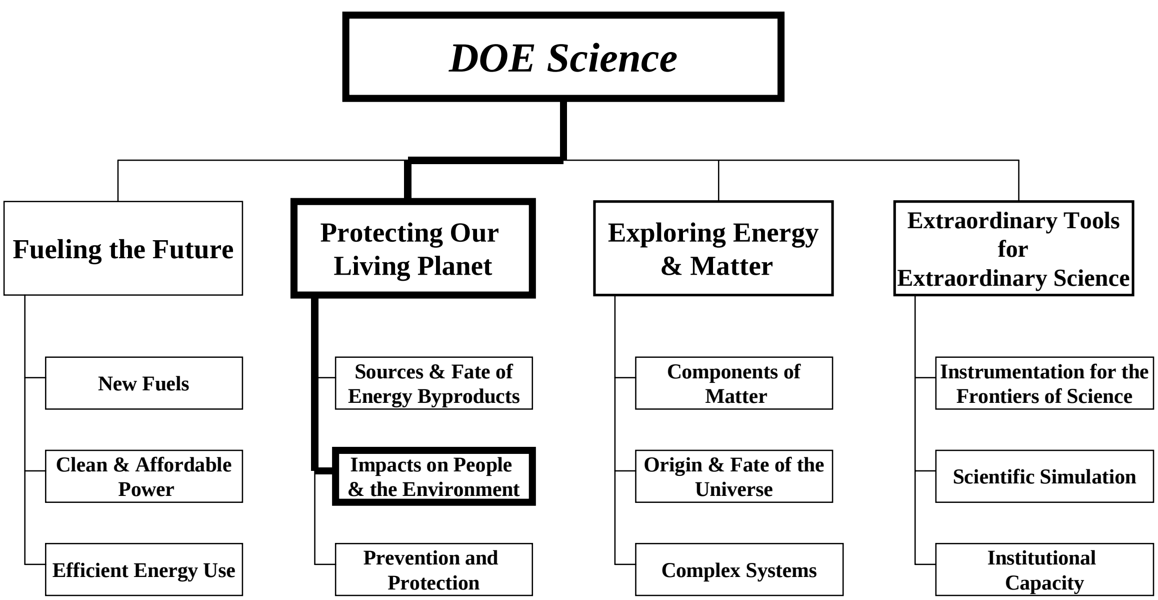
Chapter 6

Impacts on People and the Environment

Scientific Challenge: ***To understand and evaluate the effects of energy byproducts on people and the biosphere.***



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By the time of the Manhattan Project, physicists had almost a half-century of experience with radioactive elements and associated radiation. Several such elements, most notably radium, had been used since the turn of the century in efforts to treat human disease. At the same time, even the earliest scientific pioneers saw that radioactivity was not a benign blessing and that protection standards were necessary. However, it was World War II that demonstrated the atom's incredible power. While the initial focus was on the promise of nuclear energy, a new era had also arrived for biology, medicine, and environmental research.

Even during the war years, biological research was a priority. Among the ongoing efforts were health physics research for improving our knowledge of the potential dangers presented by fissionable materials, reactors, and fission products, and for proposing methods of identifying or avoiding such dangers.

Even the Human Genome Project is a surprising but logical offspring of longstanding research on health issues and genetic effects, research that is or will be the underpinning of radiation protection standards today and in the future.

Energy byproducts also interact with and have impacts on the environment. In addition to characterizing, measuring, and predicting events at the molecular level, scientists must understand their interactions for regional and global scale phenomena. A predictive understanding of relations between energy use and environmental response, including the complex interaction of the ocean, atmosphere, and land system, is required to support decisions in the energy, environment, and economic policy arena. Key to this effort are sophisticated computer models that take into account the physical, chemical, and biological processes involved. A broad spectrum of models is being developed, validated, and employed to predict long-term trends in climate and related environmental systems down to the regional level.

Human Health Impacts and Risks

Description, Objectives, and Research Performers

The Department has a broad base of information on the health effects of exposures to high doses of radiation; however, several recent studies suggest that tissues and whole animals respond to toxic substances differently at high and low doses. Thus, current research on the health effects of low-dose or low-dose-rate exposures to radiation builds on these previous studies and takes advantage of new knowledge and tools gained from the Department's human genome and structural biology research. The goal is to ascertain the health effects, from cells to whole organisms, from low-dose-rate exposures to energy and defense-related insults to ionizing radiation. This program will provide information that will decrease the uncertainty of risk at low levels, help determine the shape of the dose-response relationships after low level exposure, and achieve acceptable levels of human health protection at the lowest possible cost. Research is currently conducted at national laboratories and universities, and, to a lesser extent, other government laboratories.

Research Challenges and Opportunities

Protection of human health is a key driver in developing new energy technologies, in manufacturing, and in cleaning up contaminants from previous energy-related activities. Scientists need to determine what levels of exposure to chemicals and radiation would be consistent with achieving acceptable protection of human health. Current standards for occupational and residential exposures to radiation and chemicals are based on linear, no-threshold models that assume risk is always proportional to dose, i.e., there is no risk only when there is no dose. However, the scientific basis for these assumptions is limited and uncertain at very low doses. Much evidence suggests that the risks from exposure to low doses of radiation and chemicals may be better described by a nonlinear, dose-response relationship.

Research Activities

The program includes research to identify and characterize (1) differences or similarities between the biological damage from and responses to low doses of radiation versus normal oxidative processes in cells; (2) whether there are thresholds for low dose radiation; (3) genetic factors that affect individual sensitivity to and risk from radiation; and (4) how we communicate research results.

Accomplishments

This new research program issued its first solicitation in FY 1998. It is built on over 50 years of DOE research on the health effects of radiation and chemicals, primarily conducted at high doses. Significant (past) accomplishments that underpin this new research program include:

- A mouse assay, still in use today, was developed for assessing the risks to humans from exposure to radiation and chemicals.
- Researchers discovered DNA repair and the ability of most organisms to repair radiation and chemical damage. The DNA repair molecule was named molecule of the year by *Science* magazine in 1995.
- Researchers demonstrated that a human disease associated with susceptibility to cancer is caused by a genetically impaired ability to repair damaged DNA.
- A bacterial assay, known as the Ames test, was developed and is widely used by government and industry to identify potential cancer-causing chemicals or pharmaceuticals.
- The Human Genome Project has revolutionized the entire field of biology and spawned the biotechnology industry. It was initiated by the Department to develop biological information and tools needed to determine and understand the genetic effects of human exposures to low levels of radiation and chemicals.
- Researchers demonstrated that the microenvironment of tissues contains adhesion molecules that regulate gene expression.

Ecosystem Responses

Description, Objectives, and Research Performers

Research is conducted to understand responses of terrestrial ecosystems and organisms to changes in climate and atmospheric composition, such as temperature, moisture, and CO_2. This research will improve our understanding of (1) how terrestrial organisms and ecosystems respond to simultaneous changes in the composition of the atmosphere and in climate, (2) the biological or ecological mechanisms or pathways leading to those responses, and (3) the extent to which the responses are seen across different levels of the terrestrial ecosystem that affect humans positively or negatively. Research is conducted primarily at national laboratories and universities.

Research Challenges and Opportunities

Knowledge of possible effects of climate and atmospheric changes on ecological systems has increased over the past decade and qualitative estimates of responses to such changes can now be developed. However, scientists are still unable to make accurate quantitative predictions of the effects of changes in climate and atmospheric composition on ecosystems. A better understanding is needed of many critical processes such as the effects of climate changes and increasing atmospheric CO_2 on particular ecosystems at particular locations or regions. Researchers need to understand the climatic and non-climatic factors that influence the structure and functioning of terrestrial ecosystems. Research is also needed on the dynamic responses of ecosystems to simultaneous changes in multiple factors, particularly human-induced changes to which the ecosystems have not been previously subjected.

Research Activities

Experimental and modeling studies on different types of ecosystems investigate system responses to alterations in climate variables, atmospheric CO_2, ozone, and nutrient inputs. Two examples of this research are the Free Air CO_2 Enrichment Experiments (FACE) and the Throughfall Displacement Experiment. FACE research evaluates the responses of terrestrial plants and ecosystems, including forest, grassland, desert, and croplands, to known (increased) concentrations of atmospheric CO_2 and altered temperature and precipitation regimes. A Throughfall Displacement Experiment studies the response of a forest ecosystem to changing precipitation inputs. These studies document ecosystem responses, including changes in physiological processes, above- and below-ground growth responses, and other functional and structural responses of the experimental and control ecosystems being studied. Results will be used to develop and apply ecosystem response models that are intended to assess the consequences of human-induced environmental changes on terrestrial ecosystems.

Accomplishments

- Seven long-term experiments were initiated on the physiological and growth responses of forest, grassland and crop species, and ecosystems to variations in climate such as CO_2, temperature, and precipitation. These experiments will determine whether or not altered growth responses to elevated atmospheric carbon dioxide are sustained, how the systems respond to interannual variation in other environmental factors, including climate, and if changes in competitive interactions between species occur for limited resources that lead to different responses between species over time.

- Initial results from long-term FACE experiments show that increased CO_2 caused greater productivity and improved water use efficiency of these systems. A significant part of the productivity increase occurs below ground, involving roots, soil micro flora and the formation of soil organic matter.

- Findings from the Throughfall Displacement Experiment after six years show that changes in the seasonal timing of rainfall has a greater effect on the productivity of forest ecosystems and carbon sequestration by forests than a uniform change in rainfall applied throughout the year. Initial results of a factorial FACE experiment designed to measure the response of regenerating forests containing aspen, sugar maple and birch trees exposed to elevated carbon dioxide, elevated ozone, and elevated CO_2 plus ozone show that second-year growth of aspen and birch is increased by elevated CO_2 and decreased by elevated ozone and elevated CO_2 plus ozone compared to the controls. Insect populations, including species considered to be pest species in forests, have increased in the stands exposed to elevated CO_2, elevated ozone, and elevated CO_2 plus ozone compared to the controls, suggesting that the chemistry of trees in these treatments has been altered in a way that attracts more insects.

Regional and Global Consequences

Description, Objectives, and Research Performers

The Climate Change Prediction Program develops models that predict future climate given present and projected modifications such as changes in greenhouse gases. Efforts include increasing computational capabilities, the speed of computations, and the resolution and validity of the models. The models feed into a national effort coordinated with other agencies, including the National Science Foundation at the National Center for Atmospheric Research (NCAR). The Department's efforts have a primary focus on decade-to-century climate simulations. Capability to accurately simulate climate is currently limited by lack of understanding and modeling of the effects of clouds in climate. The Atmospheric Radiation Measurement Program (ARM) uses heavily instrumented sites and long-term observations to provide data and modeling improvements for climate prediction. Models are also developed for terrestrial carbon processes that, when coupled with atmosphere-ocean carbon models, estimate the rate and timing of atmospheric CO_2 change. Information from modeling efforts is integrated into efforts to assess the costs and impacts of potential changes in climate, including potential actions to ameliorate climate change. Research is conducted at national laboratories, universities, industrial firms, other government laboratories, and, to a minor extent, internationally.

Research Challenges and Opportunities

The most obvious challenge in climate change prediction is the increase in resolution required to achieve the regional scale simulations needed for meaningful assessments of the impacts of climate change. Increases in resolution require new models for meteorological phenomena because of differences in the scales of different phenomena. The role of clouds in climate prediction limits both global and regional predictive capability. Research to develop adequate models for cloud reflectivity and absorption is being pursued through extensive data gathering and intensive analysis and comparison of data with models. Development of effective cloud models for climate prediction will enable global and regional climate prediction over both the shorter and decade-to-century time spans. An understanding of climate variability is needed to address long term energy needs and usage impacts. A major uncertainty linking greenhouse gases and climate change is the fate of the excess CO_2 generated when fossil fuels are burned. The amount of CO_2 that remains in the atmosphere is determined by the amount taken up by terrestrial and oceanic sinks, which in turn is largely controlled by biological processes. Scientists need to understand the biophysical mechanisms of the carbon cycle to estimate capacities and locate carbon sequestration by terrestrial ecosystems and ocean biology. The effects of non-CO_2 greenhouse gases, many of them also byproducts of energy use, also need to be represented as part of integrated models to assess potential impacts of climate change.

Research Activities

The Atmospheric Radiation Measurement (ARM) Program (1) develops instruments and maintains field research sites to collect data on clouds and their role in reflecting and trapping both solar (incoming) and infrared (outgoing) atmospheric radiation and (2) collects and analyzes data for use in General Circulation Models (GCMs), the primary tool with which climate predictions are made. The Climate Change Prediction Program develops algorithms for climate modeling efforts on massively parallel computers, develops models for climate effects such as the effects of plant activity on the hydrologic cycle, develops components of major ocean and atmospheric models, and compares the output of models with data and observed phenomena. Data is collected as part of the AmeriFlux network and FACE for use in modeling the carbon cycle.

Accomplishments

- A Parallel Climate Model, developed at Los Alamos National Laboratory in collaboration with the Naval Postgraduate School to understand and predict the role of the oceans in global climate change, was successfully incorporated into the suite of models used by the National Center for Atmospheric Research to predict future climate. This model will be used by much of the scientific community in the next few years.

- An improved radiation transfer model developed by the ARM Program has been implemented in the European Center for Medium-Range Weather Forecasts (ECMWF) model used to predict weather.

- An improved cloud model was developed for the NCAR Climate System Model

- A Millimeter Cloud Radar at the ARM Southern Great Plains site is providing continuous data to improve cloud characterization and modeling.

- The first three-dimensional quantified distribution of clouds, cloud water, and cloud ice was acquired. These data will allow better representation of clouds in climate models.

- Integrated assessment models are used by decision makers and advisory bodies such as the Council of Economic Advisors to assess potential environmental and economic costs and benefits of alternative energy and pollution mitigation policies and strategies.

Portfolio Summary

This portfolio area, "Impacts on People and the Environment," encompasses research from many programs and supporting activities that crosscut the research topics covered above. The table below summarizes specific core research activities that strongly support or moderately support Impacts on People and the Environment, including human health impacts and risks, ecosystem responses, and regional and global consequences. The funding totals for these areas are an analytic tool reflecting the highly crosscutting, leveraged aspects and implications for individual research areas within DOE's science portfolio. **Because research areas may appear in multiple chapters, there will be significant instances of multiple counting, and the chapter totals will not sum to the overall science budget.** Additional details on these research areas are presented in the Research Summary Matrix and the corresponding Research Summary Profiles.

Strongly Supportive Core Research Activities Advanced Computing and Communications Facility Operations Atmospheric Radiation Measurement (ARM) Program Infrastructure Atmospheric Radiation Measurement (ARM) Program Research Atmospheric Sciences Carbon Cycle Research Climate Change Prediction Program Climate Change Technology Initiative (CCTI) Ecological Processes Economics of Global Climate Environmental and Molecular Sciences Laboratory (EMSL) Health Risks from Low Dose Exposures Natural and Accelerated Bioremediation Research Program
Moderately Supportive Core Research Activities Advanced Fusion Design Advanced Fusion Materials Research Advanced Medical Imaging Cleanup Research Computer Science to Enable Scientific Computing Energy Biosciences Focused Health Research Fusion Technologies General Purpose Plant & Equipment (GPP/GPE) Laboratory Technology Research and Advanced Energy Projects Microbial Genomics Multiprogram Energy Lab Facilities Support (MELFS) Oak Ridge Landlord Science Education Support Small Business Innovation Research (SBIR) Program

Small Business Technology Transfer (STTR) Program
NOTE: Please see Appendix A for more information on the budgets, the research performers, and other related information for each Core Research Activity.