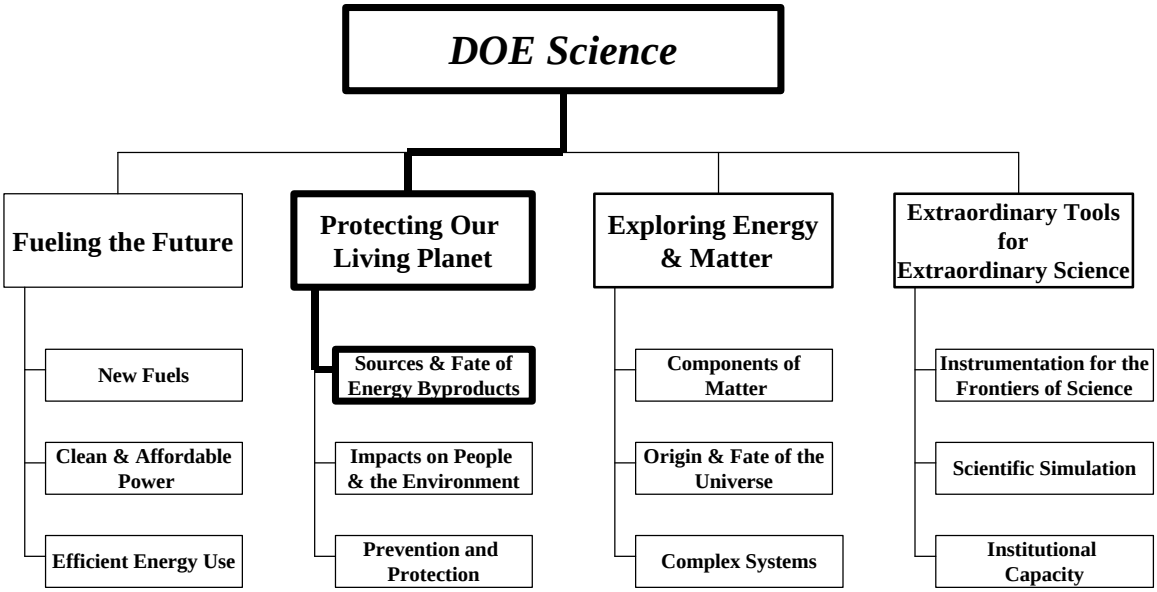
Chapter 5
Sources and Fate of Energy Byproducts

Scientific Challenge: ***To understand the molecular, atmospheric, geological, and biological pathways of energy byproducts in the biosphere.***



Chapter 5

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In the years following World War II, it became clear that concerns over the health impacts of released radioactivity depended not only on epidemiology and radiation biology, but also on knowing the fate of airborne radioisotopes. Meteorology and oceanography were no less important than biology, as was research into the ecological processes that cycled materials through plants and animals to human beings. Atmospheric and environmental studies thus became a part of the responsibilities of the Atomic Energy Commission (AEC). These early studies led the AEC and later ERDA (the Energy Research and Development Agency) to initiate environmental and ecological research and global change research programs in the United States.

Today, DOE is seeking to better understand the environmental fate of energy and defense byproducts. The transport, behavior, and fate of byproducts, such as greenhouse gases, local air pollutants (SO_x, NO_x, particulates), and other contaminants must be understood to provide a scientific basis for predicting and prioritizing, and for developing realistic standards. We need to understand how energy-related byproducts move through the biosphere. Subsurface microbial communities alter the chemistry of these byproducts, influence their transport, and offer hope to facilitate remediation of subsurface contaminants. This knowledge will improve our understanding of the feedbacks and interactions among various processes and cycles in the environment, leading to an improved predictive framework to support risk assessment and policy decisions.

Sources and Transport in the Biosphere

Description, Objectives, and Research Performers

Research is conducted on fundamental geological, atmospheric, and biological processes responsible for transporting, concentrating, and localizing energy byproducts in the subsurface, the atmosphere, oceans, and the terrestrial environment. A key component is the development and use of state-of-the-art instrumentation and facilities needed to understand these processes. Emphasis is placed on understanding atmospheric processes that affect air quality and climate change, and on determining the mechanisms that regulate the balance of carbon between the atmosphere, and terrestrial and aquatic ecosystems. Research in this area is conducted at national and other government laboratories, universities and, to a lesser extent, industrial firms.

Research Challenges and Opportunities

A major uncertainty of the greenhouse gas and potential climate change issue is what happens to the excess carbon dioxide (CO_2) generated from the burning of fossil fuels. The amount of CO_2 that remains in the atmosphere is determined by the amount assimilated by the terrestrial and oceanic environment. Assimilation is controlled in large measure by biological processes. Understanding the biophysical mechanisms of the carbon cycle —from the molecular to the ecosystem scale—provides the scientific foundation for estimating capacities and location of carbon sequestration by terrestrial ecosystems and ocean biology. There are also major scientific uncertainties in the behavior of local air pollutants (SO_x, NO_x, particulates) and radionuclides, metals and other chemical contaminants in the atmosphere and the subsurface. Research to understand complex physical, chemical, and biochemical reactions undergone by contaminants in the subsurface and the atmosphere is needed to better understand and predict their behavior and effects.

Research Activities

AmeriFlux experiments measure CO_2 fluxes at sites across North America to estimate carbon sequestration by terrestrial ecosystems. Scientists are developing analytical chemistry techniques, including sensors, for radiation and chemical monitoring. Through this, researchers are characterizing basic chemical, physical, geological, and biological processes affecting contaminant transport in the biosphere. Emphasis is placed on studies of tropospheric ozone and particulate matter to better characterize and predict air quality. Characterization of microbial communities in coastal and subsurface environments aids in understanding the role of microbes in the cycling of carbon and nitrogen and the behavior of other energy byproducts.

Accomplishments

- Research has shown that forested ecosystems represent a significant sink for carbon sequestration. This observation is key to our understanding of natural carbon cycles and to future carbon sequestration strategies.

- A method has been developed to assess the reactivity of some site contaminants at Idaho National Engineering and Environmental Laboratory (INEEL) with basalt rock formations. This method, based on secondary ion mass spectrometry, could guide the development of cleanup strategies for certain classes of contaminants.

- New methods for sensing and predicting fractures and failures in stressed rock improve our ability to predict contaminant pathways, a critical capability for monitoring and predicting the stability or movement of subsurface contaminants.

- An air quality study was conducted in the Mexico City area, resulting in better understanding of the effects of urban heat islands, neighboring terrain, and weather on the transport and fate of energy-related pollutants; a strong diurnal pattern caused by coupled photochemistry and regional meteorology was realized; pollutant transport onto regional scales was characterized. These results enhance understanding and prediction of current and future air quality in U.S. cities.

Chemical Interactions and Transformations

Description, Objectives, and Research Performers

Research is conducted on fundamental mechanisms and pathways for biotransformation and biodegradation of contaminant mixtures and for chemical reactions and interactions of energy byproducts in the subsurface and the atmosphere. Research is primarily conducted at national laboratories and universities.

Research Challenges and Opportunities

There are major uncertainties in the reactivity and transformations of atmospheric constituents and pollutants, requiring both laboratory and field studies of atmospheric chemistry and behavior. While, the degradation of many organics and the biotransformation of some inorganic

compounds in laboratory cultures have been well described, it is unclear how this information relates to the degradation and transformation of these materials in the environment. Scientists need to understand biotransformation processes such as metal biotransformations and biosequestration, coupled aerobic and anaerobic processes, co-metabolism, biotransformations in the presence of alternative electron donors/acceptors, and biotransformations catalyzed by consortia of microbes. Also needed is understanding of the mechanisms of action and the development of catalysts that are or could be used to transform energy byproducts such as carbon dioxide. There are also significant opportunities to understand the chemical and physical behavior of contaminants, such as actinides, in complex media such as the subsurface. This knowledge will assist the cleanup effort at former defense sites and contaminated industrial sites, and help to calibrate atmospheric models' responses to future pollution levels.

Research Activities

Studies are underway to determine the mechanisms and potential of microbes and microbial consortia to biotransform, biodegrade, and sequester energy byproducts such as plutonium, uranium, actinides, chromium, lead, and organic solvents. Research in the chemistry of photochemical oxidants and atmospheric aerosols is being conducted to improve atmospheric models that predict the atmosphere's response to future levels of pollutants. Basic research on actinide chemistry is also emphasized because of the importance of these elements to nuclear and medical technologies and to aid in the remediation of former weapons production sites.

Accomplishments

- A set of solvent-degrading genes from one microbe, *Pseudomonas putida*, has been successfully introduced into the radiation- and desiccation-resistant bacterium *Deinococcus radiodurans*. This exciting development indicates the potential of designing microbes that could be used to survive in high radiation environments while at the same time degrading or detoxifying other contaminants.

- New molecular fingerprinting methods have been developed to characterize microbial communities in metal contaminated environments. This will permit the observation of changes in natural communities by the presence of environmental stresses imposed by DOE relevant contaminants.

- Technetium was shown to be reduced by a hydrogenase in the metal-reducing microbe known as Geobacter. This demonstrates that microbes can provide natural catalysts for immobilization or mobilization of radionuclides.

- Research has confirmed that biogenic hydrocarbon chemistry is key to ozone and other oxidant production in the eastern United States.

- Dimethyl sulfide emissions over the North Atlantic Ocean, a source of atmospheric aerosols, have been shown to correlate with sea surface temperature. Atmospheric pollutants are transported through the environment following their attachment to these types of aerosols.

- Long-term research on heavy metals resulted in metal separation and purification technologies that resulted in the isolation of yttrium-90 from nuclear waste for subsequent use in cancer treatment.

Portfolio Summary

This portfolio area, "Sources and Fate of Energy Byproducts," encompasses research from many programs and supporting activities that crosscut the research topics covered above. The table below summarizes specific programs that strongly support or moderately support Sources and Fate of Energy Byproducts, including sources and transport in the biosphere, and chemical interactions and transformations. 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 RSPs (Combined Budget: $171.73 Million) Analytical Chemistry Instrumentation Atmospheric Radiation Measurement (ARM) Program Infrastructure Atmospheric Radiation Measurement (ARM) Program Research Atmospheric Sciences Carbon Cycle Research Cleanup Research Climate Change Prediction Program Climate Change Technology Initiative (CCTI) Geosciences Heavy Element Chemistry
Moderately Supportive RSPs (Combined Budget: $729.35 Million) Catalysis and Chemical Transformations Economics of Global Climate Energy Biosciences Experimental Program to Stimulate Competitive Research (EPSCoR) General Purpose Plant & Equipment (GPP/GPE) Laboratory Technology Research and Advanced Energy Projects Multiprogram Energy Lab Facilities Support (MELFS) Neutron and Light Sources Facilities Photochemistry and Radiation Research Science Education Support Separations and Analysis 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 Research Summary.