United States
Environmental Protection
Agency

Air and Energy Engineering
Research Laboratory
Research Triangle Park, NC 27711

Research and Development

EPA/600/SR-94/008 March 1994

EPA

Project Summary

Proceedings: The 1992 Greenhouse Gas Emissions and Mitigation Research Symposium

Sue Philpott, Compiler

The report documents results of the 1992 Greenhouse Gas Emissions and Mitigation Research Symposium, sponsored by the U.S. Environmental Protection Agency's Air and Energy Engineering Research Laboratory (EPA-AEERL), and held in Washington, D.C., on August 18-20, 1992. The symposium provided a forum of exchange of technical information on global change emissions and potential mitigation technologies. The primary objectives of the meeting were dissemination of technical information and education in recent research. Oral papers along with an international panel discussion, overheads, slides, and a GloED demonstration proved for lively exchanges in the following areas: activities in EPA, U.S. Department of Energy (DOE), and Electric Power Research Institute (EPRI) on greenhouse gas emissions and mitigation research, and AEERL's global emissions and technology databases; international activities of selected industrialized and developing countries; carbon dioxide (CO_2) emissions and their control, disposal, and reduction through conservation and energy efficiency, and carbon sequestration including utilization of waste CO_2; methane (CH_4) emissions and mitigation technologies including such topics as coal mines, the natural gas industry, key agricultural sources, landfills and other cookstove emissions and control approaches; and solar and renewable energy sources, including renewable energy options, alternative biomass fuels, advanced energy systems, solar energy developments, and woodstove emissions and mitigation. The proceedings contain 34 submitted papers.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The 1992 Greenhouse Gas Emissions and Mitigation Research Symposium, sponsored by the U.S. Environmental Protection Agency's Air and Energy Engineering Research Laboratory (EPA/AEERL) and Acurex Environmental Corporation was held August 18-20, 1992, in Washington, DC. Thirty-four speakers presented papers on recent research on global change emissions and potential mitigation technologies. The symposium Chairperson was Robert P. Hangebrauck of EPA/AEERL. This project summary includes abstracts of the papers presented at the symposium. The six sessions were:

I. Overview
II. International Activities
III. CO_2, Emissions, Control, Disposal, and Utilization
IV. Emissions and Mitigation of Meth ane and Ozone Precursors
V. Biomass Emission Sources and Sinks
VI. Energy Sources/Solar/Renewable

Session I
Overview

(Frank T. Princiotta, EPA, Session Chairperson)

"Greenhouse Warming: The Mitigation Challenge," Frank T. Princiotta, EPA)

This paper describes the symposium as a forum to discuss the state-of-the-art and research opportunities associated with the sources and mitigating releases of greenhouse gases. Essential to discussing mitigation opportunities is the understanding of fundamental driving forces for releases of these gases, relating projected emissions to anticipated global warming, examining the important greenhouse gases and their relative contributions, and understanding the penalties associated with delaying implementation of a mitigation program.

"Methane Reductions are a Cost-Effective Approach for Reducing Emissions of Greenhouse Gases," Kathleen B. Hogan and Dina W. Kruger, EPA

Methane reductions can play a large role in providing low cost, if not profitable, opportunities for reducing greenhouse gas emissions, in addition to other benefits for the atmosphere. This paper reports on opportunities for reducing emissions of methane that have been examined through a number of EPA efforts and activities developed by the Intergovernmental Panel on Climate Change. The paper concludes that efforts to encourage methane reductions will require identification and removal of a number of barriers that hinder the implementation of available technologies.

"Climate Change and Related Activities," Kenneth Freidman, DOE

This report is a brief discussion of the U.S. Department of Energy's (DOE's) activities in scientific research, technology development, policy studies, and international cooperation that are directly related to or have some bearing on the issue of global climate change. Part I describes DOE's major activities: 1) developing computer models to predict rate and magnitude of global and regional climate change, 2) understanding the systems that control the current and past climates of the Earth, and 3) exchanging and communicating data and modeling results with other climate researchers around the world. Part II focuses on DOE's related activities including scientific research; transportation; alternative fuels development; residential, commercial, and industrial efficiency; appliance and equipment efficiency; industrial process technologies; industrial waste minimization; electricity generation and use; and policy analysis.

"EPRI's Greenhouse Gas Emissions Assessment and Management Research Program," D.F. Spencer and G.M. Hidy, EPRI

This paper briefly reviews the rationale and need for an electric utility greenhouse gas emissions assessment and management research program, as well as potential cost implications to society of short-term control requirements. The balance of the paper focuses on EPRI's directly related R&D program and its key elements, namely: a) model development and model evaluation activities, b) ecological effects, c) management/mitigation research, and d) development of an integrated assessment framework. EPRI's directly related greenhouse gas research program, including co-funding, is expected to expend approximately $60 million over the next 4 years to address key aspects of this significant environmental issue.

"Global Emissions Database (GloED) Software," Lee Beck, EPA

The EPA Office of Research and Development has developed a powerful software package called the Global Emissions Database (GloED). GloED is a user-friendly, menu-driven tool for storage and retrieval of emissions factors and activity data on a country-specific basis. Data can be selected from databases resident within GloED and/or imputed by the user. The data are used to construct emissions scenarios for the countries and sources selected. References are linked to the data to ensure clear data pedigree. The scenario outputs can be displayed on thematic global maps or other graphic outputs such as bar or pie charts. In addition, data files can be exported as Lotus 1-2-3, dBase, or ASCII files, and graphics can be saved as a PCX file or exported to a printer. This paper describes GloED and how it works. It also presents future plans for software enhancements and populating the databases.

Session II
International Activities

(Jane Leggett, EPA, Session Chairperson)

"Beyond Rio," Hans van Zijst, Royal Netherlands Embassy

This brief narrative explores the Dutch perspective on the future of research and policies on climate change. Current policy goals and measures taken by the Dutch government are examined, which include issues such as energy savings, fuel consumption, traffic and transport, and the waste sector. The paper emphasizes the strong need for international cooperation in implementing the Convention on Climate Change.

Session III
CO_2, Emissions, Control, Disposal, and Utilization

(Ken Freidman, DOE, Session Chairperson)

"Carbon Dioxide Sequestration," Robert P. Hangebrauck, Robert H. Borgwardt, and Christopher D. Geron, EPA

Mitigation of global climate change will require the stabilization of atmospheric concentration of greenhouse gases, especially carbon dioxide (CO_2). CO_2 can be sequestered by flue-gas and fuel CO_2 sequestration or by atmospheric CO_2 fixation/utilization. Flue-gas sequestration involves separation/concentration, transport, and either disposal or use. Disposal options are either land or ocean based. Utilization is by either chemical or biological utilization (recycling). Flue-gas-oriented techniques in general have high economic and energy costs, but a few areas show potential and warrant research and development (R&D) attention, especially those holding promise of combined CO/sulfur dioxide (SO_2)/nitrogen oxides (NO_x) control and the integrated gasification combined cycle approaches. CO_2 disposal is neither a "sure thing" nor a permanent solution, with options needing further environmental assessment. Near term, some CO_2 recycling is possible, and R&D to examine longer-term prospects seems warranted. Atmospheric CO_2 fixation/utilization involves either enhanced terrestrial or marine fixation with utilization of the biom-

ass in some cases. Atmospheric fixation approaches which seem most attractive are those involving enhanced biomass CO_2 sequestration combined with utilization of the biomass for energy to displace fossil fuel. Of these, the most attractive for R&D appear to be advanced direct combustion using biomass and use of biomass as a source of hydrogen to leverage fossil fuel use for methanol production (Hydrocarb process).

"The NOAA Carbon Sequestration Program," Peter Schauffler, National Oceanic and Atmospheric Administration

Increasing attention is being given to oceanic techniques for sequestering carbon in various molecular forms as part of an overall global-change strategy. EPRI, through a Caltech contract, is looking at the formation and semi-permanent retention of CO_2 hydrates at ocean depths of 1,000 m or so. Similar investigations are being actively pursued by the Japanese. EPRI and NOAA, assisted by Caltech and George Washington University, are re-examining the feasibility of large-scale farming of microalgae as a way of collecting CO_2 from the atmosphere and upper ocean layers, sequestering it in liquid or hydrate form in the deep ocean and/or locking up the carbon in the farm structure, and using the farm-produced methane and perhaps methanol as a CO_2-neutral fossil fuel substitute.

"The Role of DOE Energy Efficiency and Renewable Energy Programs in Reducing Greenhouse Gas Emissions," Eric Peterson, DOE

This presentation illustrates DOE's programs in energy conservation and energy efficiency, and renewable, nuclear and fossil energy technology research and development. The history and the mission of the Office of Conservation and Renewable Energy is described. Also, overviews of other DOE-initiated programs such as the Wind Energy Program are given.

"Fuzzy Logic Control of AC Induction Motors to Reduce Energy Consumption," R.J. Spiegel and P. Chappell, EPA; J.G. Cleland, Research Triangle Institute; and B.K. Bose, University of Tennessee

Fuzzy logic control of electric motors is being investigated under sponsorship of EPA to reduce energy consumption when motors are operated at less than rated speeds and loads. Electric motors use 60% of the electrical energy generated in the U.S. An improvement of 1% in operating efficiency of all electric motors could result in savings of 17 x 10^9 kWh/yr in the U.S.. New techniques are required to extract maximum performance from modern motors. This paper describes EPA's research program, as well as early stages of work, to implement fuzzy logic to optimize the efficiency of alternating current (AC) induction motors.

"Evaluation of Methanol Production from Hydrogen and Waste Carbon Dioxide," Stefan Unnasch and Dan Luscher, Acurex Environmental Corporation

The production of methanol from waste carbon dioxide (CO_2) and hydrogen was evaluated. Using recycled CO_2 in methanol fuel would reduce the emissions of CO_2 into the atmosphere. We investigated the cost and technical status of potential non-fossil hydrogen production technologies and CO_2 recovery technologies. The primary focus for hydrogen production was an photovoltaic (PV) power sources. Methanol can be produced from CO_2 and hydrogen by reacting CO_2 with hydrogen to form carbon monoxide (CO) and water. The CO is then reacted with hydrogen to form methanol. Producing 1.0 lb of methanol with this approach would require 4.37 kWh of electrical power for the production of hydrogen and capture of CO_2. The methanol would cost over $3.00/gal if the power were derived from current PV technology; about 85% of this cost is associated with hydrogen production. This cost could be reduced by 70% with improvements in PV technology that are expected to be feasible with large scale production and projected advances in technology. Almost all of the carbon in a coal gasification system can be converted to methanol with the addition of hydrogen. Producing 1.0 lb of methanol from coal would require only 1.89 kWh of electric power.

Session IV
Emissions and Mitigation of Methane and Ozone Precursors

(M.J. Shearer, Global Change Research Center, Session Chairperson)

"Global Atmospheric Methane: Trends of Sources, Sinks and Concentrations," M.A.K. Khalil, R.A. Rasmussen, and M.J. Shearer, Global Change Research Center

The global cycle of methane is driven by emissions around 550 Tg/yr from both natural and sources related to anthropogenic activities, particularly the production of food and energy. Major sources are rice agriculture, domestic ruminants, and wetlands. Methane is removed from the atmosphere mostly by reacting with OH radicals. Some methane is removed by the soils. Over the past decade methane concentrations have been increasing at about 1%/yr or 16 ppbv/yr. A record of atmospheric methane extending back 150,000 years has been constructed from the analysis of polar ice cores. It shows that, during this time, methane concentrations have never been more than half of present levels. The recent increase of methane was probably caused by increasing emissions. Recent changes in the trend of methane may also be attributed to changing levels of OH. This paper deals with the changes in global methane concentrations in the past, the causes of increased levels at present, and the future of atmospheric methane. The present understanding of the global methane budget provides critical facts for policies related to controlling anthropogenic sources.

"Coal Mine Methane Emissions and Mitigation," David A. Kirchgessner, EPA; and Stephen D. Piccot, Science Applications International Corporation

Estimates of methane (CH_4) emissions from coal mines range from 25 to 45 Tg/yr with a recent estimate as high as 65 Tg/yr. At 46 Tg/yr, the estimate produced by this project, coal mines contribute about 10% of anthropogenic CH_4 emissions and may contribute significantly to the global change phenomenon. Although emissions from underground mines are now believed to be adequately characterized, virtually no data are available on emissions from surface mines, and data are totally lacking on emissions from abandoned/inactive mines and coal handling operations. The methodology developed to calculate emissions from underground mines is briefly described, as is the Fourier transform infrared spectroscopy technique being employed for measuring emissions from surface mines. A nitrogen-flooding technique for enhancing the recovery of CH_4 from coalbeds in advance of mining is described as a possible measure for mitigating CH_4 emissions from underground mines.

"Emissions and Mitigation of Methane from the Natural Gas Industry," Robert A. Lott, Gas Research Institute

The Gas Research Institute and EPA are co-funding and co-managing a pro-

gram to evaluate methane emissions from U.S. natural gas operations. The purpose of the program is to provide an emissions inventory accurate enough for global climate modeling and for addressing the policy question of "whether encouraging the increased use of natural gas is a viable strategy for reducing the U.S. contribution to global warming." The program is comprised of three phases: Scoping, Methods Development, and Implementation.

The purpose of Phase I was to define the problem. Phase II of the program concentrated on developing techniques for measuring steady state or fugitive emissions and for calculating the highly variable unsteady emissions from the variety of sources that comprise the gas industry. Because of the large number of sources within each source type, techniques were also developed for extrapolating emissions data to similar sources within the industry.

Phase III of the program was started in early 1992 and should be completed in early 1994. The purpose of the current phase of the program is to collect sufficient data to achieve the accuracy goal of determining emissions to within + 0.5% of production.

Based on the limited amount of data collected to date, methane emissions from the U.S. gas industry appear to be in the range of 1% of production.

"Emissions and Mitigation at Landfills and Other Waste Management Facilities," Susan A. Thorneloe, EPA

Landfills and other waste management sources of methane are amenable to cost-effective control. Consequently, these sources have been given a high priority for clarification of their emission potential. EPA is conducting research to determine the emission potential and mitigation opportunities for cost-effective control for the major sources of greenhouse gases. EPA/AEERL is responsible for developing more reliable global and country-specific estimates for the major sources of greenhouse gases including waste management, coal mines, natural gas production/distribution, energy usage, cookstoves, and biomass combustion. AEERL has gathered data that have resulted in the development of more reliable estimates for landfills. Research has been initiated to characterize the methane potential of other waste management facilities including wastewater treatment lagoons, septic sewage systems, and livestock waste.

AEERL is also documenting the current state of technology for utilization projects. Currently, 114 landfill gas-to-energy projects are occurring in the U.S. and about 200 worldwide. Technology transfer/technical assistance programs have been initiated to help encourage the utilization of waste methane and to help implement the upcoming Clean Air Act (CAA) regulations for municipal solid waste landfills. For example, AEERL is working with a consortium of local government representatives to explore the application of EPA research on methane/energy recovery from municipal solid waste landfills. AEERL also serves on the International Energy Agency Expert Working Group on Landfill Gas and the Steering Committee for the Solid Waste Association of North America. AEERL is also responsible for demonstrating innovative approaches to the control of waste methane such as the application of fuel cell technology to recover energy from landfills gas and digester gas.

This paper describes the emission potential for waste management sources and the mitigation opportunities. It also provides an overview of some of the barriers in the U.S. that affect methane utilization. This research is funded through EPA's Global Climate Change Research Program.

"Fuel Cell Power Plant Fueled by Landfill Gas," R.J. Spiegel, EPA, and G.J. Sandelli, IFC

International Fuel Cells Corporation (IFC), a subsidiary of United Technologies Corporation, is conducting an EPA-sponsored program to demonstrate methane control from landfill gas using a commercial phosphoric acid fuel cell power plant. This is the world's first commercial-scale demonstration to control methane emissions from landfills using a fuel cell energy recovery system. EPA is interested in fuel cells for this application because it is potentially the cleanest energy conversion technology available. This paper discusses the project in general and describes some results to date, with emphasis on the landfill gas pretreatment system.

"Methane Emissions from Rice Agriculture," M.A.K. Khalil, M.J. Shearer, and R.A. Rasmussen, Global Change Research Center

Rice agriculture has long been recognized as a major source of methane (CH_4). Global budgets of methane have generally included emissions of about 100 Tg/yr (Tg = 10^{12} g) from rice agriculture (range of 50-300 Tg/yr) and constituting about 20% of emissions from all sources (range 14-40%).

During the last decade, a number of systematic experiments have been reported on methane emissions from rice fields. Seasonal averages range from 0 to 40 mg/m^2/hr. Factors affecting the flux of methane include irrigation regime, fertilizer, soil temperature, and soil type.

The most recent global estimates put the emissions from rice paddies at 50 to 100 Tg/yr. The major cause of increasing methane emissions from rice paddies over the past 50 years appears to be the tremendous increase in area planted to rice. Emissions appear to have stabilized over the past decade. Future increases in methane emissions from rice will probably depend on access to irrigation and the use of organic fertilizer.

"Livestock Methane: Sources and Management Impacts," Donald E. Johnson, T. Mark Hill, and G.M. Ward, Colorado State University

Herbivorous animals, particularly ruminants, have a digestive tract that facilitates extensive symbiotic microbial digestion of dietary structural plant carbohydrates. A by-product of this symbiotic microbial process is an estimated 70 Tg of methane globally per year, primarily from cattle and buffalo. Cattle methane emissions equal 6 +/- 0.5% of their diet energy (2% by wt) for most global conditions studied. Emissions by U.S. feedlot cattle are uniquely lower at about 3.5% of diet energy. A major lack of information on size, diet, class distribution and percentage loss from developing country livestock precludes accurate definition of this source, which is about 65% of global. Manure disposal from livestock may produce an additional 12 Tg globally, primarily through anaerobic lagoons. Possible ameliorative strategies include the decreased use of lagoon disposal or the capture of this methane. General efforts should concentrate on improving productivity of beef and dairy cattle production systems, which will secondarily reduce methane.

"Ozone and Global Warming," Robert P. Hangebrauck and John W. Spence, EPA

Changes in several trace substances in the Earth's atmosphere are affecting global radiative forcing. Those substances that seem to be in the greatest state of change now and projected into the future are carbon dioxide, ozone (and its precursors and depleters), and aerosols. Conceivably, countervailing changes in the radiative forcing effects of these substances,

especially ozone and aerosols, may be temporarily hiding or at least changing the "greenhouse signal"—an unfortunate circumstance, particularly if the overall impacts that will eventually occur are unpredictable or difficult to reverse quickly. If in fact the greenhouse signal is partially being obscured at present, there is also potential for this effect becoming less significant in the decades ahead because of 1) a continuation of increases in greenhouse gas emissions, 2) saturation of the tropospheric aerosol effect plus controls on sulfur emissions, and 3) increasing tropospheric ozone. The substantial complexities in factors affecting ozone and aerosols are discussed with emphasis on ozone and its precursors, including methane, nonmethane hydrocarbons, carbon monoxide, and nitrogen oxides. Quantifying radiative forcing is of substantial importance. EPA is undertaking research to enhance the ability to estimate indirect factors contributing to forcing, including measures such as Global Warming Potentials. Many of the important but difficult factors to resolve are of the indirect type. A number of potential indirect forcing effects are identified along with an estimate of direction (sign).

"Overview of Methane Energy and Environmental Research Programs in the United Kingdom," Suzanne A. Evans, Anton van Santen, Paul S. Maryan, Caroline A. Foster, Keith M. Richards, Harwell Laboratory

The biofuels program of research and development forms an important part of the UK Department of Energy's renewable energy program. This program began in the mid-1970s as a response to the oil crisis of that time and was part of a much wider look at alternative energy supplies. The initial driving force for biofuels and other renewables research was the prospect of greater diversity, and hence security of energy supply for the nation. More recently, concerns over the environment and the need for sustainable sources of energy have added further strength to the case for using "environmentally friendly" renewables. This paper reviews the history of the biofuels program, its present content, and considers where future emphasis might lie.

Session V
Biomass Emission Sources and Sinks

(Robert Dixon, EPA, Session Chairperson)

"The Carbon Balance of Forest Systems: Assessing the Effects of Management Practices on Carbon Pools and Flux," Robert K. Dixon and Jack K. Winjum, EPA, and Paul E. Schroeder, ManTech Environmental Technology, Inc.

Forests play a major role in the Earth's carbon cycle through assimilation, storage, and emission of CO_2. Establishment and management of boreal, temperate, and tropical forest and agroforest systems could potentially enhance sequestration of carbon in the terrestrial biosphere. A biologic and economic analysis of forest establishment and management options from 94 nations revealed that forestation, agroforestry, and silviculture could be employed to conserve and sequester 1 gigaton (Gt) of carbon annually over a 50-year period. The marginal cost of implementing these options to sequester 55 Gt of carbon would be approximately $10/ton.

"Global BIOME (BIOspheric Mitigation and adaptation Evaluation) Program," Robert K. Dixon and Jack K. Winjum, EPA

Preliminary assessments suggest that forests and agroecosystems can be managed to conserve and sequester carbon, thereby reducing the accumulation of greenhouse gases in the atmosphere. Biomass utilization is a necessary component of a sustained terrestrial carbon sequestration effort. The Global BIOME (BIOspheric Mitigation and adaptation Evaluation) Program will consist of a) technical assessments of effectiveness of terrestrial biosphere management options and biomass fuel technology in reducing atmospheric accumulation of greenhouse gases, b) demonstration projects to assess the technical and economic feasibility of applying agricultural and forest management options and biomass fuel substitution, c) regional, national, and global assessments of effectiveness of terrestrial biosphere management and adaptation options, and d) assessment of practices and technologies that, if implemented, could facilitate adjustment of forest and agroecosystems to global climate change. The Global BIOME initiative is a component of EPA's Office of Research and Development national Global Change Research Program. The research is managed by the Agency's laboratories: ERL-A, ERL-C, AEERL, and AREAL. Research is conducted by EPA scientists in cooperation with universities, other federal agencies and laboratories, and contractors.

"Agricultural Management and Soil Carbon Sequestration: An Overview of Modeling Research," Robert B. Jackson IV and Thomas O. Barnwell Jr., EPA; Anthony S. Donigian Jr. and Avinash S. Patwardhan, Aqua Terra Consultants; and Kevin B. Weinrich and Allen L. Rowell, Computer Sciences Corporation

Soil carbon fluxes and pools are profoundly affected by agricultural management, which is in turn affected by national and international agricultural policies. This paper briefly describes the framework and some details of a computer modeling research strategy that is being implemented at the Athens Environmental Research Laboratory (AERL). The objective of the research is to determine the potential for U.S. agroecosystems to accumulate and sequester carbon as a means of slowing the global increase in atmospheric carbon dioxide.

"Assessment of the Biogenic Carbon Budget of the Former Soviet Union," Tatyana P. Kolchugina and Ted S. Vinson, Oregon State University

A framework was created to quantify the natural terrestrial carbon cycle of the former Soviet Union (FSU). The organization of the carbon cycle parameter and georeferenced database, which supports the framework and the calculations, which are required to establish the carbon budget, are performed with personal computer hardware and commercially available spreadsheet software. Based on the framework, net primary productivity (NPP)

for the FSU was estimated at 6.2 +/- 1.7 GT (10^9 tons) C/yr, the vegetation carbon pool at 118.1 +/- 28.5 GT C, the litter carbon pool at 18.9 + 4.4 GT C, and total soil carbon pool at 404.0 +/38.0 2GT C. The components of the carbon budget obtained with the framework were in good agreement with estimates from other published sources. The framework will allow the role of the FSU in the global carbon cycle to be assessed. The extent of forest and agricultural ecosystems within the FSU that can be technically managed on a sustainable basis to conserve and sequester carbon may also be determined with the framework.

"Household Fuels in Developing Countries: Global Warming, Health, and Energy Implications," Kirk R. Smith, Program on Environment, and Susan A. Thorneloe, EPA

Although individually small, the widespread and daily use of household stoves with poor combustion efficiency in developing countries raises questions about possible global warming and other environmental implications of their airborne emissions. To explore the possible utility of efforts to measure the emissions from representative samples of these devices, a small pilot study of greenhouse gas emissions of biomass and fossil-fuel stoves was undertaken in Manila. The results, although based on only a few measurements, indicate that such stoves may have a significant role in global greenhouse gas inventories; be subject to substantial improvement through alternative technologies; and that policy measures should consider energy and health implications as well. As a consequence, a larger set of studies is being planned for India, China, Thailand, and Brazil. This research is funded through EPA's Global Climate Change Research Program. Research on emissions and mitigation of major sources of greenhouse gases is being conducted by EPA/AEERL.

"The Potential for Energy Crops to Reduce Carbon Dioxide Emissions," R.L. Graham, Oak Ridge National Laboratory

Energy crops are herbaceous or woody plants grown specifically to produce biomass for combustion and production of electricity or for conversion to fuels such as ethanol. When grown intensively, such crops can yield up to 43 dry Mg biomass/ha/yr in the temperate zone although yields of 10 to 20 Mg are more typical.

By substituting sustainably grown biomass for fossil fuels, CO_2 emissions from energy consumption can be reduced significantly. Although biomass fuels are net emitters of CO_2, because fossil fuels are used in the production of energy crops (e.g., fertilizers, transportation), biomass fuels emit much less CO_2 than fossil fuels per unit of energy produced. A hectare of U.S. farmland on the average could produce sufficient biomass to reduce annual CO_2 emissions by 5 Mg C if such biomass were used to produce electricity that would otherwise be produced with coal.

Within the U.S., at least 131 million hectares of farmland could support energy crop production. Much of this land lies in the midwest although the southeast also contains considerable acreage. More acreage can support herbaceous energy crops than woody crops as there are herbaceous crops that can tolerate drier conditions than any woody crop.

The potential for energy crops to reduce CO_2 emissions will depend on how much land can be profitably dedicated to energy crops. Farmers will adopt energy crops when it is economically advantageous for them to do so. Power companies will adopt biomass energy when the cost of energy from fossil fuels exceeds that from biomass. Government policies and regulations affect both these relationships. Currently biomass crops must compete with subsidized agricultural crops thereby inflating the price of biomass to an energy facility. On the other hand, pollution regulations can favor energy crops as a fuel source since biomass crops can burn cleaner than coal.

Session VI
Energy Sources/Solar/ Renewable

(Robert Williams, Princeton University, Session Chairperson)

"Roles for Biomass Energy in Sustainable Development," Robert H. Williams, Princeton University

Biomass (plant matter) accounts for 15% of world energy use and 38% of energy use in developing countries. But most biomass is used inefficiently, mainly for cooking and heating in rural areas of developing countries, and often in much the same way it has been used for millennia. Biomass can also be converted into modern energy carriers such as gaseous and liquid fuels and electricity that can be widely used in more affluent societies. The most promising options are biomass-integrated gasifier/gas turbine power systems as an alternative to coal-based power plants and biofuels for fuel-cell vehicles as an alternative to gasoline for internal-combustion-engine vehicles. The prospects are good that these technologies could be competitive with conventional fossil fuel technologies at present world energy prices.

The large-scale utilization of biomass for energy can provide a basis for rural development and employment in developing countries, thus helping to curb urban migration. In addition, if biomass is grown sustainably, its production and use creates no net buildup of carbon dioxide (CO_2) in the atmosphere, because the CO_2 released during combustion is offset by the CO_2 extracted from the atmosphere during photosynthesis.

Biomass for energy can be obtained from residues of ongoing agricultural and forest product industries, from harvesting forests, and from dedicated plantations. The harvesting of forests for biomass is likely to be limited by environmental concerns. Over the next couple of decades new bioenergy industries will be launched primarily using residues as feedstocks. Subsequently, the industrial base will shift to plantations, the largest potential source of biomass.

The most promising sites for plantations are deforested and otherwise degraded lands in developing countries and excess croplands in the industrialized countries. Revenues from the sale of biomass crops grown on plantations established on degraded lands can help finance the restoration of these lands. Establishing plantations on excess croplands can be a new livelihood to farmers who would otherwise abandon their land because of foodcrop overproduction. In either case, biomass plantations can, with careful planning, substantially improve these lands ecologically relative to their present uses. But a substantial and sustained research and development effort is needed to ensure the realization and sustainability of high yields under a wide range of growing conditions. Moreover, the establishment and maintenance of biomass plantations must be carried out in the framework of sustainable economic development in ways that are acceptable to the local people.

Ultimately, land and water resource constraints will limit the contributions that biomass can make as an energy source in

advanced societies. But biomass energy can make major contributions to sustainable development before these limits are reached, if biomass is grown productively and sustainably and efficiently converted to modern energy carriers that are used in energy efficient end-use technologies.

"An Analysis of the Hydrocarb Process for Methanol Production from Biomass," Yuanji Dong and Meyer Steinberg, Hydrocarb Corporation, and Robert H. Borgwardt, EPA

A pilot plant is being designed to evaluate the technical feasibility of producing transportation fuel from biomass by the Hydrocarb process. As a basis for that design, computer simulations and experimental studies have been carried out to establish optimum process conditions for a range of feedstocks that are anticipated for pilot plant tests. This paper discusses the results of simulations to determine the operating parameters and performance when using urban wastes such as greenwaste and sewage sludge as feedstocks. The simulations were used to configure the process steps for maximum fuel (methanol) production, to determine feed rates, and to estimate thermal efficiency. The results indicate that about 77 kg of methanol can be produced from 79 kg of dry greenwaste when sludge and digester gas are fed as co-feedstocks in a ratio of 0.2. The optimum system pressure is found to be 50 atm (5 MPa). Temperatures of 900°C for gasification and 1000°C for methane pyrolysis are recommended on the bases of thermodynamics, kinetics, and the limitations of materials of construction. Thermal efficiency at these conditions is estimated to be 74%.

"Alternative Fuels from Biomass," Charles E. Wyman, National Renewable Energy Lab

Substitution of biofuels derived from cellulosic biomass for conventional fuels would reduce the accumulation of carbon dioxide in the atmosphere and the possibility of global climate change, improve our energy security and trade deficit, revitalize rural and farm economies, and address urban air pollution and waste disposal problems. The major fractions of biomass, cellulose and hemicellulose, can be broken down into sugars that can be fermented into ethanol. Through technology advances for producing ethanol, the projected cost at the plant gate has been reduced from about $3.60/gal 10 years ago to $1.27/gal, and opportunities have been identified to further drop the price to $0.67/gal, a price competitive with gasoline from oil at $25/bbl, within 10 years. Through anaerobic digestion, a consortium of bacteria can break down cellulosic biomass to generate a medium-Btu gas that can be cleaned up for pipeline-quality methane. The cost of this methane has been reduced to about $4.50/MBtu ($10^6$ Btu) for municipal solid waste (MSW) feedstocks, and technology advances could drop the price to about $2.00/MBtu. Algae could consume carbon dioxide from power plants and produce lipid oil that can be converted into a diesel fuel substitute. Projected costs for this biodiesel have dropped from almost $18.00/gal to about $3.50/gal now, with a target of $1.00/gal. Biomass can also be gasified to a mixture of carbon monoxide and hydrogen for catalytic conversion into methanol. Currently, methanol from biomass is projected to cost about $0.85/gal, and with improved technology, a cost of $0.50/gal could be realized. Catalytic processing of pyrolytic oils from biomass produces a mixture of olefins that can be reacted with alcohols to form ethers such as methyl tertiary butyl ether (MTBE) for use in reformulated gasoline to reduce emissions. Costs could be competitive today for olefins from MSW. Because biofuels technologies require little if any fossil fuel inputs, carbon is recycled through their use, reducing substantially the net amount of carbon dioxide released to the atmosphere.

"Co-production of Methanol and Power," William Weber, EPRI; Arden B. Walters, Florida Power & Light Company; and Samuel S. Tam, Bechtel Group, Inc.

Integrated Coal Gasification Combined Cycle (IGCC) is one of the emerging technologies for electric power generation from coal. Under contract with Florida Power & Light (FPL) and Electric Power Research Institute (EPRI), Bechtel is to design an IGCC/methanol co-production plant that is suitable for utility operation of a base-loaded power plant. The potential benefits of methanol co-production in an IGCC plant are identified and quantified.

Shell and Dow gasifiers are selected for this study only to illustrate the potential effects of the dry-feed and slurry-feed gasification process on methanol production. The combined-cycle power plant features the GE Model MS-7001F gas turbines, heat recovery steam generation (HRSG) with steam reheat, and duct firing. The fuel-grade methanol plant design is based on Chem Systems' Liquid Phase Methanol (LPMEOH) Process. Two operating modes of the methanol plant are considered: the recycle mode (RM) and the once-through mode (OTM).

Results from cases with the slurry-feed gasifiers and OTM plant are presented in this paper. They have indicated that methanol co-production can increase the equivalent availability of an IGCC plant to that for a natural gas fueled combined cycle plant. Methanol co-production can also reduce the risk of the lower than anticipated gasifier availability.

"EPA's Cost-shared Solar Energy Program," Ronald J. Spiegel, EPA

The objective of this program is to establish and demonstrate solar energy cost-shared commercialization projects to demonstrate how they can be used to displace fossil fuels. The program will also have a major impetus to validate the ability of solar energy to be used as a pollution mitigation technology. Further, the demonstrations will assist in removing obstacles to the marketplace for solar technologies by assisting in quantifying environmental concerns. This paper discusses a project that has just commenced in the area of photovoltaic demand-side power supplies. Additional discussion is provided relative to future projects that are being contemplated.

"Photovoltaic Developments," Jack L. Stone, National Renewable Energy Laboratory

Photovoltaics, the direct conversion of sunlight to electricity, is an environmentally pristine, renewable energy option currently used in a large number of international applications, principally non-grid-connected in remote locations. Examples include water pumping, communications, vaccine refrigeration, and village power. Over the past 15 years, a very aggressive research and development program carried out by DOE has continued to improve photovoltaic performance and reliability and has contributed to lower production costs. Along with these improvements have come a large number of new, cost-effective uses, including larger power installations in a utility environment. This technical and economic progress is reviewed to represent the current status of this renewable energy option. Near-term plans for large-scale installations in the U.S. are discussed along with the required costs for competitiveness with conventional electricity generation options.

"Advanced Energy Systems Fueled from Biomass," Carol R. Purvis and Keith J. Fritsky, EPA

The concentration of CO_2, a greenhouse gas, is increasing by an estimated 0.5% per year. CO_2 emissions from fossil fuel combustion quadrupled between 1950 and 1980. Conversion of renewable biomass to energy is CO_2, neutral and produces lower SO_2 and NO_x emissions than fossil fuel combustion.

EPA/AEERL is studying two biomass conversion technologies: conventional combustion in a boiler coupled with a steam turbine system and gasification in a gasifier coupled with an aeroderivative turbine system. In-house research is addressing the problems encountered in conventional systems with regard to emissions, tube fouling, bed agglomeration, and low thermal efficiency. Extramural research is addressing the problems of advanced systems with regard to fixed/fluidized-bed gasifiers, alkali/particulate cleanup, gas compatibility with turbines, and system efficiency. The results will provide data for owner/operators to improve system performance and for designer/developers to demonstrate advanced systems. This research will help promote biomass-for-energy as a global warming mitigation strategy by focusing on a need to maximize biomass resources through increased utilization efficiency.

"Programs and Policy Impacts Attributable to Regional Biomass Program Woodstove Research Efforts," Stephen Morgan, EPA

The decision by the CONEG Policy Research Center in the spring of 1985 to embark upon a field evaluation of woodstoves led to an ambitious and sophisticated 6-year research program that has had profound impacts on the evolution of the industry. The initial interest in exploring the claims of manufacturers about the efficiency, particulate emissions, and creosote buildup in catalytic, catalytic add-on, and non-catalytic "high tech" woodstove models readily expanded to undergird much of the conceptual thinking that informed the EPA's participatory regulations negotiations process engaging the industry, the Agency and environmentalists. Since the publication of the EPA certification standards in 1987 and the laboratory testing methodology utilized to support the standard, the Northwest Regional Biomass Program (NRBP)-sponsored research has moved on to test the field durability of certified stoves. The early, disappointing findings in that field testing identified structural, design and materials flaws that have directly contributed to improved stove designs in the second generation of certified stoves.

Sue Philpott is with Acurex Environmental Corp., Durham, NC 27713.
Keith J. Fritsky is the EPA Project Officer (see below).
The complete report, entitled, "Proceedings: The 1992 Greenhouse Gas Emissions and Mitigation Research Symposium," (Order No. PB94-132180/AS; Cost: $61.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

Official Business
Penalty for Private Use
$300

EPA/600/SR-94/008

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35