electricity and other useful thermal energy.
[7]Measured for total energy consumption, with emissions for electric power generators distributed to the primary fuels.
N/A = Not applicable
Note: Totals may not equal sum of components due to independent rounding.
Sources: Carbon coefficients from Energy Information Administration, (EIA) *Emissions of Greenhouse Gases in the United States 1996*, DOE/EIA-0573(96) (Washington, DC, October 1997). 1995 consumption estimates derived from EIA, *State Energy Data Report 1994*, Online. ftp://ftp.eia.doe.gov/pub/state.data/021404.pdf (August 26, 1997). 1996 consumption estimates based on: EIA, *Short Term Energy Outlook, August 1997*, Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A20. Macroeconomic Indicators
(Billion 1992 Chain-Weighted, Dollars Unless Otherwise Noted)

Indicators	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
GDP Chain-Type Price Index (1992=1.000)	1.078	1.102	1.208	1.379	1.600	1.891	2.262	3.0%
Real Gross Domestic Product	6742	6928	7653	8503	9431	10211	10998	1.9%
Real Consumption	4595	4714	5220	5723	6349	6969	7626	2.0%
Real Investment	969	1067	1295	1500	1739	1934	2105	2.9%
Real Government Spending	1252	1258	1301	1383	1488	1583	1640	1.1%
Real Exports	791	857	1189	1746	2332	2849	3352	5.6%
Real Imports	890	971	1366	1847	2514	3283	4153	6.2%
Real Disposable Personal Income	4964	5077	5595	6182	6884	7560	8217	2.0%
Index of Manufacturing Gross Output (Index 1987=1.000)	1.264	1.299	1.425	1.629	1.851	1.992	2.125	2.1%
AA Utility Bond Rate (percent)	7.76	7.57	7.16	7.17	7.21	7.64	8.27	N/A
Real Yield on Government 10 Year Bonds (percent)	5.23	4.99	4.29	3.83	3.58	3.69	3.97	N/A
Real Utility Bond Rate (percent)	5.22	5.28	4.64	4.37	4.05	4.15	4.49	N/A
Delivered Energy Intensity (thousand Btu per 1992 dollar of GDP)								
Delivered Energy	10.13	10.16	9.79	9.41	9.04	8.68	8.35	-0.8%
Total Energy	13.52	13.57	13.05	12.45	11.90	11.34	10.89	-0.9%
Consumer Price Index (1982-84=1.00)	1.52	1.57	1.75	2.04	2.42	2.90	3.52	3.4%
Unemployment Rate (percent)	5.60	5.38	5.38	5.79	5.51	5.55	5.66	N/A
Unit Sales of Light-Duty Vehicles (million)	14.77	15.10	15.24	15.58	16.65	17.15	17.49	0.6%
Millions of People								
Population with Armed Forces Overseas	263.6	266.1	275.6	287.1	298.9	311.2	323.5	0.8%
Population (aged 16 and over)	202.1	204.2	212.8	223.8	235.4	245.8	255.6	0.9%
Employment, Non-Agriculture	117.2	119.5	128.1	135.5	143.9	149.2	153.4	1.0%
Employment, Manufacturing	16.5	16.5	16.1	17.9	17.5	16.4	15.2	-0.8%
Labor Force	132.3	133.9	142.1	149.6	156.5	160.2	162.4	0.8%

GDP = Gross domestic product.
Btu = British thermal unit.
N/A = Not applicable.
Sources: 1995 and 1996: Data Resources Incorporated (DRI), DRI Trend0697. Projections: Energy Information Administration, AEO98 National Energy Modeling System run AEO98B.D100197A.

Reference Case Forecast

Table A21. International Petroleum Supply and Disposition Summary
(Million Barrels per Day, Unless Otherwise Noted)

Supply and Disposition	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
World Oil Price (1996 dollars per barrel)[1]	17.58	20.46	19.11	20.19	20.81	21.48	22.32	0.4%
Production[2]								
OECD								
U.S. (50 states)	9.31	9.37	9.11	8.96	8.94	8.73	8.46	-0.4%
Canada	2.43	2.51	2.55	2.46	2.59	2.62	2.66	0.2%
Mexico	3.19	3.28	3.20	3.24	3.34	3.43	3.53	0.3%
OECD Europe[3]	6.56	6.67	7.07	6.57	5.74	5.11	4.47	-1.7%
Other OECD	0.76	0.77	0.80	0.80	1.01	0.80	0.84	0.4%
Total OECD	22.25	22.60	22.74	22.03	21.62	20.70	19.96	-0.5%
Developing Countries								
Other South & Central America	3.07	3.29	4.29	4.75	5.23	6.03	6.68	3.0%
Pacific Rim	1.95	2.06	2.67	3.04	3.20	3.23	3.08	1.6%
OPEC	27.72	29.00	32.73	40.19	48.19	56.40	65.96	3.5%
Other Developing Countries	4.13	4.21	4.55	4.84	5.00	5.33	5.36	1.0%
Total Developing Countries	36.88	38.59	44.25	52.82	61.63	70.96	81.11	3.1%
Eurasia								
Former Soviet Union	6.99	7.14	7.70	9.13	9.83	10.59	11.41	2.0%
Eastern Europe	0.32	0.32	0.27	0.23	0.21	0.18	0.18	-2.3%
China	3.00	3.10	3.14	3.16	3.27	3.46	3.65	0.7%
Total Eurasia	10.31	10.55	11.10	12.54	13.31	14.23	15.24	1.5%
Total Production	69.43	71.74	78.09	87.39	96.56	105.91	116.34	2.0%
Consumption								
OECD								
U.S. (50 states)	17.73	18.31	19.82	21.15	22.70	23.66	24.39	1.2%
U.S. Territories	0.26	0.26	0.30	0.35	0.38	0.42	0.46	2.5%
Canada	1.77	1.77	1.87	2.01	2.15	2.28	2.43	1.3%
Mexico	1.96	1.98	2.25	2.39	2.74	3.00	3.27	2.1%
Japan	5.72	5.84	6.46	6.91	7.28	7.80	8.34	1.5%
Australia and New Zealand	0.96	0.97	1.05	1.10	1.20	1.24	1.29	1.2%
OECD Europe[3]	13.85	13.93	14.36	14.78	15.11	15.40	15.69	0.5%
Total OECD	42.24	43.05	45.91	48.68	51.56	53.80	55.88	1.1%
Developing Countries								
Other South and Central America	3.59	3.79	4.70	5.56	6.51	7.49	8.61	3.5%
Pacific Rim	4.89	4.55	5.38	7.13	8.44	10.07	12.03	4.1%
OPEC	4.94	5.14	5.82	6.30	7.06	7.91	8.86	2.3%
Other Developing Countries	5.27	5.44	6.06	7.19	7.94	8.75	9.66	2.4%
Total Developing Countries	18.19	18.91	21.76	26.19	29.95	34.22	39.16	3.1%

Table A21. International Petroleum Supply and Disposition Summary (Continued)
(Million Barrels per Day, Unless Otherwise Noted)

Supply and Disposition	Reference							Annual Growth 1996-2020 (percent)
	1995	1996	2000	2005	2010	2015	2020	
Eurasia								
Former Soviet Union	4.60	4.48	4.68	5.80	6.73	7.65	8.68	2.8%
Eastern Europe	1.40	1.43	1.45	1.51	1.73	1.96	2.24	1.9%
China	3.31	3.44	4.39	5.51	6.89	8.58	10.68	4.8%
Total Eurasia	**9.31**	**9.35**	**10.72**	**12.81**	**15.35**	**18.19**	**21.60**	**3.5%**
Total Consumption	**69.73**	**71.32**	**78.39**	**87.69**	**96.86**	**106.21**	**116.84**	**2.1%**
Non-OPEC Production	41.71	42.74	45.36	47.19	48.37	49.52	50.36	0.7%
Net Eurasia Exports	1.00	1.20	0.38	-0.26	-2.04	-3.96	-6.36	N/A
OPEC Market Share	0.40	0.40	0.42	0.46	0.50	0.53	0.57	1.4%

N/A = Not applicable.

[1]Average refiner acquisition cost of imported crude oil.

[2]Includes production of crude oil (including lease condensates), natural gas plant liquids, other hydrogen and hydrocarbons for refinery feedstocks, alcohol, liquids produced from coal and other sources, and refinery gains.

[3]OECD Europe includes the unified Germany.

OECD = Organization for Economic Cooperation and Development - Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States (including territories).

Pacific Rim = Hong Kong, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand.

OPEC = Organization of Petroleum Exporting Countries - Algeria, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.

Eurasia = Albania, Bulgaria, China, Czech Republic, Hungary, Poland, Romania, Slovak Republic, the Former Soviet Union, and the Former Yugoslavia.

Note: Totals may not equal sum of components due to independent rounding.

Sources: 1995 and 1996 data derived from: Energy Information Administration (EIA), *Short-Term Energy Outlook, August 1997*, Online. http://www.eia.doe.gov/emeu/steo/pub/upd/aug97/index.html (August 21, 1997). Projections: EIA, AEO98 National Energy Modeling System run AEO98B.D100197A.

Federal Energy Technology Center

Developing Technology to Meet Climate Change Concerns

The Federal Energy Technology Center (FETC), co-located at Morgantown, West Virginia, and Pittsburgh, Pennsylvania, is an international leader in addressing issues associated with climate change. The Center was created in December 1996 by consolidating the Morgantown Energy Technology Center and the Pittsburgh Energy Technology Center. These predecessor organizations have been involved in fossil energy research for the past 50 years. A total of 550 Federal employees and 550 site support contractor employees work at the FETC, roughly half at each site.

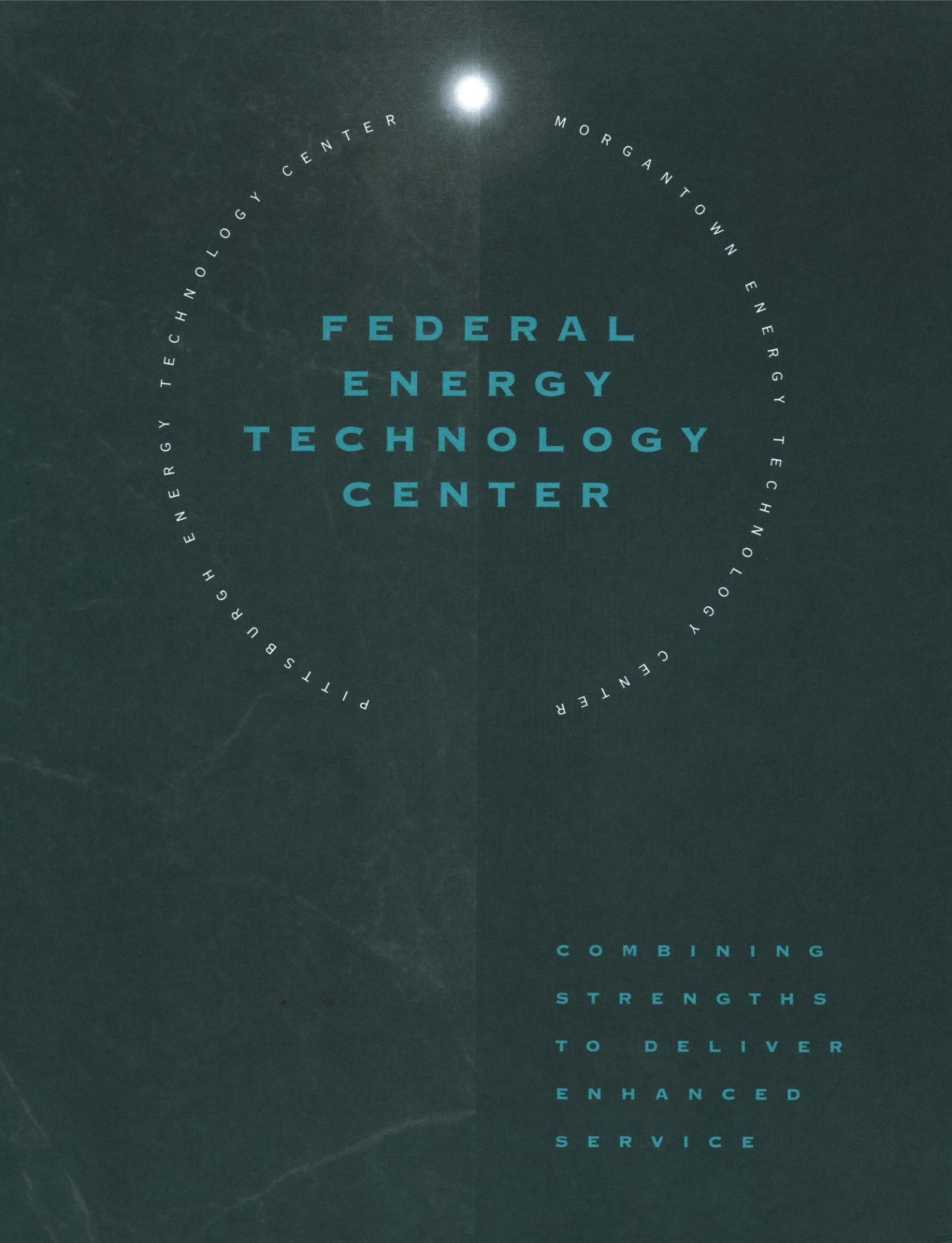
The FETC, a U.S. Department of Energy-Fossil Energy field organization, implements a broad range of energy and environmental programs. The FETC's nearly 700 research, development, and demonstration projects are conducted in partnership with industrial organizations, non-for-profit research laboratories, universities, and national laboratories. These projects are located in 49 states and in several foreign countries. The FETC also conducts hands-on research at both sites in state-of-the-art research laboratories that include bench- and pilot- scale facilities. Four of the FETC's major program areas offer new technologies for reducing greenhouse gases:

- *Coal- and natural gas-fueled advanced power generation systems.* A primary goal of the FETC power program is efficiency improvement. Higher-efficiency, advanced coal-fired systems in the FETC R&D portfolio can produce electricity with up to 50% lower CO_2 emissions than conventional coal plants. The center also works on natural gas-fueled power systems, advanced combustion turbines, and advanced fuel cells for stationary applications. Coupling turbines and fuel cells into hybrid systems can halve CO_2 emissions.

- *Converting coal and natural gas to liquid transportation fuels and chemicals.* FETC R&D to produce high quality, clean burning diesel fuels can reduce CO_2 emission by dramatically improving the efficiency of cars and trucks.

- *Natural gas exploration and production.* Building confidence in our domestic gas supply and developing lower-cost production technologies can expand the use of clean natural gas for power generation. FETC is also exploring the capture of methane, a greenhouse gas, from coal mines prior to mining and use of the stored gas in applications such as fuel cells.

- *Techniques to remove and sequester CO_2.* FETC researchers have studied biological techniques for removing CO_2 from power plants flue gases. The center is exploring techniques for disposing of CO_2 deep in the ocean where it would remain for at least one thousand years and not harm ocean life. FETC scientists are working with Argonne National Laboratory on removing, transporting, and sequestering CO_2 from advanced power generation systems. The center has also studied sequestration of CO_2 by injecting it into depleted oil and gas reservoirs, and its biological fixation using algae and other plants.


PITTSBURGH ENERGY TECHNOLOGY CENTER
MORGANTOWN ENERGY TECHNOLOGY CENTER
FEDERAL ENERGY TECHNOLOGY CENTER
COMBINING STRENGTHS TO DELIVER ENHANCED SERVICE

A More Effective and Responsive Energy Technology Center

Like you, we know it is essential to continue seeking advances in affordable energy and environmental technology — advances that provide a long-term basis for economic growth, job creation, and the restoration and preservation of our environment. At the same time, we all want a government that works better and costs less. To achieve this, we have combined the two energy technology centers at Morgantown, West Virginia, and Pittsburgh, Pennsylvania, to form a unified Federal Energy Technology Center (FETC).

The new, combined FETC will continue to manage and perform energy and environmental projects at both sites, and through our nationwide network of contractors. Our goal is to eliminate redundancy, cut administrative costs, and most important, empower our employees to be more responsive to customer needs.

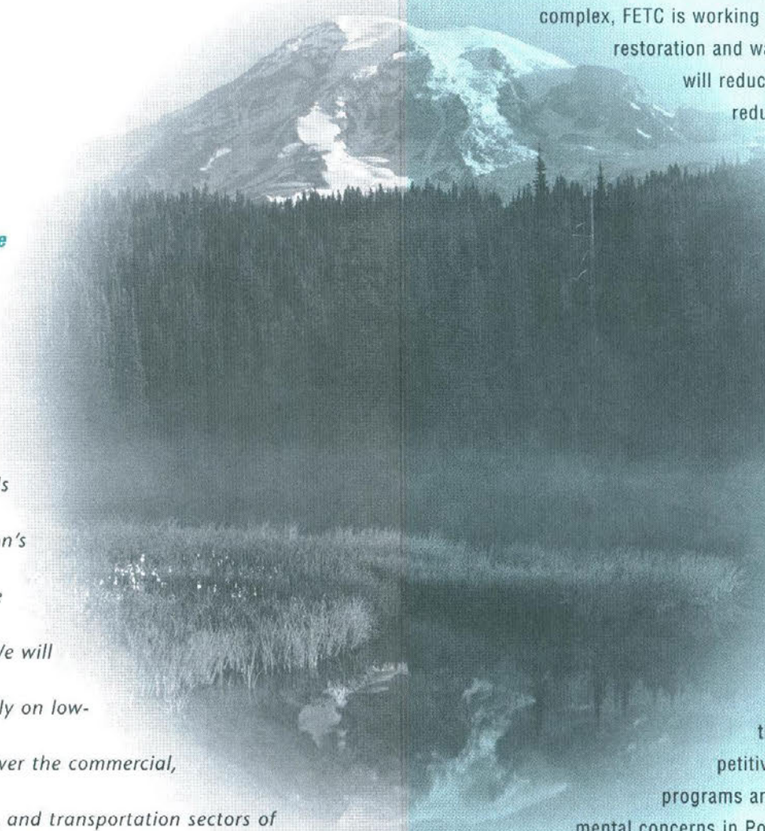
New Structure, New Synergy

Under our new structure, a single FETC management team will serve both sites. Products and programs will draw upon the best people for the job so that our partners and customers will benefit from the synergies created by each site's complementary strengths.

How will this consolidation affect you? A consolidated Center means seamless access to all the capabilities and facilities of both sites. The relationships you've built over the years will continue to deliver results and provide the continuity necessary for uninterrupted progress. You can be sure we will remain customer-focused to meet your needs.

We believe this change will greatly benefit you today, tomorrow, and over the long term. Our new, consolidated Center will help you reap dividends in enhanced project management and customer service. We look forward to working with you in this new, more efficient structure.

c o n t i n u i t y



Carrying Out the Department's Mission

Affordable electricity and other forms of energy from fossil fuels is critical to our Nation's competitiveness in the global marketplace. We will continue to rely heavily on low-cost fossil fuels to power the commercial, residential, industrial, and transportation sectors of our economy. Cleaning up the legacy of wastes at DOE's nuclear weapons complex over the next 10 years is an unprecedented challenge. To meet these challenges, our Nation must make the most of its strategy of investing in advanced technology. FETC's programs will allow us to meet these future challenges at the lowest possible cost.

p a r t n e r s h i p

Technology Partnerships: An Ongoing Strategy

FETC is working closely with customers in the domestic power generation industry to develop advanced technology options and environmental control technologies. We work with the oil and natural gas industries to develop lower cost production technologies. FETC also oversees research on improved processes to use U.S. coal resources to produce liquid transportation fuels and chemicals. Liquid fuels have potential as an economical and environmentally beneficial alternative to oil imports. For customers within the DOE weapons complex, FETC is working with industry to develop improved environmental restoration and waste management technologies. These technologies will reduce risks to workers, the public, and the environment; reduce cleanup costs; and address cleanup problems that currently have no solutions.

FETC's Cooperative Research and Development Agreements, or CRADAs, encourage U.S. private-government partnering on joint research efforts. Such cooperation can make possible and shorten the planning, research, and design stages of product commercialization. FETC also works in cooperation with U.S. colleges and universities and National Laboratories to maintain and strengthen our Nation's technology leadership.

International activities play a significant role in the Center's strategy. Worldwide interest in pollution control, coupled with the burgeoning demand for electric power in many developing countries, provides an opportunity for the U.S. power generation industry to establish a competitive position in the international arena. FETC has active programs and projects that are addressing energy and environmental concerns in Poland, Africa, Ukraine, China, India, and the Republic of Korea, as well as in North and South America.

Through the programs and partnerships facilitated by FETC, our Nation can realize all the benefits of using fossil energy — a stronger economy, increased employment opportunities, and a contribution toward improved global prosperity — while also accelerating improvements to our environment.

FETC Consolidation Principles

- *Management resources will promote the evolution of a new FETC culture that combines the best elements of the two existing organizations.*
- *FETC, a matrix organization, is structured along product lines that draw upon the best resources from both sites.*
- *Major programs as well as expertise will flow freely between sites.*

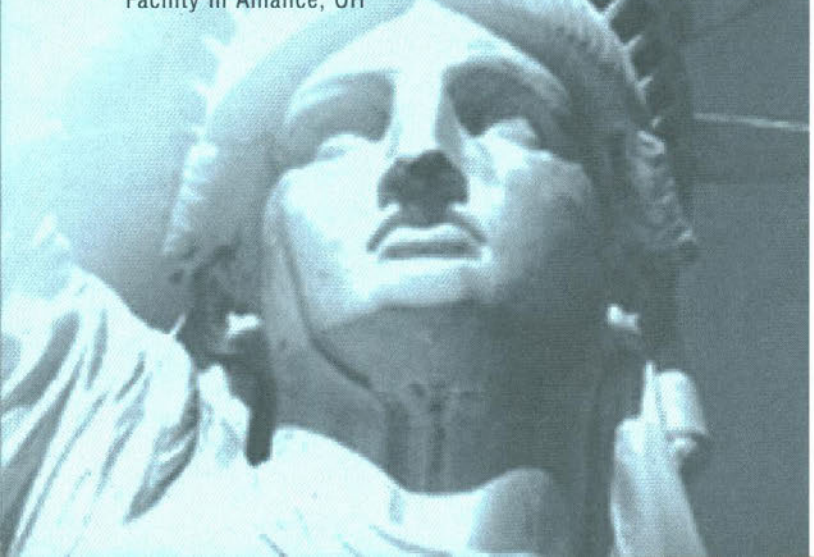
A number of specialized research facilities supported by FETC are available for cooperative work with industry and universities. These facilities include:

FETC User Facilities

- Combustion and Environmental Research Facilities
- Computational and Simulation Facilities
- Hot Gas Desulfurization Laboratories
- High-Pressure Fluidized-Bed Coal Gasifier
- Hot Gas Cleanup Process Development Unit
- Modular Gas Cleanup Reactor Facility
- National Coal Preparation Process Research Facility
- Particulate Flow Analysis Facility
- Science and Analytical Instrumentation Laboratories

Off-Site Facilities

- Natural Gas Production Field Test Sites near Rifle, CO
- The Power Systems Development Facility in Wilsonville, AL
- Clean Environmental Development Facility in Alliance, OH



FETC Core Capabilities

- Administrative Services
- Advanced Combustion Technology
- Advanced Gas Turbines
- Alternative Fuels
- Coal Liquefaction
- Coal Preparation
- Environmental and Waste Management
- Flue Gas Cleanup
- Fuel Cells
- Integrated Gasification Combined Cycle Power Systems
- Natural Gas Production
- New Fuel Forms
- Pressurized Fluidized-Bed Combustion Power Systems
- Project Management
- Systems Analysis

U.S. Department of Energy

Office of Fossil Energy

Federal Energy Technology Center

For more information, contact:

Damon Benedict
(304) 285-4913
dbened@metc.doe.gov

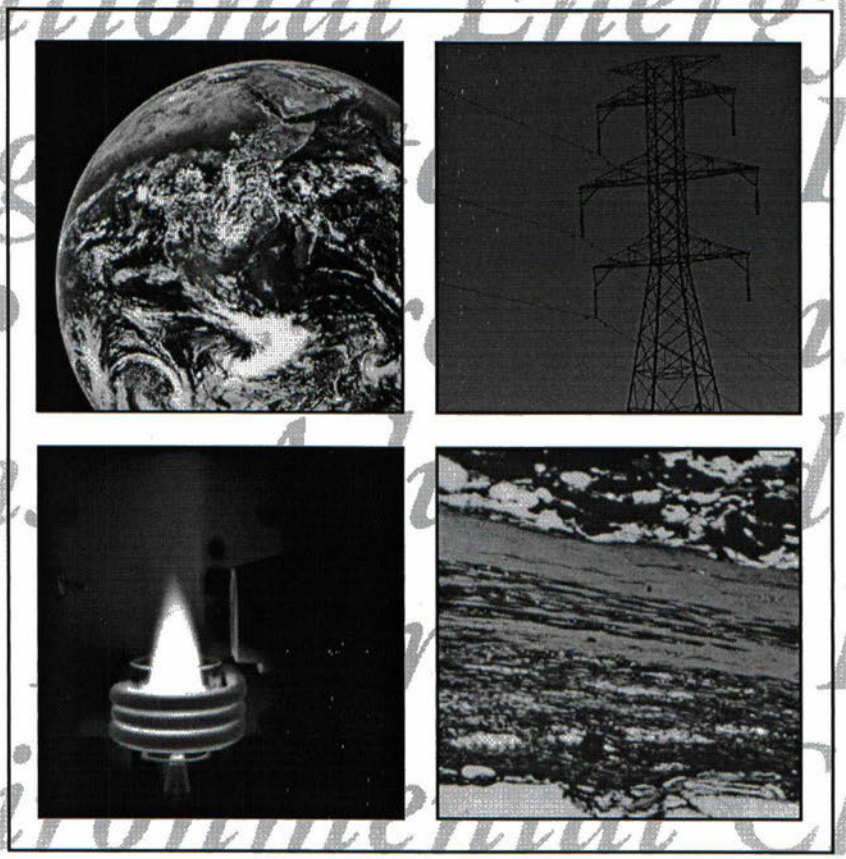
Patrice Leister
(412) 892-6126
leister@petc.doe.gov

Printed on recycled paper

July 1997

FETC

We Solve National Energy and Environmental Problems



U.S. Department of Energy
Office of Fossil Energy

Who *we are* and What *we do*

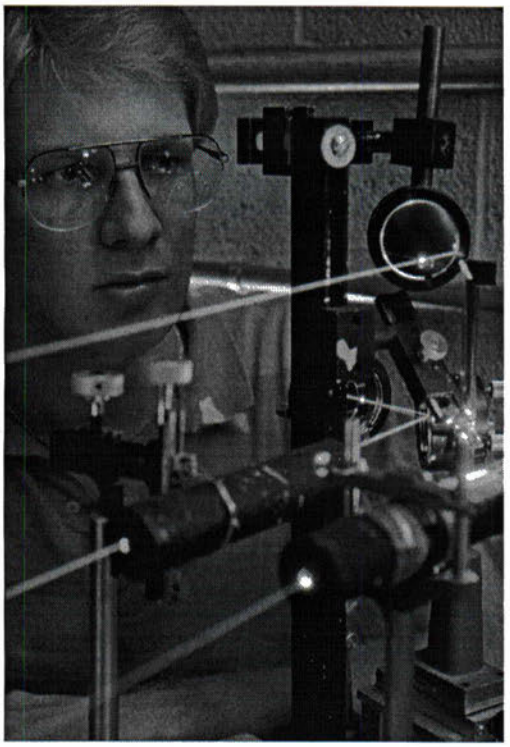
At the Federal Energy Technology Center (FETC), our strengths lie in a number of areas. We develop, manage, implement, assess, test, evaluate technologies, discover new methods of doing things, and work closely with private industry, academic institutions, national laboratories, and other government agencies. By working together, we fulfill our mission:

Solving national energy and environmental problems.

MANAGING Energy and Environmental Research and Development (R&D)

FETC's *Role*

Given the major impact of fossil energy on the economy and the environment, the government has a legitimate role to play in establishing and implementing policy. FETC's role is to provide two major products to decision makers in the Administration and Congress:



Accurate Information – Our first product is timely data on the technical, economic, and environmental implications of various policy alternatives. To establish rational policy, decision makers need accurate information. We supply them this information, such as determining the real cost and performance implications of trace metal emission control.

Advanced Technology – This is our second product. To implement rational policy, advanced technologies need to be ready to be deployed by the private sector before the government can implement a policy that requires such a technology. Given the uncertainty on the future timing and "shape" of environmental regulation, the private sector cannot accurately predict market size. Thus, private companies have little incentive to develop new technologies entirely on their own.

Project Management *Expertise*

Strong contracting and project management capabilities

With its innovative contracting and project management capabilities, FETC provides proven procurement approaches for successful partnering with industry, universities, not-for-profit organizations, and national laboratories, as well as other government agencies.

Our professional staff has the experience, knowledge, and resources to transition new energy and environmental technologies from the laboratory to the marketplace.

FETC's Acquisition and Assistance Division provided the contracting and administrative expertise needed to privatize the research capabilities of the National Institute for Petroleum and Energy Research (NIPER) in Bartlesville, Oklahoma. This transaction is being considered as a prototype for future federal laboratory privatization efforts.

FETC complements its contract management capabilities with state-of-the-art in-house facilities for carrying out R&D at bench-, laboratory-, or pilot-scale.

Fossil Energy *Expertise*

Fossil fuels will continue to drive our economy. Today, fossil fuels supply 85% of the energy we consume in the United States, and that number is expected to grow to 88% by 2015. That is why we must continue developing advanced fossil energy technologies to meet national energy demand and environmental goals.

FETC manages a portfolio of energy R&D technologies

Within five years, we will have successfully developed a "next generation" gas turbine that will surpass any competing turbine offered outside the U.S. Advanced gas turbines will generate electric power at efficiencies exceeding 60%.

An advanced fuel cell that will significantly boost the efficiency and environmental performance of 21st century natural gas- and coal-fired power plants is being developed. When commercially available, it will lower electricity costs, create more U.S. jobs in the energy industry, and provide a cleaner environment.

Our development of Low Emission Boiler Systems (LEBS) is paving the way to a new breed of boilers that cut emissions to less than one-sixth of federal New Source Performance Standards. LEBS will also improve the efficiency and reliability of tomorrow's coal plants.

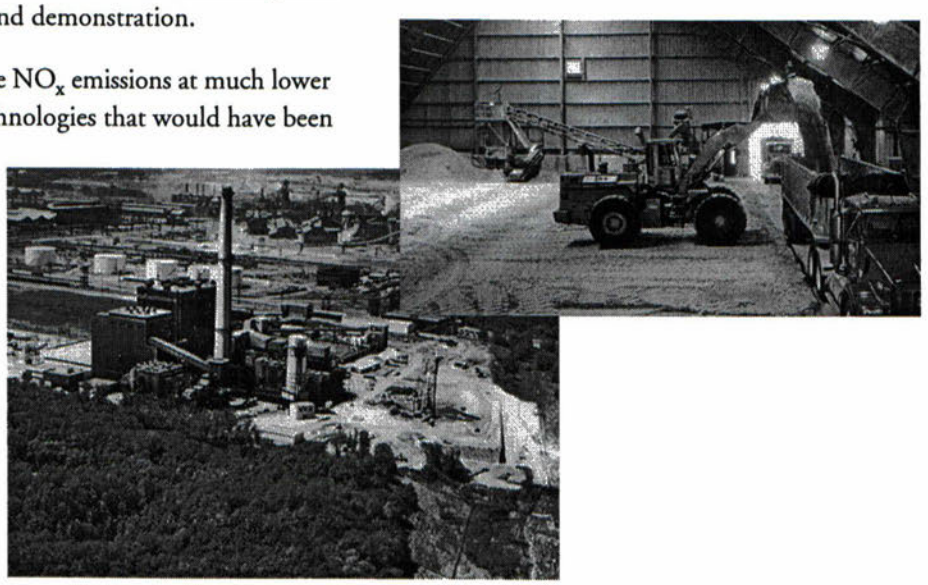
POWER magazine has called the development of fluidized bed coal combustors "the commercial success story of the last decade in the power generation business." This success [is] perhaps the most significant advance in coal-fired boiler technology in more than half a century.

Pressurized Fluidized Bed (PFB) Systems are now approaching commercial readiness. These systems can use high-ash coal and other low-value fuels. PFB systems will result in lower-cost power and substantial reductions in carbon dioxide, a greenhouse gas, compared to a traditional coal power plant.

Today...

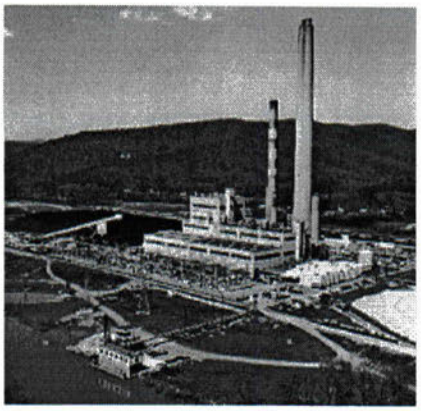
...more than $6.2 billion in domestic sales and $2.8 billion in foreign sales have resulted from the U.S. public and private investment in circulating fluidized-bed technology research, development, and demonstration.

...utility power plants have new ways to reduce NO_x emissions at much lower costs — up to 10 times lower — than the technologies that would have been available without the Federal Government's research investment.



Pure Air's design innovations, developed under the Clean Coal Technology Program, cost less than earlier units. Instead of the waste sludge commonly produced by older scrubbers (which causes landfill problems), it produces a commercially marketable gypsum material.

World-class expertise in power technologies

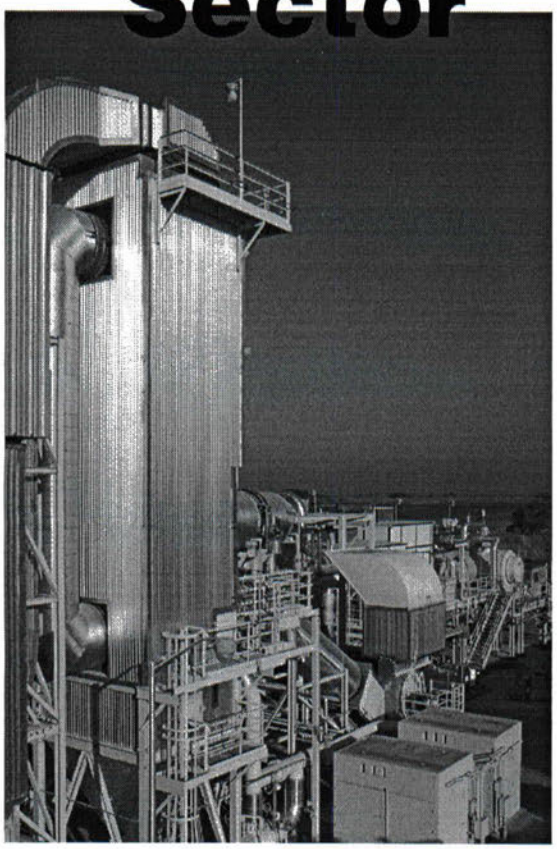


- The world's largest coal gasification power plant, the Wabash River Coal Gasification Power Plant in West Terre Haute, Indiana, demonstrates a technology that bridges the technology gap of the next millennium...being proven under the rigors of commercial service.
- The Santa Clara molten carbonate fuel cell power project, the world's largest advanced fuel cell power plant, was dedicated in 1997 and leads the way in fuel cell technology.
- Gas reburning technology successfully reduced NO_x emissions on three types of boilers by over 65 percent. Today, the technology is being used on both to coal-fired units and boilers that fire other types of fuels. This technology was the winner of the *J. Deane Sensenbaugh Award* for a new commercially successful technology that meets or exceeds mandated standards.
- Software for systems that can automatically reduce NO_x emissions and improve the overall performance of fossil fuel-fired power plants is being used commercially in seven power plants in the U.S. and the U.K. The software is based on technology in the burgeoning field of artificial intelligence.

We work *with the* Private Sector

Core Capabilities

Bench-scale to commercialization assessment capability



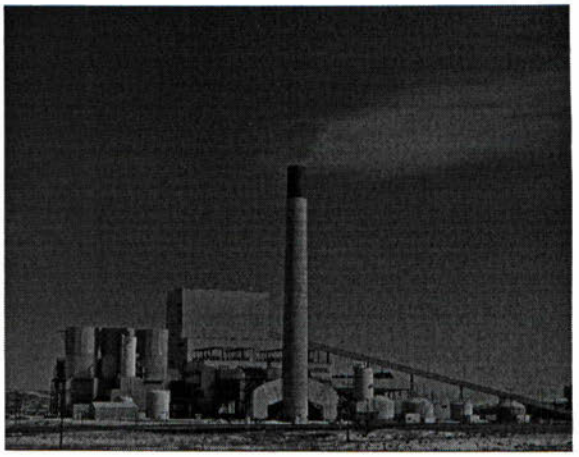
FETC's programs span the entire development process — from laboratory testing, to small, bench-scale units, to larger process development units, to proof-of-concept engineering units, and, ultimately, to commercial-scale demonstration plants.

Partnerships are key to developing innovative energy and environmental technologies to solve complex energy and environmental problems. To bring an idea through the rigorous stages of research, development, demonstration, and commercialization, a cohesive team of people possessing distinctive skills and disciplines is needed.

A core strategy is to involve industrial partners and end-users early in the technology development process as a way to ensure that the ultimate product meets the needs and preferences of the marketplace.

Energy and environmental technologies can take several years to develop and then successfully demonstrate. The cost can reach into the millions of dollars. In addition to FETC, private research organizations, venture capitalists, equipment manufacturers, marketers, legal counsel, regulatory agencies, and insurers all need to be involved in the commercialization process.

Commercializing energy and environmental technologies holds the potential for public benefits. For this reason, the FETC is willing to make long-term investments to reduce commercialization risks. The FETC extends an invitation for partnership ventures to anyone seeking research, development, demonstration, and commercialization opportunities focused on a wide range of energy and environmental technologies.



Large-scale demonstrations leading to commercial use both in the U.S. and abroad

The Clean Coal Technology Program is producing important results.

- Operation of the Nation's first three commercial-scale coal gasification combined-cycle power plants — at Tampa, Florida, Terre Haute, Indiana, and Reno, Nevada — with each facility achieving 95% or greater sulfur removal, and 90% nitrogen oxide reductions.
- The FY98 start-up of a commercial-scale advanced combustor power plant at Healy, Alaska, which will reduce sulfur dioxide by 90% or more, and nitrogen oxides by 70%.
- Completion of tests at an advanced coal processing facility in Colstrip, Montana, producing clean fuel with sulfur content as low as 0.3%, and heating value up to 12,000 Btu/lb.

FETC and GRI have been sponsoring the development of NO_x-reduction technologies. A low-cost technique emerging from this collaboration is coal and natural gas reburn technology, which can eliminate 60–75% of NO_x emissions when used in conjunction with low-NO_x burners. Today, more than one-fourth of all coal-fired capacity in the U.S. — nearly 250 boilers — have been outfitted with low-NO_x burners. By 2000, more than 75% of coal-fired boilers are expected to use this new technology along with low-NO_x burners.

> As reported by the General Accounting Office on the benefits of government-industry co-operative research and development in 1994: The Clean Coal Program "is an example of a federal program that works...Congress should support similar government-industry ventures to speed technology transfer..."

The Clean Coal Technology Program, begun in 1985, has successfully completed 20 projects, and the remainder are in design, construction or operational phases. The program has resulted in commercial development of 14 technologies, and the non-federal cost share now averages 66% per project.

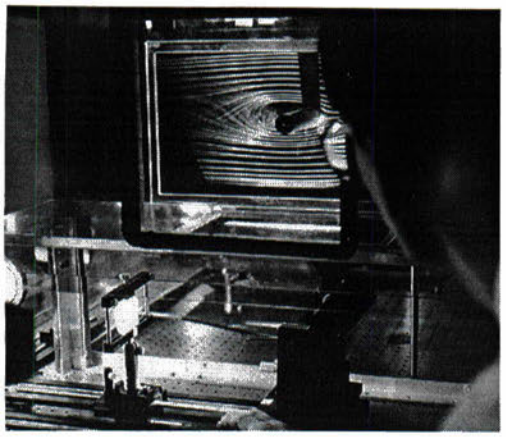
Already more than $9 billion in sales of advanced U.S. technology in the U.S. and overseas can be traced back to the achievements of the Clean Coal Technology Program. One-quarter of the coal-fired capacity in the U.S. now uses technology pioneered in the program.

Serve as the risk-sharing partner in identifying advanced technology options, understanding the user's needs, and sharing technical expertise

Increasing competition in the deregulated energy market is preventing industry from investing large amounts of money in R&D. However, affordable and environmentally sound energy supply and utilization technologies will depend on continued innovation. Industry is a critical partner in this effort.

The FETC is committed to technology advancement that is leveraged by joint partnerships with the private sector.

We must work together with industry to encourage the development and application of energy-efficiency and pollution-prevention technologies.



Energy, Environment, and Management Services

Energy Services

The government has established that federal facilities shall conserve energy and water. The National Energy Conservation Act of 1986 mandates that federal buildings use 10% less energy in 1995 than in 1985. In addition, the Energy Policy Act of 1992 and an Executive Order require total energy reductions of 20% and 30% from 1985 levels by 2000 and 2005, respectively.

The federal market for energy management is enormous. There are about 500,000 federal facilities whose average age is 42 years, and whose combined annual energy bill was approximately $8 billion in FY 1995. It is estimated that $5 billion in capital improvements will be needed to reduce energy consumption by 20%.

FETC is doing its share by initiating an internal energy audit and analysis to determine the magnitude of energy savings possible at the Center. We intend to implement energy savings, using an Energy Service Company (ESCO), to meet the 2000 requirement.

ESCOs provide the capital needed for federal sites to conserve energy, and implement the necessary facility changes. ESCOs then receive a share of the energy savings from the federal facilities over a period prescribed in the procurement as payment for their services on the project.

Energy and Environmental R&D Services

Decreased funding for R&D is a major concern for technology companies seeking to partner with the government or benefit from its expertise.

The National Technology Transfer and Advancement Act of 1996 has given federal laboratories and research centers more flexibility to create technology partnerships, reinforcing authority to grant exclusive licenses, and obligating federal employees to aid the transfer of government inventions to private hands.

Under a Cooperative Research and Development Agreement (CRADA), industry has the right to receive the option for an exclusive license in a pre-negotiated field of use. These CRADAs, encourage private companies and colleges and universities to optimize joint research efforts through partnering with the federal government. Such cooperation can shorten the planning, research and design stages of product commercialization.

COAL

Coal will continue to play a major role in meeting world energy demands well into the 21st century. Coal supplies more than 55% of our electricity and that number is expected to increase by 20% by 2015. A scientific understanding of the physical and chemical nature of coal is the foundation for engineering coal-conversion technologies and power systems. From fundamental resource characterization to waste utilization or disposal, FETC research allows coal to be used more cleanly and efficiently in existing facilities as well as in emerging technologies.

Types of Coal Research Activities:

- Direct Coal Liquefaction
- Indirect Coal Liquefaction
- Coal Preparation
- Integrated Gasification Combined Cycle Systems
- Pressurized Fluidized Bed Combustion Systems
- Externally Fired Combined Cycle Systems
- Low Emission Boiler Systems

Technical *Training*

Because FETC is a highly technical diversified organization equipped with legal, engineering, procurement and programmatic skills, we are in a position to offer training in several areas to companies in the area. Many small companies that lack the resources to offer updated courses to their staff could benefit from our capabilities.

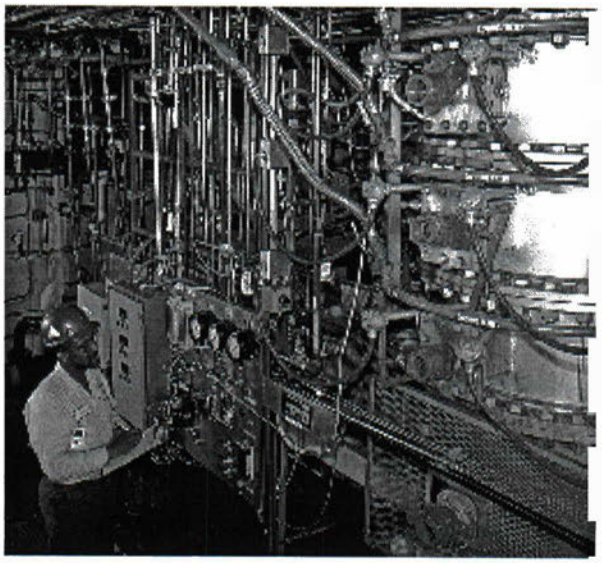
FETC Resources — Our engineers, researchers and scientists have the technical skills to conduct research and to analyze, evaluate, and manage research, development and demonstration projects conducted by others on behalf of the federal government. We are experienced in working with top-notch companies in the private sector and state entities, and have been successful in forming brokering arrangements among these parties to achieve national objectives. Assets such as these strengthen our ability to enhance and hone the skills of the local workforce.

PARTNERING not only helps us accomplish FETC's mission, it can also assist the Nation in achieving economic security.

Restek Corporation — With FETC assistance, Restek Corporation, a small business in Bellefonte, Pa., was able to keep costs down to continue developing a coating for its proprietary air sampling canister, which is in short supply, but needed by several industries to comply with the 1990 Clean Air Act. Without the CRADA, costs would have forced Restek to discontinue the project. FETC researchers worked in surface analysis to generate data on coating thickness and composition. In turn, FETC benefitted because the coating helps protect some of our research-related equipment from corrosion.

University of Pittsburgh Medical Center — Using a FETC-patented imaging technique created to study coal's flow rate, researchers at the University of Pittsburgh Medical Center solved clotting problems associated with an artificial heart pump, enabling it to be used as a permanent heart assist device. Most research done now with artificial hearts makes use of the imaging technique, which received R&D Magazine's R&D 100 Award as one of the year's top new technological developments in 1992. By assisting the medical center, FETC researchers gathered information about flow behavior in pump technology that can be applied to advanced technology applications used for pumping coal slurry projects.

Electric Power Research Institute — Researchers at FETC and the Electric Power Research Institute enhanced the design of an earlier FETC-developed technology, a neural network algorithm, which successfully predicted NOx emissions from a tangentially fired coal boiler. Through a CRADA between FETC and EPRI, the algorithm was extended to other boilers, giving utilities a way to accurately determine NOx emissions to make informed decisions that meet federal environmental requirements. Because the advanced power-generation systems of the future will have to comply with increasingly stringent standards, the algorithm is expected to play an even greater role in the long-term.



Our facilities also lend themselves well to technical training. They are used for student and teacher summer intern programs and provide training for undergraduate and post-doctoral students. Our well-equipped laboratories and machinery have been used to test and improve new technologies, chart their progress, assess their costs, performance and environmental impact. At times, a developing technology's market can be enlarged after innovative adjustments made by our engineers increase its applications. Our fossil energy facilities are world-class, and we possess a growing experience in nuclear-related technologies. More conventional learning tools, such as computers, software and conference rooms, enable FETC to offer well-rounded, training sessions for groups of various sizes.

Current Projects – In addition, our contractual work with the private sector and our outside contacts broadens our resource base and lends support to the projects we tackle. We perform work for other offices within DOE, such as Energy Efficiency and Renewable Energy, Defense Programs, Environmental Remediation and Waste Management and Nuclear Energy. We also provide services to projects conducted for the Department of State, Department of Defense, NASA and the U.S. Trade and Development Agency, and the United Nations Industrial Development Organization.

GAS

Gas-related research programs at FETC focus on barrier issues to increase domestic natural gas reserves and develop economic and environmentally acceptable processes for producing liquid fuels that are competitive with petroleum products. The FETC has more than five decades of experience in environmental issues in the supply and processing of natural gas.

Types of Gas Research Activities:

- Gas Turbine Systems
- Fuel Cell Systems
- Pyrolysis
- Gas-Solid Interactions
- Geological and Reservoir Engineering
- Regional Gas Atlases
- Gas Systems Data Bases and Modeling
- Methane Hydrates

Program Responsibilities

The Federal Energy Technology Center is responsible for implementing a broad range of technologies:

Advanced Power Systems: The Advanced Power Systems Program includes both coal- and natural-gas-fueled electric power generating systems. In the 21st century, if the R&D program is successful, today's natural gas systems, e.g., advanced turbines and fuel cells, will also be capable of functioning in a coal-fueled power plant.

Advanced Clean Fuels Technology: Coal preparation — washing or treating coal before it is used — may be the best, if not the only, way of removing certain impurities that contribute to air toxics. Also, techniques being developed for cleaning finely ground coal may facilitate utility compliance with the Clean Air Act Amendments in addition to providing a valuable export technology. The liquefaction program has two components: direct liquefaction converts coal directly into a liquid; indirect liquefaction first gasifies coal, then converts the gases into liquids.

Advanced R&D: The Advanced Research and Technology Development Program is included with the coal R&D budget, although several elements of the program, (e.g., materials R&D, Historically Black Colleges and Universities and Other Minority Institutions education and training) support all aspects of fossil energy R&D. Within the technology cross-cut category are fossil energy-wide technical and economic analyses, international program support and environmental analyses.

Natural Gas: The Natural Gas Exploration and Production Program is closely coordinated with the Gas Research Institute. The federal program provides gas producers with a better engineering "picture" of the Nation's gas resources and improved, lower-cost technologies for expanding gas production and for converting gas to liquid fuels.

Environmental Management: FETC develops high-payoff technologies to clean up DOE's nuclear component manufacturing sites and to manage DOE-generated waste faster, cheaper, and more safely than currently available environmental cleanup technologies. FETC offers cost-effective cleanup through a "virtual organization" approach by using the best and brightest from among resources in academia, private industry and governmental agencies and on-staff researchers. We now manage more than 100 environmental management activities that are providing site-specific solutions to environmental problems. The virtual organization thrust is an industry-oriented model that nurtures developers toward a viable commercial product that has broad application to the nation's cleanup activities.

Community Involvement: Several large, regional industrial companies are engaged in developing advanced systems for direct or indirect application to the power industry. Through an effort involving FETC and business leaders in the tri-state area, local companies could be encouraged to offer lower cost, high-tech manufacturing of components and subsystems that could be sold to major development organizations for packaging into a total plant or technology. Typical products could include fuel cell tube bundles or assemblies, photovoltaic assemblies, power conditioning systems, low-NOx burner assemblies, systems for cleaning combustion-generated gases and similar components.

International Energy Project Implementation: FETC carries out several energy and environmental projects in foreign countries for the U.S. Agency for International Development (USAID). We have an extensive history in bringing much-needed energy and environmental technologies to countries in very different parts of the world. In doing so, we give American technology makers a chance to penetrate a new market overseas, and work with them in coordinating and implementing projects to ensure success.

> ***India:*** Since 1982, FETC has managed a USAID-funded project designed to help India use its indigenous coal and biomass energy resources for electric power generation and to reduce its generation of greenhouse gases. A FETC employee is stationed in India.
>
> ***Poland:*** We manage a $20 million USAID program to reduce the air pollution in Krakow as a result of a 1989 cooperative agreement between Poland and the United States. A two-phase program was structured to address the main sources of sulfur dioxide emissions: coal-fired utility boilers and numerous, small, coal-fired furnaces and home stoves. American-made technologies used in this cleanup are expected to drastically reduce hazardous hydrocarbons and

FOSSIL ENERGY WASTE MANAGEMENT

The Fossil Energy Waste Management Program identifies and develops strategies to manage solid by-products generated by new coal technologies to ensure the competitiveness of these technologies. Research is also focused on developing technology to minimize or abate adverse environmental impacts of energy production and utilization. The ultimate goal is to reduce industry's costs of complying with our Nation's environmental regulations, and to reduce the impact of abandoned mines on our Nation's waterways.

Types of Fossil Energy Waste Management Activities:

- Air Toxics
- Removing Pollutants from Exhaust Gases
- Removing Carbon Dioxide from Flue Gases
- Acid Mine Drainage
- Utilization of Coal Combustion Residues at Mine Sites
- Waste Utilization and Disposal
- Remediating Contaminated Groundwater
- Contaminant Cleanup and Site Remediation

sulfur dioxide as well as reduce particulate emissions by 90%. By establishing a presence in Poland, DOE enables U.S. businesses to extend their technologies throughout Eastern Europe, where there is an acknowledged need for pollution-control and environmental-remediation technologies.

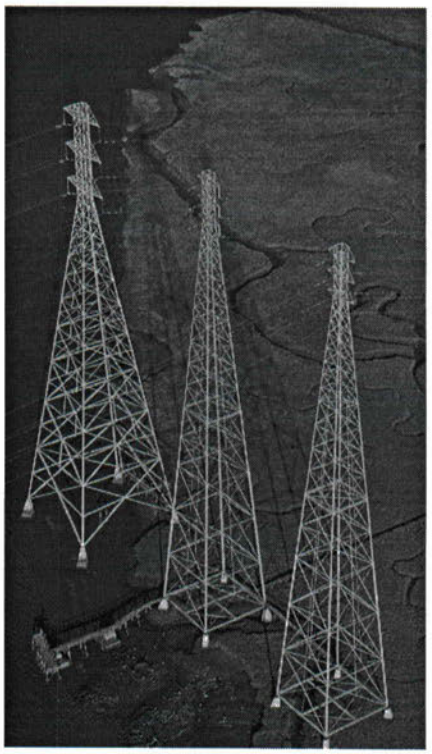
FETC was selected by the Department as the Environmental Management Center for Acquisition and Business Excellence. FETC provides acquisition planning and policy support to the DOE Assistant Secretary for Environmental Management, and will serve as a clearing house for best practices and lessons-learned relative to environmental management privatization projects.

Ukraine: On a project funded by USAID, we have completed a study involving an engineering examination and analysis of the costs of repowering a power plant in Lugansk. This study will underpin Ukraine's submission of a $200 million funding proposal to the World Bank, all with an eye toward weaning Ukraine away from the unstable nuclear generation option of Chernobyl.

Brazil: We are assisting the Brazilian government in creating an environmentally and fiscally sound energy policy so that domestic coal can be used to generate power as the hydro resources of the Amazon River near exhaustion. In addition, we organized a reverse trade mission on this topic for the U.S. Trade and Development Agency (TDA).

South Africa: We assisted TDA in developing a project that examines the extent of the coal bed methane resources in the Lebowa region, and to then assess the feasibility of commercialization of this indigenous resource for electric power generation to spur development in this energy-deprived, economically depressed region.

South Korea: FETC is helping the Republic of Korea expand its electric generation capacity to 36 gigawatts over the next 14 years by constructing 25 coal plants, 14 nuclear plants and 12 liquid natural gas facilities. The potential market share for U.S. fossil-fueled and nuclear-generation technology is in excess of $1 billion. A Memorandum of Understanding between the FETC and two research institutes in Korea grants DOE ready access to Korean governmental and industrial energy decision makers, allowing DOE to promote the benefits of buying American.



ENVIRONMENTAL MANAGEMENT TECHNOLOGY DEMONSTRATION AND COMMERCIALIZATION

The U.S. Department of Energy is facing the monumental task of cleaning up environmental contamination at nuclear weapons facilities and other sites across the nation. Under the Environmental Management Program, FETC is working to develop, demonstrate, and commercialize environmental management technologies to clean up these sites. This is being accomplished through partnerships with the private sector and other parts of DOE.

Types of Environmental Management Activities:

- Systems Analysis of Environmental Technologies
- Facility Decontamination and Decommissioning
- Industry Programs
- University Programs
- Center for Acquisition and Business Excellence

Organizational STRUCTURE

OFFICE OF THE DIRECTOR

Director: Rita A. Bajura
Deputy Director: Ralph A. Carabetta

Provides overall direction and supervision of the center's programs, finances, and administrative operations, including authorities such as awarding contracts. Serves as the focus for FETC interaction with other Federal agencies, state and local governments, the academic community, industry, and international energy groups within assigned areas. Provides policy implementation guidance and oversight for combining the center's activities, including legal and self-assessment functions.

OFFICE OF PRODUCT MANAGEMENT FOR FUELS AND SPECIALTY MARKETS

Associate Director: Leonard E. Graham

Responsible for developing new business opportunities, coordinating program and budget planning, project development, technology integration, and other product-related activities. Develops economically and environmentally sound technologies for location, extraction, conversion, distribution, storage and information transfer. Conducts research, development and demonstration product management functions, including "bench-scale to marketplace," for fuels systems, applied science, and international activities.

Products Lines:

- Domestic Business Development
- International Business Development
- Drilling, Completion, and Stimulation
- Low Permeability Gas Formation
- Natural Gas Conversion to Liquids
- Natural Gas Delivery and Storage
- Natural Gas Upgrading
- Resources and Reserves
- Strategic Energy and Environmental Development Services
- Technology Transfer
- Methane Hydrates

OFFICE OF POWER SYSTEMS FOR PRODUCT MANAGEMENT

Associate Director: Joseph P. Strakey

Ensures the development and commercialization of reliable fossil-fueled power generation and delivery technologies that are progressively cleaner, more efficient, and economical. Conducts research, development and demonstration for a suite of advanced fossil-fueled power systems, including "bench-scale to marketplace" advocacy for assigned products, especially those that deal with coal and natural gas. Coordinates program planning, budget planning, project development, technology integration and other product-related activities.

Product Lines:

- Advanced Turbine Systems
- Fuel Cells
- High Performance Power Systems
- Integrated Gasification Combined Cycle
- Low Emissions Boiler System
- Pressurized Fluidized Bed Combustion

OFFICE OF PRODUCT MANAGEMENT FOR ENVIRONMENTAL MANAGEMENT

Associate Director: Carl O. Bauer

Coordinates and implements environmental and waste management in fossil energy waste management and environmental cleanup. Ensures that solid-waste management from advanced coal technologies promotes economic and technical developments that lead to the commercialization of these technologies. Coordinates safe strategies for disposal of coal by-products, and uses technologies to explore the use of coal by-products for beneficial purposes. Also develops technologies to clean up the inventory of DOE nuclear component-manufacturing sites, and to manage DOE-generated waste faster, cheaper, and more safely than current environmental cleanup technologies.

Product Lines:

- Industry Programs
- Decontamination & Decommissioning
- Technology Applications
- Nuclear and Strategic Processes
- Center for Acquisition and Business Excellence

OFFICE OF PROJECT MANAGEMENT

Associate Director: Kenneth E. Markel

Implements the research, development, and demonstration programs and manages projects conducted by private-sector partners; supervises project management divisions that evaluate the status of technology development; coordinates conference activities; reviews project progress and results and provides assessments; participates in and provides technical expertise to product teams; champions the transfer of technical information to the research contract.

Responsibilities:

- Major projects and agreements
- Power and environmental systems
- Fuels resources
- Gas power systems
- Site support contracts
- RD&D contracts
- Environmental waste management
- Advanced crosscutting technologies

OFFICE OF SCIENCE AND TECHNOLOGY

Associate Director: Larry C. Headley

Provides overall management of on-site projects that are carried out by on-site researchers and facilities. Implements research and development projects conducted by in-house researchers either in support of the center's mission, or to develop and verify novel concepts that could lead to new products. Actively seeks and implements CRADA opportunities with external partners and develops cooperative research opportunities with universities and other DOE laboratories.

Responsibilities:

- On-site R&D
- CRADA opportunity identification
- Solids Processing and Separations
- Combustion and Cleanup
- Gaseous Fuels and Gas Cleanup
- Environmental Science and Technology
- Fuels and Chemicals
- Engineering and Operations

OFFICE OF PROGRAM SUPPORT AND SITE OPERATIONS

Associate Director: Thomas M. Torkos

Ensures the center's functions operate smoothly by managing the institutional functions required to fully support operation of the center. Coordinates administrative, operational, construction and, staff support activities, such as organization and human resources, budget and financial analysis and administration, information management systems, an on-site ES&H program, acquisition and assistance, site management, and administration of non-primary site support contracts.

Responsibilities:

- Acquisition and Assistance
- Budget and Financial Management
- Information Resources Management
- Environmental, Safety, and Health
- Human Resources
- Site Operations

OFFICE OF SYSTEMS AND ENVIRONMENTAL ANALYSIS

Associate Director: Fred R. Brown

Provides technical, environmental, and cost performance assessments of technologies based on energy and economic trend analyses. Assesses the technical, environmental and cost performance of technologies, conducts assessments of energy trends as well as detailed engineering reviews in support of research and development projects. Performs NEPA and other environmental assessments. Serves as the focal point for the system's cross-cutting management and information systems.

Responsibilities:

- Processing Engineering
- Evaluation and Planning
- Planning/Metrics
- NEPA
- Management and Communications
- EEO/Diversity

For More Information

Information on these programs can be found on the DOE Fossil Energy "home page" now available through the Internet World Wide Web. The URL addresses for the Fossil Energy network are:

Fossil Energy Headquarters: http://www.fe.doe.gov

Pittsburgh Energy Technology Center: http://www.fetc.doe.gov

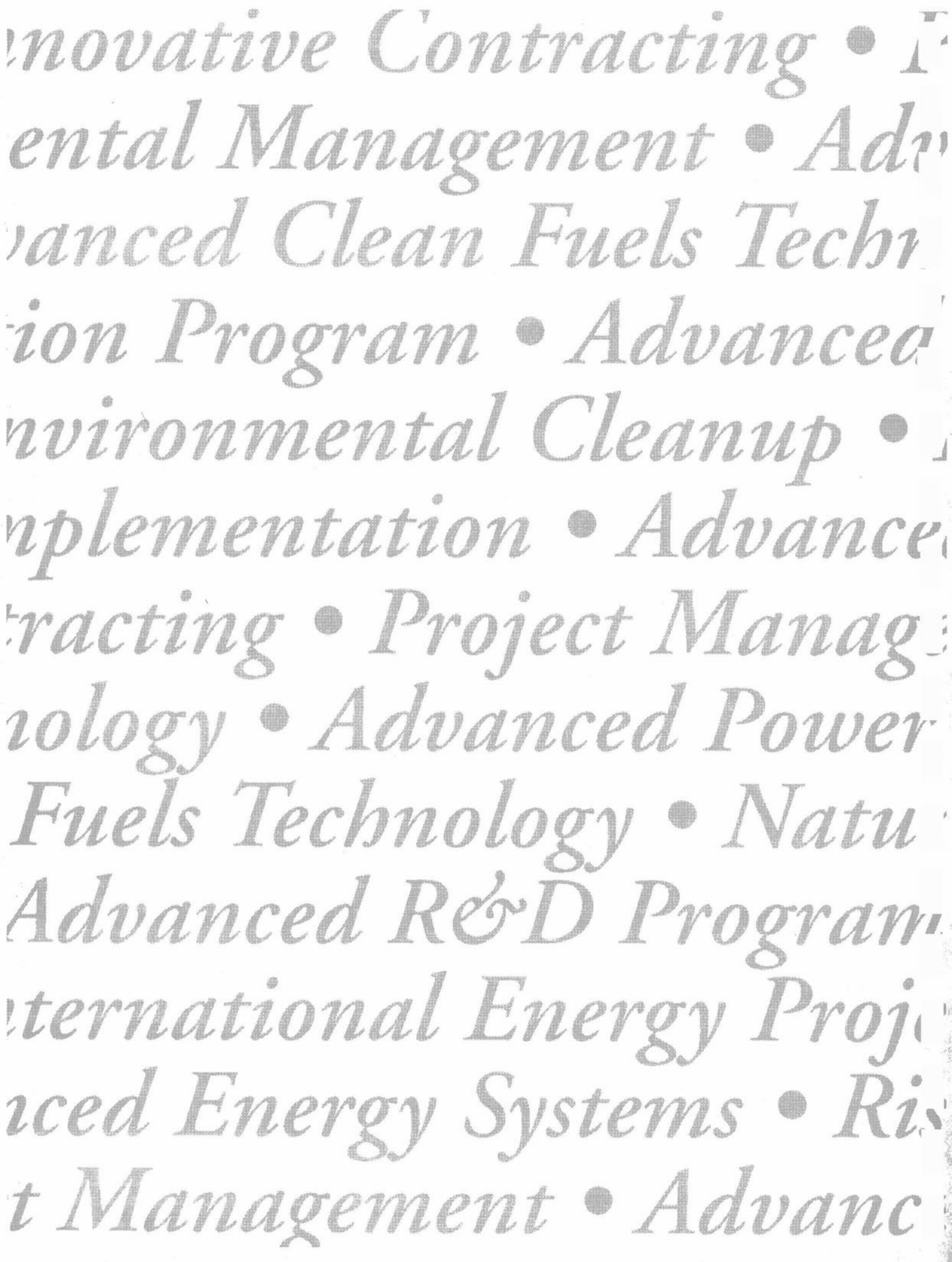
National Petroleum Technology Office: http://www.npto.gov

KeyFETC *Contacts*

	Phone	E-Mail
Rita A. Bajura Director	412/892-6122 304/285-4511	rbajur@fetc.doe.gov
Ralph A. Carabetta Deputy Director	412/892-5729	carabett@fetc.doe.gov
Carl O. Bauer Associate Director Product Management for Environmental Management	304/285-4912	cbauer@fetc.doe.gov
Fred R. Brown Associate Director Systems and Environmental Analysis	412/892-5942	fbrown@fetc.doe.gov
Leonard E. Graham Associate Director Product Management for Fuels & Specialty Markets	304/285-4714	lgraha@fetc.doe.gov
Larry C. Headley Associate Director Science and Technology	304/285-4314	lheadl@fetc.doe.gov
Kenneth E. Markel, Jr. Associate Director Project Management	304/285-4364	lgraha@fetc.doe.gov
Joseph P. Strakey Associate Director Power Systems Product Management	412/892-6124	strakey@fetc.doe.gov
Thomas M. Torkos Associate Director Program Support and Site Operations	412/892-6125	torkos@fetc.doe.gov

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
Fax 412/892-6127

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
Fax 304/285-4292


novative Contracting •
ental Management • Adv
anced Clean Fuels Techn
ion Program • Advanced
nvironmental Cleanup •
nplementation • Advance
racting • Project Manag
nology • Advanced Power
Fuels Technology • Natu
Advanced R&D Program
ternational Energy Proj
nced Energy Systems • Ri
t Management • Advanc

Clinton Presidential Records
Digital Records Marker

This is not a presidential record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

This marker identifies the place of a publication.

Publications have not been scanned in their entirety for the purpose of digitization. To see the full publication please search online or visit the Clinton Presidential Library's Research Room.

The U.S. Department of Energy

MORGANTOWN ENERGY TECHNOLOGY CENTER

METC

MORGANTOWN ENERGY TECHNOLOGY CENTER