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Project Summary

Proceedings: The 1995 Symposium on Greenhouse Gas Emissions and Mitigation Research

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The report documents the 1995 Symposium on Greenhouse Gas Emissions and Mitigation Research, sponsored by the U.S. Environmental Protection Agency's Air Pollution Prevention and Control Division (EPA/APPCD), in Washington, DC, on June 27-29, 1995. The symposium provided a forum of exchange of up-to-date information on emission sources contributing to global climate change and state-of-the-art mitigation technologies and practices. Presentations related to: activities in EPA, U.S. Department of Energy (DOE), and Electric Power Research Institute (EPRI) on greenhouse gas emissions and mitigation research, and APPCD's global emissions and technology databases; carbon dioxide (CO_2) emissions, disposal, and control; methane (CH_4) emissions and mitigation technologies including such topics as coal mines, the natural gas industry, key agricultural sources, and landfills; renewable energy options including alternative biomass fuels; and advanced energy systems. The proceedings include 44 papers, visuals, and abstracts.

This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, 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 1995 Symposium on Greenhouse Gas Emissions and Mitigation Research, sponsored by EPA/APPCD and Acurex Environmental Corporation was held June 27 through 29, 1995, in Washington, DC. Forty-four presentations were made on recent research on global change emissions and potential mitigation technologies. The symposium Chairperson was Michael A. Maxwell of EPA/APPCD. This project summary includes abstracts of the symposium presentations. The five sessions were:

I. Overview of National and International Efforts

II. Emissions from Anthropogenic Sources

III. Mitigation of Methane and Other Greenhouse Gases

IV. Biomass Utilization

V. Renewables and Advanced Energy Efficient, End-Use Technologies

Session I

Overview of National and International Efforts (Frank T. Princiotta, EPA, Session Chairperson)

"Greenhouse Warming: The Uncertainties and the Mitigation Challenges," Frank T. Princiotta Director, APPCD, EPA

Analysis will be presented dealing with some of the most significant issues associated with potential greenhouse gas warming. Using a projection model, the uncertainties regarding projected warming

will be quantified. Given these uncertainties, ranges of likely warming will be presented and potential impacts discussed. An analysis will also be included identifying countries most responsible for greenhouse gas emissions and their contribution to carbon dioxide and methane emissions. Also, an analysis will be presented indicating the relevance of the key greenhouse gases to global warming. Various mitigation strategies will be discussed and their impacts on global warming identified. Biomass will be highlighted as a key alternative to fossil fuels.

"Climate Change Activities in EPA's Office of Policy, Planning, & Evaluation (OPPE),"
Kurt Johnson, EPA

OPPE coordinates EPA climate policy and supports the development of U.S. positions on climate change. OPPE's analytical activities include: assessing the potential costs and benefits of policy options to reduce the risks of global warming, and recommending ways to reduce greenhouse gas emissions in the most cost-effective way possible; reviewing the effectiveness of the U.S. Climate Change Action Plan and other countries' climate change plans; proposing actions that could ensure that the U.S. will meet the Administration's commitment to reduce greenhouse gas emissions to 1990 levels by the year 2000; preparing studies on the potential impacts of climate change; and working as part of an interagency process to develop U.S. policy under the Framework Convention on Climate Change.

"Pollution Prevention at a Profit,"
Amy C. Olson, EPA

The EPA's Atmospheric Pollution Prevention Division (APPD) aims to profitably prevent pollution through new and innovative voluntary public/private partnership programs that overcome market barriers to advance energy efficiency. Promoting energy-efficient technologies and techniques to prevent pollution, EPA's Green Lights, Energy STAR Buildings and Equipment, and methane reduction and recovery programs have achieved measurable economic and environmental successes. Working within the framework of President Clinton's *Climate Change Action Plan* which strives to respond to the threat of global climate change while strengthening the economy, APPD provides solutions that create jobs, encourage economic investment, and establish new product markets.

"Energy Partnerships for a Strong Economy: A Better Climate for Jobs,"
Arlene F. Anderson, DOE

The U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy has responsibility for implementing many of the actions contained in the President's Climate Change Action Plan. These programs (Energy Partnerships For A Strong Economy) are in part programs that are also being implemented by DOE in response to the Energy Policy Act of 1992. With Fiscal Year 1995 funding in hand, DOE and its many partners are saving money and environmental emissions that would not have been saved had it not been for the increased emphasis placed on these programs. A sample of DOE's program accomplishments follows.

"Climate Change and the Value of Technological Innovation Under Uncertainty,"
Stephen C. Peck and Thomas J. Teisberg, EPRI

In this paper, we use a small-scale "integrated assessment" model to explore the role of technological innovation in the context of uncertainty about the costs of climate change and the state of future carbon-free energy technologies. We find that if future technology is better, optimal emissions in the future are significantly lower, while optimal emissions in the near term may be slightly higher. We also find that a 10% increase in the probability of even modestly improved technology may be worth $130 billion in present value. These results indicate that the state of future technology matters in developing a strategy for addressing climate change, and that there are potentially large payoffs to actions we might take to promote improvements in future technology. Developing carbon-free energy technologies is a key step toward a sustainable development future.

"The Global Future: Environment vs. Development,"
John Kadyszewski, Winrock International

Some members of the international community have been surprised at the strongly negative reaction from many countries in the developing world to proposals for global cooperation to reduce greenhouse gas emissions. These representatives of developing countries see any agreements to reduce future greenhouse gas emissions as placing unnecessary constraints on their opportunities for development. They view energy as critical to economic development. Per capita energy consumption in the U.S. and Europe dwarfs per capita energy consumption in the developing world. Global environmental objectives are construed as in conflict with national development objectives.

This paper reviews projected greenhouse gas emissions associated with power generation in China, India, and Central America. Current projections show emissions from China and India overtaking emissions from the U.S., Europe, and Japan early in the next century. Unilateral reductions by the U.S., Europe, or Japan cannot prevent dramatic increases in future emissions. Data from Central America are used to demonstrate viable commercial alternatives to the expanded use of fossil fuels and their associated emissions.

How can the world meet environmental and development objectives? The paper argues that thoughtful management of public global capital pools can create a system under which objectives can be met. Changes in how multilateral investment institutions use their capital can have dramatic impact on future investment decisions made by private companies. In this modified investment climate, private companies would have incentives to build cleaner systems today and to develop a new generation of technology for tomorrow. Without change, demands for development will place additional pressure on the environment and increase the likelihood of global tension.

Session II

Emissions From Anthropogenic Sources
(M.A.K. Khalil, Oregon Graduate Institute, Session Chairperson)

"Global Emissions Inventories,"
Jane Dignon, Lawrence Livermore Laboratory

Many trace chemical species in the atmosphere are radiatively important and may affect climate and air quality. Detailed and accurate emissions inventories are essential for understanding the changing chemical composition of our atmosphere, and to establish compliance with international treaties. Currently climate and chemistry model predictions are limited by the paucity of quality emissions data input. This paper presents the most up-to-date compilation of emissions inventories for radiatively important trace species. It reports the spatial and temporal charac-

teristics of the emissions along with some interpretive comments. Except for most of North America and Western Europe, detailed regional inventories are scarce for almost all radiatively important trace species.

"CO_2 Emission Calculations and Trends,"
Tom Boden and Gregg Marland, Oak Ridge National Laboratory
Bob Andres, Institute of Northern Engineering, University of Alaska-Fairbanks

Evidence that atmospheric CO_2 levels have risen during the past several decades is irrefutable. Most of the observed increase in atmospheric CO_2 is believed to result from CO_2 releases from fossil fuel burning. The United Nations (UN) Framework Convention on Climate Change (FCCC) held in Rio de Janeiro in June 1992 reflects global concern over increasing CO_2 mixing ratios and their potential impact on climate. One of the convention's stated objectives is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." Specifically, the FCCC asks all 154 signing countries to inventory their current greenhouse gas emissions, and it sets non-binding targets for some countries to control emissions by stabilizing them at 1990 levels by the year 2000.

This paper describes the compilation, processing, and availability of the most comprehensive CO_2 emissions database presently available. The paper also discusses caveats in the database, efforts to improve it, and CO_2 emission trends. The database offers global, regional, and national annual estimates of CO_2 emissions resulting from fossil fuel burning, cement manufacturing, and gas flaring in oil fields for 1950-1992. Estimates are derived from energy data published by the UN and the U.S. Department of Energy, and cement production data published by the U.S. Bureau of Mines. This CO_2 emission database is essential to carbon cycle research, provides estimates of the rate at which fossil fuel combustion and cement production have released CO_2 to the atmosphere, and offers baseline estimates for those countries compiling FCCC 1990 CO_2 emission inventories.

According to these estimates, global CO_2 emissions from fossil fuel consumption, cement production, and gas flaring have grown almost 4-fold since 1950. The 1992 estimate of 6097 million metric tons of carbon ended a string of eight consecutive years of growth in global CO_2 emissions and represents a 1.2% decline from 1991. The 1991 estimate of 6172 million metric tons of carbon is the highest CO_2 emission estimate since the data record began in 1950, but includes 130 million metric tons of CO_2 being emitted to the atmosphere from the Kuwaiti oil field fires.

Regionally, a marked decline in CO_2 emissions continues for Eastern Europe, and Western Europe experienced its first decline in emissions since 1987-88. However, regions where populations continue to grow—such as Africa, Centrally Planned Asia, Central and South America, the Far East, and Oceania—show corresponding increases in CO_2 emissions. In 1950, North America, Eastern Europe, and Western Europe (including Germany) accounted for 89.1% of global CO_2 emissions from fossil fuel burning, cement production, and gas flaring, whereas the remaining six regions accounted for only 10.9% Now these six regions contribute 41.1% of the CO_2 emitted globally

Nationally, the U.S. continues to be the largest single source of fossil-fuel-related CO_2 emissions with 1332 metric tons of carbon emitted in 1992. The top three emitting countries—the U.S., China, and Russia—were responsible for 43.2% of the world's emissions from fossil fuel burning in 1992. The top 20 emitting countries accounted for ~80% of all the world's emissions.

"Rice Agriculture: An Important Source of Atmospheric Methane,"
M.A.K. Khalil, M.J. Shearer and R.A. Rasmussen, Oregon Graduate Institute

In all the global budgets of atmospheric methane, emissions from rice agriculture have been among the largest single sources. Early estimates were as high as 300 Tg/yr, but upon careful examination of the data, the estimates were reduced to about 100 Tg/yr. In time, as direct flux measurements became available, it was found that there was considerable variability in the whole season of emissions of methane from different types of rice fields. The global estimates now are even lower, about 60 Tg/yr. Even so, rice fields constitute a major source of methane. The emissions of methane from rice fields may have been higher at some earlier time in recent decades than they are now. Because of limitation of land readily adaptable to rice agriculture, the use of inorganic fertilizers, and the short growing cycles of recent hybrid varieties, future emissions may not increase greatly.

"Developing Improved Methane Emission Estimates for Coal Mining Operations,"
Stephen D. Piccot, Sushma S. Masemore, Eric S. Ringler, Southern Research Institute
David A. Kirchgessner, EPA

The EPA's APPCD has sponsored research to improve emissions data and establish more representative emissions inventories for coal mining operations. The focus of this effort has been on the uncertain sources of emissions including surface mines, post-mining coal handling, abandoned underground mines, and inactive surface and underground mines. Measurement data collected at 5 surface mines, 20 abandoned underground mines, and 1 coal handling facility are presented. The significance of these individual sources, and their emissions processes, is also examined. Measurement priorities are also discussed.

"Methods for Estimating Methane Emissions from the Domestic Natural Gas Industry,"
David A. Kirchgessner, EPA
R. Michael Cowgill, Matthew R. Harrison, Lisa M. Campbell, Radian Corporation

Anthropogenic emissions of methane are suspected of making a significant contribution to the phenomena associated with global climate change. Early, gross estimates based on scarce data suggested that the global natural gas and coal industries each may contribute 10 to 15% of the annual anthropogenic methane inventory. This possibility made the importance of improving the industry-specific emissions estimates apparent. The data would be useful in determining where emissions could be most economically reduced if that approach were deemed prudent; the data would also be useful in evaluating the advisability of switching from coal to natural gas fuel as a near-term measure for reducing methane emissions to the atmosphere. The project described has the goal of estimating methane emissions from the domestic gas industry to within ±0.5% of production or ±100 Billion Cubic Feet. Emission estimates are nearly complete and appear to be converging on

1.75% of production with a 1992 base year.

"GloED and GloTech: Global Emissions and Technology Database Software," Lee L. Beck, EPA

This paper describes two powerful software packages being developed by EPA. One is an emissions inventory software called GloED, and the other is a technology software called GloTech. GloED compiles country and source specific inventories of emissions of greenhouse gases by combining emission factors and activity data. GloTech computes cost and environmental impacts of technologies and technology combinations. Both software packages are very user-friendly, integrate the data with their references, and rely heavily on graphics to assist the user.

"Overview of EPA'S Global Climate Change Research Program on Waste Management," Susan A. Thorneloe, EPA Randy Strait and Michiel Doorn, E.H. Pechan & Associates, Inc. Bart Eklund, Radian Corporation

This paper provides an overview of ongoing research at EPA's APPCD, the former Air and Energy Engineering Research Laboratory, on greenhouse gas emissions from waste management. Sources being evaluated include landfills, open dumps, waste piles, wastewater (treated and untreated), septic sewage, and agricultural waste. Earlier estimates have suggested that waste management accounts for ~70 teragrams (10^{12} grams) per year (Tg/yr) of methane (CH_4) globally or 19% of total global CH_4 anthropogenic emissions of 360 Tg/yr. However, the estimate ranges from 54 to 95 Tg/yr and is considered very uncertain due to limitations in available data for establishing credible emission factors and limitations in country-specific activity data. Since landfills and possibly other waste sources are amenable to cost-effective control, these sources have been given a priority for developing more reliable estimates and identifying cost-effective opportunities for greenhouse gas (GHG) reductions. Primarily due to the ability to utilize the CH_4 for its energy potential, this is a relatively cost-effective source of GHG emissions to control. Emission sources that are amenable to control—such as landfills—have been given a high priority for clarification. The research described in this paper is funded through EPA's Global Climate Change Research Program. This research is part of a larger EPA research program to develop more reliable GHG emission estimates for the major sources and to identify cost-effective opportunities for reducing GHG emissions. This research is being conducted in support of the goals established at the United Nations Conference on Environment and Development in 1992 and the Climate Change Action Plan.

"Greenhouse Gases from Widely Used Small-Scale Combustion Devices in Developing Countries: Phases I-II: Stoves in India and China; Phase III: Charcoal Kilns in Thailand," Kirk R. Smith and Junfeng Zhang East-West Center Susan A. Thorneloe, EPA

Small combustion devices such as stoves and charcoal kilns in developing countries are individually small, but so numerous that, depending on their emission factors, they could possibly influence global inventories of greenhouse-related gases. A pilot study in Manila found that such devices do seem to have high enough emission factors to be of interest, and thus a larger set of studies is being undertaken in India, China, and Thailand to determine emission factors for a wide range of the kinds of stove/fuel combinations and charcoal kilns of common use in developing countries.

Session III

Mitigation of Methane and Other Greenhouse Gases (Rhone Resch, EPA, Session Chairperson)

"The EPA STAR Program and the Natural Gas Industry," Kathleen Hogan, EPA

This paper describes the Natural Gas STAR Program, a cooperative, voluntary program between the Natural Gas Industry and EPA to implement pollution prevention techniques in a cost-effective manner. Specifically, the STAR Program encourages natural gas companies to adopt cost-effective practices and technologies that reduce emissions of methane—the primary component of natural gas. Methane is a potent greenhouse gas—20 times more effective than CO_2 at trapping heat in the atmosphere.

In addition to reducing the threat of global warming, companies that participate in the Natural Gas STAR Program also save money by reducing leaks and losses of the product they sell. In 1993, the first partial year of the program, transmission and distribution partners saved 1.3 billion cubic feet of natural gas worth almost $3 million. The 1994 program results are expected to generate even greater savings.

"Significant Sources of Methane Emissions in the Natural Gas Industry," Matthew R. Harrison and R. Michael Cowgill, Radian Corporation David A. Kirchgessner, EPA

Methane, the major constituent of natural gas, is a potent greenhouse gas believed to increase the effect of global warming when released to the atmosphere. Reducing methane emissions would lessen this effect, as well as save money and increase energy efficiency by decreasing the amount of gas product lost. This project quantified methane emissions from the natural gas industry. Major sources and quantities of methane emissions are summarized, emission estimation methods are described, and potential candidates for reducing methane emissions are discussed.

"Utilization and Control of Landfill Methane by Fuel Cells," J.L. Preston and J.C. Tricciola, International Fuel Cells Corporation R.J. Spiegel, EPA

The EPA has conducted a program to control methane emissions from landfills using a fuel cell. The fuel cell would reduce air emissions affecting global warming, acid rain, and other health and environmental issues. By producing usable energy, it would also reduce our dependency on foreign oil. This paper discusses the Phase II and Phase III results of the EPA program underway at International Fuel Cells Corporation. In this program, two critical issues were addressed: (1) a landfill gas cleanup method that would remove contaminants from the gas sufficiently for fuel cell operation, and (2) successful operation of a commercial fuel cell power plant on the lower-heating value waste methane gas.

"Methane Recovery from Landfills and an Overview of EPA/APPCD's Landfill Gas Research Program," John G. Pacey, Emcon Associates

Susan A. Thorneloe, EPA Michiel Doorn, E.H. Pechan & Associates, Inc.

Clean Air Act (CAA) regulations for new and existing municipal solid waste (MSW) landfills which were proposed in MAY 1991 are scheduled to be promulgated in August 1995. These regulations are expected to require up to 400 landfills to install and maintain a landfill gas (LFG) extraction and control facility to reduce landfill air emissions. These emissions include nonmethane organic compounds (NMOCs) which contribute to tropospheric ozone, methane which is a potent greenhouse gas, and toxic compounds which are of concern to public health. In addition, landfills that are subject to New Source Review may also be considered for controls to reduce landfill air emissions. Control options include flaring the gas or combustion with energy recovery which include (1) direct use of the gas as medium heating value fuel, (2) generation of electricity using reciprocating engines, gas or steam turbines, or fuel cells, and (3) upgrading the gas to pipeline quality or to produce vehicular fuel. Many landfill owners will be evaluating their options for controlling landfill air emissions and will be considering if it is practical and economical to minimize potential control costs though the development of a LFG utilization project.

This paper summarizes ongoing research at EPA's APPCD (the former Air and Energy Engineering Research Laboratory) on LFG utilization. Research was conducted to identify the technical issues and solutions through interviews conducted with industry experts in the U.S., Europe, and Australia. The U.S. developers and operators who were interviewed represent over 70% of the projects in the U.S. Technical issues associated with the use of LFG as compared to natural gas—which is the primary fuel cell–can result due to chlorinated and toxic compounds, particulate and reduced heating value when compared to natural gas [18.6 vs. 37.2×10^6 J/m^3(500 vs. 1000 Btu/scf)]. A recent database of LFG-to-energy projects that has been developed through a collaborative program between EPA/APPCD and the Solid Waste Association of North America (SWANA), indicates that there are currently 137 LFG-to-energy projects in the U.S. and 9 in Canada. This paper will summarize statistics and industry trends resulting from this database, and discuss the nontechnical and technical issues and solutions. Other EPA/APPCD research that will be discussed in this paper is a recent overview of emerging technologies for LFG utilization and research regarding the demonstration of fuel cells for LFG utilization.

The research described is funded through EPA's Global Climate Change Research Program. This research is part of a larger EPA research program to develop more reliable emission estimates for the major sources of greenhouse emissions and to identify cost-effective opportunities for reducing greenhouse gas emissions. This research is being conducted in support of the goals established at the United Nations Conference on Environment and Development in 1992 and the Climate Change Action Plan.

"Case Studies of Sewage Treatment with Recovery of Energy from Methane," William H. Hahn, Science Applications International Corporation

Energy recovery from biogas generated from wastewater treatment processes is universally cost- effective and has gained widespread acceptance. The technology exists to allow full use of biogas, and the extra costs of incorporating this energy source into a system are small. The payback period for installation of biogas energy recovery at plants having anaerobic digesters is short, typically less than 6 years. Recovery and use of biogas accomplish energy conservation and pollution prevention goals, and also cost savings, making this an obvious choice for application in all treatment plans that employ anaerobic digestion for stabilizing wastewater biosolids.

Other energy conservation and municipal pollution prevention activities can be integrated with use of biogas, as demonstrated by the Sunnyvale plant, including collection and use of landfill gas, recovery of waste heat, water reclamation, and municipal water conservation. Often, wastewater treatment plants are located near municipal landfills, and could potentially develop the landfill gas as an additional energy source. Advantages lie not only in the cost savings from energy recovery from the landfill gas, but also in meeting regulatory and safety concerns posed by landfill gas emissions.

The examples of the Orange County and Los Angeles plants show that energy conservation not only conserves natural resources, but can also lead to increased ability to comply with air emissions regulations. The greenhouse gas carbon dioxide is released by all wastewater treatment and biosolids management processes. Converting biosolids to fuel achieves substantial benefit from the wastes before carbon dioxide is ultimately released. In addition, nonrenewable energy sources such as natural gas are replaced by the renewable energy from wastewater, without adversely affecting receiving water quality.

Plants can address environmental mandates in an integrated framework based on energy conservation, through the use of renewable resources. As the case studies prove, activities that conserve energy also reduce pollution costs.

"Assessment of CO_2 Capture, Utilization, and Disposal," Howard J. Herzog, Massachusetts Institute of Technology

The capture and sequestration (via utilization or disposal) of CO_2 is the only greenhouse gas mitigation option that will allow use of our large fossil fuel resources without a buildup of atmospheric CO_2. This paper assesses the current status and research needs of this mitigation option as applied to fossil-fuel-fired power plants.

"'Front Line' CO_2 Abatements from the Steel Industry," Britt R. Gilbert, TORESCO, Ltd.

Worldwide CO_2 emissions from conventional steelmaking exceed 1.1 billion tons per year. But a new generation of ironmaking technologies will significantly decrease these emissions by perhaps 75% in the coming decades.

One of these new ironmaking technologies, the COREX® process, was the central technology in an iron/methanol co-production facility being developed by the author near Pittsburgh. The author presents carbon balances for iron/methanol co-production that show dramatic reductions in CO_2 emissions, compared to conventional iron and methanol production. He discusses the factors which ultimately doomed his project, and assesses the likelihood of success in the near term for similar projects based on new iron and steelmaking technologies. Such projects are now beginning to be built, and are yielding dramatic decreases in CO_2 emissions. He details how a CO_2 trading program would greatly hasten the adoption of these new ironmaking technologies by the steel industry.

"Electrochemical Reduction of CO_2 to Fuels," Daniel L. DuBois, National Renewable Energy Laboratory

A potentially useful approach to liquid fuel synthesis in the future may involve the direct electrochemical reduction of CO_2. This paper describes some of the problems which must be overcome for this approach to become feasible. Possible energy and CO_2 sources are discussed briefly. The major focus of the discussion is on the properties which catalysts for electrochemical CO_2 reduction should possess. A brief review of various catalytic systems currently under study in a number of laboratories is presented to assess the present state of the art and the problems which need to be overcome.

"The Carnol Process for CO_2 Mitigation from Power Plants and the Transportation Sector," Meyer Steinberg, Brookhaven National Laboratory

A CO_2 mitigation process is developed which converts waste CO_2 primarily recovered from coal-fired plant stack gases with natural gas, to produce methanol as a liquid fuel and coproduct carbon as a materials commodity. The Carnol process chemistry consists of methane decomposition to produce hydrogen that is catalytically reacted with the recovered waste CO_2 to produce methanol. The carbon is either stored or sold as a materials commodity. A process design is modeled and mass and energy balances are presented as a function of reactor pressure and temperature conditions. The Carnol process is a viable alternative to sequestering CO_2 in the ocean for purposes of reducing CO_2 emissions from coal burning power plants. Over 90% of the CO_2 from the coal burning plant is used in the process which results in a net CO_2 emission reduction of over 90% compared to that obtained from conventional methanol production by steam reforming of methane. Methanol as an alternative liquid fuel for automotive engines and for fuel cells achieves additional CO_2 emission reduction benefits. The economics of the process are greatly enhanced when carbon can be sold as a materials commodity. Improvement in process design and economics should be achieved by developing a molten metal (tin) methane decomposition reactor and a liquid phase, slurry catalyst, methanol synthesis reactor directly using the solvent saturated with CO_2 scrubbed from the power plant stack gases. The benefits of the process warrants its further developments.

Session IV

Biomass Utilization (Robert H. Williams, Princeton University, Session Chairperson)

"Demonstration of a 1 MWe Biomass Power Plant,"

Carol R. Purvis, EPA
Patrick Myers, RTI
Mounir Mazzawi, Mech-Chem Associates, Inc.

The EPA's NRMRL/APPCD, formerly EPA's Air and Energy Engineering Research Laboratory (AEERL), is cooperating with the Research Triangle Institute to demonstrate that converting wood energy to electrical power results in waste utilization, pollution alleviation, and energy conservation.

The project is expected to demonstrate the technical, economic, and environmental feasibility of an innovative energy conversion technology, producing approximately 1 MWe, at the Marine Corps Base, Camp Lejeune, NC. Camp Lejeune will supply wood waste for power plant operation while minimizing transport and maximizing local waste resource utilization. The technology for the process and the site at Camp Lejeune have been selected, design specifications are presently underway, and installation, start-up, testing, and demonstration will soon follow. This paper provides details of the status of this project.

"Development of a New Generation of Small Scale Biomass Fueled Electric Generating Power Plants," Joe D. Craig, Cratech, Inc. Carol R. Purvis, EPA

There exists a need by a large worldwide market for greatly improved small scale (1 to 20 MWe per unit) biomass-fueled power plants. These power plants will significantly increase the efficiency of generating electric power from wood and bagasse as well as converting non-traditional fuel sources such as rice hulls, animal manure, cotton gin trash, straws, and grasses to electricity. Advancing the technology of biomass-fueled power plants will greatly expand the use of this environmentally-friendly sustainable 24 h/day source of electrical power for industry and communities worldwide. This paper briefly describes the status of a biomass-fueled power plant being development by Cratech, Inc.

"Installation of an ENERGEO Biomass Power Plant at a Lumber Company," Charles F. Sanders ENERGEO, Inc. Carol R. Purvis, EPA

ENERGEO, Inc. is engaged in a demonstration test program of its AGRIPOWER 200 unit fueled with biomass at Sutton Lumber Company in Tennga, GA. The objective of the program is to evaluate the operating and performance characteristics of the system using lumber wastes for fuel. The program is scheduled to accumulate 8000 hours of operation over a period of 1 to 2 years. The program became a reality due to initial funding from the U.S. Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP) and the EPA Air and Energy Engineering Research Laboratory (now referred to as APPCD, Research Triangle Park).

The AGRIPOWER unit operates with an "open" Brayton cycle using a fluid bed combustor and several heat exchangers to heat compressed air which in turn drives a turbine/generator (T/G) set. The T/G set, which includes the compressor and a recuperator, is a Solar "Spartan" unit packaged for this application by Alturdyne, Inc. The combustor utilizes in-bed and freeboard combustion zones, and the above-bed zone is well mixed to provide uniform temperatures.

Design specifications call for consumption of 829 lb/h (376 kg/h) of fuel with a lower heating value of 4,270 Btu/lb (9.92 MJ/kg). The net electrical power output will be approximately 200 kW-hr/hr. This corresponds to a heat rate of 17,700 Btu/kW-hr (41.3 MJ/kW-hr). The capital cost of an AGRIPOWER 200 unit will be approximately $2,250/kW of capacity.

"An Indirectly Heated Thermochemical Reactor for Steam Reforming/Gasification of Biomass and Other Carbonaceous Materials," Momtaz Mansour, Manufacturing and Technology Conversion International, Inc.

Manufacturing and Technology Conversion International, Inc. (MTCI) is a process and hardware oriented energy and environmental technology development company located in Columbia, MD, with manufacturing and development facilities in Santa Fe Springs, CA, and Curtis Bay, MD. Based on the principles and merits of

pulse combustion, the Company is developing clean coal burners and fluid-bed combustors, low NO_x combustors, particulate emissions control devices, and (now entering the market) the indirectly heated steam reformer/gasifier for waste-to-energy conversion and the conversion of coals, renewables, and industrial and municipal wastes (including toxins) into clean fuel forms for IGCC and combined-cycle power systems. For the pulp and paper industry the MTCI technology steam reformer/gasifier can process all kinds of spent liquor for energy and process chemical recovery.

"Cost Versus Scale for Advanced Plantation-Based Biomass Energy Systems in the U.S.,"
Christopher I. Marrison and Eric D. Larson, Princeton University*

A unique feature of biomass energy systems is that feedstock must be gathered from a wide area around the energy production facility. For a small-scale facility, transport costs will be relatively low, but capital cost per unit of output will be high. For a large-scale facility, transport costs will be high, but capital costs will be relatively low. At some intermediate scale, the total cost of energy should reach a minimum. This paper examines the effects of scale on the prospective costs of producing electricity and alcohol fuels from plantation-grown switchgrass in North Central and Southeast regions of the U.S.

Site-specific biomass cost-supply curves for the years 2000 and 2020 are developed using projections of the Oak Ridge National Laboratory for switchgrass yields and costs as a function of land capability class. A geographic information system (GIS) is used to analyze soil quality distributions and road transport distances.

Conversion technologies considered include one commercial electricity generating technology—the steam Rankine cycle, and one nearing commercial readiness, the gasifier/gas turbine combined cycle. Two alcohol fuels are considered: methanol via thermochemical gasification and ethanol via enzymatic hydrolysis. Both of these processes have the potential to be commercially ready early in the next century or sooner. Estimates of installed capital costs for all of these conversion systems are drawn from published and other sources.

In all cases, the minimum cost of electricity (COE/min) or alcohol (COA/min) is reached at plant capacities that are larger than conventional wisdom might suggest. Up to these capacities, the rate of decrease in unit capital costs is more rapid than the rate of increase in biomass transportation costs. However, around the capacity corresponding to COE/min or COA/min, there is a wide range over which costs change very little. In general, higher biomass yields lead to larger capacities at COE/min or COA/min. Costs are higher in the NC than SE region, and (in both regions) costs are lower using year-2020 biomass costs compared to year-2000 costs.

"Greenhouse Gas Implications and Mitigation Opportunities for Integrated Biomass Systems,"
Jane Hughes Turnbull, Electric Power Research Institute
Ulf Boman, Vattenfall Utveckling AB

Integrated biomass energy systems that include crop resources grown as fuel offer a means of displacing fossil fuel systems and thus the emissions of carbon dioxide produced by the combustion of fossil fuels. Energy crops directly utilize carbon dioxide as a nutrient; therefore, a biomass power system is a "closed loop" carbon system only so far as the conversion part of the system is concerned. Other aspects of the total fuel cycle will impact the "no net carbon dioxide" axiom. Trade-offs among options associated with production, handling, and transportation will impact costs, energy inputs, or other system values. Fossil fuel inputs associated with agricultural or forestry equipment need to be considered. Fossil fuel use in the production and distribution of agricultural chemicals also is a significant concern. Coproducts should be evaluated insofar as they may displace alternative production systems that would use added quantities of fossil fuels. Intelligent selection of crops, rotation periods, and agricultural practices can also affect the extent to which carbon may be sequestered using lands that have been in conventional agriculture. The potential for soils, on which high-yielding energy crops are grown, to be used as carbon sinks is only beginning to be appreciated. Soil carbon sequestration may well become as important a means for mitigating greenhouse gas emissions as the use of biomass energy systems to displace fossil fuels.

"Cost of Producing Herbaceous and Woody Biomass Crops in the U.S.,"
Marie E. Walsh, Oak Ridge National Laboratory

Switchgrass and hybrid poplar are potential renewable sources of liquid fuels, power, and chemicals. This paper estimates the full economic cost (i.e., variable cash, fixed cash, and opportunity cost of owned resources) of producing these energy crops in six regions in the U.S. Average production costs vary by region, ranging from $29 to $59/dry ton ($26-54/Mg) for switchgrass bales and $61 to $83/dry ton ($55-75/Mg) for poplar chips. Within a region, production costs decline substantially as yields increase. Estimated biomass prices needed to ensure comparable profitability with conventional crops are lower for switchgrass than for hybrid poplar, and are higher in the Lake States and Corn Belt than for other regions of the U.S.

"Methanol and Hydrogen from Biomass for Transportation, with Comparisons to Methanol and Hydrogen from Natural Gas and Coal,"
Robert H. Williams, Eric D. Larson, Ryan E. Katofsky, Jeff Chen, Princeton University

Methanol and hydrogen produced from biomass via indirectly heated gasifiers and their use in fuel cell vehicles would make it possible for biomass to be used for road transportation, with zero or near-zero local air pollution and very low levels of life-cycle CO_2 emissions, if the biomass feedstock is grown sustainably. Moreover, because this approach to using biomass for transport fuels involves such an efficient use of land, it offers the potential for making major contributions in reducing dependence on insecure sources of oil for transportation.

Biomass-derived methanol and hydrogen would be roughly competitive with these fuels produced at much larger scale (to exploit scale economies) from coal, even with relatively high biomass feedstock prices. While biomass-derived methanol and hydrogen would not be able to compete with the production of these fuels from natural gas in the near term, natural gas prices are expected to rise substantially over the next decade or so. With natural-gas prices expected by 2010, biomass would be nearly competitive with natural gas in the production of these fuels. A carbon tax that would increase the cost of owning and operating fuel cell vehicles on natural gas-derived fuels by less than 2% would be adequate to tip the economic balance in favor of biomass.

The production of methanol for export in developing regions could provide sus-

tainable new income streams for rural areas in developing regions while bringing competition and fuel price stability to world markets in transport fuels.

"Hydrogen from Biomass via Fast Pyrolysis," E. Chornet, M. Mann, D. Wang, D. Montane, S. Czernik, and D. Johnson, National Renewable Laboratory

The mission of DOE's Hydrogen Program is to encourage and support the development of safe, practical, and economically competitive hydrogen technologies and systems to meet transitional and large-scale energy needs. By 2025, the percentage of energy from oil imports to the U.S. could be reduced from the current 50 to 60% to less than 25%, if hydrogen energy were to contribute only 10% to the overall energy use. The Hydrogen Program will meet these challenges with fundamental and applied research, systems demonstrations, and systems studies.

Pyrolysis of biomass and steam reforming of the resultant oils is being studied as a strategy for the production of hydrogen. New technologies for the rapid pyrolysis of biomass provide compact and efficient systems to transform biomass into vapors that are condensed to oils, with yields as high as 75 to 80% by weight of the anhydrous biomass. A process of this nature has the potential to be cost competitive with conventional means of hydrogen production.

The use of biomass is an alternative to producing hydrogen from petroleum and natural gas, and the environmental benefits are several fold. If the biomass is grown on a sustainable basis as an energy crop, there is a zero net carbon dioxide contribution to the atmosphere. Biomass crops can be grown as barriers between crop land and natural water systems, to prevent fertilizer runoff. Furthermore, crop rotation and harvesting can be timed to offer habitat to birds and animals. Waste biomass from sources such as agriculture and urban waste can also be used to produce hydrogen by this process. Using this source of biomass mitigates landfill disposal and eliminates the methane produced during natural decomposition.

Using hydrogen as a fuel offers additional environmental benefits. Hydrogen can be used in a fuel cell to produce electricity, with water as the only product. When combusted, for example in an internal combustion engine, far fewer nitrogen oxide compounds are released than during the combustion of fossil fuels. There are no carbon monoxide, carbon dioxide, or particulates emitted when hydrogen is converted to energy.

"The Hynol Process," Robert H. Borgwardt, EPA

This paper describes a process currently under evaluation by EPA for production of transportation fuel from biomass. If biofuel is to significantly impact petroleum displacement and greenhouse emissions in the transportation sector, maximum yield of fuel energy from the available biomass supply must be obtained. It will also be necessary to supplement biofuel with other fuels or leverage its production by use of a cofeedstock. The fuel should also be compatible with vehicles powered by fuel cells which promise considerable overall future environmental benefits. Methanol appears to be the best alternative fuel to meet these requirements, and this investigation is focused on thermochemical technologies that can increase methanol yield from biomass by utilizing natural gas as cofeedstock. The process currently under evaluation produces methanol in three basic steps: hydrogasification of biomass followed by steam reforming to synthesis gas and conversion of the synthesis gas to methanol. Hydrogen derived from the natural gas is recycled to the gasifier to provide part of the thermal energy for gasification; the remaining energy required for gasification is obtained by heat exchange with the reformer effluent. This assessment was carried out using the process simulator *Aspen Plus*. The assumptions necessary for such simulations are, wherever possible, consistent with those published elsewhere for other process options. Results indicate that testing in actual equipment is needed, with stringent conditions to be met in each process step if the expected efficiency is to be realized.

Session V

Renewables and Advanced Energy Efficient, End-Use Technologies (Thomas D. Bath, NREL, Session Chairperson)

"Greenhouse Gas Mitigation: The Potential for Renewable Energy," Thomas D. Bath and Jack Stone, National Renewable Energy Laboratory

This paper reviews the opportunity for different forms of renewable energy to reduce emissions of greenhouse gases, domestically and in the international context. It builds on the results of earlier work, by several groups, intended to explore this potential. This work showed that these technologies can play a significant role in the longer term (25 years or more). The paper also identifies additional possibilities to enhance these opportunities. Key factors in the outcome are technology progress, energy market characteristics, and the influence of energy and environmental policies. In particular, the paper explores the potential for synergisms between energy and environmental policies. Our general conclusion is that major changes in all of these areas are necessary to reduce domestic and global emissions.

"Pollution Prevention by Consumer Choice: The Green Pricing Option," Lloyd Wright, EPA

Allowing consumers to choose clean energy resources for their electricity needs may be one of the most cost-effective options to reduce greenhouse gases. Through a concept known as green pricing, participating consumers voluntarily pay a small premium to support renewable energy technologies. Even at fairly low participation rates of 1-5%, significant pollution reduction benefits are achieved. In addition to delivering greenhouse gas reductions at less than $50 per metric ton, green pricing can dramatically transform the U.S. renewable energy market. This market-based approach also helps electric utilities prepare for a competitive energy marketplace. And all of this is achieved voluntarily, with no costs to nonparticipants, the government, or electric utilities.

"Risk, Accounting and Strategic Planning Issues in Integrated Resource Planning (IRP) Resource Selection," Shimon Awerbuch, Independent Economic Consultant

This paper reviews what has been learned from the valuation of new manufacturing technologies, and extends the results to energy resource options. Traditional IRP procedures can be misleading: they rely on one attribute, dollars per kilowatt-hour, which does not properly capture the important benefits renewables provide through risk reduction, flexibility, overhead reductions, and supply-demand equilibrium. When properly evaluated using

these concepts, photovoltaics and other renewables appear considerably more cost effective than previously believed. Proper valuation of externalities, the present value costs of which are significantly understated in most analyses using inappropriate discount rates, swings the balance further in favor of renewables.

"Pollution Mitigation and Photovoltaic Demand-Site Results from the U.S. Environmental Protection Agency Photovoltaic Demonstrations," Edward C. Kern, Jr. and Daniel L. Greenberg, Ascension Technology, Inc. Ronald J. Spiegel, EPA

The EPA, 21 electric power companies in the U.S., and the Electric Power Research Institute are conducting two nationwide Photovoltaic (PV) Demand-Side Management (DSM) projects. Ascension Technology is responsible for system design, balance-of-systems equipment design and fabrication, installation supervision, field instrumentation, and data acquisition, monitoring, and evaluation. The principal goal of the two projects is to investigate the environmental and DSM benefits of distributed, grid-tied PV systems as pollution-mitigating energy replacements for fossil fuels. In 1993-4, 11 electric utilities installed PV on homes, schools, hospitals, offices, and light commercial buildings. In 1994-5, 12 electric utilities are installing PV systems on larger commercial, educational, and industrial building rooftops.

"Photovoltaic Energy Impacts on U.S. CO_2 Emissions," S.C. Morris, J.C. Lee, P.D. Moskowitz, and G.A. Goldstein, Brookhaven National Laboratory

The potential role of photovoltaic (PV) technology in reducing CO_2 emissions was evaluated in an energy-environmental economic systems model. The model examines the role of PV energy systems in a competitive market environment. PV technology is already competitive for certain niche markets. Further growth in those markets is expected as well as expansion into other markets. Decreasing cost penalties should provide greater incentive for expansion of niche markets. This analysis indicated that, while PV was not projected to be competitive as a general source of electricity supply to the grid by 2030, it did become an attractive technology for this purpose after 2010 under carbon emission constraint, even if the carbon constraint was limited to stability of emissions at the 1990 level.

"Electric Vehicles: A Source for Energy Security and Clean Air," Lawrence G. O'Connell, Electric Power Research Institute

Electric vehicles (EVs) can help solve the problems created by the transportation sector's heavy dependence on petroleum-based fuels. Studies show that using EVs could significantly decrease emissions that contribute to urban air quality problems. Further, they emit less carbon dioxide than gasoline-powered vehicles, and therefore could be part of a greenhouse gas reduction strategy. In addition, because only a small portion of electricity used in the U.S. is generated from oil, replacing conventional vehicles with EVs could help move the nation toward greater energy security. In recognition of these potential benefits, legislation and regulations are encouraging, and even mandating, zero emission vehicles, or EVs, production and use. Automakers have responded by starting EV development programs that promise viable vehicles in time to meet the legislative requirements. The electric utility industry, in turn, has been laying the foundation for the infrastructure to support wider use of this beneficial technology.

"Why Not Plug Your House and Workplace Into Your Fuel Cell Car?," Robert Williams and Kelly Kissock, Princeton University

As an alternative to the internal combustion engine, the fuel cell offers the potential for providing transportation services with zero or near-zero pollutant emissions, with large reductions in greenhouse gas emissions, and with reduced energy insecurity through the use of a wide range of feedstocks for fuel as alternatives to oil from politically unstable regions. Moreover, there are good prospects that, when mass-produced, fuel cell cars would be able to compete with internal combustion engine cars on a life-cycle basis, owing to their greater energy efficiency and prospective lower maintenance costs, and perhaps even on a first-cost basis.

If the fuel cell comes to replace the internal combustion engine in transportation applications, it could radically transform not just transportation but stationary power generation as well—if "the building is plugged into the car when the car is not being driven." This possibility is motivated by consideration that fuel cell vehicles could potentially provide heat and power for buildings with zero pollution, with very little noise, and without the need for operating personnel, and by the fact that while cars are operated during 10 years of useful life for only 3,500 to 5,000 hours (about a half hour a day), the fuel cell itself might last 50,000 to 60,000 hours or more.

This paper assesses technical and economic aspects of cogenerating electricity and heat for residential and commercial buildings using proton-exchange-membrane (PEM) fuel cells in cars. Because PEM fuel cells typically operate at temperatures of less than 100 °C, particular attention is paid to the design and control of the heat recovery and storage system and its interface with the thermal requirements of buildings. System performance is simulated on an hour-by-hour basis for residential and commercial buildings.

This preliminary investigation suggests that the idiosyncratic concept of "fuel cell car cogeneration" is not whimsical and should be given careful consideration as an innovative element in the portfolio of options that could be deployed by the distributed utility of the future.

Free-Piston Stirling Engines for Domestic Cogeneration and Biomass Energy Conversion," W.T. Beale, Sunpower, Inc.

This successful development of long-life free-piston machines for domestic refrigeration has brought into existence Stirling engine designs which can be configured for electric power generation using biomass or other sustainable energy sources. This paper describes the design and performance of machines suitable for near-term commercial production for natural gas and biomass-fired domestic and light industrial congeneration at the 1 to 10 kW power range.

"Commercialization of Wind Power and Its Potential Impact on Greenhouse Gas Emissions," Susan Hock, NREL John B. Cadogan, DOE Joseph M. Cohen and Bertrand L. Johnson, Princeton Economic Research, Inc.

Commercialization and deployment activities associated with wind power have accelerated recently, in the U.S. and abroad. The current installed base of util-

ity-connected wind power is summarized and derivative calculations of electric generation and associated displacement of greenhouse gas emissions are made. Technology and market development trends are reviewed and DOE-sponsored wind technology development and deployment activities are discussed. Finally, an overview of competitive market considerations is given, including an analysis of the projected competitiveness of wind power compared to gas-fired generation to the year 2005.

"Fuzzy-Logic-Based Adaptive Control of AC Induction Motors for Energy Optimization,"
R.J. Spiegel and P.J. Chappell, EPA
M.W. Turner, RTI

Fuzzy-logic control of alternating-current (AC) induction motors is being investigated under sponsorship of EPA for energy efficiency optimization and performance enhancement. An energy optimizing controller utilizing fuzzy logic has been developed to improve the efficiency of motor/drive combinations running at various load and speed conditions. The energy optimizer is complemented by a sensorless speed controller which maintains motor shaft revolutions per minute (RPM) to produce constant output power. Efficiency gains from approximately 1 to 20% are obtained from laboratory demonstration with commercial motors and drives. Motor shaft RPM is controlled to within 0.9%.

"Fuzzy-Logic-Based Adaptive Control of a Variable Speed Wind Turbine,"
R.J. Spiegel, EPA
B.K. Bose, University of Tennessee

Fuzzy-logic control of a variable-speed wind turbine is being investigated under sponsorship of EPA for efficiency optimization and performance enhancement. The control system consists of three fuzzy-logic controllers: a controller to track the turbine generator speed with wind velocity to extract the maximum output power; a controller to optimize the generator airgap magnetic flux for efficiency improvement; and a controller to provide for robust speed control against wind gusts and turbine oscillatory torque. The paper describes the control system which has been developed, as well as early stages of work to validate the design and document the performance obtained.

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***Keith J. Fritsky** is the EPA Project Officer (see below).*
The complete report, entitled "Proceedings: The 1995 Symposium on Greenhouse Gas Emissions and Mitigation Research," (Order No. PB96-96-187752; Cost: $85.00 – $170.00, subject to change) will be available only from:
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