Appendix XVI

Summary of Benefits from Commission Funding of EPRI's Collaborative Climate Research Program 1998-2002

Tom Wilson
Electric Power Research Institute
Palo Alto, California

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Abstract

The overall goal of this project (PIER Contract 500-97-043) was to study the phenomenon of climate change and from the understanding gained, to begin to provide the information necessary to evaluate possible actions for addressing the impacts of climate change. The overwhelming majority of this report focuses on a California-specific assessment, which applies and dramatically extends a decade of basic research results developed by EPRI's global climate change research program.

The Commission also provided funding to participate in EPRI's collaborative research program. While not focusing specifically on California in most instances, the collaborative research efforts funded by the Commission helped develop methods and concepts that were later applied in the California assessment. The collaborative research program also shed light upon many of the fundamental concepts and issues that are critical to Californian's understanding of this truly global environmental issue.

This appendix provides a brief overview of the collaboratively funded efforts that the Commission contributed to, describes the specific uses of Commission funds, and lists the deliverables provided to the Commission.

The Commission contributed to two EPRI climate research areas that address 11 topical areas:

- Assessment of uncertainty in climate change predictions
- Carbon cycle analyses
- Impacts of climate change on human health
- Impacts of climate change on ecosystems and biodiversity in the United States
- Effects of climate change on market-based systems
- Framework for integrated assessment of global climate change policy proposals
- Integrated assessments of costs and benefits of climate change management proposals
- Analysis of the costs of CO_2 emission reduction proposals
- Assessment of the impacts of the Kyoto Protocols on U.S. competitiveness
- Costs of adaptation options
- Energy technology strategy for addressing global climate change.

Each of these topical areas is discussed in Section 1. Section 2 provides a brief summary of deliverables and findings.

1. Introduction

1.1 Overview of the Collaborative Program and Deliverables

The principal focus of the EPRI research areas that the Commission contributed to is to create technical articles for publication in peer-reviewed, academic journals. Consequently, with few exceptions, the deliverables resulting from these research efforts are in the public domain. Those deliverables that are EPRI reports are available to the public via the Commission. The next 11 sections provide brief descriptions of each research area and key results.

1.2 Assessment of Uncertainty in Climate Change Predictions

The objective of the colloaborative research effort on climate change predictions is to better understand the uncertainty associated with climate scenarios and, in particular, to explore the uncertainty inherent in alternative approaches for providing regional climate scenarios. Climate impacts are largely local and regional phenomena. To understand the potential implications of climate change, one has to project climate changes at regional as well as global levels. Two fundamental approaches for providing regional scenarios were explored: regional climate models (which are based on the same fundamental physical principles as general circulation models, GCMs) and statistical downscaling (which links GCMs with historic regional weather data).

Commission funding in this case was used to conduct California-specific analyses. Funds were used to augment support of the existing Project to Intercompare Regional Climate Simulations (PIRCS) being coordinated by Iowa State University and funded by EPRI/ACACIA. They allowed Iowa State to (1) expand the analysis of the initial suite of (short-term) regional climate model simulations and (2) extract California-specific data outputs from longer-term RCM simulations. The California-specific data from both suites of experiments were examined to investigate how the climate change signal observed in GCM runs is affected by resolving in the RCM runs mesoscale features that appear crudely or not at all in global climate models. Examination of the climate change signal's influence on the hydrologic cycle was emphasized. The principal variables examined were precipitation, snowpack, and temperature.

Results from the California portion of this effort were summarized at a public meeting in June 2000 at the Commission (see Appendix I). Dr. William Gutowski of Iowa State University presented results from two widely used RCMs, RegCM2 (National Center for Atmospheric Research) and HIRHAM (Danish Meteorological Institute). Having higher resolution than GCMs, RCMs model a portion of the earth's surface and can be "nested" within a GCM. Current methods linking GCMs and RCMs use "one-way" nesting, which means that the RCM model is run using boundary conditions from the GCM, but it does not provide feedback to the GCM. RCMs apply the same basic physical equations of motion, energy, and momentum as GCMs, but,

because of their higher spatial resolution (typically 50 km or less), are better able to simulate the effects of topography on weather and climate. Present computing limitations have restricted the use of RCMs to simulations of subcontinental regions and for periods of, at most, a few years. In contrast, GCMs have been applied globally for century-length or longer simulations. RCM research efforts have focused on improving simulations of current or past climate for periods of a few months to a few years. A limited set of future climate simulations (up to 10 years) that is driven by GCM-generated climate change projections is available.

RegCM2 and HIRHAM were used to model climate change in the western United States at a resolution of 50 km. These RCM simulations were driven by climate change projections from the HadCM2 (Johns et al., 1997) which has a resolution of approximately 300 km. Given their higher spatial resolution, RegCM2 and HIRHAM do resolve much of the topographic variation in the Coastal Range, the Central Valley, and the Sierra Nevada. RegCM2 and HIRHAM simulations were presented for current climate, and of future climate under conditions of increased greenhouse gas concentrations estimated for the decade 2040-2049**.**

Of the 21 GCMs examined by Dr. Tom Wigley for the Climate Scenarios workshop, the HadCM2 model simulated the highest amount of precipitation in California. Interestingly, the regional models, RegCM2 and HIRHAM, project a larger increase in precipitation over California than does the HADCM2 model. RegCM2 estimates an increase in temperature of 2 to 3°C (4 to 5°F) over the state, but projects an increase in precipitation of 3-5 mm/day in northern California and 0-1 mm/day in southern California. In contrast, the GCMs project greater precipitation increases in southern California than in northern California. RegCM2 and HIRHAM estimate changes in winter snowpack water content, varying by location, from no change to a 50% decrease.

Although these efforts provided a better understanding of the efficacy of regional climate modeling, they represent only small, initial steps. The findings of this research emphasize the need for significant methodolgical enhancements. The results were not directly used in the California analysis because they only addressed one GCM scenario for one decade rather than transient changes over they century for a range of GCM simulations.

Other deliverables from the overall collaborative effort yielded a series of studies that add to the understanding of the efficacy of regional climate modeling and statistical downscaling. Specific topics ranged from comparisons of different RCMs and comparisons of basic methods to assessments of the state of the art for modeling climate extremes. The collaborative effort resulted in deliverables listed in Table 1.

Table 1. Deliverables related to assessment of uncertainty in climate change predictions

Deliverable	Date
R.W. Arritt, W.J. Gutowski Jr., and E.S. Takle, "Regional Climate Simulations for Impact Assessment under the Project to Intercompare Regional Climate Simulations (PIRCS)	*EPRI Interim Report*, TR-111887 Printed December 1998.
R.L. Wilby, T.M.L. Wigley, D. Conway, P.D. Jones, B.C. Hewitson, J. Main, and D.S. Wilks, "Statistical Downscaling of General Circulation Model Output: A Comparison of Methods"	Published in *Water Resources Research*, 34, 2995-3008, 1998 November.
K.E. Kunkel, R.A. Pielke Jr., and S.A. Changnon, "Temporal Fluctuations in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review"	Published in the *Bulletin of the American Meteorological Society*, 80(6), 1077-1098, June 1999.
Wilby, R.L. et al. (2000), "Hydrological Responses to Dynamically and Statistically Downscaled Climate Model Output"	Published in *Geophysical Research Letters*, 27(8), 1199-1202.
Meehl, G.A., W. Collins, B. Boville, J.T. Kiehl, T.M.L. Wigley and J.M. Arblaster (2000), "Response of the NCAR Climate System Model to Increased CO_2 and the Role of Physical Processes"	Published in *Journal of Climate*, 13, 1879-1898.
Pan, Z., J.H. Christensen, R.W. Arritt, W.J. Gutowski Jr., E.S. Takle, and F. Otieno, "Evaluation of Uncertainties in Regional Climate Change Simulations"	Accepted by *Journal of Geophysical Research — Atmospheres* on 27 March 2001.
"Analysis of Regional Climate Model Results for Simulations of Future Climates"	Submitted for publication on 3/15/02, published April 2002, *EPRI Technical Report*, 1005162.
Workshops on Fast-Breaking Climate Issues	Workshop overview featured in *Quick News* (June 2001 issue). Workshop agenda, participants, bibliography, and presentations posted to the ACACIA website (www.acacia.ucar.edu/workshops.html).
Hakkarinen, C., S. Nishinomiya, and T. Wigley, "Climate Change and Precipitation Extremes – Summary of an ACACIA Workshop"	Submitted to the *Transactions of the American Geophysical Union* on 27 December 2001.
R.L. Wilby and T.M.L. Wigley, "Future Changes in the Distribution of Daily Precipitation Totals Across North America"	*Geophysical Research Letters*, 29(7), pp. 39-1 to 39-4, 2002.
W.J. Gutowski, S.G. Decker, R.A. Donavon, Z. Pan, R.W. Arritt, and E.S. Takle, "Temporal Scale of Precipitation Errors in a Central U.S. Regional Climate Simulation"	Submitted to *Journal of Climate* on 2 July 2002.
C.J. Anderson, R.W. Arritt, E.S. Takle, Z. Pan, W.J. Gutowski, R. da Silva, and PIRCS modelers, "Hydrologic Processes in Regional Climate Model Simulations of the Central United States Flood of June-July 1993"	Submitted to *Journal of Hydrometeorology* on 6 February 2002.

1.3 Carbon Cycle Analyses

The objective of this research is to develop an improved understanding of the global carbon cycle. This understanding is essential both for evaluating the potential effectiveness of greenhouse gas emissions reduction proposals and for predicting the magnitude and rate of possible climate change. The research approach is to work with an international, interdisciplinary team of researchers to develop and test improved models of the carbon cycle. Regional carbon flux measurements and local field experiments provide new sources of information against which these new models can be assessed.

This research develops and applies improved global carbon cycle models that can be used to identify key uncertainties and investigate the consequences of alternative policy scenarios. The research models, along with new data from experiments and environmental monitoring, were applied to help reduce some of the large uncertainties concerning the role of terrestrial ecosystems in the carbon cycle and hence on atmospheric carbon levels.

Commission funds were used to contribute to the Carbon Cycle Model Linkage Project — Phase 2 (CCMLP-2). Funds partially supported EPRI management of the effort and the activities of several of the member teams via the project coordinator, the Max-Planck-Institut fuer Biogeochemie in Germany. This research effort resulted in a series of deliverables addressing critical issues such as the potential implications of uncertainty about CO_2 fertilization, gaining a retrospective appreciation of the implications of landuse change in the 20th century, terrestrial feedback effects consistent with the IPCC SRES scenarios, and an evaluation of carbon cycle models using actual atmospheric concentrations (Table 2).

Research results developed by CCMLP-2 made substantial contributions to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC). Chapter 3 of Working Group I's report was entitled "The Carbon Cycle and Atmospheric Carbon Dioxide." The Co-ordinating Lead Author for this Chapter was a Principle Investigator of one of the CCMLP-2 research teams and a Co-Director of the Max Planck Institute. Thus, the CCLMP-2 research and the deliverables listed in Table 2 played a significant role in forming the international scientific basis for understanding of the global carbon cycle. Policies to stabilize future atmospheric carbon dioxide concentrations will depend critically on the physical processes in terrestrial and oceanic biospheres. Key findings of this recent research unfortunately indicated that uncertainty associated with the carbon cycle increased relative to the Second Assessment Report of the IPCC. Another important result was the demonstration that the long-run anthropogenic emission rates must drop more than 90% below current levels if we are to achieve atmospheric carbon dioxide stabilization.

Table 2. Deliverables related to carbon cycle analyses

Deliverable	Date
D.W. Kicklighter, M. Bruno, S. Dönges, G. Esser, M. Heimann, J. Helfrich, F. Ift, F. Joos, J. Kaduk, G.H. Kohlmaier, A.D. McGuire, J.M. Melillo, R. Meyer, B. Moore III, A. Nadler, C. Prentice, W. Sauf, A.L. Schloss, S. Sitch, U. Wittenberg, and G. Würth, "A First-Order Analysis of the Potential Role of CO_2 Fertilization to Affect the Global Carbon Budget: A Comparison of Four Terrestrial Biosphere Models"	Accepted by *Tellus* on 20 October 1998
R. Meyer, F. Joos, G. Esser, M. Heimann, G. Hooss, G. Kohlmaier, W. Sauf, R. Voss, and U. Wittenberg, "The Substitution of High-Resolution Terrestrial Biosphere Models and Carbon Sequestration in Response to Changing CO_2 and Climate"	Published in *Global Biogeochemical Cycles*, 13(3), 785-802, September 1999
McGuire, A.D., S. Sitch, J.S. Clein, R. Dargaville, G. Esser, J. Foley, M. Heimann, F. Joos, J. Kaplan, D.W. Kicklighter, R.A. Meier, J.M. Melillo, B. Moore III, I.C. Prentice, N. Ramankutty, T. Reichenau, A. Schloss, H. Tian, L.J. Williams, and U. Wittenberg, "Carbon Balance of the Terrestrial Biosphere in the Twentieth Century: Analyses of CO_2, Climate and Land-use Effects with Four Process-Based Ecosystem Models"	Accepted for publication in *Global Biogeochemical Cycles* on 22 September 2000
Joos, F., I.C. Prentice, S. Sitch, R. Meyer, G. Hooss, G. Plattner, S. Gerber, and K. Hasselmann, "Global Warming Feedbacks on Terrestrial Carbon Uptake under the IPCC Emission Scenarios"	Published in *Global Biogeochemical Cycles*, Vol. 15, No. 4, p. 891, 2001
R.J. Dargaville, M. Heimann, A.D. McGuire, I.C. Prentice, D.W. Kicklighter, F. Joos, J.S. Clein, G. Esser, J. Foley, J. Kaplan, R.A. Meier, J.M. Melillo, B. Moore III, N. Ramankutty, T. Reichenau, A. Schloss, S. Sitch, H. Tian, L.J. Williams, and U. Wittenberg, "Evaluation of Terrestrial Carbon Cycle Models with Atmospheric CO_2 Measurements: Results from Transient Simulations Considering Increasing CO_2 Climate and Land-use Effects"	Submitted to *Global Biogeochemical Cycle* on 8 August 2002

1.4 Impacts of Climate Change on Human Health

The objective of this research is to develop an improved understanding of the potential for climate change to affect human health and the steps society could take to reduce or avoid potential damages. The approach is to promote development of integrated assessment models of possible health effects and to gain a better understanding of particular health effects of concern. EPRI health research includes joint sponsorship of an EPRI-federal research program coordinated by the National Oceanic and Atmospheric Administration (NOAA) and funding of specific, more-focused research efforts ranging from the potential impacts of heat waves to vector-borne diseases.

Commission funding provided partial support for two in-depth studies. One effort is an epidemiological study of Ross River virus conducted with the Australian National University (with review by the U.S. Center for Disease Control). The second is an effort in coordination with Stanford University to build a credible, quantitative integrated model of the important direct and indirect effects of climate change on the incidence of malaria. Both efforts are described in more detail in the paragraphs below.

- *Ross River virus epidemiology study*. This project (see Woodruff et al., 2001 in Table 3) was designed to understand the temporal and spatial distribution of an arboviral disease, Ross River virus disease (RRVD), in association with climatic and other environmental variables. El Nino/Southern Oscillation (ENSO) events were used as the primary variable for the development of predictive models. The results were used to determine the predictability of this disease to improve the adaptation, mitigation and control of this and other arboviral diseases. This information is applicable both in Australia, where the analyses will be carried out, and in the state of California.

  RRVD is a mosquito-borne disease that can cause an epidemic polyarthritis. Wetter and warmer summers are likely to result in higher background disease levels, with a wider disease spread both seasonally and geographically, and with more frequent occurrence. There appears to have been a real increase in cases over the past two decades. Approximately 37,800 cases were reported between 1991 and mid-1998. RRVD has a significant economic and social impact. The mean duration of incapacity reported by the patients in one study was in the range of five weeks to three months. About 7-9% of patients are unable to walk unaided after six months, and some patients progress to a chronic and incapacitating illness.

  The main mosquito vectors of RRVD breed in saltmarsh or inland freshwater pools and streams. This provides for an excellent ecological experiment since few local governments in Australia conduct routine insecticiding or mosquito habitat destruction and there is little human intervention in outbreaks. There are different vector/virus cycles in different parts of the country.

  This project explored how the temporal and spatial distribution of a mosquito-borne disease can change with changes in weather patterns. Extensive weather and health data were used. The large number of cases provided sufficient statistical power to analyze disease patterns at both national and regional levels. Understanding of how mosquito species change their range under different weather patterns, including ENSO events, adds significant information to how California can adapt to, mitigate, and control arboviral diseases, both those currently in the state and those that may be introduced.

Table 3. Deliverables related to impacts of climate change on human health

Deliverable	Date
N.Y. Chan, F. Smith, T.F. Wilson, K.L. Ebi, and A.E. Smith, "An Integrated Assessment Framework for Climate Change and Infectious Diseases"	Submitted to *Environmental Health* Perspectives on 30 September 1998 Published in *Environmental Health* Perspectives 1999;107:329-337
N.Y. Chan, M.T. Stacey, A.E. Smith, K.L. Ebi, and T.F. Wilson, "An Empirical Mechanistic Framework for Heat Related Illness"	Submitted to *Climate Research* on 20 December 1999 Published in *Climate Research* 2001;16:133-143
Bernard, S.M., and K.L. Ebi, "Comments on the Process and Product of the Health Impacts Assessment Component of the National Assessment of the Potential Consequences of Climate Variability and Change for the United States"	Submitted to *Environmental Health Perspectives* on 8 December 2000 Published in *Environmental Health Perspectives* 2001;109(Suppl 2):177-184
Bernard, S., J. Samet, A. Grambsch, K.L. Ebi, and I. Romieu, "The Potential Impacts of Climate Variability and Change on Air Pollution-related Health Effects in the United States"	Submitted to *Environmental Health Perspectives* on 19 September 2000 Published in *Environmental Health Perspectives* 2001:109(Suppl 2):199-210
Gubler, D.J., P.R. Reiter, J.A. Patz, K.L. Ebi, W. Yap, and R. Nasci, "Climate Variability and Change in the United States: Potential Impacts on Vector- and Rodent-borne Diseases"	Submitted to *Environmental Health Perspectives* in October 2000 Published in *Environmental Health Perspectives* 2001:109(Suppl 2):223-233
Huynen, M., P. Martens, D. Schram, M. Weijenberg, and A. Kunst, "The Impact of Cold Spells and Heat Waves on Mortality Rates in the Dutch Population"	Submitted to *Environmental Health Perspectives* on 14 September 2000 Published in *Environmental Health Perspectives* 2001:109, 463-70.
Woodruff, R., C.S. Guest, M.G. Garner, N. Becker, J. Lindesay, T. Carvan, and K. Ebi. "Early and Late Warning of Ross River Virus Epidemics Based on Regional Climatic Data in Australia"	Submitted to *Epidemiology* on 21 June 2001 Published in *Epidemiology* 2002;13:384-93
J. Hartman, K. Ebi, K.J. McConnell, N. Chan, and J. Weyant, "Climate Suitability for Stable Malaria Transmission in Zimbabwe under Different Climate Change Scenarios"	Published in *Global Change & Human Health*, 3(1), 2002.

The Murray area was chosen for the study because of the long record of human epidemics and the (comparative) wealth of information available on virus, host and vector populations. Widespread epidemics of RRVD occurred in 1992-1993. When they occur, outbreaks tend to commence in late spring or early summer (November-December). Maximum monthly notification rates are usually recorded in late summer or early autumn (February-April). Two regions within the Murray area were studied. Region 1 is on the edge of the large internal landmass of Australia, and experiences hot dry summers and cold winters, while Region 2 (further south and closer to the moderating influence of the coast) has a temperate climate pattern. The vegetation of Region 1 is characterized by grasslands, and for Region 2 by temperate forests and shrubs. Average yearly rainfalls are higher in Region 2 (563 mm) than Region 1 (343 mm). The majority of rainfall occurs in winter and early spring in both regions, and is generally lowest in summer (December-February). Rainfall varies substantially from year to year, however, and heavy falls have been recorded in summer, whilst long drought periods can occur. The number and intensity of rainfall events over southeastern Australia have been related to the ENSO cycle.

Single variable analyses found that total monthly rainfall and the number of rainy days per month for all months from August to November were positively associated with the occurrence of epidemics. The strongest relationships were in August and September. Low evaporation levels and low relative humidity (a proxy for low temperatures) from October to January were significant predictors in both regions, but were dropped from later models because of correlation with temperature (a better predictor).

Regional specific early and late warning models were developed based on two predictable epidemic patterns, following either high summer rainfalls or high winter rainfalls. Other variables included temperature and sea surface temperature. A prerequisite, relating to host-virus dynamics, was lower than average spring rainfall in the pre-epidemic year. The sensitivity of the model was 96% for Region 1 and 73% for Region 2. The authors concluded that early warning of climate conditions conducive to outbreaks of RRVD is possible at the regional level with a high degree of accuracy. The models developed may have application as a decision tool for health authorities to use in risk management planning.

- *Integrated assessment framework for malaria*. In the second effort, Dr. Kris Ebi of EPRI worked with Dr. Nathan Chan (Talus Solutions) and Dr. John Weyant and several graduate students from Stanford University to develop a quantitative integrated assessment framework for malaria (see Hartman et al., 2002 in Table 3). This work built on an earlier EPRI study that examined the effects of climate change on infectious disease in the context of an integrated assessment framework (see Chan et al. in Table 3). The linkages identified include disease transmission dynamics, ecologic factors, and

sociologic factors. The goal of this effort was to develop a credible quantitative integrated model of the important direct and indirect effects of climate change on the incidence of malaria.

Malaria is one of the most predominant infectious diseases worldwide, endemic in many areas of the tropics. There is much interest in understanding whether climate change would change the range of the *Anopheles* mosquito, especially in subtropical and highland areas. Most of the published research reports qualitative or descriptive results of the direct and indirect factors that may influence the incidence of this disease. This effort built on this existing knowledge base to develop insights into the sensitivity of the malaria system to various drivers, including ecology, sociology, and climate.

The authors developed a model of future climate suitability for stable *Plasmodium falciparum* malaria transmission in Zimbabwe. Current climate suitability for stable malaria transmission was based on the MARA/ARMA model of climatic constraints on the survival and development of the *Anopheles* vector and the *Plasmodium falciparum* malaria parasite. The COSMIC program was used to explore the potential future geographic distributions of malaria using 16 projections of climate in 2100.

Results are provided in detail in Hartman et al., 2002 in Table 3. In the baseline climate suitability scenario, 40% of Zimbabwe was suitable for stable transmission. The magnitude and direction of change varied for the four GCMs, following the direction and amplitude of projected precipitation change. Under the smallest scenario of climate change, with a climate sensitivity of 1.4°C and a stabilization of greenhouse gases at 350 ppmv, the projected net change was small with a maximum increase of 5% in the area of stable malaria transmission in the UKMO and GISS models and a decrease of 1% in the CCC GCM. Under the highest scenario of climate change, where the climate sensitivity was set at 4.5°C and the stabilization scenario was equivalent to 750 ppmv, the projected net change varied from the HEND model projecting that only 3% of Zimbabwe may be suitable for malaria transmission to the UKMO model suggesting that 96% of Zimbabwe may have climate suitable for stable transmission. Even with little net change in climate suitability, as in the CCC 350_1.4°C scenario, there is the potential for redistribution of areas that are suitable, with the central plateau becoming more suitable for transmission and the lowveld areas becoming slightly less suitable.

The results suggest that, assuming no future human-imposed constraints on malaria transmission, changes in temperature and precipitation could alter the geographic distribution of malaria in Zimbabwe, with previously unsuitable areas of dense human population becoming suitable for transmission. Across all scenarios, the highlands become more suitable for transmission, while the lowveld and areas with low precipitation show varying degrees of change, depending on climate sensitivity and

greenhouse gas emission stabilization scenarios, and depending on the general circulation model used. The methods employed can be used within or across other African countries.

Other deliverables from this collaborative effort include the development of an empirical framework for better understanding the key drivers of heat-related illness, significant contributions to the U.S. National Impacts Assessment sections of health, an assessment of the potential effects of climate variability and change on prevalence of vector- and rodent-borne diseases, and a study of the effect of cold spells and heat waves on mortality rates in the Netherlands.

In addition, the EPRI-federal joint program is expected to result in a significant stream of publications.

1.5 Impacts of Climate Change on Ecosystems and Biodiversity in the United States

The objective of this research is to develop an improved understanding of the transient effects of climate change on ecosystems and biodiversity. Ecosystem change has enormous implications in terms of our understanding of the carbon cycle and in terms of potential impacts of climate change. The EPRI research effort this topic generates, analyzes, and synthesizes scientific knowledge about ecosystem and biodiversity impacts of climate change, and evaluates the consequences should significant ecosystem changes occur.

The technical approach is to provide continuing support and guidance to the Vegetative Ecosystem Modeling and Analysis Project (VEMAP-2). EPRI was a founder of the VEMAP consortium in 1995 and an anchor supporter along with NASA and the U.S. Forest Service ever since. The initial phase of the VEMAP project brought together six ecological modeling teams to study the biogeographical and biogeochemical aspects of climate change. The contractors compared the simulations of three biogeography models (BIOME2, DOLY, and MAPSS) and three biogeochemistry models (BIOME-BGC, CENTURY, and TEM) for the conterminous United States under contemporary conditions of atmospheric CO_2 and climate. The contractors also compared the simulations of these models under doubled CO_2 and a range of climate scenarios. In addition, the contractors simulated a coupled response by using the biogeography model outputs as inputs to the biogeochemistry models.

Phase II of VEMAP was initiated in 1998. It has focused on ecosystem responses to transient changes in climate and the chemistry of the atmosphere. Changes in climate and atmospheric CO_2 concentration have the potential to change the function and structure of terrestrial ecosystems. In VEMAP II, the contractors have explored terrestrial ecosystem responses to past and possible future transient changes in these physical and chemical environmental factors. This

focus on transient dynamics has brought increased realism and increased interpretive potential to questions of ecosystem response to global changes.

Commission funding was used to support two of the key VEMAP members, the Marine Biological Laboratory in Woods Hole Massachusetts and Lund University in Sweden. One of the key activities of VEMAP during this period was the central role it played in supplying ecosystem inputs to the U.S. National Impacts Assessment. This research also played a large role in evaluating and refining the models that provided the basis for the California-specific ecosystem assessment.

Key deliverables from these efforts include a range of papers from VEMAP members. Some of the papers addressed fundamental modeling choice such as approaches for simulating the competition between tree and grass ecosystems. Others focused on the role of ecosystems in determining net North American carbon fluxes. Four deliverables from this effort are listed in Table 4.

Table 4. Deliverables related to impacts of climate change on ecosystems and biodiversity in the United States

Deliverable	Date
C. Daly, D. Bachelet, J.M. Lenihan, R.P. Neilson, W. Parton, and D. Ojima, "Dynamic Simulation of Tree-Grass Interactions for Global Change Studies"	Submitted to *Ecological Applications* on 29 July 1998
D. Schimel, J. Melillo, H. Tian, A.D. McGuire, D. Kicklighter, T. Kittel, N. Rosenbloom, S. Running, P. Thornton, D. Ojima, W. Parton, R. Kelly, M. Sykes, R. Neilson, B. Rizzo, and L. Pitelka, "Carbon Storage by Natural and Agricultural Ecosystems of the US 1980-1993"	Accepted by *Science* on 15 December 1999
Melillo, J., H. Tian, D. Kicklighter, A.D. McGuire, J. Clein, B. Moore III, and C. Vörösmarty, "Ecological Constraints on Carbon Sequestration in North America"	Submitted to *Science* on October 2000
Bachelet, D., R.P. Neilson, T. Hickler, R.J. Drapek, J.M. Lenihan, M.T. Sykes, B. Smith, and S. Sitch, "Past and Future Carbon Sources and Sinks in the Conterminous USA"	Submitted to *Global Biogeochemical Cycles* on 17 August 2001

1.6 Effects of Climate Change on Market-Based Systems

The objective of this research is to develop an improved understanding of the potential effects of climate change on sectors of the economy (i.e., here we are looking at the potential effects of changes in climate on the economy rather than the potential effects of climate policy on the economy). Much of the concern about climate change relates to concerns about potential effects

on particularly climate-sensitive sectors of the economy such as agriculture, water resources, coastal properties, and timber. The results of this U.S. regional research effort provided the foundation for the California-specific impacts analyses documented throughout this report and will be discussed only briefly.

Commission funding contributed to the development of a U.S. regional assessment of potential climate effects. The study developed estimates of potential market impacts from climate change in regions of the United States. It extended earlier EPRI-funded research to develop national-level estimates of impacts in key market sectors that are expected to be impacted by climate change [*The Economic Impact of Climate Change on The United States Economy* (edited by Robert Mendelsohn and James Neumann) Cambridge University Press, Cambridge, UK, 1998]. The regional impacts effort utilized and, in some cases, extended the analytical approaches developed for these national-level sectoral studies. The research examined six regions within the contiguous United States that correspond roughly to the regions evaluated in the U.S. National Assessment Report. The six regions include the states in the Northeast (12), Southeast (11), Lake States (8), Great Plains (8), Southwest (6), and Pacific Northwest (3). This grouping corresponds to available economic data and reflects relatively homogeneous conditions across states. The sectors to be analyzed include agriculture, forestry, energy, water, and coastal effects.

Because climate change and its potential effects are expected to occur in the future, the study relied on projected 2060 base economic assumptions. Thus, the study started with estimates of population and economic activity in each region in 2060. Relying on the climate sensitivities estimated for the national study, the study projected regional impact estimates for a set of climate scenarios. The climate scenarios included three uniform change temperature scenarios (1.5°, 2.5°, and 5.0°C) and four precipitation change scenarios (-10, +0, +7, and +15%). This is a broader range of precipitation scenarios than was considered in the national-level study. The broader range of precipitation scenarios is important on a regional level since regions may well experience precipitation reductions as well as increases. The CO_2 atmospheric concentration was assumed to be 530 ppmv (710 ppmv in the forestry study). Regional impacts were estimated for each sector for all 12 uniform climate scenarios. In addition, estimates were made for a limited set of GCM climate scenarios. The results for this research are published in Mendelsohn, Robert (ed.), *Global Warming and the American Economy: A Regional Assessment of Climate Change*, Edward Elgar Publishing Inc., 2001.

Other key results from this research effort were the completion of the first long-term open-air CO_2 enrichment study, an effort that examined the impacts of elevated CO_2 on Ponderosa Pine in California, soil studies from the Duke Forest FACE experiment, and an assessment of the implications of uncertainty in climate projections for uncertainty in impacts projections. The four deliverables for this effort are listed in Table 5.

Table 5. Deliverables related to effects of climate change on market-based systems

Deliverable	Date
D. Tissue, K. Griffin, and J. Ball, "Photosynthetic Adjustment in Field-grown Ponderosa Pine Trees after Six Years Exposure to Elevated CO_2"	Submitted to *Tree Physiology* on 31 March 1998
J. Andrews, K. Harrison, R. Matamala, and W. Schlesinger, "Separation of Root Respiration from Total Soil Respiration Using ^{13}C Labeling During Free-Air CO_2 Enrichment (FACE)"	Submitted to *Soil Science Society of America Journal* on 15 October 1998
Mendelsohn, R. (ed.), *Global Warming and the American Economy: A Regional Assessment of Climate Change*	Published by Edward Elgar Publishing, Inc. in 2001
Mendelsohn, R., M. Schlesinger, and L. Williams (2000), "Comparing Impacts across Climate Models"	Published in *Integrated Assessment*, 1, 37-48

1.7 Framework for Integrated Assessment of Global Climate Change Policy Proposals

The objective of this task is to develop models capable of comparing the costs and benefits of climate management alternatives generated by policymakers. EPRI's approach is to co-fund development and refinement of several integrated assessment modeling systems that employ alternative, complementary approaches. Multiple frameworks are required to demonstrate the robustness of policy results and provide the capability to examine a wide range of critical issues. Preliminary frameworks developed with EPRI support include (a) a detailed, process-level Global Change Assessment Model (GCAM) developed by Battelle Pacific Northwest Nationla Laboratories (PNNL) and its reduced-form counterpart, Mini-CAM, and the Second Generation Model (SGM); (b) the EPPA and Integrated Global Systems Model (IGSM) developed at MIT; and (c) the Integrated Climate Assessment Model (ICAM) developed by Carnegie-Mellon University. The integrated assessment frameworks are research-grade models that incorporate modules representing the major processes of concern with respect to climate change. Key features include (a) simulation of future greenhouse gas emissions based on economic growth assumptions, (b) simulation of carbon cycle and other processes which determine atmospheric greenhouse gas concentrations, (c) simulation of climate system responses to changes in atmospheric greenhouse gas concentrations, and (d) simulation of the reaction of environmental and economic systems to changes in key climate variables. The research effort supported extension of the existing frameworks to incorporate new scientific and economic information and to improve analytical methodologies. Key enhancements between 1998 and 2002 include incopration of multiple greenhouse gases (emissions, reduction cost curves, and life cycle) in the models, more detailed treatment of sinks (forests and land-use change), and improved models of the energy economy.

Commission funds were used to supplement the development of the PNNL integrated assessment models to modify the MAGICC model so that it can be integrated into the Mini-CAM framework. MAGICC calculates atmospheric concentrations of greenhouse gases based on scenarios of emissions and assumptions about removal of gases from the atmosphere. It also provides regional gridded estimates of temperature and precipitation for these greenhouse gas concentration levels. Including MAGICC in the Mini-CAM allows more detailed agricultural adaptation and impact studies to be conducted within the integrated assessment framework. Commission funds were also used to create an enhanced transportation sector in the SGM. Transportation currently contributes about one-third of U.S. CO_2 emissions, and transportation emissions around the world are expected to increase rapidly over the next few decades. Including a more detailed transportation sector in the SGM allows more credible analyses of potential climate policies and more complete asssessments of the potential for hydrogen to play a key role in the global energy system.

Key deliverables from this effort (note that the methodological advances in PNNL's integrated assessment framework resulted in applications papers listed in later research areas that detail applications of frameworks for integrated assessment or technology assessment purposes) include pioneering work at MIT to incorporate non-CO_2 greenhouse gases in their integrated assessment framework, efforts by MIT to link their two-dimensional global climate model to regional and local air pollution models, an ongoing effort by MIT to examine uncertainty in integrated assessments and how that uncertainty propogates through the model, and an assessment by Manne and Richels of the implications of including endogenous technology cost reductions (learning by doing) in an integrated assessment model. Four key deliverables from this effort are listed in Table 6.

Table 6. Deliverables related to framework for integrated assessment of global climate change policy proposals

Deliverable	Date
J. Reilly, R. Prinn, J. Harnisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, J. Melillo, P. Stone, A. Sokolov, and C. Wang, "Multi-Gas Assessment of the Kyoto Protocol"	Published in *Nature*, 40, 17 October 1999.
Mayer, M., C. Wang, M. Webster, and R.G. Prinn, "Linking Local Air Pollution to Global Chemistry and Climate"	Submitted to *J. Geophys. Res.* on June 2000. Also available in *MIT Joint Program Report 63* (2000).

Table 6. Deliverables related to framework for integrated assessment of global climate change policy proposals (cont.)

Deliverable	Date
Webster, M.D., M. Babiker, M. Mayer, J.M. Reilly, J. Harnisch, R. Hyman, M.C. Sarofim, and C. Wang. "Uncertainty in Emissions Projections for Climate Models"	Submitted to *Atmospheric Environment* on 31 July 2001. Also published in *MIT Joint Program on the Science and Policy of Global Change*, Report No. 79, August 2001 (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt79.pdf).
A. Manne and R. Richels, "The Impact of Learning-by-Doing on the Timing and Costs of CO_2 Abatement"	Submitted for a special issue of *Energy Economics* on 18 July 2002.

1.8 Integrated Assessments of Costs and Benefits of Climate Change Management Proposals

The objective of this task is to apply models capable of comparing the costs and benefits of climate management alternatives generated by policymakers. National and international proposals for managing greenhouse gases are evaluated, providing a consistent and comprehensive basis for policy makers to use in weighing alternative approaches.

Commission funding contributed to assessments conducted by the MIT Joint Program on Global Change. These funds were used to partially fund efforts to (1) extend current analyses of multi-gas calculations and sinks (MIT efforts to date have provided many of the initial analytical insights into multi-gas constraints), (2) extend analyses of the role of international emissions trading (this work will investigate the relationship between the marginal abatement curves generated by the MIT computable general equilibrium model and technology curves), (3) extend analyses of the effects of local air pollution policy on global climate, (4) provide for analysis of emerging policy proposals, and (5) support the integration of several new submodules into the IGSM. This contract will also help support development of an updated project description report. The output of the MIT program is large and important. For a complete listing see http://web.mit.edu/afs/athena.mit.edu/org/g/globalchange/www/.

Key deliverables from this overall research effort address topics such as the role of the Kyoto Protocol in achieving stabilization of atmospheric concentrations of greenhouse gases, the long-range objective of the U.N. Framework Convention on Climate Change; the importance of capital stock tunrover in addressing the climate issue, new ways of assessing the relative contributions of reductions of the various greenhouse gases as part of a multi-gas climate policy,

an assessment of the economics of emission reductions, and an assessment of the implications of uncertainties in key climate system properties. Five key deliverables from this effort are listed in Table 7.

Table 7. Deliverables related to integrated assessments of costs and benefits of climate change management proposals

Deliverable	Date
A.S. Manne and R.G. Richels, "The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?"	Submitted to the *Energy Journal* on 9 September 1998.
H. Jacoby and I.S. Wing, "Adjustment Time, Capital Malleability and Policy Cost"	Published in *The Energy Journal*, Kyoto Special Issue, 73-92, 1999.
Manne, A.S. and R.G. Richels (2000), "A Multi-Gas Approach to Climate Policy – with and without GWPs"	*Nota Di Lavoro Della Fondazione Eni Enrico Mattei – Fondazione Eni Enrico Mattei Working Paper Series*, 44.2000, June (available on the Internet at the following address: http://www.feem.it/web/activ/wp/abs00/00.html).
Edmonds, J. and R. Sands, "What are the Control Costs of Reducing Carbon Emissions – The Costs of Reducing the Paths of CO_2 Concentrations"	Published in Chapter 6 of the fourth volume in *The Economics of Important Public Policy Issues*, University of Chicago Press, in press. The purpose of the conference "Global Climate Change: The Science, Economics, and Politics" (which was held on April 6, 2001) was to produce a volume that will serve as a "handbook" on global climate change that will be readily accessible to policy makers. The conference was conducted by the George Bush School of Government and Public Service, Texas A&M University.
C. Forest, P. Stone, A. Sokolov, M. Allen, and M. Webster, "Quantifying Uncertainties in Climate System Properties with the Use of Recent Climate Observations"	*Science*, 295, pp. 113-117, 4 January 2002.

1.9 Analysis of the Costs of CO_2 Emission Reduction Proposals

The objective of this research is to develop and apply models that provide useful insights into the potential costs of climate policies. The approach is to hire world-class experts to develop and apply models to address policy costs at international, regional, national, state, and sectoral levels. This research also provides essential cost information for use in integrated assessments of costs and benefits. Efforts funded over the term of this contract include research at MIT and Battelle on the cost components of their models, development and application of the MERGE model by

Alan Manne of Stanford and Richard Richels of EPRI, development and application of the State-Level Impact Model (SIAM) at Charles River Associates, support for the Stanford Energy Modeling Forum, and other, shorter-term efforts.

Commission funds under this task provided partial support for Richard Richels and Alan Manne to extend and apply the MERGE model. Three topics will be explored: (1) implications of including a suite of non-CO_2 greenhouse gases, (2) the implications of an "escape valve" policy, and (3) implications of the United States not ratifying the Kyoto Protocol. Manne and Richels have produced several papers based on utilizing the new multi-gas version of MERGE, including the *Nature* paper listed in Table 8 that explores different approaches for valuing reductions among greenhouse gases in implementing climate policies. Initial escape valve analyses by Manne and Richels led to the commissioning of a paper by MIT on the subject.

All of the EPRI contractors funded by this task contributed to the landmark special issue of *Energy Policy* titled "The Costs of the Kyoto Protocol: A Multi-Model Evaluation." Five key deliverables from this research area are listed in Table 8.

Table 8. Deliverables related to analysis of the costs of CO_2 emission reduction proposals

Deliverable	Date
E.J. Balistreri, "Operationalizing Equilibrium Unemployment: A General Equilibrium External Economies Approach"	Submitted to the *Journal of Economic Dynamics and Control* on 6 November 1998
C. MacCracken, J. Edmonds, S. Kim, and R. Sands, "Economics of the Kyoto Protocol"	Published in *The Energy Journal*, Kyoto Special Issue, 25-71, 1999
Babiker, M., J.M. Reilly, and H.D. Jacoby (2000), "The Kyoto Protocol and Developing Countries"	Published in *Energy Policy*, 28, 525-536
Manne, A.S. and R.G. Richels, "An Alternative Approach to Establishing Trade-offs Among Greenhouse Gases"	Published in *Nature*, volume 410, pp. 675-7, 5 April 2001
R.C. Hyman, J.M. Reilly, M.H. Babiker, A. De Masin, and H.D. Jacoby, "Modeling Non-CO_2 Greenhouse Gas Abatement"	Submitted to *Environmental Modeling and Assessment* on 4 November 2002

1.10 Assessment of the Impacts of the Kyoto Protocols on U.S. Competitiveness

The objective of this research is to produce analyses of trade issues created by climate policies. The approach is to develop models capable of examining a wide range of global trade issues in

the context of climate policies. If only developed countries and countries in transition to market economies (those belonging to Annex I of the U.N. Framework Convention on Climate Change) adopt policies to reduce greenhouse gas emissions, industries in developing countries will have a systematic cost advantage over similar industries in Annex I countries. This will also be the case if only a subset of developing countries agree to limit emissions. In this case, the advantage will accrue to nonparticipating developing countries. This ongoing EPRI research developed and applied a modeling framework to assess the impact of climate change management proposals on U.S. competitiveness, a critical issue to California given its role in the U.S. economy.

The Commission did not provide funding for this task. Four key deliverables are listed in Table 9. They explored the international implications of restrictions on international trade (e.g., supplementarity constraints that were proposed by the European Union in the late 1990s as part of the Kyoto Protocol implementation discussions), and multisector studies of the implications for competitiveness of various forms of international climate policy.

Table 9. Deliverables related to assessment of the impacts of the Kyoto Protocols on U.S. competitiveness

Deliverable	Date
P.M. Bernstein, W.D. Montgomery, T.F. Rutherford, and G-F. Yang, "Effects of Restrictions on International Permit Trading: The MS-MRT Model"	Submitted to the *Energy Journal* on 9 December 1998
Böhringer, C. and T.F. Rutherford, "Decomposing the Cost of Kyoto – A Global CGE Analysis of Multilateral Policy Impacts"	Submitted to *The Journal of Environmental Economics and Management* on August 2000
Böhringer, C. and T.F. Rutherford, "Carbon Abatement and International Spillovers — A Decomposition of General Equilibrium Effects"	Accepted by *Environmental and Resource Economics* on 23 August 2001
M. Babiker and T. Rutherford, "The Economic Effects of Border Measures in Subglobal Climate Agreements"	Submitted to *The Energy Journal* on 25 August 2002

1.11 Costs of Adaptation Options

The objective of this task is to provide information, data, and methodologies for assessing the feasibility and cost-effectiveness of adaptation options for environmental and economic systems potentially affected by global climate change. The emphasis of international and domestic policy discussions about climate have focused on defining near-term national emissions targets. Adaptation actions that make good business sense could provide some insurance against climate change.

Commission funding for this task was reprogrammed from the collaborative program to extend the analyses developed by UC-Davis for the California-specific analyses.

The deliverable for this effort (Table 10) was a research plan for adaptation that was developed in consultation with a broad group of stakeholders and researchers. The research plan eventually led to a workshop on adaptation in Potsdam, Germany, in Fall 2001 and to a book scheduled for release in July 2003.

Table 10. Deliverable related to costs of adaptation options

Deliverable	Date
"Adaptation to Climate Change – A Research Agenda"; sponsored by EPRI, Department of Energy, Environmental Protection Agency, National Oceanic and Atmospheric Administration, National Science Foundation, and H. John Heinz III Center for Science, Economics and the Environment; prepared by The Washington Advisory Group, LLC; Washington, DC	Printed May 1999

1.12 Energy Technology Strategy for Addressing Global Climate Change

The objective of this task is to develop a technology strategy for addressing climate change. The approach EPRI has taken is to initiate a multiyear, international collaborative research effort centered at Battelle Pacific Northwest Laboratory. If concern about possible climate change leads to requirements to substantially reduce greenhouse gas emissions, there may be significant costs to the global economy. The size of the ultimate bill, however, can be reduced through successful R&D on both the supply and demand sides of the energy sector. Economic analysis suggests that the potential savings could be trillions of dollars over the next century. These savings would free up valuable resources for further addressing the threat of climate change or for meeting other societal needs. The ongoing Energy Technology Strategy Project, funded by EPRI and over a dozen international co-funders and collaborators, has two principal activities. The assessment phase, which began in 1998, developed regional energy projections, prepared an inventory of current technology development efforts, and characterized the attributes of new technologies needed to reduce the costs of future carbon constraints. The strategy development phase, the primary activity during 1999 and early 2000, performed a portfolio analysis to identify attractive R&D opportunities, and assess transition and implementation issues.

Commission funding supported a wide range of the project activities, including assessments of the efficacy of regulatory strategies for climate change, study of the economic principles for guiding development of future climate policies, exploration of principles for implementing a technology strategy, and creation of a high-level document summarizing key project findings.

Results from these efforts have been widely disseminated through presentations, briefings, peer-reviewed publications and through a high-level summary document, *A Global Energy Technology Strategy for Addressing Climate Change*, available in electronic format at http://gtsp.pnl.gov. Phase II of the project is now under way; it will explore key technology areas in much greater depth and will address key issues in implementing a technology strategy. The project has had a substantial impact on elevating the role of technology in both domestic and international climate policy discussions. Table 11 lists deliverables related to energy technology strategy.

Table 11. Deliverables related to energy technology strategy for addressing global climate change

Deliverable	Date
J. Edmonds, J. Dooley, and S. Kim, "Long-Term Energy Technology Needs and Opportunities for Stabilizing Atmospheric CO_2 Concentrations"	Submitted to the *American Council on Capital Formation* on 27 September 1998
P.R. Shukla, "Technology Strategy for India: Modelling and Analysis of Energy and Carbon Mitigation"	Submitted for presentation at the *Steering Group Meeting for Technology Strategy Project* organized by Battelle, Pacific Northwest National Laboratory, Washington D.C., 16 October 1998
J.J. Dooley and P.J. Runci, "Developing Nations, Energy R&D, and the Provision of a Planetary Public Good: A Long-term Strategy for Addressing Climate Change"	Accepted pending revision to the *Journal of Environment and Development*, August 1999
"Mid- and Long-term Strategies for Technology Deployment to Address Climate Change in China – Beijing Workshop Report"; sponsored by the Global Technology Strategies Project; Beijing, People's Republic of China; 6-7 May 1999	Published by Battelle 1999
Edmonds, J.A., P. Freund, and J.J. Dooley (2000), "The Role of Carbon Management Technologies in Addressing Atmospheric Stabilization of Greenhouse Gases,"	Proceedings of the 5th International Conference on Greenhouse Gas Control Technologies (GHGT5), Cairns Convention Centre, Australia, 13-16 August
Edmonds, J., "Atmospheric Stabilization: Technology Needs, Opportunities, and Timing"	Submitted to the Aspen Institute (for peer-review and inclusion in published workshop proceedings) on 8 September 2001
J. Edmonds, J. Clarke, J. Dooley, S. Kim, and S. Smith, "Stabilization of CO_2 in a B2 World: Insights on The Roles of Carbon Capture and Disposal, Hydrogen, and Transportation Technologies"	Accepted for a special issue of *The Energy Journal* on 22 October 2002

2. Conclusions

It should be noted that, as with all successful research efforts, the real benefits of this research are not the specific deliverables (see Table 12 for specific deliverables), but rather how these findings influence future research efforts and future policies that help society to effectively address the issue of climate change. The scientific and economic contributions made possible by the Commission participation in EPRI's collaborative research program are substantial in their own right and have significantly affected U.S. and global thinking about the science and economics of climate change. Key benefits from the research include the following:

- Improved the understanding of regional climate modeling in California.
- Provided significant contributions to carbon cycle findings in the IPCC Third Assessment Report.
- Provided the analytical basis for ecosystem assessments in the U.S. National Impacts Assessment.
- Significantly influenced the market impacts findings in the U.S. National Impacts Assessment.
- Fundamentally advanced the understanding of the role of non-CO_2 greenhouse gases in international domestic efforts to address climate change.
- Helped elevate the role of technology innovation in international and domestic discussions of climate policies.
- Continued to inform policy discussions regarding the key principles of effective climate policies.

Climate change is a truly global issue. The collaborative research efforts funded by the Commission have provided benefits both to California's citizens and to others around the world.

Table 12. Overview of collaboratively funded deliverables 1998-2002

Research topic	Deliverable	Date
Assessment of Uncertainty in Climate Change Predictions	R.W. Arritt, W.J. Gutowski, Jr., and E.S. Takle, "Regional Climate Simulations for Impact Assessment under the Project to Intercompare Regional Climate Simulations (PIRCS)	*EPRI Interim Report*, TR-111887 Printed December 1998
	R.L. Wilby, T.M.L. Wigley, D. Conway, P.D. Jones, B.C. Hewitson, J. Main, and D.S. Wilks, "Statistical Downscaling of General Circulation Model Output: A Comparison of Methods"	Published in *Water Resources Research*, 34, 2995-3008, 1998 November
	K.E. Kunkel, R.A. Pielke Jr., and S.A. Changnon, "Temporal Fluctuations in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review"	Published in the *Bulletin of the American Meteorological Society*, 80(6), 1077-1098, June 1999
	Wilby, R.L. et al. (2000), "Hydrological Responses to Dynamically and Statistically Downscaled Climate Model Output"	Published in *Geophysical Research Letters*, 27(8), 1199-1202.
	Meehl, G.A., W. Collins, B. Boville, J.T. Kiehl, T.M.L. Wigley and J.M. Arblaster (2000), "Response of the NCAR Climate System Model to Increased CO_2 and the Role of Physical Processes"	Published in *Journal of Climate*, 13, 1879-1898.
	Pan, Z., J.H. Christensen, R.W. Arritt, W.J. Gutowski Jr., E.S. Takle, and F. Otieno, "Evaluation of Uncertainties in Regional Climate Change Simulations"	Accepted by *Journal of Geophysical Research – Atmospheres* on 27 March 2001.
	"Analysis of Regional Climate Model Results for Simulations of Future Climates"	Submitted for publication on 3/15/02, published April 2002, *EPRI Technical Report*, 1005162.
	Workshops on Fast-Breaking Climate Issues	Workshop overview featured in *Quick News* (June 2001 issue). Workshop agenda, participants, bibliography, and presentations posted to the ACACIA website (www.acacia.ucar.edu/workshops.html).
	Hakkarinen, C., S. Nishinomiya, and T. Wigley, "Climate Change and Precipitation Extremes – Summary of an ACACIA Workshop"	Submitted to the *Transactions of the American Geophysical Union* on 27 December 2001.

Table 12. Overview of collaboratively funded deliverables 1998-2002 (cont.)

Research topic	Deliverable	Date
Assessment of Uncertainty in Climate Change Predictions (cont.)	R.L. Wilby and T.M.L. Wigley, "Future Changes in the Distribution of Daily Precipitation Totals across North America"	*Geophysical Research Letters*, 29(7), pp. 39-1 – 39-4, 2002.
	W.J. Gutowski, S.G. Decker, R.A. Donavon, Z. Pan, R.W. Arritt, and E.S. Takle, "Temporal Scale of Precipitation Errors in a Central U.S. Regional Climate Simulation"	Submitted to *Journal of Climate* on 2 July 2002
	C.J. Anderson, R.W. Arritt, E.S. Takle, Z. Pan, W.J. Gutowski, R. da Silva, and PIRCS modelers, "Hydrologic Processes in Regional Climate Model Simulations of the Central United States Flood of June-July 1993"	Submitted to *Journal of Hydrometeorology* on 6 February 2002.
Carbon Cycle Analyses	D.W. Kicklighter, M. Bruno, S. Dönges, G. Esser, M. Heimann, J. Helfrich, F. Ift, F. Joos, J. Kaduk, G.H. Kohlmaier, A.D. McGuire, J.M. Melillo, R. Meyer, B. Moore III, A. Nadler, C. Prentice, W. Sauf, A.L. Schloss, S. Sitch, U. Wittenberg, and G. Würth, "A First-Order Analysis of the Potential Role of CO_2 Fertilization to Affect the Global Carbon Budget: A Comparison of Four Terrestrial Biosphere Models"	Accepted by *Tellus* on 20 October 1998
	R. Meyer, F. Joos, G. Esser, M. Heimann, G. Hooss, G. Kohlmaier, W. Sauf, R. Voss, and U. Wittenberg, "The Substitution of High-Resolution Terrestrial Biosphere Models and Carbon Sequestration in Response to Changing CO_2 and Climate"	Published in *Global Biogeochemical Cycles*, 13(3), 785-802, September 1999
	McGuire, A.D., S. Sitch, J.S. Clein, R. Dargaville, G. Esser, J. Foley, M. Heimann, F. Joos, J. Kaplan, D.W. Kicklighter, R.A. Meier, J.M. Melillo, B. Moore III, I.C. Prentice, N. Ramankutty, T. Reichenau, A. Schloss, H. Tian, L.J. Williams, and U. Wittenberg, "Carbon Balance of the Terrestrial Biosphere in the Twentieth Century: Analyses of CO_2, Climate and Land-use Effects with Four Process-based Ecosystem Models"	Accepted for publication in *Global Biogeochemical Cycles* on 22 September 2000.
	Joos, F., I.C. Prentice, S. Sitch, R. Meyer, G. Hooss, G. Plattner, S. Gerber, and K. Hasselmann, "Global Warming Feedbacks on Terrestrial Carbon Uptake under the IPCC Emission Scenarios"	Published in *Global Biogeochemical Cycles*, Vol. 15, No. 4, p. 891, 2001.

Table 12. Overview of collaboratively funded deliverables 1998-2002

Research topic	Deliverable	Date
Carbon Cycle Analyses (cont.)	R.J. Dargaville, M. Heimann, A.D. McGuire, I.C. Prentice, D.W. Kicklighter, F. Joos, J.S. Clein, G. Esser, J. Foley, J. Kaplan, R.A. Meier, J.M. Melillo, B. Moore III, N. Ramankutty, T. Reichenau, A. Schloss, S. Sitch, H. Tian, L.J. Williams, and U. Wittenberg, "Evaluation of Terrestrial Carbon Cycle Models with Atmospheric CO_2 Measurements: Results from Transient Simulations Considering Increasing CO_2 Climate and Land-use Effects"	Submitted to *Global Biogeochemical Cycle* on 8 August 2002.
Impacts of Climate Change on Human Health	N.Y. Chan, F. Smith, T.F. Wilson, K.L. Ebi, and A.E. Smith, "An Integrated Assessment Framework for Climate Change and Infectious Diseases"	Submitted to *Environmental Health Perspectives* on 30 September 1998 Published in *Environmental Health Perspectives* 1999;107:329-337.
	N.Y. Chan, M.T. Stacey, A.E. Smith, K.L. Ebi, and T.F. Wilson, "An Empirical Mechanistic Framework for Heat Related Illness"	Submitted to *Climate Research* on 20 December 1999 Published in Climate Research 2001;16:133-143.
	Bernard, S.M. and K.L. Ebi, "Comments on the Process and Product of the Health Impacts Assessment Component of the National Assessment of the Potential Consequences of Climate Variability and Change for the United States"	Submitted to *Environmental Health Perspectives* on 8 December 2000. Published in *Environmental Health Perspectives* 2001;109(Suppl 2):177-184
	Bernard, S., J. Samet, A. Grambsch, K.L. Ebi, and I. Romieu, "The Potential Impacts of Climate Variability and Change on Air Pollution-related Health Effects in the United States"	Submitted to *Environmental Health Perspectives* on 19 September 2000. Published in *Environmental Health Perspectives* 2001:109(Suppl 2):199-210.

Table 12. Overview of collaboratively funded deliverables 1998-2002 (cont.)

Research topic	Deliverable	Date
Impacts of Climate Change on Human Health (cont.)	Gubler, D.J., P.R. Reiter, J.A. Patz, K.L. Ebi, W. Yap, and R. Nasci, "Climate Variability and Change in the United States: Potential Impacts on Vector- and Rodent-borne Diseases"	Submitted to *Environmental Health Perspectives* in October 2000. Published in *Environmental Health Perspectives* 2001:109(Suppl 2):223-233.
	Huynen, M., P. Martens, D. Schram, M. Weijenberg, and A. Kunst, "The Impact of Cold Spells and Heat Waves on Mortality Rates in the Dutch Population"	Submitted to *Environmental Health Perspectives* on 14 September 2000. Published in *Environmental Health Perspectives.* 2001:109**,** 463-70.
	Woodruff, R., C.S. Guest, M.G. Garner, N. Becker, J. Lindesay, T. Carvan, and K. Ebi, "Early and Late Warning of Ross River Virus Epidemics Based on Regional Climatic Data in Australia"	Submitted to *Epidemiology* on 21 June 2001. Published in *Epidemiology* 2002;13:384-93.
	J. Hartman, K. Ebi, K.J. McConnell, N. Chan, and J. Weyant, "Climate Suitability for Stable Malaria Transmission in Zimbabwe under Different Climate Change Scenarios"	Published in *Global Change & Human Health*, 3(1), 2002.
Impacts of Climate Change on Ecosystems and Biodiversity in the U.S.	C. Daly, D. Bachelet, J.M. Lenihan, R.P. Neilson, W. Parton, and D. Ojima, "Dynamic Simulation of Tree-Grass Interactions for Global Change Studies"	Submitted to *Ecological Applications* on 29 July 1998
	D. Schimel, J. Melillo, H. Tian, A.D. McGuire, D. Kicklighter, T. Kittel, N. Rosenbloom, S. Running, P. Thornton, D. Ojima, W. Parton, R. Kelly, M. Sykes, R. Neilson, B. Rizzo, and L. Pitelka, "Carbon Storage by Natural and Agricultural Ecosystems of the US 1980-1993"	Accepted by *Science* on 15 December 1999
	Melillo, J., H. Tian, D. Kicklighter, A.D. McGuire, J. Clein, B. Moore III, and C. Vörösmarty, "Ecological Constraints on Carbon Sequestration in North America"	Submitted to *Science* on October 2000.

Table 12. Overview of collaboratively funded deliverables 1998-2002 (cont.)

Research topic	Deliverable	Date
Impacts of Climate Change on Ecosystems and Biodiversity in the U.S. (cont.)	Bachelet, D., R.P. Neilson, T. Hickler, R.J. Drapek, J.M. Lenihan, M.T. Sykes, B. Smith, and S. Sitch, "Past and Future Carbon Sources and Sinks in the Conterminous USA"	Submitted to *Global Biogeochemical Cycles* on 17 August 2001.
Impacts of Climate Change on Market-Based Systems	D. Tissue, K. Griffin, and J. Ball, "Photosynthetic Adjustment in Field-grown Ponderosa Pine Trees after Six Years Exposure to Elevated CO_2"	Submitted to *Tree Physiology* on 31 March 1998
	J. Andrews, K. Harrison, R. Matamala, and W. Schlesinger, "Separation of Root Respiration from Total Soil Respiration Using ^{13}C Labeling During Free-Air CO_2 Enrichment (FACE)"	Submitted to *Soil Science Society of America Journal* on 15 October 1998
	Mendelsohn, R. (ed.), *Global Warming and the American Economy: A Regional Assessment of Climate Change*	Published by Edward Elgar Publishing, Inc. in 2001.
	Mendelsohn, R., M. Schlesinger, and L. Williams (2000), "Comparing Impacts Across Climate Models"	Published in *Integrated Assessment*, 1, 37-48.
Framework for Integrated Assessment of Global Climate Change Policy Proposals	J. Reilly, R. Prinn, J. Harnisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, J. Melillo, P. Stone, A. Sokolov, and C. Wang, "Multi-Gas Assessment of the Kyoto Protocol"	Published in *Nature*, 40, 17 October 1999
	Mayer, M., C. Wang, M. Webster, and R.G. Prinn, "Linking Local Air Pollution to Global Chemistry and Climate"	Submitted to *J. Geophys. Res.* on June 2000. Also available in *MIT Joint Program Report 63* (2000)
	Webster, M.D., M. Babiker, M. Mayer, J.M. Reilly, J. Harnisch, R. Hyman, M.C. Sarofim, and C. Wang, "Uncertainty in Emissions Projections for Climate Models"	Submitted to *Atmospheric Environment* on 31 July 2001. Also published in *MIT Joint Program on the Science and Policy of Global Change*, Report No. 79, August 2001 (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt79.pdf).
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Table 12. Overview of collaboratively funded deliverables 1998-2002 (cont.)

Research topic	Deliverable	Date
Integrated Assessments of the Costs and Benefits of Climate Change Management Proposals	A.S. Manne and R.G. Richels, "The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?"	Submitted to the *Energy Journal* on 9 September 1998
	H. Jacoby and I.S. Wing, "Adjustment Time, Capital Malleability and Policy Cost"	Published in *The Energy Journal*, Kyoto Special Issue, 73-92, 1999
	Manne, A.S. and R.G. Richels (2000), "A Multi-Gas Approach to Climate Policy – with and without GWPs"	*Nota Di Lavoro Della Fondazione Eni Enrico Mattei – Fondazione Eni Enrico Mattei Working Paper Series*, 44.2000, June (available on the Internet at the following address: http://www.feem.it/web/activ/wp/abs00/00.html).
	Edmonds, J. and R. Sands, "What are the Control Costs of Reducing Carbon Emissions – The Costs of Reducing the Paths of CO_2 Concentrations"	Published in Chapter 6 of the fourth volume in *The Economics of Important Public Policy Issues*, University of Chicago Press, in press. The purpose of the conference "Global Climate Change: The Science, Economics, and Politics" (which was held on April 6, 2001) was to produce a volume that will serve as a "handbook" on global climate change that will be readily accessible to policy makers. The conference was conducted by the George Bush School of Government and Public Service, Texas A&M University.
	C. Forest, P. Stone, A. Sokolov, M. Allen, and M. Webster, "Quantifying Uncertainties in Climate System Properties with the Use of Recent Climate Observations"	*Science*, 295, pp. 113-117, 4 January 2002.
Analysis of the Costs of CO_2 Emission Reduction Proposals	E.J. Balistreri, "Operationalizing Equilibrium Unemployment: A General Equilibrium External Economies Approach"	Submitted to the *Journal of Economic Dynamics and Control* on 6 November 1998
	C. MacCracken, J. Edmonds, S. Kim, and R. Sands, "Economics of the Kyoto Protocol".	Published in *The Energy Journal*, Kyoto Special Issue, 25-71, 1999

Table 12. Overview of collaboratively funded deliverables 1998-2002 (cont.)

Research topic	Deliverable	Date
Analysis of the Costs of CO_2 Emission Reduction Proposals (cont.)	Babiker, M., J.M. Reilly, and H.D. Jacoby (2000), "The Kyoto Protocol and Developing Countries"	Published in *Energy Policy*, 28, 525-536.
	Manne, A.S. and R.G. Richels, "An Alternative Approach to Establishing Trade-offs Among Greenhouse Gases"	Published in *Nature*, volume 410, pp. 675-7, 5 April 2001.
	R.C. Hyman, J.M. Reilly, M.H. Babiker, A. De Masin, and H.D. Jacoby, "Modeling Non-CO_2 Greenhouse Gas Abatement"	Submitted to *Environmental Modeling and Assessment* on 4 November 2002.
Assessment of the Impacts of the Kyoto Protocol on U.S. Competitiveness	P.M. Bernstein, W.D. Montgomery, T.F. Rutherford, and G-F. Yang, "Effects of Restrictions on International Permit Trading: The MS-MRT Model"	Submitted to the *Energy Journal* on 9 December 1998
	Böhringer, C. and T.F. Rutherford, "Decomposing the Cost of Kyoto – A Global CGE Analysis of Multilateral Policy Impacts"	Submitted to *The Journal of Environmental Economics and Management* on August 2000.
	Böhringer, C. and T.F. Rutherford, "Carbon Abatement and International Spillovers — A Decomposition of General Equilibrium Effects"	Accepted by *Environmental and Resource Economics* on 23 August 2001.
	M. Babiker and T. Rutherford, "The Economic Effects of Border Measures in Subglobal Climate Agreements"	Submitted to *The Energy Journal* on 25 August 2002.
Costs of Adaptation Options	"Adaptation to Climate Change – A Research Agenda"; sponsored by EPRI, Department of Energy, Environmental Protection Agency, National Oceanic and Atmospheric Administration, National Science Foundation, and H. John Heinz III Center for Science, Economics and the Environment; prepared by The Washington Advisory Group, LLC; Washington, DC	Printed May 1999
Energy Technology Strategy for Addressing Global Climate Change	J. Edmonds, J. Dooley, and S. Kim, "Long-Term Energy Technology Needs and Opportunities for Stabilizing Atmospheric CO_2 Concentrations"	Submitted to the *American Council on Capital Formation* on 27 September 1998
	P.R. Shukla, "Technology Strategy for India: Modelling and Analysis of Energy and Carbon Mitigation"	Submitted for presentation at the *Steering Group Meeting for Technology Strategy Project* organized by Battelle, Pacific Northwest National Laboratory, Washington D.C., 16 October 1998

Table 12. Overview of collaboratively funded deliverables 1998-2002 (cont.)

Research topic	Deliverable	Date
Energy Technology Strategy for Addressing Global Climate Change (cont.)	J.J. Dooley and P.J. Runci, "Developing Nations, Energy R&D, and the Provision of a Planetary Public Good: A Long-term Strategy for Addressing Climate Change"	Accepted pending revision to the *Journal of Environment and Development*, August 1999
	"Mid- and Long-term Strategies for Technology Deployment to Address Climate Change in China – Beijing Workshop Report"; sponsored by the Global Technology Strategies Project; Beijing, People's Republic of China; 6-7 May 1999	Published by Battelle 1999.
	Edmonds, J.A., P. Freund, and J.J. Dooley (2000), "The Role Of Carbon Management Technologies in Addressing Atmospheric Stabilization of Greenhouse Gases",	Proceedings of the 5th International Conference on Greenhouse Gas Control Technologies (GHGT5), Cairns Convention Centre, Australia, 13-16 August.
	Edmonds, J., "Atmospheric Stabilization: Technology Needs, Opportunities, and Timing"	Submitted to the Aspen Institute (for peer-review and inclusion in published workshop proceedings) on 8 September 2001.
	J. Edmonds, J. Clarke, J. Dooley, S. Kim, and S. Smith, "Stabilization of CO_2 in a B2 World: Insights on The Roles of Carbon Capture and Disposal, Hydrogen, and Transportation Technologies"	Accepted for a special issue of *The Energy Journal* on 22 October 2002.