Report of the College of Engineering Dean's Committee on Globally Sustainable Development: Energy and Its Environmental Impacts

October, 2004

Committee:

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Executive Summary

World primary energy demand is expected to increase by a factor of 3 by 2050. The supply costs are enormous; in the three decades 2000-2030, $16 trillion will be invested in energy supply infrastructure to meet rising demand. Most of the primary energy supply in 2030 will be provided by conventional means (fossil fuels).

Atmospheric greenhouse gas concentrations, mainly CO_2, have rapidly increased in the past century due to combustion of fossil fuels, and now are at their highest levels in the past 420,000 years (and perhaps in the past 20,000,000 years). The anthropogenic atmospheric greenhouse gas increase has been accompanied by an increase in global temperature. Unless greenhouse gas emissions are stabilized, global climate change may lead to consequences that substantially alter conditions of life as we know it.

Stabilization of CO_2 presents enormous challenges that are likely to persist for a century, and perhaps much longer. New methods of generating and converting energy with reduced greenhouse gas emissions will be needed, energy sources different from those that have prevailed in the past will need to be developed and exploited, new ways of distributing and storing energy must be devised. The opportunity to participate in the solution of the world's largest and most persistent problem presents unprecedented opportunities and rewards.

The committee recommends the College implement its strategic priority in Energy and Its Environmental impacts immediately and seek to incorporate this initiative into a University-wide Center for Sustainable Development. To begin implementation, we recommend the College:

- Create an executive committee of Cornell academics to provide on-going advice to the Director of the Institute and to provide guidance of the programs of the Institute.
- Create an external advisory board composed of experts from industry, government and other universities.
- Search for a Director of the Institute. This individual should have a clear and broad vision of the central issues of energy and its environmental impacts, and a firm grasp of what universities can contribute.
- Enable the Director to hire four new faculty. All interested schools and departments in the College can propose candidates; each hire would have his or her tenure home in an existing department. The Director of the Institute and the Institute Executive Committee will guide the search.
- Provide office space for the Institute.
- Provide $1M/year over a five-year start-up period, exclusive of the costs of hiring new faculty. The College, participating Departments and Schools within the College, and the University would need to provide these funds initially. We envision the funds to be used as follows:
  - $600,000/year seed money for the redirection of research of existing College faculty, half provided by the Dean and half by Departments and Schools whose faculty members apply for seed monies,

- $400,000/year for fellowships, national workshops, salary for the Director’s Assistant, and miscellaneous expenses.

A University-wide Center for Sustainable Development incorporating the present effort, might look as shown on the diagram on the next page.

Center for Globally Sustainable Development

Institute for Sustainable Energy Systems

- Prediction of system impacts of global climate change
- Energy efficiency & conservation
- Primary energy sources (fossil, nuclear, solar, wind, biomass)
- Energy conversion (prime movers, fuel cells, H_2 produc-tion, ethanol production)
- Carbon sequestration
- Energy storage & distribution
- Waste management

Institute for Sustainable Business Enterprises

- Developing economies (Africa, South Asia)
- Rapidly emerging powers (China, India)
- Effecting change in US infrastructure

Institute for Adaptation to Global Climate Change

- Agricultural impacts & responses
- Ecosystem responses to climate change
- Population displacement
- Water management
- Rebuilding the built environment (buildings, cities, highways…) to adapt to climate change

Institute for Policy & Analysis

- Relating research in the physical & biological sciences and engineering to economic and socially viable systems
- Population and demographic policy
- Public education
- National security
- Integrating US policies with the community of nations

Institute for Legal & Regulatory Responses to Global Climate Change

- Legal challenges to massive changes in US infrastructure
- New international regulatory systems required by energy & climate change concerns
- International treaties and laws on energy & its environmental impacts
- International agreements (on carbon trading, etc.)

Table of Contents

Introduction

In October 2003, Dean Fuchs appointed a committee to assess the current capability of the College of Engineering to contribute in an important way to the technological solutions of energy supply, usage, distribution, and storage. The primary motivation for this initiative was the recognition of the primacy of energy impacts on the global environment; the major role of technology on the mitigation and control of these impacts; and the importance to the national economy of secure energy supply lines. Both imperatives can be addressed by developing energy sources that are not based on fossil fuels.

The combination of world population growth and the increasing standard of living of those currently living in poverty will lead to a dramatically increased demand for energy. Rapid economic development in China already is placing strains on petroleum supply: this is a trend that almost certainly will continue. In 2000, world population was 6.1×10^9 people utilizing about 12×10^{12} watts (12 terrawatts, TW) of primary power. Population is projected to increase to 9.8×10^9 people, and primary energy demand is projected to increase by a factor of three by 2050. Any increase in power demands above 12 TW, the amount the entire world currently utilizes, must be provided with no greenhouse gas emissions in order to stabilize greenhouse gas effects at twice the levels existing at the beginning of the 20th century. The engineering demands and economic consequences of providing the additional energy capacity provide enormous challenges that are likely to persist for a century, and perhaps much longer. New methods of generating and converting energy with reduced greenhouse gas emissions will be needed, energy sources different from those that have prevailed in the past will need to be developed and exploited, new ways of distributing and storing energy must be devised. The technological challenges are daunting, but the opportunity to participate in the solution of the world's largest and most persistent problems presents unprecedented opportunities and rewards.

In scattered locations throughout the university, Cornell already is engaged in research addressing energy and its environmental impacts, and, in some of these activities is a national leader. The committee was asked to identify additional resources needed to establish capabilities in the College of Engineering where they may be lacking, and to propose a structure that will coordinate, focus, and assist in research in energy and its environmental impact.

The committee met frequently, usually weekly, since its formation. Energy and the environment cover an enormous amount of technological, scientific, economic, political, and social territory, and the committee first addressed which of the manifold segments could constitute a workable and appropriate subset for us to consider. The committee recognized that Cornell University had much to offer on this wide range of issues, and that the entire range constitutes what might be called "global sustainable development." As a committee in engineering, our role is one of technology and science. We therefore decided to limit our scope to technological and scientific issues, and to admit policy matters only when doing so informed the science and engineering. Furthermore, only the global environmental impacts due to energy production and utilization would be included rather than all possible questions of the environment. In accepting this limitation, we implicitly agreed with Holdren (2003) who wrote, "Many of the most difficult and dangerous environmental problems at each of these levels of economic development --- from the damage that the very poor do to the immediate environment, and thus to themselves, to the damage that the very rich do to the global environment, and thus to everybody --- arise from the harvesting, transport, processing, and conversion of energy. In light of all this, it has become increasingly clear that energy is the core of the environmental problem; environment is the core of the energy problem; and the energy--environment intersection is the core of the sustainable development problem."

Thus, we envision a scientific and technological attack on the problems facing the world in dealing with energy and its environmental impacts. In this effort, the developing and less developed parts of the world are as important as those in our country and other developed nations. Our intent is to recognize this and adopt a truly global research perspective.

After informing ourselves about organized activities in energy-environment interaction at peer universities, the committee held a university-wide workshop on January 22, 2004, to determine what related research already was being carried out at Cornell. This Cornell "inventory" revealed areas of strength, as well as critical areas in which there is little or no activity. Our deliberations pointed to promising research paths, and the inventory suggests to us steps that can be taken to knit Cornell's current activities into a comprehensive program that will be at the forefront of research and innovation.

The Problem and the Opportunity

Energy drives the world economy and is the origin of much global conflict. Its present global rate of use is 12 TW, or 2 kW per capita Hoffert et al. (2002). Today, a little more than 85% is from fossil fuels. The growth rate of energy consumption is 2%, much faster than the population growth rate, which is closer to 1.5% Cohen (1995). It is estimated that primary energy production will increase by factor of 3 by 2050 Wirth et al. (2003).

Energy production and utilization in stationary power production, portable power, in machinery for production and transportation, and in heating and air conditioning make modern life possible and, together with food production and the provision of shelter, remain the most basic features of social concern and of engineering responsibility. Energy periodically rises to the top of societal concern on two grounds, its supply and the effects of its usage. The principal supply concerns today arise because of the concentration of petroleum, a particularly useful energy source, in regions of the world prone to political instability. In the longer term, the world supply of conventional sources of oil is expected to reduce dramatically. Figure 1 shows the most authoritative current projection. Supplies will dwindle at a rate depending on growth rate of demand, but all scenarios point to effective depletion this century.

Non-conventional petroleum supplies (tar sands, etc.) will continue to be available, but the costs can be expected to be higher, and other fuels must eventually supplant oil as a transportation fuel.

Energy usage concerns in the past have mainly focused on human health and safety: air and water pollution caused by the combustion of fossil fuels; damage to human health due to radiation hazards associated with nuclear power; and risks to safety arising from nuclear proliferation and terrorist acquisition of radioactive materials.

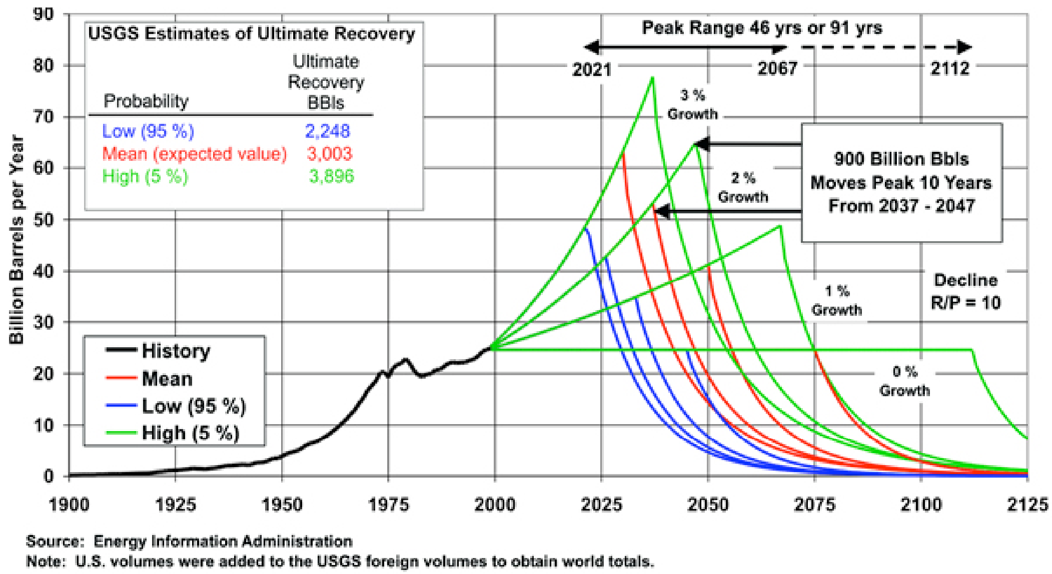

Figure 1. Projection of world oil production. Woods et al. (2004).

Environmental impacts on human health related to energy usage have been of concern to the engineering community for decades. Since the 1960's the use of alternative materials, fuel injection and computer control have led to a doubling in automobile fuel economy. Over the same period the emissions of pollutants responsible for photochemical smog have been reduced as much as a hundred-fold through a combination of engine controls, emissions controls, and new manufacturing technologies. The most recent production models actually have cleaner air coming out of their tail pipes than the urban air of many cities. Energy supply and air quality will certainly continue to be of fundamental societal importance, but entirely new issues concerning energy production and utilization recently have arisen.

The newer issue surrounding this perennial topic is on a planetary scale - global warming due to greenhouse gas emissions caused by energy usage (IPCC, 2001). This new dimension to energy production and utilization is likely to prove to be the one of greatest social concerns of this century. While debate still exists as to the seriousness of the warming effects of greenhouse gas buildup in the atmosphere, most scientists now believe it to be a cause for concern if not alarm. Correcting the problems caused by greenhouse gases is complex, beginning with political and public policy directions, economics, and ultimately, engineering implementation. Whether or not the administration in the United States accepts that a real problem looms, U. S. industry is global in scope, and must sell products in a worldwide market, and that market now perceives global warming as a major concern.

The problems of reliable energy supply and global environmental sustainability point to a need for reconfiguration of energy supply sources, distribution methods, and utilization technologies over the course of this century. The engineering opportunities are enormous. The current investment in energy supply alone, which is mainly in existing technologies, is about $530 billion/year, and the total world energy investment needed in 2001- 2030 is $16 trillion. This does not account for the total world investment in prime movers for vehicles of all kinds, energy conversion equipment for residential and industrial heating, cooling, and lighting, and other major capital investment in energy conversion systems. A substantial fraction of this will need to be replaced in the next few decades, and a good part of this should anticipate major shifts in fuel types.

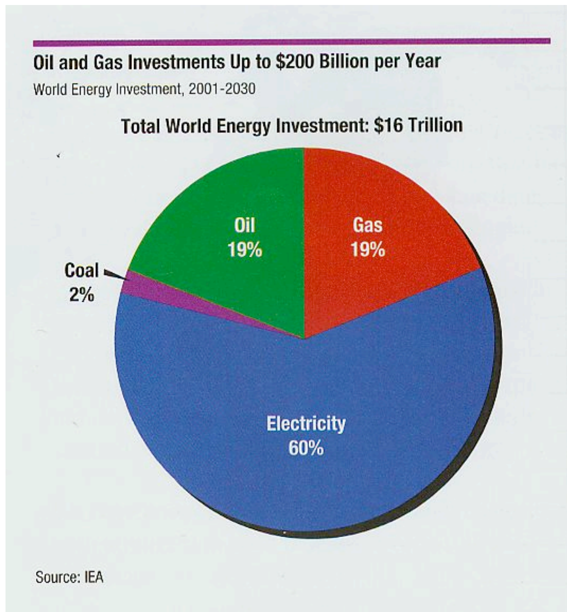

Figure 2. World energy investment is $16 trillion. The annual energy investment is estimated to be $ 530 billion. From ExxonMobil (2004) and IEA *World Energy Outlook, 2003*.

Rarely do problems appear that are so universal - individual defensive actions by localities, nations, or continents cannot prevent damaging local consequences. Problems of a global scope require solutions of a global scale. In the near future, we expect to see our government follow the lead of some of our major industries and devote the kind of resources needed to address the scientific and technological problems of anthropogenic climate change. Cornell can either lead in the engineering issues of energy and the environment, or follow. The solutions will entail multi-billion dollar initiatives and research funding will be in the hundreds of millions, some of which is already emerging. The University is well suited to attack the complexity of the systems and issues involved, with the many areas of expertise needed. In particular, we believe the College should take the lead in developing a University-wide initiative in this critical emerging area. All departments in the College have an immediate and important role to play, if they wish: BEE, CBE, CEE, EAS, ECE, MAE and MSE have been active on the committee producing this report.

Background

As most people now know, the build up of greenhouse gases (GHG) in the atmosphere tends to increase mean global temperature and therefore change global climate, and mankind is rapidly adding to atmospheric greenhouse gas concentrations. The most significant greenhouse gases are carbon dioxide, methane, tropospheric ozone, chlorofluorocarbons (CFCs), and nitrous oxide. Water vapor also is a major greenhouse gas, but not the direct consequence of human activity. Carbon dioxide, the inevitable accompaniment of combustion of fossil fuels, is the most significant of the greenhouse gases added to the atmosphere by man. That atmospheric concentrations of greenhouse gases of anthropogenic origin have increased rapidly since pre-industrial times is not in dispute by the scientific community. Carbon dioxide concentrations, for example, are now nearly one-third greater than in 1850 IPCC (2001), and higher than at any time in the

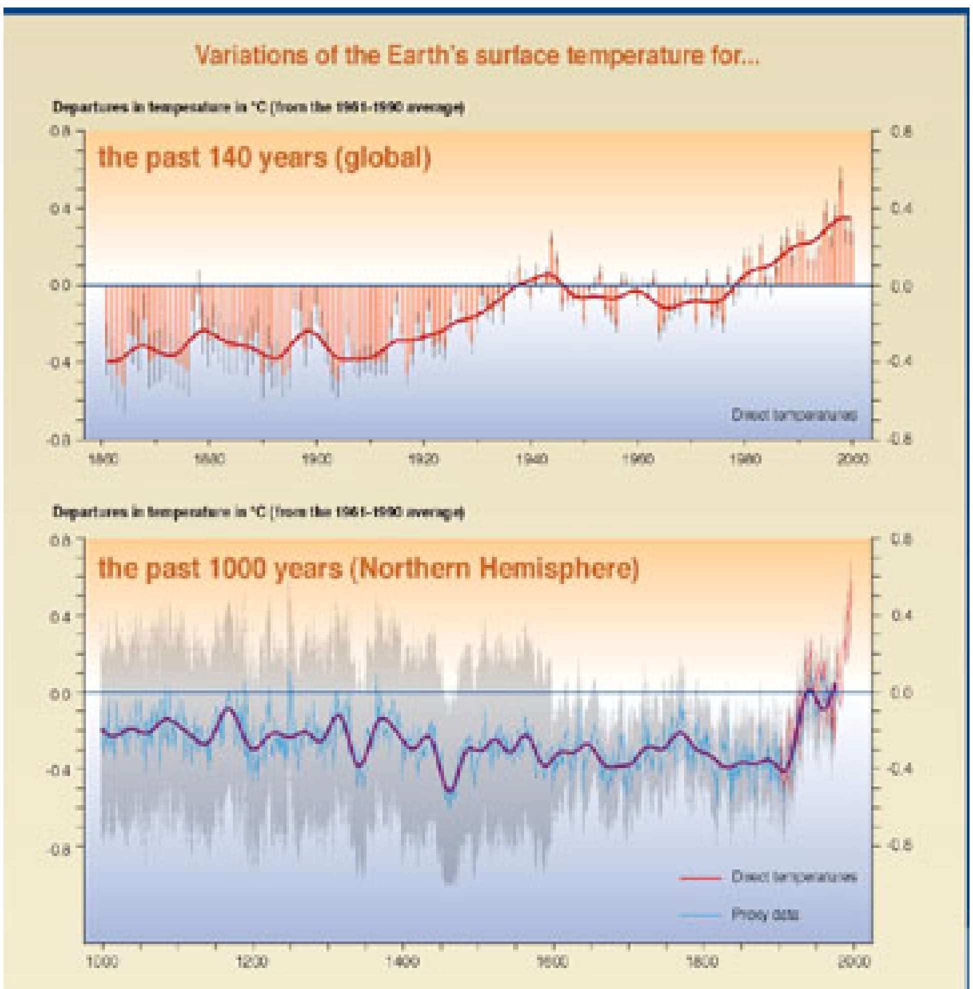

Figure 3. Temperature changes over the instrumental record (upper panel), and over the previous millennium (lower panel). From IPCC (2001).

past 420,000 years (and probably higher than in the past 20 million years (Berner and

Kothavala, 2000; Petit et al., 1999).

There also is no dispute that an increase of greenhouse gas concentrations, in and of themselves, will lead to an increase in the average temperature of the atmosphere. Since 1900, the average temperature in the Northern Hemisphere has increased by about 0.5˚, and the past decade was the warmest in the instrumental record (1861-2004). Since other factors (solar output, and the like) affect global temperature, what does remain in some dispute is the correlation between the increases in greenhouse gas concentrations and temperature, and predictions of future climate. Nevertheless, global temperatures are increasing, and this increase correlates with increased GHG concentrations, as suggested by figures 3 and 4.

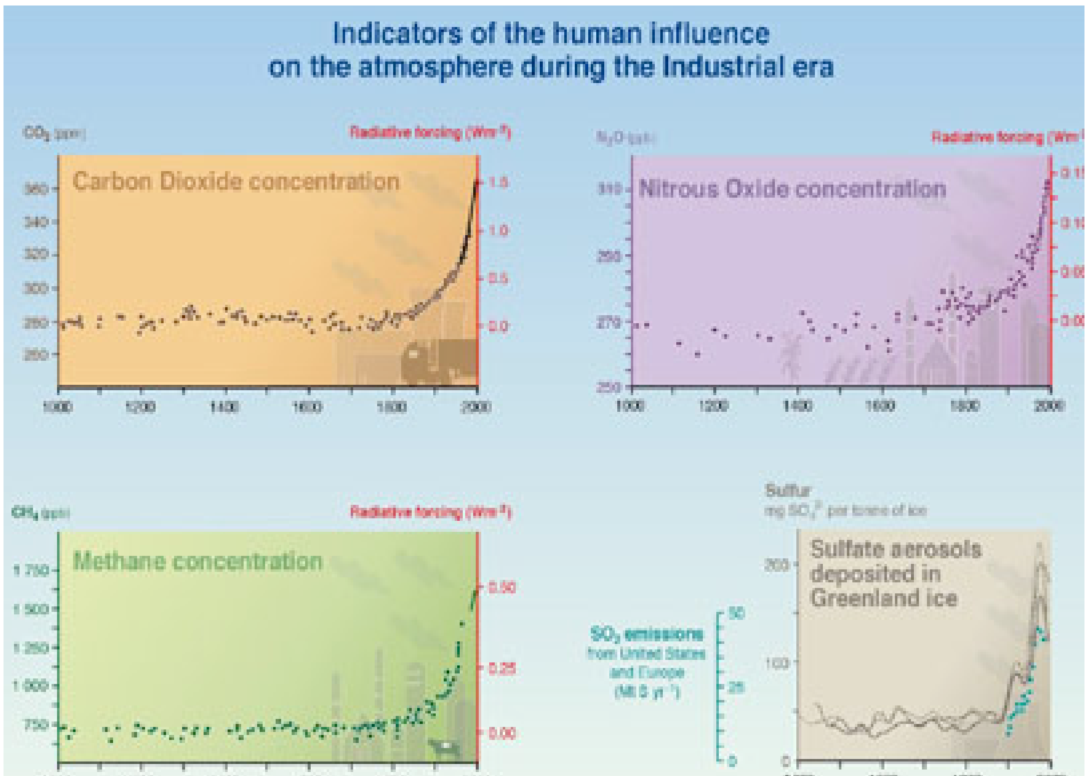

Figure 4. Increases of greenhouse gases and aerosols over the past millennium correlate with temperature increases (Figure 3). From IPCC (2001).

Furthermore, computer models of climate, upon which the prediction of future climate scenarios depend, have become increasingly reliable. The test of predictive models is their ability to capture historical records. Figure 5 illustrates model performance over the period of instrumental record. Three graphs indicate model predictions when forced only by natural forcing (a), by greenhouse gas emission forcing only (b), and by the combination of the two (c). In each case the observational data are displayed, and when both natural and anthropogenic forcings are included, the agreement with observation is very good. This is indicative not only of model reliability, but also shows that the temperature increase is attributable to increased GHG concentrations.

While some advocate a wait-and-see position on global warming, others argue that failure to control carbon emissions amounts to an uncontrolled global experiment with potentially catastrophic results later in this or the next century. Increased

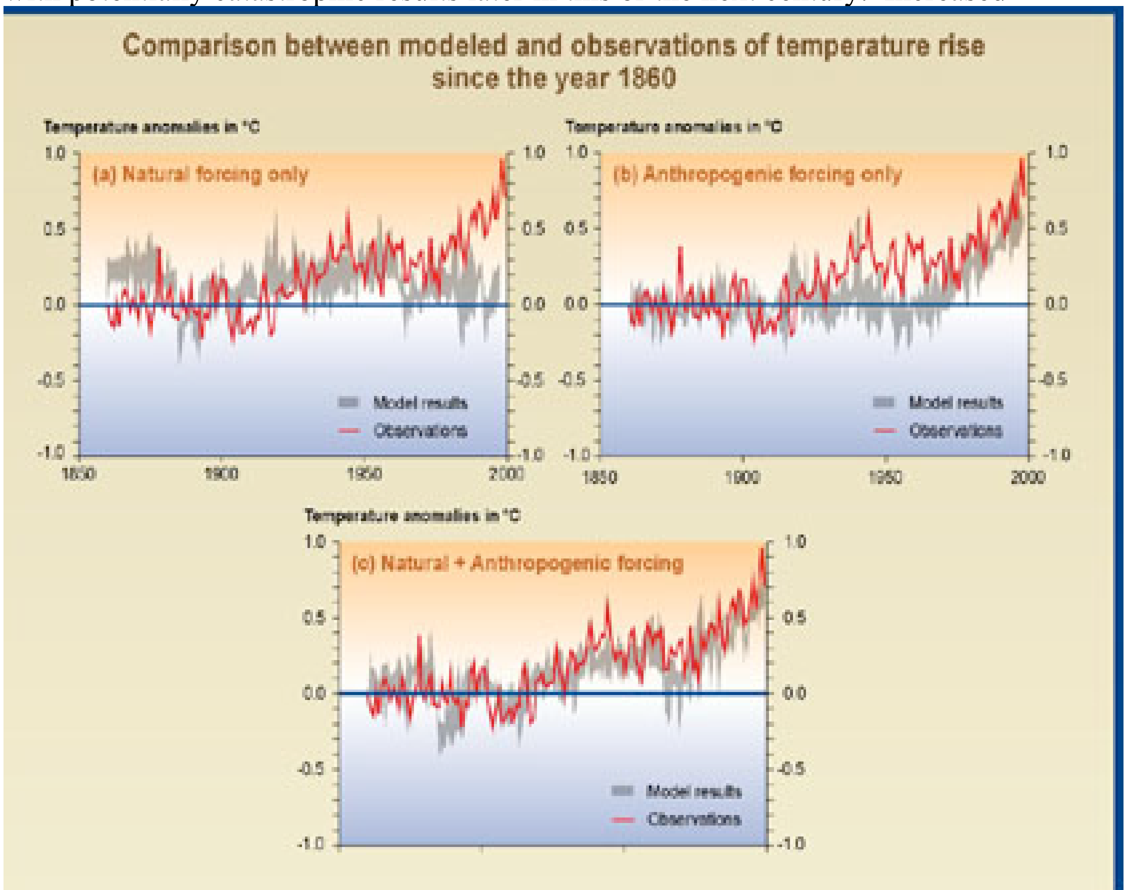

Figure 5. Temperature increases from model predictions compared to observation. From IPCC (2001).

temperatures have been projected to lead to increases in the global mean sea level and to changes in rainfall and severe weather. Large uncertainties exist in projected climatic impacts arising from the complexity of the earth-ocean-atmosphere system, and on the likely costs and benefits of various mitigation and adaptation strategies. Increases in GHG concentrations require a long time to lead to stabilized atmospheric temperatures, as shown in Figure 6. This figure shows what the temperature rise in 2100 would be if greenhouse gases are stabilized at various levels, and what the ultimate change in temperature would be at equilibrium – a state that takes centuries to attain.

National and international leaders will make decisions on policy responses. These policies could include programs to reduce emissions of greenhouse gases, to apply biological or technological approaches that would remove CO_2 from the atmosphere (carbon sequestration), or simply to adapt to changes in global climate (earth systems engineering, building of dikes, etc.). Engineers will inevitably help to identify feasibility and costs of alternative policy scenarios and to devise engineering solutions consistent with these scenarios.

Immediate and pragmatic economic considerations, however, argue for action on technological controls on carbon emissions that do not require certain prediction of future

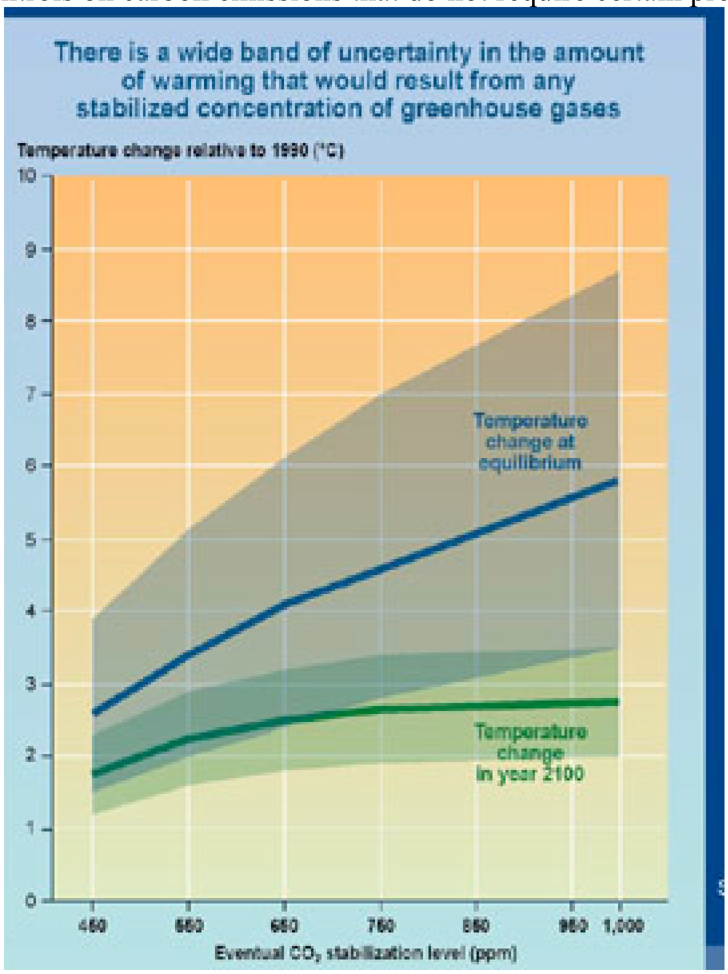

Figure 6. Temperature rises in 2100 and in final steady state given various GHG concentrations (in CO_2 concentration equivalents). The ultimate temperature equilibrium occurs over a few centuries. From IPCC (2001).

consequences. Most of the countries comprising our major trading partners are determined to reduce emissions of greenhouse gases. Sales to these countries will be subject to emissions standards they adopt. Exports of automobiles, stationary and portable electric power production equipment, and many other products relying on combustion of fossil fuels will be affected. Consequently, a substantial group of industries in the United States led by automobile manufacturers and energy companies can be expected to develop technologies in response to regulation elsewhere even if similar regulations are not in force here. Thus, climate impact policies will have major economic effects and shape directions of our energy future. Other environmental impacts, such as environmentally friendly life-cycle design of products also demand, and are beginning to receive, attention.

These new directions promise some of the most exciting and important new opportunities and challenges for engineers in this century. Cornell should be a leader in this critical area.

Possible Engineering Responses

To address the need for a prodigious growth in energy demand, to reduce the emissions of greenhouse gases, and to move towards energy security, new methods of utilizing energy (e.g., fuel cells) and introduction of primary energy production using new fuels and renewables will take place on a massive scale in the next few decades. It is likely that a number of new technologies will be put into effect simultaneously. The committee attempted to assess the prospects and limits of several technologies.

First, conservation and improvements in energy efficiency are essential. Buildings (residential and industrial) consume about 40% of all primary energy usage in heating, cooling, lighting, and other electrical power, and produce 47% of the carbon emissions. Conservation in the building sector is clearly an important target to pursue aggressively by engineers and architects. Much can be done with existing technology. More can be done with additional research, for example in new lighting technologies.

Conservation will not reduce emission rates sufficiently to stabilize greenhouse gas concentrations. The limits of conservation are apparent when levels of energy consumption in the U.S. (equivalent to 6.2 tonnes of oil per capita or 10 kW per capita) are compared with the average worldwide levels of energy consumption (~1.4 tonnes per capita or nearly 2 kW per capita). Worldwide population growth and improvements in standards of living will almost certainly lead to substantial increases in energy consumption. This will be primarily met by combustion of fossil fuels, including coal - the "dirtiest" and most abundant convenient choice. Such increase in fossil fuel usage would lead to an accelerated increase in greenhouse gas emissions. These emissions could be substantially reduced, or entirely eliminated, if a means were found to prevent the release of CO_2 and other greenhouse gases into the atmosphere when fossil fuels are burned.

A variety of approaches to carbon mitigation are possible. Some involve a shift to carbon-free energy sources, such as:

- Nuclear power (fission, maybe fusion later on)
- Renewable power sources, i.e., wind power, biomass, solar power
- Hydrogen-fueled fuel cells provided the hydrogen is produced without carbon emission.

Nuclear fission power has well-known end-of-pipe pollution and serious security problems; it will be difficult to obtain public acceptance in the U.S. for a major expansion of nuclear power in the foreseeable future Garwin & Charkak (2001). Nevertheless, it can be anticipated that the use of nuclear fission power will increase dramatically elsewhere in the world, as news stories about China's plans indicate, as well as the history of capacity growth shown in Figure 7. Fusion does not seem to be a practical prospect until mid-century or beyond.

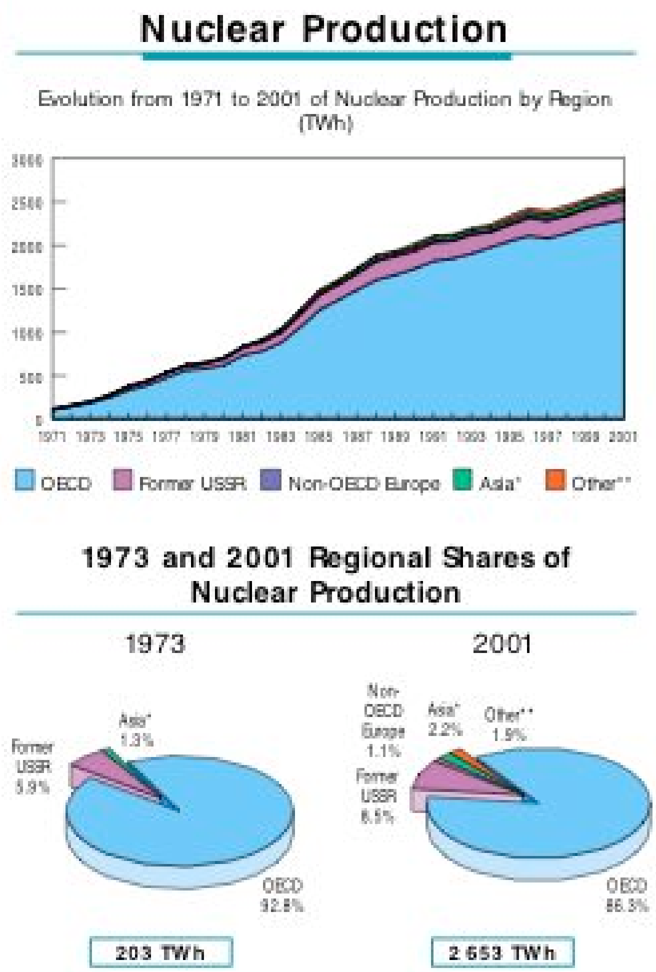

Figure 7. World production by nuclear sources from 1973 to 2001. From the International Energy Agency, IEA *Key World Energy Statistics* (2003b).

Renewable sources, while likely to grow in importance, probably will be unable to meet the energy requirements. For example, even stabilizing the CO_2 levels in the atmosphere at twice the pre-industrial revolution level of 280 parts per million by volume (ppm) would require at least 15 TW of new carbon-free power by 2050 (Hoffert et al., 2002). This is more power than the total we presently produce (12TW). Biomass contributions are limited by low efficiency of photosynthesis (yielding about 0.6 W/m^2) and the land area therefore required (although biomass also could be generated in the oceans). To produce 10 TW from biomass requires a land area comparable to all existing agriculture (Hoffert, et al., 2002). Solar photovoltaic and wind energy are better, producing about 15 W_e/m^2, but also require large land areas and better technology. Both are intermittent and dispersed sources. Thus wind and solar power present challenges of cost and dramatically new electrical grid distribution systems.

The transition to a hydrogen economy is a widely touted prospect, and ultimately may be the preferred choice for mobile power production, as well as distributed small-scale electricity generation. The largest challenges to a hydrogen economy are hydrogen generation, storage, distribution, and end-use conversion to electricity, heat, or mechanical motion. Much time will be needed to move in this direction. Hydrogen is a secondary energy source, and for the next decade or two, the economically practical production of hydrogen fuel is most likely to involve fossil fuels as a primary energy source, with its attendant and very massive problem of CO_2 management. After that, it may be possible to shift production to renewable sources.

An alternative approach to carbon-free energy sources recognizes the likelihood that fossil fuels will remain the mainstay for the next century or more, and aims to reduce or eliminate CO_2 releases to the atmosphere by capturing and sequestering the carbon (Lackner, et al., 1999; Reichle, et al., 1999). The oceans and the terrestrial ecosystem are

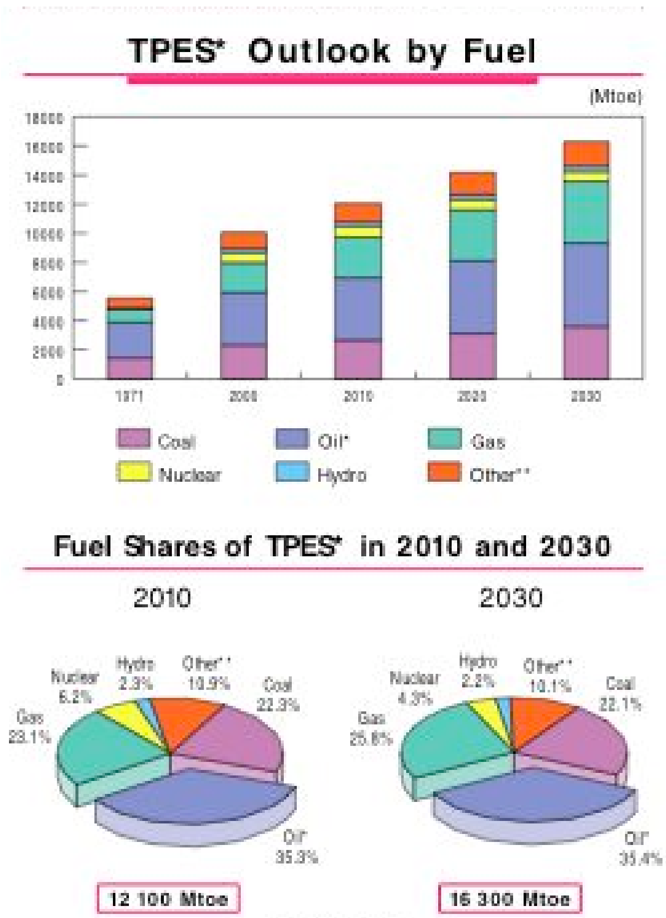

Figure 8. Projections for world total primary energy supply in the next three decades. Note the continued reliance on fossil fuels. From IEA *Key World Energy Statistics* (2003b).

natural sinks of CO_2, and suggestions have been made of ways to enhance their rate of uptake. Biological sequestration of this kind is but one path to carbon removal. Another is fossil-carbon sequestration. The idea is to separate the energy content of fuels from their carbon content (Socolow, 2002). This could involve converting natural gas or coal into hydrogen and carbon dioxide, and using the hydrogen as the source of energy. Alternatively, if it were possible to capture and sequester CO_2 either from the atmosphere or from an exhaust stream, then fossil fuels could be used much as they are now. Once captured, carbon dioxide would be sequestered with one of several possible techniques; promising methods of sequestration are in carbonate minerals, other suggestions involve storage in deep aquifers or the oceans. The hydrogen would be used as the fuel. Since the sole combustion product of hydrogen is water vapor, such a hydrogen economy originating with fossil fuels presumably would be environmentally benign, in contrast to the direct combustion of fossil fuels. The engineering challenges to this are apparent: the environmental consequences of large-scale carbon dioxide sequestration would need to be studied; a hydrogen fuel infrastructure would need to be developed. The new infrastructure requires technologies for producing hydrogen, methods of distributing, storing, and handling hydrogen as safely for the public as those now used for hydrocarbon fuels. Furthermore, the availability of an economical way to produce hydrogen would open the door to the widespread adoption of fuel cells, and perhaps new energy conversion systems.

Inventory of Cornell Energy/Environment Research

The energy/environment workshop on January 22 brought together about 50 faculty members (see the call to the workshop and attendee list in Appendix I). Many outlined their research activities relating to energy and the environment. The workshop revealed the following:

- Extensive efforts in BEE, CEE, and CBE in biomass research. The extent and quality of this effort makes Cornell a national leader in biomass energy, as Cornell's designation as a Sun grant center affirms.
- Strong programs in Chemistry and in MSE in fuel cell research, including the Cornell Fuel Cell Institute (CFCI).
- Through ECE, Cornell leads PSerc, Power Systems Engineering Research Center, a 13 NSF university consortium focused on the national electrical power grid.
- Strength in gas hydrates, a massive untapped methane source, in EAS and CBE.
- Strength in climate modeling in EAS.
- Strength in CEE and MAE in coastal, lake, and small-scale ocean physical processes, especially mixing and air/water transport processes.
- Strength in MAE in atmospheric turbulence.
- Strength in MAE, CBE and Physics in turbulence of particulates and aerosols.
- Strong programs in MAE and AEP in combustion, and chemical kinetics of hydrocarbons.

- A major DOE program (COBRA) in LPS in fusion plasma processes.

Cornell Directions

The committee's survey of possible engineering approaches leads us to believe that the areas of greatest promise in the next decade or two lie in energy generation by renewables, fossil fuel combustion and hydrogen generation with CO_2 capture and sequestration, and research in the elements of a hydrogen economy (production, storage and distribution, fuel cell development), and climate modeling integrated with projections of CO_2 source locations and emission levels.

Cornell's existing efforts in energy/environment interactions are squarely in these areas. Our strengths are impressive, but there are gaps that need to be filled to permit a comprehensive and coordinated attack on this set of problems. Among those gaps we have identified are experts in the following:

- Energy systems engineering. A senior hire in this area is advisable, preferably someone with the perspective and vision to integrate and lead the entire energy/environment effort in the College. This individual may have disciplinary expertise covering one or more of the other areas listed below.

- Carbon capture and sequestration. Expertise in this area is believed to be central to global warming mitigation in the near term (50 years), during which fossil fuels will continue to be the dominant primary energy sources.

- Atmospheric chemistry, physical oceanography, and transfer processes between the atmosphere, land, and sea. Understanding and projecting the magnitude of the effect of the greenhouse effect on global warming relies on numerical climate models. The reliability of these models, in turn, depend on how well they capture processes - like cloud cover and heat fluxes between the atmosphere and the oceans and land masses - that require empirical modeling assumptions about imperfectly understood physical processes. Results of climate models are sensitive to these assumptions, and it is on these issues that most scientific uncertainty about global warming remains.

- Renewable energy technology. Hydrogen storage and distribution systems, wind power, fuel cells, and electrical grid adaptations to distributed generation.

Hiring priorities and specific directions for the program will be decided by the governing bodies of the energy institute, as suggested in our recommendations.

Recommendations

In recognition of the central importance of energy and its environmental impacts to the greatest concerns of human society – war and peace, social and economic well being, and shared environment - the College of Engineering should act vigorously on the initiative it has already adopted. We strongly recommend the creation of the Cornell Institute for Energy Technology and Climate Stabilization. The Institute will devote itself to research promising the greatest benefit to the scientific and technological solution to global problems of energy supply and utilization aiming towards acceptable environmental interaction. We recommend the College immediately take the following steps to establish the Institute:

- Create an executive committee of Cornell academics to provide on-going advice to the Director of the Institute and to provide guidance of the programs of the Institute.
- Create an external advisory board composed of experts from industry, government and other universities.
- Search for a Director of the Institute. This individual should have a clear and broad vision of the central issues of energy and its environmental impacts, and a firm grasp of what universities can contribute.
- Enable the Director to hire four new faculty. All interested schools and departments in the College can propose candidates, and each hire would have his or her tenure home in an existing department. The Director of the Institute and the Institute Executive Committee will guide the search.
- Provide office space for the Institute.
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    - \$400,000/year for fellowships, national workshops, salary for the Director's Assistant, and miscellaneous expenses.

We envision the functional structure of the Institute to be built around six overlapping focus areas (Figure 9):

1. energy systems and energy security;
2. primary energy resources (biomass, wind, hydrocarbon, nuclear, solar);
3. energy conversion devices and processes (hydrogen production, fuel cells, new prime movers, and related technology);
4. energy storage and distribution (new grid technologies effectively integrating distributed energy production schemes, batteries, hydrogen fuel containment and distribution, disposal of energy waste products;
5. environmental impact mitigation (carbon sequestration, siting of power production, interaction with atmospheric and oceanic dynamics and chemistry);
6. energy efficiency and conservation (new indoor heating and cooling technology, new lighting technology).

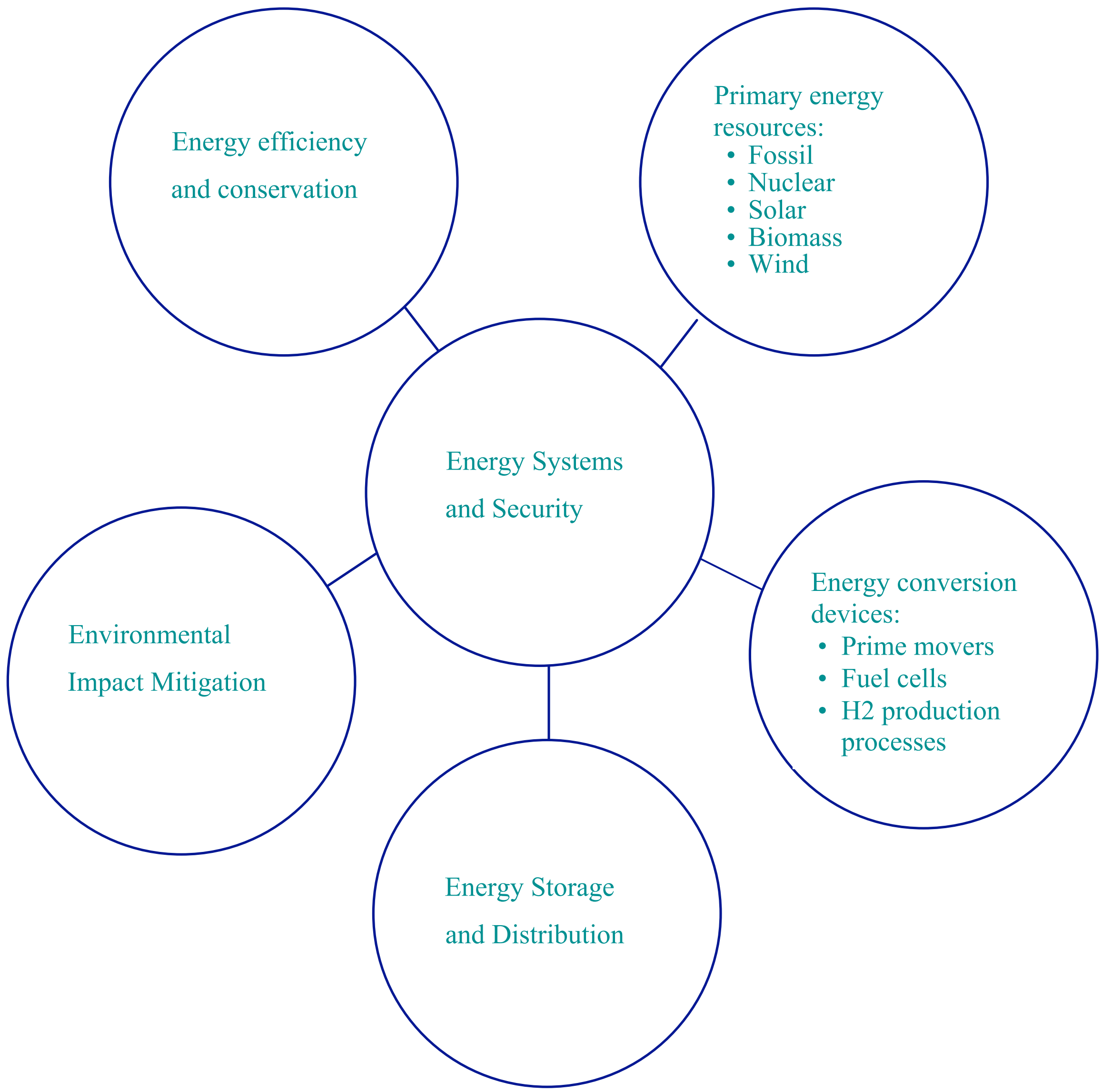
Energy efficiency and conservation
Primary energy resources:
• Fossil
• Nuclear
• Solar
• Biomass
• Wind
Energy Systems and Security
Environmental Impact Mitigation
Energy conversion devices:
• Prime movers
• Fuel cells
• H2 production processes
Energy Storage and Distribution

Figure 9

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Appendix I – Call to Workshop

"New Initiative on Energy and the Environment"
10 A.M.-3:30 P.M.
Thursday, January 22, 2004
111 Upson Hall

The Dean of Engineering, at the recommendation of the Directors and Chairs of the Schools and Departments in the College, has constituted a committee (membership list attached separately) with the following charge:

"To recommend future research activities of the College of Engineering that will contribute in an important way to solutions of energy supply, usage, distribution, and storage through the application of science and engineering consistent with responsible stewardship of Earth's global environment; to propose additional resources needed to provide College capabilities where needed; and to propose a framework to achieve these ends."

To this end, we ask all who have a potential research interest in areas relating to energy and its environmental impacts to attend a workshop on January 22. The purpose of the workshop is to assess the research activities currently underway in these areas at Cornell. The crucial role of policy in issues of such large social importance is understood. However, for the purposes of this workshop, policy matters are of interest to the extent they inform technological and scientific considerations.

The workshop will be held in 111 Upson Hall. The room is reserved from 10am to 3:30 pm, with lunch provided in the adjacent lounge from 12:30-1:30. We intend to begin promptly at 10 am.

The business of the day will be informal discussions of research. We ask attendees to be prepared to give a short description of their relevant research interests, with perhaps 2 or 3 transparencies. We will have a computer projector at hand, but in the interests of minimizing the swap times needed as computers are hooked up, we would be pleased if overheads were used instead. It would also be useful if copies of overheads could be left with the committee.

Those who would like to participate but are unable to attend, please let us know by email, preferably with a copy to your department chair.

We ask that you respond by email to **vig1** with your interest in participation. It would be appreciated if, in your response, you would give a very brief statement of the research you will discuss.

Attendees January 22, 2004 Workshop

Hector Abruna, Chemistry & Chemical Biology
Lou Albright, BEE
Dan Aneshansley, BEE
Brad Anton, CBE
Tom Avedisian, MAE
Mark Bain, Center for the Environment
Muawia Barazangi, EAS
Larry Brown, EAS
Joe Burns, TAM: V. Provost
Larry Cathles, EAS
Paulette Clancy, CBE
Lance Collins, MAE
Edwin Cowen, CEE
Kerry Cook, EAS
Rudiger Dieckmann, MSE
Frank DiSalvo, Chemistry & Chemical Biology, CCMR
Betta Fisher, MAE
Ephrahim Garcia, MAE
Kifle Gebremedhin, BEE
Al George, MAE
Emmanuel Giannelis, MSE
Fred Gouldin, MAE
Jim Gossett, CEE
David Hammer, ECE
W. Jewell, BEE
Terry Jordan, EAS
Sid Leibovich, MAE
Chekesha Liddell
Michel Louge, MAE
George Malliaras, MSE
Tim Mount, AEE
Chris Ober, MSE
Clif Pollock, ECE
Steve Pope, MAE
Norm Scott, BEE
Dick Shuler, CEE & Econ
Jery Stedinger, CEE
Abe Stroock, CBE
Robert Thomas, ECE
Ken Torrance, MAE
Bruce van Dover, MSE
Francis Vanek
Larry Walker, BEE
Zellman Warhaft

Other faculty expressed interest but were unable to attend, or are known to have research interests in areas connected to energy and its environmental impacts. Among these are,

Dieter Ast, MSE - solar energy
Terry Cool, AEP, combustion
George Malliaras, MSE- photovoltaics
Dick Shealey, ECE – alternative lighting (light panels)
Tom O'Rourke, CEE – NEES – earthquake prevention
Rachel Davidson, CEE – risk assessment and siting of infrastructure

Appendix II – Programs at Peer Institutions

Programs, some very well funded, have been started at other universities. We surveyed those at our peer institutions, and found the following program emphases.

- **MIT Laboratory for Energy and the Environment**
  - Lab brings together collaborating faculty and staff in 13 departments to address relationships between energy and the environment.
  - The mission of the LEE is to make significant innovative contributions to energy and environmental sustainability including the improvement of technologies, structures, and policies that will lead to cleaner, more effective, efficient, and equitable products and processes. In order to advance this aim, MIT has identified four goals:
    * Carry out multidisciplinary research that leads to holistic assessment of problems and of solution options in meeting demand for energy and resource production and use.
    * Serve as a platform for MIT-wide integrative research on energy and the environment
    * Inform decision-making in public and private sectors
    * Prepare a new generation of leaders
  - Web site: http://lfee.mit.edu/about/

- **Stanford Global Climate and Energy Project**
  - Advanced transportation systems
  - Electric power generation systems with lower greenhouse emissions
  - Production, distribution and use of hydrogen
  - Production distribution and use of biomass fuels
  - Advanced nuclear technologies
  - Renewable energy supplies
  - Carbon sinks, CO_2 separation and storage
  - Coal utilization
  - Materials, combustion and systems science
  - Enabling infrastructure
  - Geoengineering

- **Princeton Environmental Institute**

- PEI coordinates environmental education, research and outreach
- 60 associated faculty are in natural sciences, engineering, social sciences and humanities
- Undergrad program offers certificate in Environmental Studies
- Organized as:
  - Carbon Mitigation Initiative
  - Energy Group
  - Center for Environmental BioInorganic Chemistry
  - Center for Biocomplexity
- Web site: http://web.princeton.edu/sites/pei/

- **National Hydrogen Energy University Research (HEURI) initiative**
  - An initiative spearheaded by University of Michigan
  - Proposed basic research & education initiative, supporting the creation of a hydrogen economy, established at the nation's leading research universities
  - Establish six university centers of excellence nationwide that would:
    - Conduct basic research in areas that limit the use and adaptation of hydrogen energy technologies.
    - Educate the technical and business workforce required to grow and sustain the nation's hydrogen economy.
    - Transfer the research methodologies and technologies to U.S. companies for implementation and commercialization.
  - HEURI Research Areas:
    - Hydrogen production
    - Hydrogen storage
    - Hydrogen utilization (stationary, mobile, micro)
    - Sustainability, economic, and social issues

Appendix III Conversion Factors

General Conversion Factors for Energy

To: / From:	TJ	Gcal	Mtoe	MBtu	GWh
From:	*multiply by:*				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3412	1

Conversion Factors for Mass

To: / From:	kg	t	lt	st	lb
From:	*multiply by:*				
kilogram (kg)	1	0.001	9.84×10^{-4}	1.102×10^{-3}	2.2046
tonne (t)	1000	1	0.984	1.1023	2204.6
long ton (lt)	1016	1.016	1	1.120	2240.0
short ton (st)	907.2	0.9072	0.893	1	2000.0
pound (lb)	0.454	4.54×10^{-4}	4.46×10^{-4}	5.0×10^{-4}	1

Conversion Factors for Volume

To: / From:	gal U.S.	gal U.K.	bbl	ft^3	l	m^3
From:	*multiply by:*					
U.S. Gallon (gal)	1	0.8327	0.02381	0.1337	3.785	0.0038
U.K. Gallon (gal)	1.201	1	0.02859	0.1605	4.546	0.0045
Barrel (bbl)	42.0	34.97	1	5.615	159.0	0.159
Cubic foot (ft^3)	7.48	6.229	0.1781	1	28.3	0.0283
Litre (l)	0.2642	0.220	0.0063	0.0353	1	0.001
Cubic metre (m^3)	264.2	220.0	6.289	35.3147	1000.0	1

Source: *Key World Energy Statistics* 2003, International Energy Agency