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ICCP ESTABLISHED 1991 INTERNATIONAL CLIMATE CHANGE PARTNERSHIP

June 12, 1997

Dear Colleagues,

On behalf of the International Climate Change Partnership, I would like to welcome all of you to the International Climate Change Conference & Technologies Exhibition.

We are very excited about this year's conference. We are honored to welcome more than one hundred distinguished experts in the fields of climate change, public policy and industry to share their knowledge and insights as speakers. Participants have traveled from across the United States and around the world to be a part of these discussions.

The timing of this conference is very appropriate as efforts proceed at the international level to develop a protocol or other legal instrument to address the increase of greenhouse gas emissions. Increasingly, policymakers will turn to the private sector to expand the development and dissemination of technologies that reduce the threat of global climate change. With just under six months until COP 3 in Kyoto, Japan, we offer this conference as an opportunity to discuss the policies, both existing and proposed, which address global climate change, as well as policies that may inhibit technology dissemination and enhancement.

We are especially excited about the second day of the conference where various industry sectors will have the opportunity to discuss, more specifically, the issues concerning them. These concurring sessions will focus primarily on five sectors including energy supply and electricity generation, buildings and energy efficiency, transportation, forestry and agriculture, and industrial.

Also, please do not miss the Technologies Exhibition which will be open throughout the conference. The exhibition will feature emerging efficient climate-friendly technologies and programs.

Our thanks go to the U.S. Environmental Protection Agency for all of their assistance in organizing the conference as well as the U.S. Department of Commerce, U.S. Department of Energy and the U.S. Department of State for their cooperation.

We hope you enjoy the conference!

Sincerely,

Kathryn Shanks

Kathryn Shanks, BP Exploration
Chairperson, ICCP

2111 Wilson Blvd. Suite 850 Arlington, VA 22201 Telephone: 703-841-0626 FAX: 703-243-2874

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Elmer Holt, U.S. Department of Energy, Washington, DC
Tom Jacob, DuPont, Wilmington, DE
Kurt Johnson, U.S. Environmental Protection Agency, Washington, DC
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James Turnure, U.S. Environmental Protection Agency, Washington, DC
Ford West, The Fertilizer Institute, Washington, DC
Steven Winnett, U.S. Environmental Protection Agency, Washington, DC (formerly)

MODERATOR AND SPEAKER INDEX

Daniel Albritton
NOAA Aeronomy Lab
325 Broadway, R/E/AL
Boulder CO 80303
phone 303 497 5785
fax 303 497 5340

Stephen O. Andersen
U.S. EPA
401 M St SW (6205J)
Washington DC 20460
phone 202 233 9069
fax 202 233 9576

Ken Andrasko
US IJI
1000 Independence Ave SW
Washington DC 20585
phone 202 586 3179
fax 202 586 3485/3486

Michael Ashford
Econergy International
1925 K St. NW #230
Washington DC 20006
phone 202 822 4980
fax 202 822 4986

Howard Aylesworth, Jr.
Aerospace Industries Assn.
1250 Eye St. NW
Washington DC 20005-3924
phone 202 371 8456
fax 202 371 8471

Jay Baker
Ford
17000 Rotunda C130
Dearborn MI 48121
phone 313 845 3597
fax 313 323 8295

Nazir Bhagat
U.S. Dept .of Commerce
14th and Constitution
Washington DC 20230
phone 202 482 3855
fax 202 482 5666

Jared Blum
PIMA
1001 Pennsylvania Ave.
Washington DC 20004
phone 202 624 2709
fax 202 628 3856

Carl Brady
General Electric
M/D S158
One Neumann Way
Cincinnati OH 45215
phone 513 552 5459
fax 513 552 5005

Thomas Bruulsema
The Potash and Phosphate Inst.
18 Maplewood Dr.
Guelph ON N1G 1L8
Canada
phone 519 821 5519
fax 519 821 6302

Dick Cataldi
Assn. of American Railroads
50 F Street, NW
Washington DC 20001
phone 202 639 2100
fax 202 639 2179

Paul Cicio
Int'l Federation of Ind. Energy Consumers
c/o Dow Chemical
1776 Eye St. NW #575
Washington DC 20006
phone 202 429 3411
fax 202 429 3467

Stephen Connors
Massachusetts Inst. of Technology
The Energy Laboratory Rm. E40-465
77 Massachuseets Ave.
Cambridge MA 02139-4307
phone 617 253 7985
fax 617 253 8013

Jim Crawford
American Standard
PO Box 9010HW
Tyler TX 75711-9010
phone 903 581 3280
fax 903 581 3381

Mark Criscuolo
WESCO Distribution
Commerce Court
Four Station Square Suite 700
Pittsburgh PA 15219
phone 412 454 2244
fax 412 454 2520

Yvo de Boer
The Netherlands Ministry of Housing
Climate Change Department
PO Box 30945
The Hague GX 2500
The Netherlands
phone
fax

Stephen Deady
Embassy of Australia
Trade Policy Branch
1601 Massachusetts Ave. NW
Washington DC 20036-2273
phone 202 797 3000
fax 202 797 3209

John DeCicco
ACEEE
1001 Connecticut Ave. NW #801
Washington DC 20036
phone 202 429 8873
fax 202 429 2248

Carmen Difiglio
U.S. Dept. of Energy
Mail Stop PO-62
1000 Independence Ave. SW
Washington DC 20585
phone 202 586 4444
fax 202 586 4447

Phil Dougherty
Westvaco Corp.
180 Westvaco Rd.
Summerville SC 29484
phone 803 851 4750
fax 803 875 7185

Mitch Dubensky
American Forestry and Paper Inst.
1111 19th St. NW #800
Washington DC 20036
phone 202 463 2700
fax 202 463 4703

Daniel Dudek
EDF
257 Park Ave. South
New York NY 10010
phone 212 505 2100/203 938 3
fax 212 505 0892/203 938 4

Bob Duffin
Motorola
Mail Drop AZ-34/EL40
2100 E. Elliott Rd.
Tempe AZ 85284
phone 602 244-6688
fax 602 413 7918

Paul Dugard
ICI Klea
3411 Silver Side Rd.
Wilmington DE 19850
phone 302 887 4344
fax 302 887 7740

MODERATOR AND SPEAKER INDEX

K.G. Duleep
Energy and Environmental Analysis
1655 N. Ft. Myer Dr.
Arlington VA 22209
phone 703 528 1900
fax 703 528 5106

Ian Edwards
Pioneer Hybrid Seed
7300 NW 62nd Ave.
Johnston IA 50131
phone 515 270 4029
fax 515 253 2478

Kevin Fay
ICCP
2111 Wilson Blvd. #850
Arlngton VA 22201
phone 703 841 0626
fax 703 243 2874

Tony Fiorentino
Pratt & Whitney
400 Main St.
E. Hartford CT 06108
phone 860 565 2798
fax 860 565 4017

Dick Fruehan
Carnegie-Mellon University
Wanner Hall
5000 Forbes Ave.
Pittsburg PA
phone 412 268 2677
fax 412 268 7247

Kenneth Galbreath
St. Laurent Paperboard
15400 Sherbrook E
Montreal QE H1A 3S2
Canada
phone 514 642 9251 x 301
fax

David Gardiner
U.S. EPA
401 M St. SW
Washington DC 20460
phone
fax

Mark Ginsburg
U.S. Dept. of Energy
1000 Independence Ave. SW
Washington DC 20585
phone
fax

Malti Goel
Technology Bhawan
Department of Science & Technology
New Delhi . 110016
India
phone 91 11 696 02023,/696 2819
fax 9111 686 2418

John Grupenhoff
Nat'l. Assn. of Physicians for the Envmt.
6410 Rockledge Dr. #412
Bethesda MD 20817
phone 301 571 9791
fax 301 530 8910

Pamela Herman
U.S. EPA
Office of Policy, Planning & Evaluation
401 M St. SW
Washington DC 20460
phone 202 260-4407
fax 202 260 0512

Kathleen Hogan
U.S. EPA
Atmospheric Pollution Prevention Div.
401 m St. SW MC 6202J
Washington DC 20460
phone 202 233 9312
fax 202 233 9575

Elmer Holt
U.S. Dept. of Energy
1000 Independence Ave SW
Washington DC 20585
phone
fax

Doug Horstman
Maytag
1310 G St. NW #720
Washington DC 20005
phone 202 639 9420
fax

George Joy
U.S. Department of Commerce
PNGV Secretariat
14th & Constitution, NW Rm. 4845
Washington DC 20230
phone 202 482 6268
fax 202 482 6275

Pat Keegan
IIEC
750 First St. NW #940
Washington DC 20002
phone 202 842 3388
fax 202 842 1565

John Kinsman
Edison Electric Institute
701 Pennsylvania Ave. NW
Washington DC 20004
phone 202 508 5711
fax 202 508 5150

Daniel Klein
ICF Resources Inc.
9300 Lee Hwy.
Fairfax VA 22031-1207
phone 703 934 3065
fax 703 691 3349

Allen Koleff
Stone Container Corp.
1979 Lakeside Pkwy. #300
Tucker GA 30084
phone 770 621 6704
fax 770 621 6733

Ken Kraly
Cosmair Inc.
Clark Facility
200/222 Terminal Ave.
Clark NJ 07066
phone 908 499 6641
fax

Peter Kuch
U.S. EPA
RNS, OPD
401 M St. SW
Washington DC 20460
phone 202 260 2753
fax 202 260 2300

Jean-Marie Libre
Elf Atochem/EFCTC
phone 331 4900 7887
fax 331 4900 8091

Chuck Linderman
Edison Electric Institute
701 Pennsylvania Ave. NW
Washington DC 20004-2696
phone 202 508 5655
fax 202 508 5150

Rodric Livingston
Appropriate Technology International
1828 L St. NW #1000
Washington DC 20036
phone 202 293 4600 x224
fax 202 293 4538

MODERATOR AND SPEAKER INDEX

Lee Lynd
Dartmouth College
Dartmouth NH
phone 603 469 8873
fax 603 646 3856

Richard Mattocks
Environomics
36 West 35th St., Suite 5E
New York NY 10001
phone 212 564 7188
fax

Robert McFadden
AAMA
1401 H St. NW #900
Washington DC 20005
phone 202 326 5523
fax 202 326 5528

Don McLeay
Air Canada
PO Box 9000
Montreal QE H4Y 1C2
Canada
phone 514 422 6824
fax 514 422 7606

Mark McNaughton
McNaughton Homes
4400 Deer Path Rd. #201
Harrisburg PA 17110
phone 717 234 4000
fax 717 234 2000

Mark Menzer
ARI
4301 N. Fairfax Dr.
Arlington VA 22203
phone 703 524 8800
fax 703 528 3816

Mark Moser
RCM Digesters
PO Box 4715
Berkeley CA 94704
phone 510 658 4466
fax

Roger Naill
AES
1001 N. 19th St.
Arlington VA 22209
phone 703 522 1315
fax 703 528 4510

Bill Nicholson
Potlatch Corp.
244 California St. #610
San Francisco CA 94111
phone 415 956 2975
fax 415 956 2971

Mike Nisbet
JAN Consultants
428 Lansdowne
Montreal QE H3Y 2V2
Canada
phone 514 931 6272
fax 514 931 6414

John Novack
Edison Electric Institute
701 Pennsylvania Ave. NW
Washington DC 20004-2696
phone 202 508 5655
fax 202 508 5150

Mary Novack
WEFA Group
25 Burlington Mall Rd.
Burlington MA 02173
phone 617 221 0340
fax 617 221 4809

Frank Nutter
Reinsurance Association of America
1301 Pennsylvania Ave., NW #900
Washington DC 20004
phone 202 638 3690
fax 202 638 0936

Jim Olson
General Motors
3044 W. Grand Blvd.
Detroit MI 48202
phone 313 556 7566
fax

John Palmisano
Enron Europe
4 Millbank
London . SW1P 3ET
United Kingdom
phone 44 171 316 6733
fax 44 171 316 5391

Rafe Pomerance
U.S. Department of State
2201 C St. NW Rm. 7831
Washington DC 20520
phone 202 647 2232
fax 202 647 0217

Bob Price
IIEC
750 First St. NW #940
Washington DC 20002
phone 202 842 3388
fax 202 842 1565

Terry Pritchett
General Motors
3044 W. Grand Blvd.
Detroit MI 48202
phone 313 556 7566
fax

Donald Reicosky
USDA-ARS
803 Iowa Ave.
Morris MN 56267
phone 320 589 3411 x144
fax 320 589 3787

Robert Repetto
World Resources Inst.
1709 new York Ave. NW
Washington DC 20006
phone 202 638 6300
fax 202 638 0036

Clark Row
Row Associates
PO Box 619
Edgewood MD 21040
phone 410 538-3111
fax 410 538 3111

Neil Sampson
Sampson & Associates
5209 York Rd.
Alexandria VA 22310
phone 703 924 6704
fax 703 924 6733

Jim Sand
Oak Ridge National Laboratory
PO Box 2008
Oak Ridge TN 37831
phone 423 574 0714
fax 423 574 9338

Fred Schoenborn
Mobil Corp.
Real Estate Services
11911 Freedom Dr. #400
Reston VA 22090-5606
phone 703 742 6354
fax 703 742 6382

MODERATOR AND SPEAKER INDEX

Paul Schumacher
Wisconsin Electric
231 W. Michigan
Milwaukee WI 53203

phone 414 221 3421
fax 414 221 2169

Jeff Seabright
US AID
Office of Energy, Environment & Technology
Washington DC 20523

phone 703 875 4465
fax 703 875 405

Kathryn Shanks
BP Exploration
Aberdeen
Scotland
phone 44 1224 834 133
fax 44 1224 834 051

Scott Sklar
Solar Energy Industries Assn.
122 C. St. NW 4th fl
Washington DC 20001

phone 202 383 2600
fax 202 383 2670

JR Spradley
Counselor
3315 Ardley Court
Falls Church VA 22041

phone 703 998 1219
fax 703 998 1219

Mark Stanga
York International
1725 Jefferson Davis Hwy. #204A
Arlington VA 22201

phone 703 415 0020
fax 703 415 0467

Michael Stanton
AAMA
1401 H St. NW #900
Washington DC 20005

phone 202 326 5523
fax 202 326 5528

Ross Stevens
Stevens Associates
c/o DuPont Nemours Bldg. Rm. 9523
1007 Market St.
Wilmington DE 19898

phone 302 774 3046
fax

Ronald Sutherland
Argonne National Lab
955 L'Enfant Plaza SW #6000
Washington DC 20024

phone
fax 202 488 2413

Joel Swisher
Econergy International
1925 K St. NW #230
Washington DC 20006

phone 202 822 4980
fax 202 822 4986

Martin Tallett
ENSYS Energy & Systems
523 Sergeantville Rd.
Flemington NJ 08822

phone 908 788 7332
fax 908 782 3768

Maria Tikoff
U.S. EPA
401 M St. SW (6202J)
Washington DC 20460

phone
fax

Mark Trexler
Trexler and Associates
1131 SE River Forest Rd.
Oak Grove OR 97267

phone 503 786 0559
fax 503 786 9859

James Turnure
U.S. EPA
Office of Policy, Planning & Evaluation
401 M St. SW MC 2176
Washington DC 20460

phone 202 260 2784
fax 202 260 0512

Raymond Vickery, Jr.
U.S. Dept. of Commerce
ITA Rm. 3832
14th & Constitution
Washington DC 20230

phone 202 482 1461
fax

Ford West
Fertilizer Institute
501 2nd St. NE
Washington DC 20002

phone 202 675 8250
fax 202 544 8123

Christopher Whaley
Department of the Environment
43 Marsham Street, Rm. 3254
London . SW1P 3P4
England
phone 44 171 276 3000
fax 44 171 276 8355

Steven Younis
Conceptual Engineering Group
2137 Defense Hwy. #12CD
Crofton MD 21114-2420

phone 410 721 2909
fax 301 858 9531

David Zilberman
University of California
207 Gianinni Hall
Berkeley CA 94720

phone 510 642 6570
fax 510 643 8911

Cooperative Endeavors: A Case Study of Success

Presented to the International Conference on Climate Change
June 12, 1997

Presented by:

Jay Baker, ICEL Technical Chair
Manager, Manufacturing Technology
Ford Motor Company
17000 Rotunda Drive, Room C130
P.O. Box 6010
Dearborn, MI 48121-6010
Tel: (313) 845-3597
Fax: (313) 323-8295

Introduction

Partnerships and cooperative agreements abound in the environmental arena today. From official participation in a voluntary government program, to a less formal memorandum of understanding between a corporation and a non-governmental organization, cooperative relationships not only benefit the participating organizations, but also their common goals.

The old adage that there is "strength in numbers" applies to cooperative endeavors. By working together, individuals and groups can leverage each others' respective strengths and resources to better achieve their objectives. The benefits of relying on one another for expertise in specific areas are diverse and extensive. Advantages of participating in cooperative environmental partnerships may include:

- Improved access and exchange of information.
- Cost minimization.
- Promotion and facilitation of business opportunities.
- Improved dialogue between groups.
- Coordinated approach to complex issues.
- Technology development and transfer opportunities.

The International Cooperative for Ozone Layer Protection

To better illustrate the benefits of cooperative endeavors, this section will highlight an organization which has used the collaborative approach to great advantage.

The International Cooperative for Ozone Layer Protection (ICOLP) was organized in 1989. Founded by several multi-national corporations and the Environmental Protection Agency, ICOLP's initial mission was to resolve shared environmental problems through the exchange of technical information. The coalition was comprised of corporations, U.S. and foreign government agencies, academic organizations and non-profit associations.

ICOLP has helped its international members and non-members alike to eliminate most of the ozone-depleting solvents (ODSs) from manufacturing processes through the exchange of technical innovations in a non-proprietary manner. As a result, members found alternative solutions to old technologies in an efficient and cost-effective manner. Participation in ICOLP has proved extremely valuable to member companies. The activities of the group have demonstrated that protection of the environment can be good for both a corporation's public image and its bottom line. In some cases, substitute processes and technologies which were once thought to be prohibitively expensive have turned out to be more economical than the technologies they replaced. By adopting new technologies developed under the ICOLP umbrella, participants have proved their commercial viability, demonstrated environmental leadership and encouraged other companies to follow suit. Through this approach, members succeeded in phasing out ozone-depleting solvents well ahead of the schedule prescribed by the Montreal Protocol.

Not only have ICOLP members shared information and phased-out their own uses of ODSs, they have also worked in over sixteen countries, bringing new technologies and lessons learned to those in the developing world. To help companies in developing countries reduce their dependence on ODSs, ICOLP members utilized technology cooperation, which uses long-term business partnerships to promote innovation and entrepreneurship. Building on these relationships, companies in industrialized countries worked together with their counterparts in developing countries to devise strategies tailored to the particular needs of each company and region. Through direct collaboration, workshops, technical manuals, and a computerized database, ICOLP provided companies in developing countries with the technical assistance and information needed to make the transition to ozone-safe technologies.

Global Technology Cooperation

ICOLP members have been active in a number of international conferences in order to focus on transferring the benefits of their research to others in developed and developing countries. The organization has sent teams of experts around the world to share information. In 1991 and 1992, ICOLP, the U.S. EPA, and SEDUE, Mexico's environmental agency, coordinated a joint venture project in Mexico. Technology workshops were held where ICOLP experts discussed control and replacement technology options.

In 1993, ICOLP and the World Bank joined forces to oversee technology cooperation projects to phase out ODS use in Brazil, China, India, Malaysia, Mexico, Thailand and Turkey. The project focused on these seven countries because they were responsible for fifty percent of the solvent use in developing countries at that time. The goals of the project were to increase awareness of ozone depletion and ODS use, introduce companies to ODS-free technology, and assist companies in their phaseout efforts by helping them access funds through the Multilateral Fund of the Montreal Protocol. Because of these workshops, developing countries now have more information, and are able to make informed decisions which result in cost savings and protection of our environment.

ICOLP Tools

Through the use of practical tools, ICOLP has fostered protection of the environment, disseminated information on new technologies, improved quality in manufacturing processes and held down costs.

As a means of distributing information quickly and efficiently to accelerate the global phaseout of ODSs, ICOLP developed OZONET, and international online database. OZONET, now housed at the United Nations Environment Programme, provides accessible and timely information on ODS alternative technologies. The database features an electronic mail system where users can seek specific information from experts on alternative processes and technologies, legislation and related government and industry activities.

Another way in which information has been assembled and distributed is through the EPA/ICOLP Alternatives Manuals. To date, eight manuals have been published, focusing on alternative technologies to CFC-113 and methyl chloroform in specific areas from metal and circuit board cleaning to aircraft maintenance. These manuals, generously funded by EPA, are the primary product of ICOLP's information-sharing activities and serve as the basis for ICOLP's worldwide technology cooperation initiatives. They are excellent examples of how working together on a shared technical issue can build and enhance relationships between often adversarial groups.

Staff at the U.S. EPA, and specifically Dr. Steven Andersen of the Stratospheric Protection Division, were instrumental in facilitating meetings between ICOLP member companies and EPA representatives to discuss technological issues that were summarized in the manuals. By working together on these handbooks, ICOLP companies helped EPA officials to better understand the use of alternatives in manufacturing processes. It is also important to note that in developing these alternative technologies, ICOLP and its partners made a conscious decision not to pursue patents. Rather than keeping new technologies proprietary, methods and substances were publicly tested, verified, and documented and then shared globally. Hard copies of the manuals are distributed free of charge, and can also be downloaded from the Internet.

ICOLP to ICEL -- The Next Generation

In 1995, ICOLP changed it's name to the International Cooperative for Environmental Leadership (ICEL), to reflect a shift in focus and to better capture the overall mission of the group. Building on ICOLP's great success with the phaseout of ozone-depleting solvents from 1990 to 1995, ICEL is now focusing on global climate change, energy efficiency, and broader environmental, health and safety management issues, such as ISO 14001. ICEL is a global partnership promoting innovative environmental solutions, and like ICOLP, voluntary cooperation allows regulatory bodies to work constructively with industry outside of the traditional command-and-control style of governing, by planning and implementing joint projects. ICEL holds a public forum twice each year which provides an opportunity to discuss emerging environmental issues. The group also sponsors technical projects, ranging from global warming and climate change issues, to conformal coating and electronics flux technology. Member companies and affiliates are dedicated to finding solutions to common environmental challenges in ways that maintain or improve product quality.

Conclusion

ICOLP, and now ICEL, has been instrumental in devising solutions to environmental problems, as well as providing cooperation opportunities that have benefited the participating organizations in many ways. ICEL member companies are pro-active organizations that want to be on the leading edge of technology development. By using alternatives suggested by ICOLP/ICEL, companies and governments have realized savings in the multiple millions of dollars. Programs implemented with the assistance of ICOLP/ICEL have ended up being good for the environment, and have also contributed to the competitive advantage of participating companies. By supplying new processes and technologies, ICOLP/ICEL has enhanced existing business relationships and has paved the way for future opportunities.

Kathleen Hogan
Acting Director
Atmospheric Pollution Prevention Division

U.S. EPA
401 M Street, NW 6202J
Washington, DC 20460
(202)233-9190
E-mail: hogan.kathleen@epamail.epa.gov

Real World Programs, Real World Strategies, Real World Successes

Overview

Global climate is a complicated issue; it can be difficult to understand and therefor difficult to address. In 1995, the Intergovernmental Panel on Climate Change, a panel of over 2,500 of the worlds most distinguished scientists in the field, concluded that "the balance of evidence suggests that there is a discernible human influence on the global climate." This is the first time that scientists in the field have reached a consensus that global warming is occurring. Carbon dioxide levels in the atmosphere have increased by about 30% from the mid 1700s to 1990, while the concentration of methane has more than doubled. These trends can be attributed largely to human activities, and a major part of it can be attributed to fossil fuel use. The increase in global average surface temperature and the rise in sea level over the past 100 years are possible adverse impacts of climate change. It is becoming increasingly important that we take steps to identify and implement viable solutions to the problem not only on a national level, but also on an international level. In short, the evidence shows that the threat of global warming must be taken seriously.

In the United States energy sources and uses account for 89 percent of harmful greenhouse gas emissions, resulting primarily from the burning of fossil fuels - coal, oil and natural gas. The urgent need to curb greenhouse gas emissions makes energy efficient technology an increasingly attractive solution. Technology makes it possible for everyone to use energy more wisely. Already, the United States has seen tremendous growth in the development and marketing of energy efficient technologies. Most of these technologies are already available and financially attractive. However, they remain vastly *underutilized. Encouraging the widespread use of today's energy-efficient technologies represents* a sizeable opportunity to limit emissions of greenhouse gases while encouraging economic competitiveness and productivity in the market-place.

Solutions -- Technology is a major part of the solution.

Importantly, the technology needed to use energy more efficiently and effectively is available today. While R&D on technology is important for longer term solutions, numerous technologies are on the shelf today which are financially attractive in their own right and which are vastly underutilized.

The real challenge is to overcome market barriers currently limiting higher demand for highly efficient technology. Encouraging the more widespread use of today's energy-efficient technologies represents a sizable opportunity to limit emissions of greenhouse gases while simultaneously enhancing economic productivity. Today there are numerous technologies which can reduce energy use by 30, 40, even 50 percent in all areas of life. In addition, they often offer highly attractive rates of return, in most cases higher than most alternative investment options. These technologies have the potential to reduce U.S. energy use in 2010 by 20-30 percent while improving economic productivity.

Opportunities -- Businesses and consumers have a number of opportunities available to them. Addressing these opportunities presents a wide range of options for them to capitalize on the growing market for energy efficiency. Business opportunities fall into three major categories:

1. "Getting your own house in order." Efficient technologies enable companies to use energy

wisely, reducing economic drag within the organization while earning the deserved environmental recognition. Companies and organizations involved with EPA's Green Lights and ENERGY STAR Buildings Program are seeing savings on their energy bills of over 30 percent. This means there is potential for savings of $.30 - $.60 per square foot.

2. Marketing highly efficient products into a growing market. Efficient technology is good for the environment, good for businesses, and saves money. Many organizations are being successful in increasing annual revenue by promoting and marketing energy efficiency. As Green Lights and ENERGY STAR Buildings Allies, producers, manufacturers and service providers of efficient technologies are seeing sizable growth in their own businesses

3. By looking for international opportunities, businesses are opening the doors to a number of opportunities. The market for energy efficiency is expanding and will continue to grow as countries around the world strive to meet their economic goals while improving their competitiveness.

Realizing the opportunities -- Market analysis of a variety of products show that over the next decade we will move into a trillion dollar market for high efficiency products and services. Numerous organizations have had a great deal of success implementing these strategies. I will illustrate areas in which these opportunities exist by highlighting several examples of businesses that have successfully integrated these strategies into their organizations.

Confluence of Climate Change Policies and International Trade

Remarks by Raymond E. Vickery Jr.
Assistant Secretary for Trade Development
U.S. Department of Commerce
Before
The International Conference on Climate Change
Baltimore, Maryland June 13, 1997

The mission of the International Trade Administration, which I represent, is to help develop U.S. trade policy and undertake trade promotion activities in order to expand U.S. exports and create domestic jobs. Indeed, the importance of trade to the U.S. economy is apparent from the fact that the export sector of the U.S. economy supports about 11 million jobs. Moreover, 14 percent of the more than 11 million jobs created since President Clinton took office have been related to increases in U.S. exports. Our keen interest in following the global climate change issue and the international negotiations in limiting greenhouse gas (GHG) emissions is therefore easily explained.

Trade promotion success is vitally dependent, not only upon trade policy negotiations, but also, increasingly upon negotiations on Multilateral Environmental Agreements (MEAs) such as the Framework Convention on Climate Change. The President and Vice President have made it clear that sound policy can enhance environmental protection while simultaneously safeguarding U.S. jobs. Indeed, this Administration is committed to the belief that environmental regulation, properly formulated and implemented, can actually lead to greater U.S. international competitiveness.

The International Trade Administration's focus on the promotion of Environmental Technology Exports, through a public-private partnership with the Environmental Technology Trade Advisory Council, made up of CEOs of some of the leading U.S. environmental firms, has already paid handsome dividends in increasing U.S. exports and jobs. Since we created a separate Office of Environmental Technology Exports three years ago, U.S. exports of environmental technologies has increased 50 percent to $14.5 billion per year.

Similarly, an FCCC treaty, if agreed and implemented, could greatly expand the market for U.S. energy conservation and renewable energy industries. A 1995 study by Haiger Bailly estimates that the annual market for energy efficiency technologies will rise from about $40 billion today to $125 billion in 2015. On the other hand, the near to medium increases in the costs of fossil fuel energy which could result from limitations on emissions of carbon dioxide, the major GHG, could adversely impact the competitiveness of U.S. basic industries (such as steel, aluminum, paper and chemicals), that underpin our manufacturing sector. Thus, the FCCC negotiations, and the adoption of sustainable development policies at home and abroad, could have significant potential impact on U.S. trade and competitiveness and on the market for

U.S. environmental technology exports.

MEAs

Multilateral Environmental Agreements (MEAS) are proliferating in the global economy. There are at least 180 MEAs in process. Prior to the Montreal Protocol limiting ozone-depleting substances in 1990, environmental agreements did not include trade measures. Since then, at least eighteen of these MEAS, including the Montreal Protocol and the Basel Convention, employ trade measures to achieve environmental objectives. Others, such as Prior Informed Consent and Domestically Prohibited Goods, proscribe trade in certain goods perceived to be hazardous. Still others grant preference or endorsement to goods judged eco-friendly or produced by a certain recognized process. Thus, Multilateral Environmental Agreements increasingly affect the trade and competitive posture of industries and nations. For example, the Basel Convention could affect as much as $9 billion in U.S. exports of recycled materials.

Because of the emphasis and early adoption of environmental protection in the United States and better compliance by U.S. businesses, U.S. goods and services -- including environmental training and management services -- become generally more competitive if our trade competitors adopt similar regulations or standards. Similarly, because the United States has a competitive edge in renewable energy and coal gasification, these industries would face expanded overseas opportunities if the Framework Convention on Climate Change (FCCC) is implemented. Less obvious, but important, is the enhanced competitiveness for some relatively energy-efficient firms operating within an energy intensive industry. By being involved in MEA negotiations ITA can help elucidate the trade ramifications of MEAs and, at the same time, influence the growth of emerging trade promotion opportunities for environmental technologies. Trade policy concerns, however, must also consider any negative consequences of new MEAs for U.S. industries.

The Committee on Trade and the Environment (CTE), chaired by the U.S. Trade Representative, focuses primarily on World Trade Organization (WTO) disciplines, seeking to ensure that MEAs do not create unfair nontariff barriers to trade, and to assess if WTO rules need to be modified due to environmental considerations. CTE does not actively participate in MEA negotiations. Nor do the Interagency negotiators for MEAs participate on a regular basis in the CTE. At the Ministerial Conference in Singapore, WTO reported that its work on the relationship between MEAs and WTO disciplines is far from complete. The Conference also called for all parties to increase communications between their trade and environmental experts.

FCCC

Turning to the U.N. Framework Convention on Climate Change (FCCC), let me briefly summarize its status and the key issue of concern to U.S. basic industries.

Growing concern about the possible effects of anthropogenic emissions of greenhouse gases (GHG) on the world's climate system led to the establishment, in 1988, to the Intergovernmental Panel on Climate Change (IPCC). The purpose of the IPCC was to assess the scientific evidence on climate change, its socioeconomic impacts, and potential response strategies. Its First Assessment Report, issued in 1990, has served as the basis for international negotiations on a treaty to stabilize atmospheric concentrations of GHG at levels that would prevent dangerous interference with the climate system. Over 160 countries are now Parties to the FCCC, which was adopted May 9, 1992, and ratified by the United States in October of that year, after receiving the advise and consent of the Senate. Although the critical level of GHG was not defined in the First Assessment Report, developed countries agreed to take the lead in reducing emissions and other actions to mitigate or adapt to climate change.

In April 1995, at the First Conference of the Parties (COP-1) in Berlin, the Parties agreed to negotiate further commitments for limiting GHG emissions, but with the proviso that any negotiated limits would apply only to Annex-1 countries, i.e. OECD and Central and East European economies in transition. At COP-2 in Geneva last year, the United States agreed that there was a need to negotiate GHG emission limits that were binding on each of the Parties in Annex-1. A significant focus of the ongoing efforts leading to COP-3, in Kyoto this December, is to assess the various options for the type of medium term target, emissions trading schemes, questions of compliance and enforcement, and advancing the commitment of developing countries.

The U.S. proposal before the FCCC seeks to:

-- Define emission targets in terms of budgets over a multi year period to ensure flexibility

-- Establish procedures to ensure adequate reporting, measurement, review and compliance

-- Permit emissions trading between the Parties and "joint implementation," through which countries without emission budgets could create and transfer emissions reduction credits achieved by qualified projects and

-- Establish long term goals and periodic review of the agreement in light of new knowledge

Another key focus of the U.S. proposal, which is not shared by most other countries at present, is to seek increased commitments from the non-Annex-1 countries, which includes major high growth emitters such as China, India and Brazil. Specifically, the United States is seeking to require developing countries to report on their inventory of GHG emissions, to implement no cost methods to reduce their GHG emissions, and to establish a process for reviewing developing country reports and emission reduction strategies. It also seeks to set a date certain for binding commitments for all Parties and the development of graduation mechanisms (from **non** Annex-1 into Annex-1) for strengthening the obligations of developing countries.

Because the principal GHG is carbon dioxide resulting from the consumption of fossil fuels, any binding constraints on U.S. emissions of GHG, without a similar constraint on non Annex-1 countries, could lead to a relative increase in U.S. energy costs and a potential decline in U.S. competitiveness in energy intensive industries such as ferrous and non-ferrous metals, chemicals, and paper. Consequently, it is feared by some that there may be a "carbon leakage" or the migration of energy intensive industries from Annex-1 to non Annex-1 countries. Thus, due to "carbon leakage," a wrong agreement reached at COP-3 may not be fully effective in reaching a decrease in global Carbon dioxide emissions, and at the same time, have a negative impact, not only on the production of high carbon fuels such as coal, but also on the competitiveness of many U.S. basic industries. Understandably then, these U.S. industries have been vocal opponents of the FCCC as it is currently being negotiated.

Sectoral Impacts

Although a number of gases, including carbon dioxide, methane, CFCs, and nitrous oxide, contribute to the greenhouse effect, carbon dioxide accounts for about 80 percent of the current greenhouse gas emissions caused by human activity. Moreover, carbon dioxide will account for over 90 percent of the projected growth in U.S. emissions of GHG. Fossil fuel combustion is the main source of carbon dioxide emissions. Although all fossil fuels contain carbon, coal contains about 1.75 times as much carbon per unit of heat energy as natural gas and about 1.25 times that of oil. Low-cost substitutes for fossil fuels used in electricity generation, transportation, heating and cooling, and manufacturing processes will take time to develop. In the meantime, lower energy consumption or fuel switching would be needed to reduce carbon dioxide emissions from fossil fuel combustion.

Energy efficiency in the United States has improved greatly since the oil shocks of the 1970's. The ratio of energy use per dollar of real gross national product declined by 28 percent between 1973 and 1990. Nevertheless the U.S. economy remains more energy intensive than those of most of our major foreign competitors. Moreover, coal accounts for 57 percent of U.S. electricity generation, compared with 20 percent in Canada, 15 percent in Japan, 16 percent in Italy, 52 percent in Germany, 26 percent in Belgium, 36 percent in the Netherlands, and less than 3 percent in Sweden, Switzerland, and Norway. An additional factor in limiting U.S. emissions of GHG is that its population is expected to rise 17.5 percent in the period 1990 to 2020, compared to 2.5 percent for Europe, with 45 percent of the U.S. increase due to immigration from other countries.

The economic impact of carbon taxes would not be uniform across industries or throughout the various regions of the United States given the substantial differences in their fuel mix and energy requirements. According to a 1988 survey, the regional shares of total energy consumed in the manufacturing sector were: Northeast 11.2 percent, Midwest 23.3 percent, South 52.8 percent, and West 12.7 percent. Only about 3 percent of the electricity requirement of the Pacific coast states, and 18 percent of that of the New England states, is coal fired. On the other hand coal, which would be the fuel hardest hit by a carbon tax, accounts for about 75 percent of the electricity generated in the Mountain, West North Central, East North Central, and East South Central states. Coal use for electricity varies by state from little or none in Maine, Vermont, Rhode Island, Idaho, California, and Hawaii to 90 percent or more in Indiana, Ohio, West Virginia, Kentucky, North Dakota, Colorado, New Mexico, Utah, and Wyoming.

In the manufacturing sector the heaviest use of energy occurs in the basic industries - primary metals, chemicals, rubber, plastics, building materials, paper, and coal and petroleum products. These industries account for about 85 percent of the energy used in the U.S. manufacturing sector. They also account for about 23 percent of the employment and 31 percent of the value added in manufacturing. In contrast industrial machinery and equipment, electronics, and transportation equipment combined accounted for only about 4 percent of energy use. Not only do the basic industries account for a relatively large share of total energy used in manufacturing, some are also intensive users of energy. For example, BTUs required per dollar of value added were about 65,000 for primary aluminum, 96,000 for steel, 151,000 for hydraulic cement, 192,000 for nitrogenous fertilizers, and 96,000 for paperboard. (These industry characteristics are detailed in Table 1). If they suffer any migration due to increased energy costs, then some of the upstream and downstream industries may suffer losses in competitiveness as well.

The Need for A Climate Change Treaty

Having pointed out that the FCCC, if negotiated improperly, may have adverse impacts for some of the basic industries should not in anyway imply that we should abandon FCCC. There is a near consensus throughout the globe that climate change is a serious long term issue. The world indeed owes a debt of gratitude to these leaders, including the President and the Vice-President, who have exhibited the wisdom and foresight to highlight the potential threats of global warming and the need for cooperative action.

The scientific evidence for the occurrence of global warming and for relating it to increased levels of GHG has also been mounting steadily, leaving little choice but to accept the reports of the IPCC panel, composed of 2500 leading scientists from around the world, and research by the National Oceanographic and Atmospheric Administration, which is a part of the Department of Commerce. So also is the evidence that some of the potential consequences of global warming may have some serious harmful effects due to changes in weather patterns, agricultural impacts, river floods, increased shoreline erosion and growth in insect population. Moreover, some actions taken to reduce GHG emissions, such as energy conservation, have incidental benefits in the form of fuel savings and reduction in local pollution as well.

Furthermore, because of the long lead times involved in changing GHG concentrations in the atmosphere, it is imperative that we adopt some sort of hedging strategies **now** that minimize the need for more precipitous and costlier actions **later**. Promulgating binding emission reduction targets well in advance of their implementation provides a clear market signal and a long lead time for corrective action. Industries can then take advantage of ongoing turnovers in capital stock, rather than retire equipment prematurely, in order to switch to production methods or fuels that emit less GHG. The announcement at the end of COP-2 for the need for binding emission targets serves as a signal to world markets of the future course of policy and the resolve by the FCCC Parties to carry through with its implementation.

Thus, as the science, the seriousness of potential consequences of inaction, and the need for setting policies now to hedge against long term risks have become clearer, the policy debate has been increasingly shifting to the economic issues, particularly the costs to the U.S. (and the world) economy of alternative options being discussed by the FCCC for reducing GHG emissions. There is already a sizable effort inside and outside the U.S. government to model the economic impacts of quantitative emission limits or "budget" options. The Interagency Analytical Team, guided by Undersecretary for the Economics and Statistics Administration, has focused on three economic models to help analyze the impact of various "budget" and policy implementation options (proposed in the FCC) on the U.S. economy. Although the IAT has not completed its analysis, preliminary results and those obtained by several academic institutions seem to indicate that, with judicious choice of policy options, the *expected benefits from the projected reductions in GHG concentrations could* significantly outweigh the costs.

The IAT analysis is also incomplete with respect to the impact of the proposed policy options on U.S. trade. Because many U.S. industries, particularly those in the printing, information technologies and telecommunications, avionics, electronics, industrial machinery, medical and scientific instrumentation, many consumer goods, and the service sector are not energy intensive, it is hard to assert that the reasonable options for reducing GHG emissions would make the U.S. economy uncompetitive. Indeed, there are many sectors in which the U.S. is very competitive that will enjoy increased global demand as a result of an FCCC treaty. These sectors include energy conservation, renewable energy, mass transit, materials recycling, improved materials, engineering services, coal gasification, advanced turbines, and industrial process equipment and controls. Further, the President has, in a letter to Congressman Dingell, assured Congress that "the U.S. delegation will not accept any outcome or agree to any process that adversely affects the United States and its industrial competitiveness."

<u>The Need for Minimizing Adverse Impacts</u>

Thus, given the national and international interest in moving forward towards a treaty to limit GHG, and at the same time, recognizing the importance of basic industries to the U.S. manufacturing base, the eventual treaty must be designed to minimize potential adverse trade impacts on U.S. basic industries. Addressing the concerns of those sectors and developing sound U.S. negotiation options and domestic strategies that minimize the adjustment hardships and premature write-offs of capital in the adversely impacted sectors is therefore quite urgent. To this end, my office in ITA will be commissioning a study to review the data and recent studies, and solicit views from basic industries on the trade impacts of proposed treaty options to limit GHG emissions. I expect the Industry Sector Advisory Groups, established by ITA to advise the U.S. Government on trade policy issues, to be very helpful in this regard.

In the meantime, my office will continue to work through the interagency Advocacy Network, set up to advocate on behalf of U.S. exports, to bring FCCC non-signatories, like China, India and Brazil, to accepting Joint Implementation and increased commitments under the FCCC. For example, I accompanied Vice President Gore to China and ITA continues to work through the Joint Committee on Commerce and Trade to impress upon China that we expect increasing cooperation and commitment from them under the FCCC. I do believe with continued advocacy and working with multilateral development banks and the international business community we can obtain increased commitments from the fast growing developing countries regarding their GHG emissions.

Time, however, is running short as we proceed to Kyoto and beyond. It seems to me that it would be in industry's interest to have an early treaty with flexibility and long lead time for implementation rather than the prolonged uncertainty of inaction. Moreover, I am convinced that we can work with U.S. industry to design a treaty that will advance some industries, not disadvantage others, and help both our country and the world at large. I encourage industry to come forward and help us develop an accurate picture about the trade impacts and work with us and other relevant agencies to design and negotiate such a treaty.

TABLE 1

MANUFACTURING ENERGY CONSUMPTION

SIC CODE	INDUSTRY GROUP	000 BTUs PER DOLLAR OF VALUE ADDED	PERCENT OF TOTAL ENERGY	PERCENT OF TOTAL EMPLOYMENT	PERCENT OF VALUE ADDED
29	Petroleum & Coal Products	127.0	31.2	0.6	2.0
33	Primary Metal Industries	45.9	14.0	3.8	4.5
26	Paper & Allied Products	36.7	11.5	3.2	4.5
32	Stone, Clay & Glass Products	29.5	4.7	2.7	2.7
28	Chemicals & Allied Products	22.5	21.2	4.3	10.9
24	Lumber & Wood Products	13.0	2.0	3.7	2.3
22	Textile Mill Products	10.8	1.3	3.5	2.1
20	Food & Kindred Products	7.6	4.8	7.7	10.2
30	Rubber & Misc. Plastics Products	5.6	1.2	4.5	3.7
34	Fabricated Metal Products	4.4	1.7	7.8	6.3
31	Leather & Leather Products	3.3	0.1	0.7	0.4
25	Furniture & Fixtures	3.1	0.3	2.7	1.7
37	Transportation Equipment	2.4	1.7	9.5	11.4
36	Electronic & Electric Equipment	2.2	1.1	8.3	8.2
39	Misc. Manufacturing Industries	2.2	0.2	2.0	1.5
35	Industrial Mach. & Equipment	2.0	1.4	9.9	10.2
21	Tobacco Products	1.4	0.1	0.2	1.4
23	Apparel & Other Textile Products	1.3	0.3	5.6	2.6
27	Printing & Publishing	1.3	0.1	7.8	7.5
38	Instruments & Related Products	1.3	0.6	5.1	6.0
	Unallocated Admin.			6.4	
	All Manufacturing	12.0	100.0	100.0	100.0

Source: DOE and Bureau of the Census

Review of Economic and Energy Sector Implications of Adopting Global Climate Change Policies

Mary H. Novak,
Senior Vice President, WEFA Energy Services
Presented at the International Conference on Climate Change
Hyatt Regency Inner Harbor, Baltimore, Maryland
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Introduction

In July 1996, Timothy Wirth, Under Secretary for Global Affairs (U.S. State Department), presented the position of the Administration of the United States at the Second Conference of the Parties signatory to the Framework Convention on Climate Change. He outlined in broad terms the basic components of a binding agreement to limit carbon emissions that the US would be willing to support.

This announcement came amidst loud cries from stakeholders that the scientific evidence of global warming is not compelling, much less its anthropogenic origins. Further, the stakeholders and many economists warned that the economic consequences of ameliorating an as-yet unsubstantiated problem are significant.

While the Administration has investigated many mechanisms to reduce the estimates of economic cost associated with adopting global climate change targets, there is sufficient evidence from numerous studies that impel the Administration to recognize there is a significant cost to abatement. As the scientific evidence supporting the assertion that rapid increases in greenhouse gas emissions attributable to developed economies are disturbing the ecological balance is still under scrutiny, the Administration has also recognized that new scientific evidence may develop which further reduces the risk of dire climate change. While acknowledging these concerns, the Administration is putting forward potential agreements for negotiation in the global community which identify carbon emission targets for the mid- to long-term.

As the Administration moves forward on this issue, there is increasing interest in the scientific evidence, the potential economic consequences of ameliorating the risk, and the Administration's goals. The Administration's definition of the medium term is approximately 15-20 years forward. The implication is that there will be binding targets in place for 12-15 years forward, and planning targets for 7-10 years forward. For long-lived, expensive capital planners, the stakes are high.

Economic Growth, Energy Consumption and the Greenhouse Effect

Economic welfare and energy use are interdependent. Developed economies are highly dependent on energy, principally commercially-produced energy products. The process of economic development in emerging economies will increase their reliance on commercial energy. While the level of energy use per capita and the reliance upon particular fuels is expected to vary widely, improved welfare is only achievable under both current and best available technology conditions through large increases in fossil fuel combustion.

Historically, increasing energy consumption has led to increasing local environmental degradation. Energy use and production emit many pollutants. However, for the past thirty years, the developed economies have worked to reduce the environmental impact of increasing energy use, particularly degradation due to local pollutants.

For example, in the US the passage of the Clean Air Act of 1970, presaged a long-term effort to limit the emission of these pollutants. These regulations have concentrated on controlling emissions of local pollutants based on scientific evidence that these emissions degrade water, land or air quality. The control of local pollutants has largely been met by a combination of fuel-switching, technological change that reduces the energy resource requirement, or technological development that captures the emissions. Many of these regulations were initially estimated to carry substantial price tags to accomplish the goal. However, given sufficient lead time, industry has met the emission limits through technological development that captured the emissions, moderating the price of pollution control. Further, these improvements in energy and environmental efficiency are expected to have two longer term impacts:

1. the developed economies are reversing the environmental damage sustained before imposition of environmental regulations, while meeting all of the energy requirements of a substantially larger population, and

2. the energy and environmental efficiencies gained through this process are being introduced to emerging economies, limiting the damage to their ecosystems.

Limiting carbon emissions presents a unique challenge to the global community. The scientific evidence remains scanty whether the current carbon accumulation is an emerging trend with dire consequences (many global atmospheric scientists still reserve judgment). Even with this uncertainty, many scientists and environmentalists have cautioned world leaders on the potential risk they are taking in delaying action to reduce carbon emissions.

Through numerous studies, it has been established that the cost of carbon abatement is very high because the economies of the world are dependent on energy services. There are no inexpensive substitutes for energy. Historical adaptation to increased energy prices has been accomplished over an extended period of time. The transition periods have been marked by slower than expected economic growth.

As carbon emissions cannot yet economically be technologically "captured", to meet carbon emission limits energy use must be reduced by an almost equal amount. Some fuel-switching can ameliorate part of the reduction, but the potential for switching to lower carbon-content fuels is fairly limited.

Thus, the choice is a difficult one:

- Acting too slowly may risk irreversible environmental damages.
- Acting too aggressively risks imposing large, and perhaps unnecessary, costs on the global economy.

Political leaders have been challenged to develop a prudent hedging strategy in the face of climate-related uncertainties. To do so requires a clear understanding of the potential global economic consequences of actions to ameliorate what remains only a "potentially" damaging change in atmospheric conditions.

Implications for the US: Defining the Gap

While the "no regrets" or "low-regrets" agenda is being actively pursued, even an optimistic interpretation of its impact on reducing carbon emissions from the energy sector results in rising emission levels. (Due to the uncertainty surrounding the verifiable nature of non-energy sector carbon emissions, most analysts presume that there will be little ability to offset energy sector carbon emissions with non-energy carbon savings.) The current estimates, which include the effects of programs funded under the Climate Change Action Plan, report significant growth. In the *Annual Energy Outlook 1996* (AEO 1996) from the Energy Information Agency, U.S. carbon emissions are projected to be almost 19% above 1990 levels by 2005, and 24% above 1990 levels by 2010, and nearly 30% by 2015.

U.S. Carbon Emissions
(Million Metric Tons)

1990	1337.2
1995	1413.2
2005	1585.2
2010	1660.0
2015	1735.1

Source: Annual Energy Outlook, 1996

Meeting the target emission level established under the Convention would represent an extraordinary challenge. As the current proposals have used 1990 as the "appropriate" level of carbon emissions, it is worthwhile to keep in mind that EIA's preliminary estimate of carbon emissions for 1995 exceeded this level by nearly 6%.

Estimates of the 2005 Emission Gap Under a Stabilization Scenario
(Million Metric tons)

	Carbon Emissions		
	2005 Baseline	1990 Level	Gap
AEO 1996	1585	1337	248
GRI 1996	1610	1337	273
WEFA 95/96	1628	1337	291

While the EIA outlook presents a daunting challenge, it is relatively conservative. The outlooks prepared by the Gas Research Institute and WEFA Group project emissions in excess of the EIA outlook. Both of these forecasts are less optimistic than the EIA about the success of the current "no regrets" programs. Also, both the GRI and the WEFA forecasts report electricity sales increasing at a higher rate than is reported in the EIA/AEO projections. (For the period 1995 to 2005, WEFA projected electric sales growth of 1.7% per year, GRI projected growth of 1.9% per year, versus the AEO96 growth projection of 1.34% per year.)

Implications for the Energy Sector

Rising carbon emissions are directly related to the projected increase in fossil fuel use, which is attributable to the growing energy demand of an expanding population, rising real incomes and economic activity. By 2005 the U.S. is projected to consume almost 24% more energy than the 87.3 quadrillion Btu (quads) consumed in 1990, driven by projected increases in population (0.9% per year) and real economic activity (GDP growth of 2.3% per year). Carbon emissions are projected to rise nearly 19% above 1990 levels by 2005. The slightly slower growth in carbon emissions is attributable to the increasing market share projected for natural gas and renewables.

A commitment to stabilize the energy sector's carbon emissions at 1990 levels implies a dramatic reduction from currently projected levels. As there is no cost-effective technology currently available to capture CO_2 once it is produced, actions to achieve a reduction in carbon emissions from the energy sector over the next few decades fall into three broad categories: substituting a non-carbon-emitting fuel for fossil fuel use; substituting a lower emitting fuel for higher emitting fuels; or using less energy. Each of these involve costs.

Use of Non-Carbon-Emitting Technologies

Some emission reductions could be achieved through the increased use of nuclear, hydro, and renewable energy in the generation of electricity. However, it is unlikely with current attitudes that these technologies could produce a major portion of the reductions necessary to reach a carbon emission target.

Fuel Substitution

Switching from fossil fuels with higher carbon emission rates to those with lower emission rates can provide some of the reductions needed to reach a target. However, the potential here is also limited over the next ten to twenty years.

Gas is already intensively used in the residential, commercial and industrial sectors, and its use in electrical generation is projected to expand. Petroleum currently plays a very small role in the stationary market: coal and natural gas dominate. Coal is used almost exclusively in the power generation market. Only 2.5 quads of coal are consumed directly in the industrial market, mainly in applications which can take advantage of other attributes of the fuel. Increasing the stationary energy market's reliance on natural gas is limited over the next ten years to twenty years not only by the constraints of capital in-place, but by the availability of natural gas and natural gas pipeline capacity.

The transportation market also provides few mid-term opportunities for wide-spread fuel substitution. Alternative-fuel vehicles are projected to increase under the provisions of the Energy Policy Act (EPAct), Clean Air Act Amendments (CAAA) and various state programs designed to improve local air quality. However, capital constraints in combination with infrastructure constraints will limit their role over the mid-term. These constraints imply that substitution of natural gas for coal or petroleum will alleviate some of the carbon emissions from the energy sector, but substitution cannot bear the burden alone.

Lower, More Efficient Fuel Use

Achieving a carbon emission target through reductions in energy use would require cutting energy use by approximately the same amount as the desired change in carbon emissions from the basecase. To the extent that some of the reductions would be obtained with the two previous options, the necessary reduction in energy use would be less.

Currently, the administration is supporting a "no regrets" and "low regrets" policy through federal programs under EPAct and the Climate Change Action Plan. The impact of these policies has already been included in current emission estimates, and new initiatives are under investigation.

In addition, the market is substituting natural gas for petroleum and coal in new electrical generation, but these changes are generally included in the current emission projections. With limited additional opportunities for non-carbon technologies and fuel substitution over the medium term, meeting any carbon emission target would probably necessitate some form of intervention in the market. None of these options are without economic consequences.

Several options for achieving this goal would be:

1. introducing carbon or energy taxes;
2. creating targeted programs to encourage (via subsidies) or mandate (via standards) a more rapid introduction of energy-saving capital into new and replacement decisions;
3. setting performance standards that would encourage the retirement of the least energy efficient capital stock;
4. combinations of these options and the fuel substitution option.

Economic Assessments

Many studies have been performed over the past ten years to establish the economic "risk" of action and inaction. The studies of the possible impact of global warming generally concentrated on determining the economic consequences of stabilization at 1990 levels or reduction of carbon emissions to a fraction of the 1990 level. In most analyses, the industry was given 15-20 years to meet the target emission level.

WEFA Group was recently commissioned to review these earlier studies, and compare them to the Department of Energy's 1996 analyses. The results are clear: there is a high economic cost to the US economy of ameliorating carbon emissions.

Parameters of the Studies

- Adoption of the targets by the U.S. and other developed countries.
- Targets set at a fraction of 1990 emission levels.
- Target achievement date of 15 to 20 years for earlier studies.
- In earlier studies, carbon taxes were used as a proxy for the marginal cost of abatement (other mechanisms may be used, but theory indicates that they would cost at least as much); more recent work has used carbon permits, auctions or distributions as a proxy for the marginal cost of abatement. (Effectively, a market determined carbon "tax".)
- Carbon tax revenues were offset by reduction in other tax revenues: generally, personal income taxes.

Impact on the U.S. Economy: Comparison of Studies

The results of earlier analyses of carbon abatement studies indicates large economic costs would be incurred under the proposals studied. Most of the earlier studies investigated a target emission level of 90% of 1990 emissions to be achieved in 2010.

The effect on the U.S. economy would be greater than that felt by most other developed economies (U.S. major trading partners), due to expectations of greater population growth here in the U.S.

Earlier Study Results for the U.S. in 2010*

			EMF12 (94)					
	EPRI (94) DRI (92)		DGEM GOULDER		Rest of EMF12		OECD Study (92)	
	H	L	H	L	H	L	H	L
Carbon Tax (as reported)	$384 ($89)	$200 ($92)	$50 ($90)	$50 ($90)	$260 ($90)	$160 ($90)	$306 ($90)	$126 ($90)
Carbon Tax (in $94)	$450	$210	$56	$56	$292	$180	$343	$141
Loss of GDP (%)	4.2%	4.2%	1.7%	1.2%	1.5%	0.9%	1.3%	0.9%
1994 GDP Dollar Loss per metric ton reduction	$820	$591	$218	$154	$147	$94	$160	$117

*Studies performed between 1992 and 1995, analyzing a target emission level of 90% of 1990 levels by 2010.

The U.S. Department of Energy's recently released their preliminary analysis of recent proposals. Their results confirm some of the earlier work, and show large, significant losses in real output of the U.S. economy from adoption of these proposals.

Macroeconomic Impacts Across Emission Targets:
U.S. Dept. of Energy/EIA Preliminary Results
(Assumes Permit Auction Revenues Rebated All to Consumers)

	(Pct. Diff from Baseline)		
Target Carbon Emission Level in 2010	**GDP Effects in 2005/7**	**GDP Effects in 2010**	**GDP Effects in 2015**
0.9*1990	-0.9%	-1.5%	-1.6%
0.9*1990 in 2005; 0.8*1990 in 2010	-1.8%	-1.7%	-2.8%
0.8*1990 in 2005	-3.6%	-1.5%	-4.5%

Note: The Permit Price projections and the GDP Effect projections are WEFA estimates based on the charts, tables and text presented at the Climate Change Analysis Workshop, June 1996.

Business and Consumer Impacts

Perhaps the most important question is: "How does a change in real GDP that is the result of a dramatic change in the "price of energy" affect businesses and consumers?" While it is well recognized that changes in the overall output of the economy negatively effect all of us, business and consumer effects for our region bring the point home more clearly. Unfortunately, not as much work has been done in this area. The most illustrative study was performed for the Electric Power Research Institute. The national results for a $100 carbon tax case -- which approximately stabilizes emissions at 1990 levels in 2000, but does not meet the stabilization target for 2010, and a $200 case which approximates stabilization are shown. The study does provide key observations of the sub-national results for the $100 case. For simplicity sake, these results can be thought of as a "change per $100 carbon tax or permit value."

Economic Impact on the U.S. Economy of Imposing Carbon Taxes
(Carbon Taxes reported in 1992$ per metric ton; phased in 1995 to 2000 and maintained; GDP Losses reported as Percent Difference from Baseline)

Carbon Tax		Carbon Emissions		GDP Losses	
2000	2010	2000	2010	2000	2010
$100	$100	1.03*1990	1.1*1990	0.7%	2.3%
$200	$200	0.98*1990	0.94*1990	0.9%	4.2%

Source: Electric Power Research Institute study.

National Impacts

The results reported above reiterate the economic cost of adopting carbon abatement policies. In this study, the $100 carbon tax approximately stabilizes emissions in 2000, but it takes a near doubling of the tax rate to sustain stabilization at the 1990 level of emissions.

The economic cost is significant. To stabilize emissions in the U.S., assuming a five-year phase-in of the tax plus a two year notice period, will cost nearly 1% of the baseline GDP estimate. Maintaining stabilization will cost up to 4.2% of the GDP estimate by 2010.

Employment Impacts:

- Under a $100 carbon tax case, total employment is reduced 0.4%. However, employment shifts, towards the Northeast and the Pacific Southwest.
- Mining employment is hit hard. The coal and the oil/gas producing regions are hit hardest. However, there are also significant employment declines in the region that runs from the upper Midwest down through St. Louis and across to Atlanta. These employment losses are derived from two impacts. First, direct costs will increase substantially in excess of other regions. Second, these regions due to their intensity of manufacturing will be heavily influenced by the demand feedback from the reduced economic performance and the trade impact attributable to the unilateral adoption of the carbon tax. Employment in the Pacific Northwest will also suffer losses. Although its electricity price impact is low, this region has a high concentration of transportation equipment manufacturers and metals producers. Higher energy costs depress both of these industries.
- Employment in the Pacific Northwest will also suffer losses. Although its electricity price impact is low, this region has a high concentration of transportation equipment manufacturers and metals producers. Higher energy costs depress both of these industries.

Electricity Prices and Employment Under a $100 Carbon Tax Case in 2010
(percent difference from baseline)

	Industrial Electricity Prices	Total Manufacturing Employment	Total Non-farm Employment
U.S. Total	34.2%	-0.1%	-0.3%
New England	26.4%	1.1%	0.5%
Middle Atlantic	30.3%	0.7%	0.1%
South Atlantic	41.3%	-0.3%	-0.5%
East North Central	48.5%	-0.9%	-0.5%
East South Central	35.3%	-0.1%	-0.6%
West North Central	54.4%	-0.9%	-0.5%
West South Central	45.1%	-0.6%	-1.1%
Pacific Northwest	23.4%	0.1%	-0.1%
Pacific Southwest	16.8%	1.3%	0.2%

Source: EPRI Study

Industry Impacts:

- Energy industries top the list of affected industries. Nearly matching their affects are related industries such as transportation equipment, mining machinery, and engines and turbines.
- There is limited correlation between the change in prices and the change in demand. That is because some of the strongest impacts are attributable to the change in consumer demand for goods and services due to changes in real disposable income (the macroeconomic feedback effect).

Impact of a $100 Carbon Tax Case on Selected Industries in 2010
(percent difference from baseline)

Industry	Price Effect	Output Effect
Coal Mining	173.716	-23.58
Gas Utilities	36.008	-15.34
Electric Utilities	29.629	-13.96
Petroleum Refining	28.629	-5.14
Misc. Petroleum Products	10.353	-4.05
Hydraulic Cement	16.890	-3.53
Primary Aluminum	10.874	-4.51
Primary Ferrous Metals	8.526	-4.21
Nonferrous Metal Mining	3.840	-5.97
Iron Ore Mining	7.902	-4.74
Primary Copper	4.052	-5.98
Paperboard Mills	6.005	-2.50
Misc. Chemical Products	3.919	-3.62

Source: EPRI Study

Impacts on Rest of World Economies

The preceding section reviewed the outlook for the US under various carbon abatement scenarios using macroeconometric models of the US economy and CGE global models. As an adjunct to the macroeconometric studies, the US Departments of Energy and Commerce commissioned analyses to quantify the impact of carbon limitation programs in the OECD on developing countries. These analyses were performed to ascertain if the imposition of OECD fossil fuel taxes or restrictions would benefit developing countries.

The two studies of the impact of carbon restriction on the Rest of World economies expanded on analysis of the adoption of the following measures by the OECD:

- Carbon Tax Case: Stabilization by 2010 achieved through a carbon tax of approximately $200 per metric ton.
- Restrictions Case: Coal and petroleum use in stationary markets held to 1990 levels.

For both studies, there were a common set of 23 countries analyzed using econometric models of these economies and their energy sectors. In these reports, the authors explained the mechanisms through which the changes in the OECD economies were transmitted to the developing countries:

1. Carbon taxes in OECD countries sharply reduce OECD energy consumption, reducing the developing countries' energy exports, and cutting world energy prices.
2. Reduced OECD incomes lower the demand for developing countries products.
3. Higher OECD export prices raise the price that the developing countries must pay for imports of manufactured goods from the OECD,
4. but also improve the competitiveness of the developing countries in the supply of manufactured goods, allowing them to increase market share significantly.

5. Higher OECD interest rates (in response to higher inflation) increase the interest payments burden on the net debtor countries.

Impact on Developing Countries Real GDP of Carbon Emission Reduction Programs in the OECD

	Carbon Tax Study		Restrictions Study	
	1991-2000	2001-2010	1991-2000	2001-2010
China	1.3	1.7	0.20	1.43
India	2.0	2.0	0.23	0.79
Korea	2.2	6.0	1.57	1.94
Taiwan	2.1	6.0	1.02	1.78
Malaysia	0.8	0.8	-0.23	1.23
Hong Kong	0.6	1.8	-0.75	-0.67
Indonesia	0.5	0.7	-0.72	-0.99
Philippines	0.6	1.1	-1.48	-1.34
Singapore	0.9	2.7	-0.17	-0.28
Thailand	0.8	1.1	-0.38	-0.61
Total Asia	**1.5**	**2.8**	**0.20**	**0.96**
Brazil	1.0	1.5	0.71	1.93
Mexico	2.6	5.7	0.63	1.83
Argentina	0.6	0.8	-0.82	-2.50
Chile	-0.3	-2.3	-0.94	-2.25
Colombia	-0.4	-2.7	-0.30	-0.42
Ecuador	-2.3	-11.7	-1.07	-2.21
Peru	-0.6	-7.6	-1.15	-2.78
Venezuela	-0.9	-4.8	-0.86	-1.18
Total L.A.	**1.0**	**1.3**	**0.12**	**0.59**
Algeria	-1.2	-4.4	-0.97	-1.45
Egypt	-0.8	-3.8	-1.13	-2.94
Iran	-0.6	-2.1	-1.07	-2.03
Nigeria	-2.0	-7.9	-1.20	-2.50
Saudi Arabia	-1.5	-9.5	-0.77	-0.55
Total ME&A	**-1.0**	**-5.1**	**-1.01**	**-1.74**
Total	**0.8**	**0.8**	**-0.01**	**0.44**

Source: Studies performed for the US Departments of Energy and Commerce

The results for each country are highly dependent on their energy resources and requirements, their current position in manufacturing, and their access to capital under the scenario. The two studies' results are shown below. It is important to remember that in both the tax case and the restrictions case, the world prices of primary energy supplies fall.

As expected, the resource rich energy exporting countries of the Mideast & Africa (and Venezuela) would suffer under any carbon reduction scenario. Over the next twenty years, these economies are not projected to reduce their dependence on fuel exports as their primary income source. As transportation use was not limited in the "restrictions" study, the results are not as onerous as in the carbon tax case. However, both cases show an increasing economic deterioration relative to the baseline.

In Latin America and Asia, we have categorized the countries to highlight an important result of these two studies. It is appropriate at this point to underscore the positive results estimated for the 23 countries study -- 0.8% GDP increases for the tax case and an average increase of 0.3% for the restrictions case.

Within the Latin America group, there are clear winners and losers. The countries already industrialized -- Mexico, Brazil -- are able to take advantage of the "exporting" of the OECD's energy-intensive manufacturing that would occur under carbon tax proposals. These countries would gain sales not only in the OECD, but also become the suppliers for other developing countries. To the extent that energy-intensive manufacturing relocates from OECD to developing countries, carbon dioxide emissions are effectively relocated rather than reduced. This phenomenon is referred to as carbon "leakage".

Argentina is on the cusp. The trade-off between lower energy prices that is an element of the tax study played a role in increasing the benefit of the scenario to Argentina, whereas its exposed debt position contributed to its poor performance in both cases. However, the truly developing countries of Latin America -- Chile, Colombia, Ecuador and Peru -- are hamstrung by their dependence on the OECD for export dollars as well as by their debt burdens.

Similar results are shown for Asia. The winners are the economies already established. The losers are the emerging economies.

The aggregate results for the world regions are deceiving: the disparity between the winners and losers begs for a reclassification of the countries between "newly developed" and "developing." Across the world, the newly developed have been identified as clear winners - positioned to take advantage of a self-imposed economic constraint within the OECD.

The losers, on the other hand, would not only suffer because of economic reversals within the OECD, but would require additional help from the OECD to support these economies, when the OECD would be in a worsened position to supply it.

These studies, which conclude that the costs of controlling carbon emissions in the OECD may be somewhat higher than the costs estimated by other models, impart significant information to the debate. The non-OECD world will not participate equally in the "leakage" of industrial activity: the few winners take all.

Lessons Learned

These economic studies come to some common conclusions:

- The economic cost of carbon abatement is expensive,
- the cost of uni-lateral action (an economy goes it alone) is very expensive with little quantifiable evidence that global emissions are reduced,
- developed country multi-lateral actions are also very expensive, but there is some quantifiable evidence that global emissions are reduced,
- and, global actions have only been theoretically addressed.

Paralleling these findings, the energy analysis shows that currently, we are technologically unprepared to give up fossil fuels. As a result,

- carbon is not stabilized without a high tax,
- stabilization of carbon is elusive,
- technology is the only long-term answer, and
- targeted programs may be appropriate to force technology development.

Global Climate Change: Mitigation Opportunities High Efficiency Large Chiller Technology

Presented by Mark V. Stanga
Vice President, Government Affairs
YORK International Corporation
International Climate Change Conference
June 12-13, 1997
Baltimore, Maryland

YORK

Background Assumptions and Information

- Relationship between global climate change and anthropogenic CO_2 emissions is assumed.
- Global energy system remains over-whelmingly based on fossil fuel burning.
- Conservative average large chiller energy efficiency.
- Technical references include OECD, U.S. EPA, U.N. IPCC, HVAC industry technical literature, and York International market studies and product specifications.
- No new CO_2 emissions policy measures are introduced through 2010.

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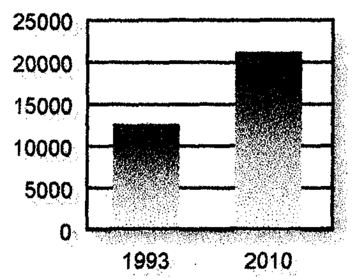
World Electricity Consumption 1993-2010



- North America will remain region with highest electricity consumption per capita.
- Developing countries in Rest Of World (ROW) will require significant expansion of existing power generation systems.

Reference: OECD 1996 World Energy Outlook

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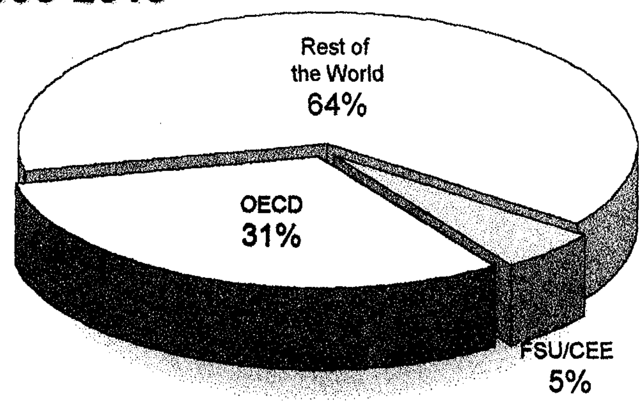
Increase in Annual Primary Energy Demand 1993-2010



Reference: OECD 1996 World Energy Outlook

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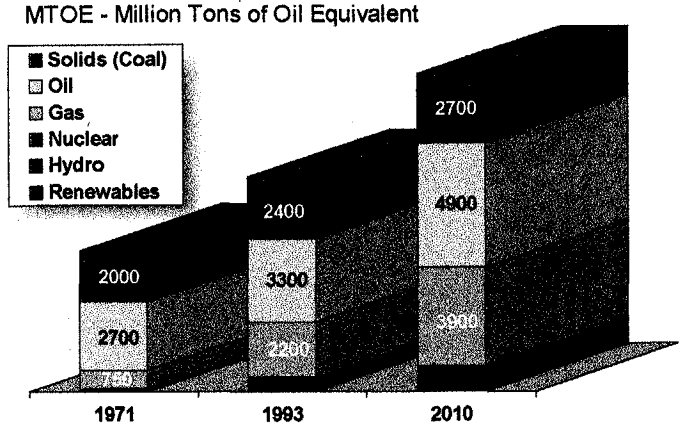
World Primary Energy Demand (1971-2010)

MTOE - Million Tons of Oil Equivalent



Reference: OECD 1996 World Energy Outlook

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Shares of World Solid Fuel Consumption

	1971	1993	2010
OECD	50%	44%	37%
ROW	20%	39%	52%
FSU/CEE	30%	17%	11%

Reference: OECD 1996 World Energy Outlook

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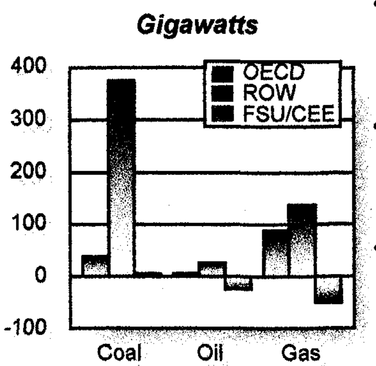
Increase in World Fossil Fuel Generating Capacity, 1993-2010



- Worldwide power generating capacity could reach 4500 gigawatt by 2010.
- ROW will require significant expansion of existing power generation systems
- Choice of power generation fuel in ROW determined by local availability; thus, coal dominates China and South Asia

Reference: OECD 1996 World Energy Outlook

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Regional Power Generating Capacities (Gigawatts)

	1993	2010
OECD	1764	2384
ROW	703	1590

- OECD countries' power generating expansion financed by domestic savings.
- ROW countries lack domestic funds to expand power generating capacity.

Reference: OECD 1996 World Energy Outlook

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Environmental Implications of Increased Energy Consumption

- Annex I parties to the Framework Convention on Climate Change are committed to adopting policies and measures to return greenhouse gas emissions to 1990 level by 2000.
- First Conference of Parties to FCCC concluded in 1995 (Berlin Mandate) that current commitments by Annex I parties would not be sufficient in themselves and further commitments beyond 2000 would be needed.
- U.N. Intergovernmental Panel on Climate Change stated in 1995 in second report that balance of evidence suggests a discernable human influence on the global climate.

Reference: FCCC SBSTA Scientific Assessments: Second Assessment Report of IPCC(1996)

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Current CO_2 Emissions and Future Trends

- World energy demand to increase 46% by 2010 from 1993 levels.
- World CO_2 emissions to increase 50% by 2010 from 1990 levels .
- In the U.S., CO_2 emissions from fossil fuel consumption account for 85% of total U.S. greenhouse gas emissions.
- In recent years (1990-93), CO_2 emissions from fossil fuel consumption in the U.S. increased approx. 2.4%.

OECD 1996 World Energy Outlook/Inventory of U.S. Greenhouse Gas Emissions and Sinks. U.S. EPA (1994)

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Current CO_2 Emissions and Future Trends

- World primary energy demand is expected to grow steadily over the next decade or longer as it has over the last two decades.
- Fossil fuels will account for almost 90% of total worldwide primary energy demand in 2010.
- A structural shift in the shares of different regions in world energy demand is likely to occur, with the OECD share of demand falling in favor of ROW.

OECD 1996 World Energy Outlook/Inventory of U.S. Greenhouse Gas Emissions and Sinks. U.S. EPA (1994)

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Average Annual Increase in Energy Demand and Related CO_2 Emissions

	1971-1993		1993-2010	
	Energy	CO_2	Energy	CO_2
OECD	1.5%	0.8%	1.4%	1.3%
ROW	5.5%	5.2%	4.3%	4.2%
FSU/CEE	1.3%	0.9%	2.5%	2.6%
World	2.2%	1.8%	2.2%	2.3%

- Worldwide carbon intensity improved by 9% from 1971 to 1993, due largely to OECD's substantial increase in nuclear power (less than 1% to 11%).
- Future intensity worsens due to less nuclear power.

Reference: OECD 1996 World Energy Outlook

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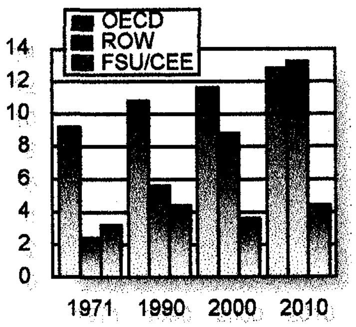
World Carbon Dioxide Emissions

Billion tons of CO_2



- CO_2 emissions in 2010 projected to grow by 50% of 1990 level.
- Most of emissions increase due to ROW countries, where it is expected to more than double.
- OECD countries expect approx. 20% increase in emissions from 1990 levels.
- Global CO_2 emissions in 2010 are projected to be 31.5 billion tons.

Reference: OECD 1996 World Energy Outlook

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Current CO_2 Emissions and Future Trends in U.S.

- U.S. CO_2 emission from fossil fuel consumption totalled 1,239 million metric tons.
- The combustion of fossil fuels accounts for 99% of total U.S. CO_2 emissions.
- Approximately 88% of U.S. energy is produced through fossil fuel combustion.
- The industrial and commercial end use sectors jointly account for 50% of U.S. CO_2 emissions.

Reference: Inventory of U.S. Greenhouse Gas Emissions and Sinks. U.S. EPA (1994)

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Installed and Projected Large Chiller Base (Worldwide)

- Presently there are approximately 80,000 large chillers in service in the U.S., and about 140,000 worldwide.
- Market projections suggest that the installed world large chiller base will increase to approximately 193,000 by 2005, and will increase to approximately 215,000 by 2010.
- End-users are replacing old, less efficient chillers slowly, especially in the U.S.
- U.S. shipments of chillers to building owners worldwide was a record 9444 units in 1995, but only 40% were used in U.S. to replace old chillers - demand was up in Asia, the Middle East, and Latin America.

Reference: Air Conditioning and Refrigeration Institute Statistics/YORK International 1996 World Market Studv

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Today's installed chiller base produces an equivalent of 87,500,000 tons of carbon dioxide emissions annually.

87,500,000 tons of CO_2

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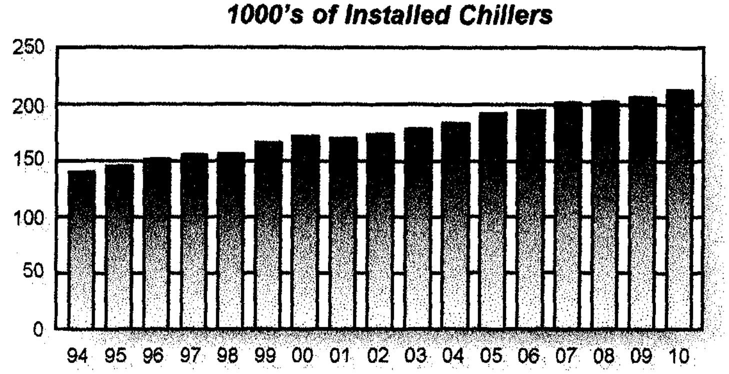
Projected Worldwide Large Chiller Installed Base 1993-2010



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The projected chiller installed base for 2010 would produce 134,000,000 tons of carbon dioxide emissions per year.

134,000,000 tons of CO_2

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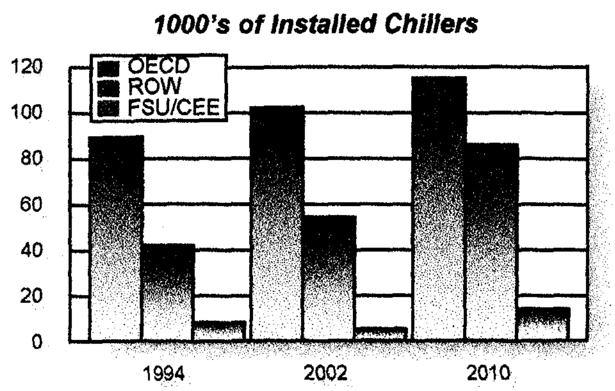
Projected Worldwide Large Chiller Installed Base, By Region



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CO_2 Emissions Trends

Conclusions

- World primary energy demand is expected to grow steadily over the next decade, with fossil fuels accounting for almost 90% of total worldwide primary energy demand in 2010.
- A structural shift in the shares of different regions in world energy demand is likely to occur, with the OECD share of demand falling in favor of the ROW countries.
- Projected world energy demand increase presents a major global climate change mitigation opportunity through high efficiency large chillers.

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Importance of Chiller Performance

- Chiller operation typically accounts for 25 to 30% of total energy consumption in buildings.
- Chiller energy efficiency improvements present a focused opportunity to reduce overall building energy consumption, thereby lowering CO_2 emissions.
- The HVAC industry constantly improves chiller operating efficiency.

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Improvements in Chiller Technology

- Better tube performance
- Increased surface area
- More efficient compressors
- Higher efficiency motors
- Use of lower leaving tower water temperatures
- Use of Variable Speed Drives

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Traditional Chiller Specification :

design full-load kw/ton and 85°F entering condenser water

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Nearly 99% of all chiller run hours are at off-design conditions.

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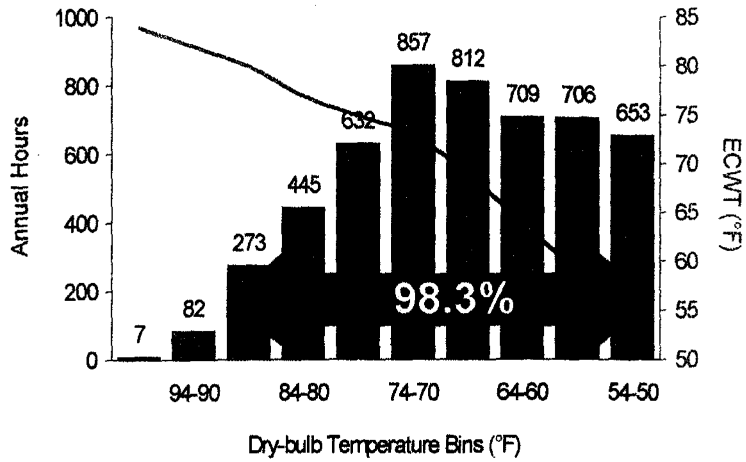
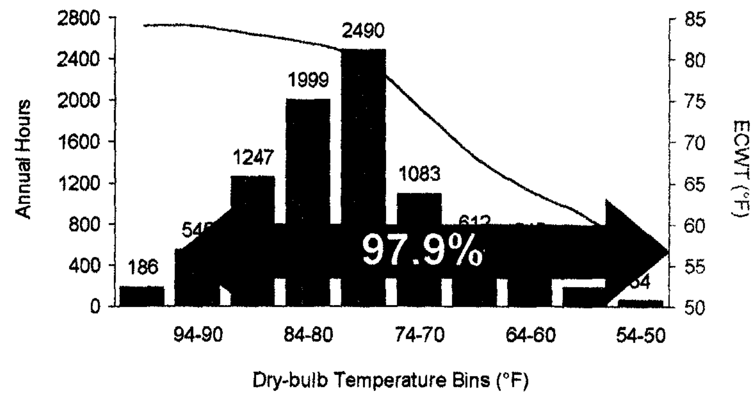
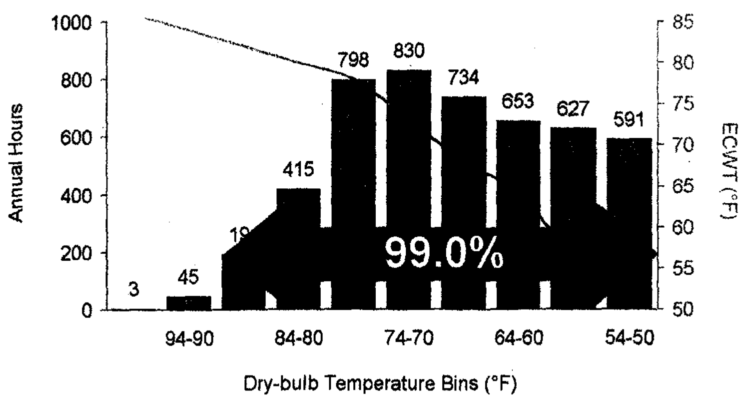
Washington D.C. Weather



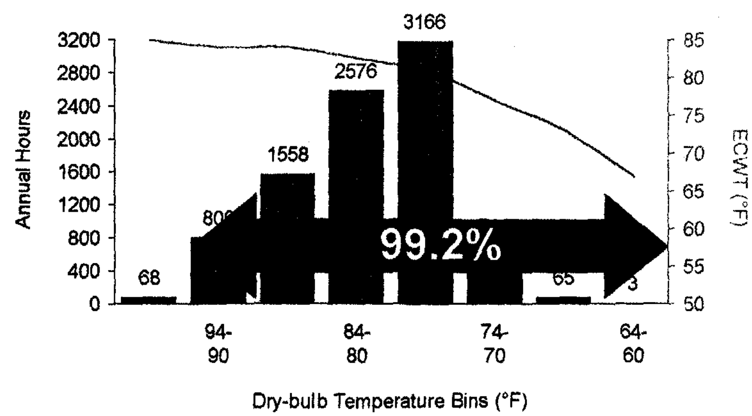
Nakhon Phanom, Thailand Weather



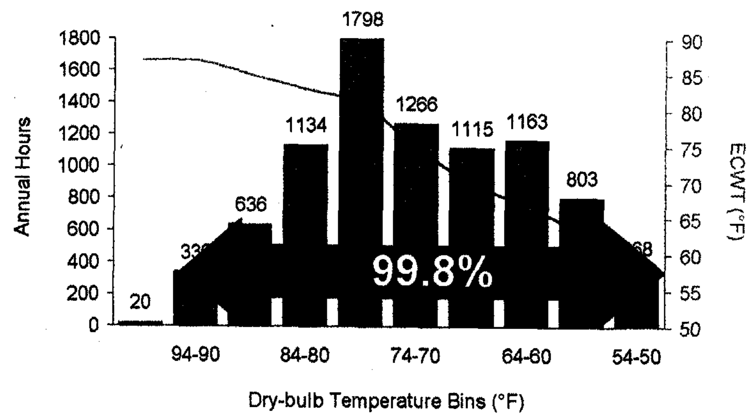
Osan, Korea Weather



Saigon, Vietnam Weather



Taipei, Taiwan Weather



Total Equivalent Warming Impact (TEWI)

- Sums the global warming components of a chiller and its operation
  - Global Warming Potential (GWP) of the refrigerant gas
  - Converts the electrical consumption of the chiller to an equivalent effect of pounds of carbon dioxide
- For large tonnage chillers, global warming due to refrigerant GWP is insignificant with respect to electrical consumption, therefore, the effect of the refrigerant will not be covered in the scope of this seminar

Reference: ASHRAE Journal April 1992, *"Global Warming Implications of Replacing CFCs"*

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Total Equivalent Warming Impact

- "n" is the assumed time horizon of global warming effects
- "α" is used to convert from whatever units are used for annual fuel use to the corresponding CO_2 emissions
- "E" is the annual energy consumption in kilowatt-hours
- "L" is the operational lifetime of the chiller in years

$$TEWI_n = Mass_{refrigerant} \times GWP_{refrigerant} + \alpha \times E_{annual} \times L_{years}$$

Reference: ASHRAE Journal April 1992, *"Global Warming Implications of Replacing CFCs"*

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TEWI Calculation Assumptions

- Average 33% power plant efficiency
- "α" for changing electricity consumption to CO_2 is 1.5 lb. CO_2/kWh (or 0.67 kg CO_2/kWh) of electricity using weighted average of values for coal-, gas- and oil-fired power plants, nuclear plants and hydroelectric power based on generating capacities in North America

Reference: ASHRAE Journal April 1992, *"Global Warming Implications of Replacing CFCs"*

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Example Calculation

Normal operation of a 450 ton chiller at 0.52 kW/ton (full-load) located in Washington, D.C. with Variable Speed, 1000 lb. refrigerant charge, R-134a, 25 year chiller lifetime

$$TEWI_{100} = M \times GWP + \alpha \times E_{annual} \times L_{years}$$

$$TEWI_{100} = (1{,}000 \times 1200) + (1.5 \text{ lb } CO_2/kWh \times 460{,}000 \text{ kWh} \times 25 \text{ yrs.})$$

6.5% 93.5%

Global Warming Gas Production = 9250 tons of CO_2

Reference: Calculations based on published industry full and part-load efficiency data

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Large Tonnage Chiller TEWI Comparison Washington, D.C.

- **Chiller 1 - 450 ton, 0.60 kW/ton, constant speed**
- **Chiller 2 - 450 ton, 0.52 kW/ton, variable speed, low entering condenser water temperature**

Reference: Calculations based on published industry full and part-load efficiency data

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Large Tonnage Chiller TEWI Comparison Washington, D.C.

Chiller	Variable Speed	RWEP	kWh/year	Million lbs. of CO_2
1	N	N	825,000	1.25
2	Y	Y	460,000	0.69

Reference: Calculations based on published industry full and part-load efficiency data

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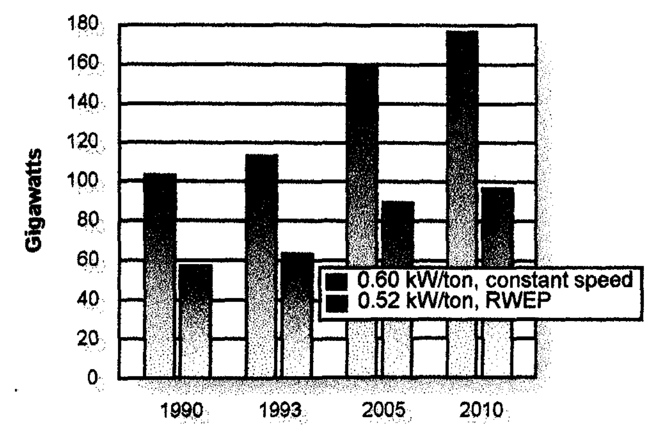
World Energy Use Attributable to Large Chillers, Compared by Efficiency



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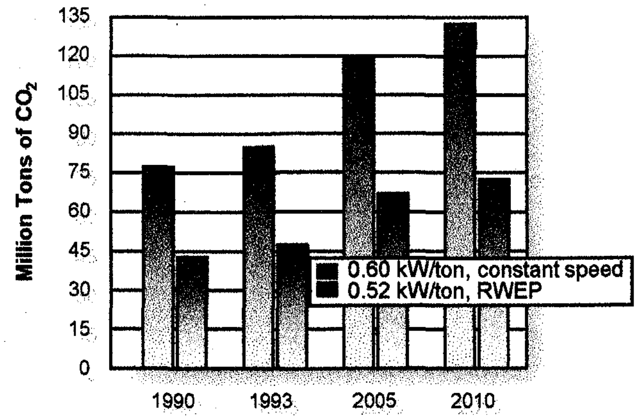
CO_2 Emissions Associated with Projected Increase in World Large Chiller Base



Note: CO2 emissions due to chiller electric consumption only

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Currently available high efficiency chiller technology can avoid **65,000,000 tons** of CO_2 emissions per year by 2010

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Conclusion

Presently available high energy efficiency chiller technology has the ability to substantially reduce energy consumption from large chillers. If this technology is widely implemented on a global basis, it will result in a significant reduction in CO_2 emissions worldwide.

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REDUCING ELECTRIC SECTOR CO_2 EMISSIONS UNDER COMPETITION:
Facilitating Technology Development and Turnover on Both Sides of the Meter

Stephen R. Connors
Director, Analysis Group for Regional Electricity Alternatives
The Energy Laboratory, Room E40-465
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
77 Massachusetts Avenue, Cambridge, MA 02139-4307 USA
tel: 617/253-7985, fax: 617/253-8013, email: connorsr@mit.edu

INTRODUCTION:

Recent analysis of the New England electric sector shows that aggressive pursuit of energy conservation, renewables, and other forms of non-CO_2 emitting resources will be required to achieve even the most modest CO_2 reduction targets. Superimpose upon this fact the near-term manifestations of a restructured electricity market (competitive bulk power prices, possible increases in demand, transition uncertainties, and poorly defined long-term development responsibilities), and a recipe for inaction–with respect to CO_2–emerges.

Today's climate change debate–like many infrastructure/environment issues–is characterized by (1) complex problems, (2) dispersed solutions and (3) finite resources. Quality environmental science obviously plays a central role in identifying reduction targets and describing scientific and economic uncertainties. Similarly, a solid understanding of the energy supply-chain is required if cost-effective, coordinated action is to occur. Competitive market structures–with their accompanying dissaggregated and dispersed technological decisionmaking–are indicative of the challenges energy and environmental regulators will face in promoting an environmentally responsible and balanced energy market with finite fiscal resources.

This paper reviews the technological and institutional challenges of achieving real, long-term reductions in CO_2 emissions in the electric sector. Beginning with a New England case study, factors associated with energy infrastructure turnover, as well as new technology development and deployment are addressed, with particular attention given to policies which promote highly integrated and coordinated, cost-effective, reductions in CO_2 emissions. Opportunities for joint implementation of CO_2 reductions will be discussed, as well as strategies which leverage CO_2 emissions reductions to achieve reductions in other emissions, and to facilitate cost and environmental risk mitigation. With such insights, technological and institutional requirements of a true "no regrets" strategy can be defined.

NEW ENGLAND ELECTRIC SECTOR CO_2 REDUCTIONS: YOU CAN'T GET THERE FROM HERE

How difficult will it be to substantially reduce electric sector CO_2 emissions? In 1992, OECD countries agreed to voluntarily reduce GHG emissions to 1990 levels by 2000, and presumably keep them there. Current negotiations among participants in the FRAMEWORK CONVENTION ON CLIMATE CHANGE are suggesting reductions of between ten and twenty percent below 1990 levels by 2010. Simulations of the New England electric power sector[1] under various technology portfolios indicate that these goals will be technologically, let alone institutionally, very difficult to achieve.

Table One shows the basic technological aspects of eight alternative energy mix strategies devised to meet New England's electric service requirements, while addressing the issue of CO_2 emissions reductions. Each strategy combines the introduction of new natural gas fired combined-cycle generation with alternate levels of demand-side management (DSM)–predominantly technology driven conservation, and for half of the strategies, 1400 MWs of windpower. Each class of technology is phased in during the twenty-year study period (1995-2014). Note that the level of DSM the region's electric utilities are currently pursuing (Ref. DSM) represents a 10% reduction in twenty-year electricity demand, and an 11% reduction in capacity requirements from the no-DSM electricity demand baseline. On the generation side, from 2008 to 2013 roughly half of the region's 6300 MWs of nuclear generation is retired. This means that for the Ref. DSM strategy nearly half of the 7140 MWs of new generation added goes towards replacing the retired nuclear generation, as opposed to meeting growing electricity needs. In the Double DSM strategies, nearly all the new gas-fired generation goes to offset the lost nuclear units. The Triple and Quadruple DSM strategies actually experience an net reduction total generating capacity by the last year of the study period.

TABLE ONE: Technology Characteristics of Eight Multi-Option Energy Mix Strategies for the New England Electric Sector

Multiple Option Energy Mix Strategies	New Generation		DSM/Conservation Impacts			
	Nat. Gas	Wind	Peak Gr.	Demand Gr	Peak Red.	Dem. Red.
Nat. Gas CC w/ Ref. DSM	7140	0	1.06	1.29	-11.1	-9.7
w/ Ref. DSM & Wind	7140	1417	1.09	1.32	-11.2	-8.3
w/ Double DSM	3540	0	0.46	0.57	-21.0	-16.6
w/ Double DSM & Wind	3540	1417	0.49	0.62	-21.3	-15.2
w/ Triple DSM	520	0	-0.08	-0.16	-29.1	-21.2
w/ Triple DSM & Wind	520	1417	-0.06	-0.09	-29.4	-19.9
w/ Quadruple DSM	0	0	-0.72	-0.56	-37.7	-25.2
w/ Quadruple DSM & Wind	0	1417	-0.69	-0.49	-37.8	-24.1
	(MW-2014)		(%/yr.)		(% from No-DSM Ref.)	

1 NEW ENGLAND POWER POOL. (1996) *Annual Report*, NEPOOL. Holyoke, MA. In 1996 the six state New England region consumed 114.7 TWh of electricity. The region's peak electricity demand was 19.5 GWs (August), and was served by roughly 27 GWs of generation capacity. New England's generation mix is very heterogeneous, with baseload nuclear and coal generation accounting for 26% and 16% of annual electricity output. Intermediate units are predominantly oil and gas fired steam generation with some new gas-fired combined-cycle units. These comprise 29% of 1996's electricity generation (GWh). Generation from wood, refuse, and hydropower comprised 12% of generation, while peaking units (combustion turbines, diesels, and pumped storage) added another 2%. Imports accounted for the remaining 16% of output. With current electricity demand forecasts, the region's electric utilities do not foresee a need for additional generation stock until around 2005. These expectations are likely to change based upon changes in the economy and energy efficiency standards, the price/demand effect competition in the electric sector might bring, and the future availability of existing power plants such as the region's troubled nuclear units.

Figure One shows the electricity demand trajectories for each of the four DSM levels. Note how the additional levels of DSM are phased in over time, with the additional efficiency improvements for the Quadruple DSM option ending in 2010. Figure Two shows the CO2 emissions resulting from these eight strategies (employing four levels of DSM) under moderate fuel cost assumptions. Under the "business as usual" Ref. DSM strategy, by 2014 New England electric sector CO2 emissions will increase to over 80% above 1990 levels. This sharp increase in CO2 emissions is caused predominantly by low long-term growth in electricity demand as indicated in Table One, but is acerbated by the loss in non-carbon emitting generation sources over time; imported hydropower in 2001, and the retirement of nuclear units in 2008, 2009, 2012 and 2013. To make up the difference new and existing fossil generation increases its overall generation, leading to an even greater increase in CO2 emissions.

High DSM strategies are especially sensitive to the loss of non-carbon emitting generation sources. While total electricity demand tends to be relatively flat or declining for the aggressive DSM strategies, their CO_2 emissions rise sharply in later years. While Ref. DSM CO_2 emissions are roughly 85% higher than 1990 emissions in 2014, they are still 60%, 40%, and 25% over 1990 emissions for the double, triple and quadruple DSM strategies *with* windpower. This indicates that reducing CO_2 emissions to or below 1990 levels–and keeping them there–will be *very* difficult. Both the aggressive DSM and 1,400 MWs of windpower options constitute technically feasible, but institutionally challenging resource strategies.[2]

For the quadruple DSM strategies, this rise in CO_2 emissions to 25% over 1990 emissions in 2014 occurs rapidly over the final four years. Why this happens is shown in Figures Three and Four. Figure Three shows the distribution of electric generation by fuel and generation technology for the Ref. DSM strategy without wind. Figure Four shows the same range of annual generation sources, but for the *Triple* DSM and Wind strategy. Note that for the Ref. DSM strategy, when nuclear generation begins to decline in 2008, new natural gas-fired generation is available to replace it. Generation from existing fossil sources, coal and residual oil remains relatively constant. This is not the case in Figure Four for the Triple DSM and Wind strategy. Here only a modest amount of new generation is built. Old, less efficient, and more carbon-dense oil-fired generation must be used to make up some of the lost nuclear.[3] These results are symptomatic of an electric industry driven by

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2 These high DSM strategies are technologically achievable since it is believed that there are sufficient lighting fixtures, electric motors and other energy consuming devices in service that could be replaced with more energy efficient components. However, with competition imminent, continued support for broad systematic energy conservation efforts is unlikely. Similarly, electric utility efforts to promote large-scale introductions of renewable energy sources such as windpower are also less likely. Whether competition will finally help or hinder such technologies remains to be seen.

3 Not shown are the impacts on other emissions. For the aggressive DSM strategies, NO_x, SO_2 and other emissions can actually *increase* in later years, relative to the Ref. DSM strategy. Here the increased emissions from the older fossil resources actually eclipse the emissions reductions attained from additional conservation, resulting in a net emissions increase. See Connors, S.R. and E.T. O'Neill. 'No Good Deed Goes Unpunished: The End of IRP and the Role of Market-Based Environmental Regulation in a Restructured Electric Industry', *Proceedings of the United States Association for Energy Economics 17th Annual North American Conference,* Boston, MA. October 1996.

"capacity mix," as opposed to "energy mix," planning. That is, the decision to build new generating capacity is driven primarily by the need to meet future peak load (MW) requirements, not to attain a balanced generation (GWh) mix. Failure to balance peak load capacity needs with overall fuel mix and environmental performance is one of the first great challenges to a competitive electric market.

FIGURE ONE: Electricity Demand Trajectories for Four DSM/Conservation Options

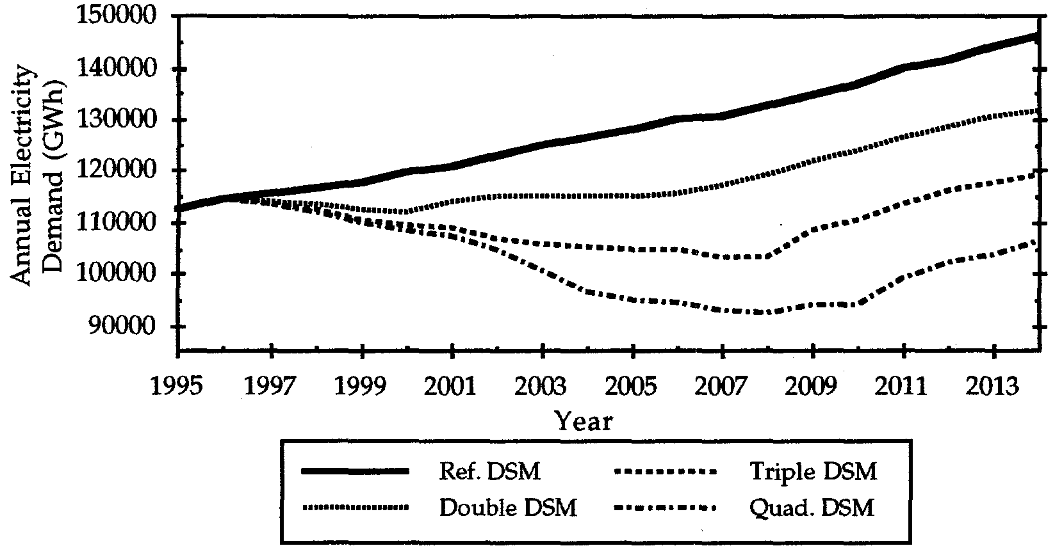


FIGURE TWO: Carbon Dioxide Emissions of Eight Multi-Option Energy Mix Strategies for the New England Electric Sector

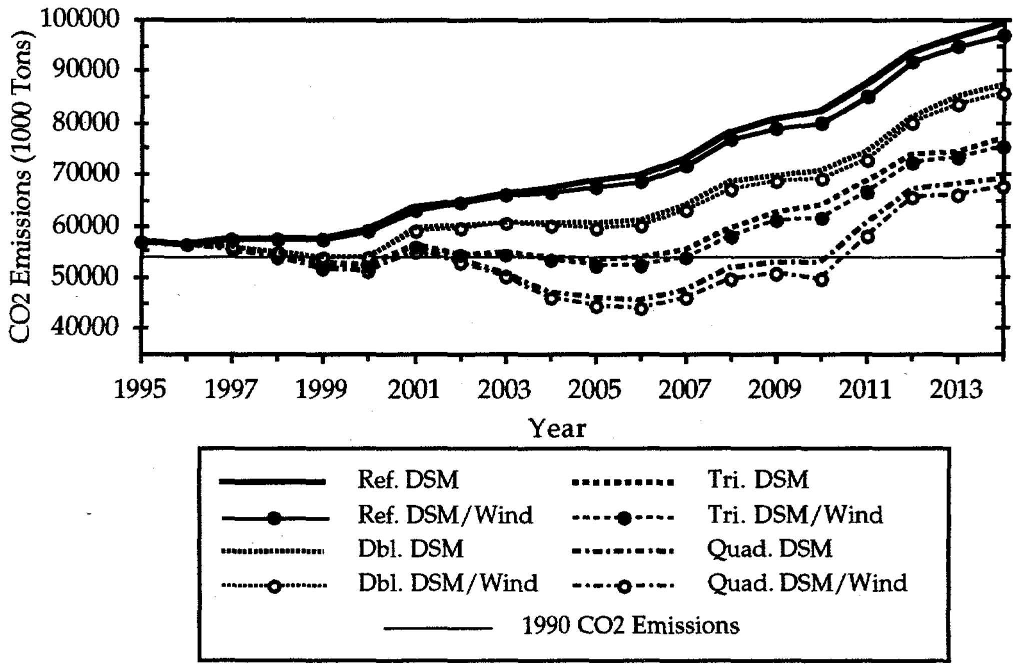


FIGURE THREE: Generation by Fuel/Technology Type for the Reference DSM and No Windpower Strategy[4]

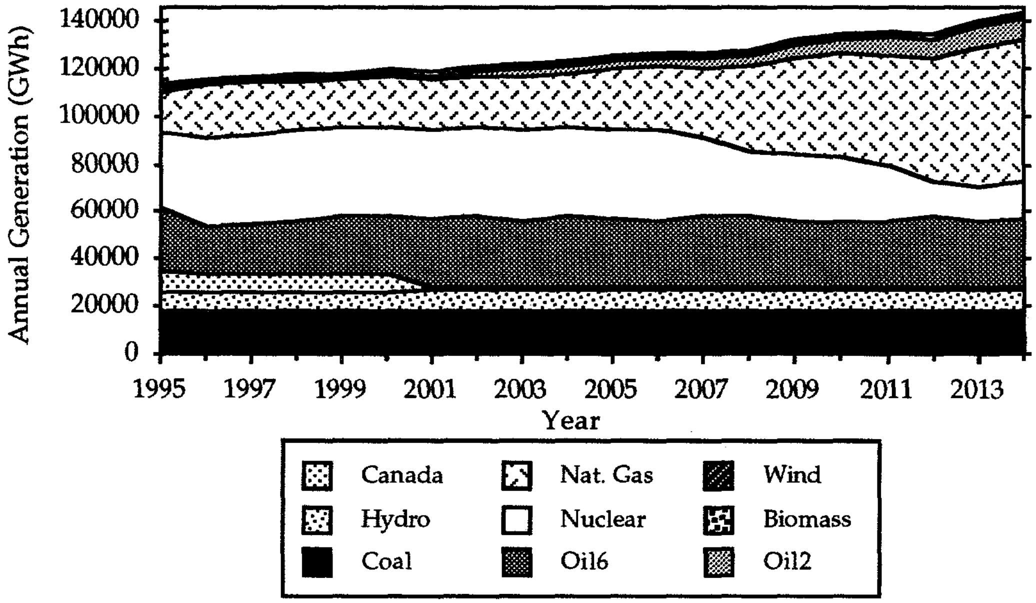
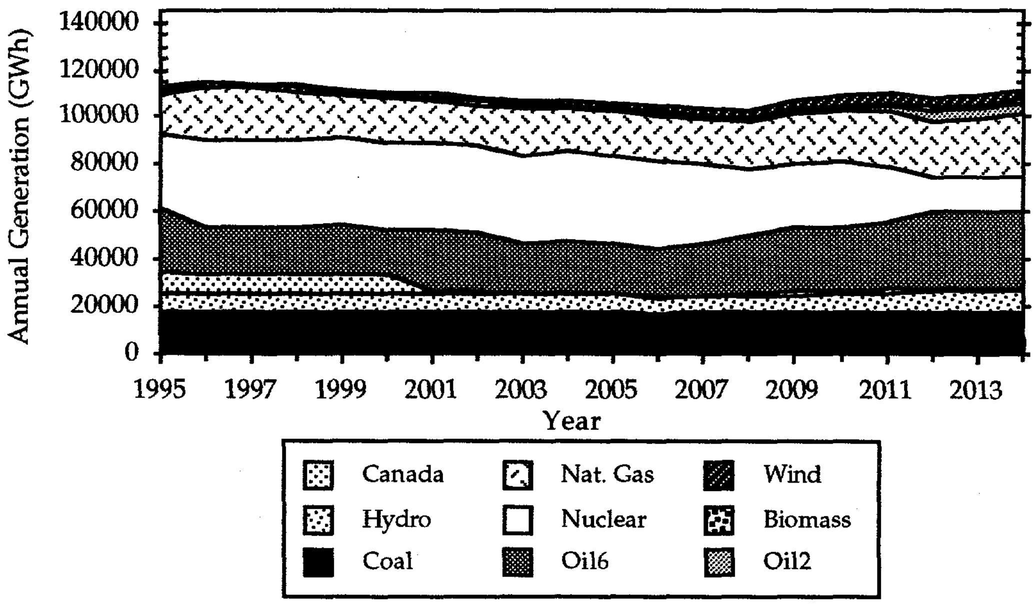


FIGURE FOUR: Generation by Fuel/Technology Type for the Triple DSM and Windpower Strategy



4 In Figures Three and Four, Canada refers to power purchases from Canada, predominantly hydropower. Oil6 refers to residual oil-fired generation. Oil2 refers to distillate oil-fired generation, predominantly peaking units, but also combined-cycle units during wintertime. Biomass refers to generation fueled primarily by forestry industry wastes. A significant amount of natural gas is currently being burned in existing rankine cycle power plants to meet environmental regulatory requirements.

TECHNOLOGICAL CHALLENGES TO REDUCING CO_2 EMISSIONS

The New England case study identifies the huge challenges industrialized countries' electric sectors will face if significant long-term reductions in CO_2 emissions are required. The fact that it is easier to achieve CO_2 reductions in the electric sector)than in the transportation sector[5]), and that New England is not dominated by coal-fired generation (like so much of the U.S.), indicates that New England might be one of the *easier* CO_2 reduction case studies. So what is it likely to take, technologically, to meet CO_2 reduction targets in general?

Supply-Side Coordination. The above example shows many of the technological dynamics that need to be considered when looking at how to reduce CO_2 emissions.[6] New efficient gas-fired generation can be considered an interim CO_2 reduction option, but only when it is used to displace existing higher CO_2 emitting units. Therefore, supply-side coordination is key. Natural gas generation did not help New England reduce CO_2 emissions since it either went to meet increased electricity demand, or replace decommissioned non-CO_2 emitting nuclear generation. New non-CO_2 emitting generation technologies (wind, solar, hydro, biomass, geothermal, nuclear, etc.) therefore must be developed and deployed when meeting increased demand, or replacing retiring resources. While many would argue that monopoly utilities historically did a poor job of supply-side coordination (thus leading to competition initiatives), the loss of long-time horizon utility Integrated Resource Planning (IRP) efforts in no way insures us that coordination will be better in the future. Such IRP initiatives not only sought to coordinate near-term resource activities, they also signaled technology and project developers what level and mix of resources to pursue.

Demand-Side Coordination. The New England case study is also informative, in that is shows us that demand-side efforts must be highly coordinated as well. Not shown above was the fact that aggressive DSM and wind strategies cost more.[7] The present value cost premium these strategies face is due more to the arithmetic of discounting front-loaded capital expenses, than it is the fact that the technologies cost significantly more. Therefore timing of resource additions becomes important aspect of a strategy's cost-effectiveness. Coordination with respect to CO_2 and other emissions reductions occurs on several levels. Similar to above, end-use efficiency improvements which displace the least efficient uses of electricity, or can be piggybacked on top of ongoing construction (new and retrofit), maximize the cost and emissions effectiveness of DSM efforts. As noted above, coordination between supply-side and demand-side initiatives, and among new and existing generation and demand is also required. When DSM and new generation technologies can be coordinated to displace dirty generation, meet growing demand, and avoid

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5 In fact, in transportation CO_2 reduction discussions, electrification of transportation is viewed as a primary option for weaning the industry off fossil fuels.

6 CO_2 emissions are focused on in this paper, instead of greenhouse gas emissions, since CO_2 is the predominant greenhouse gas emitted in the electric sector.

7 See Connors, S.R. and E.T. O'Neill. 'No Good Deed Goes Unpunished' mentioned above for a discussion of the cost aspects of the alternative New England energy mixes.

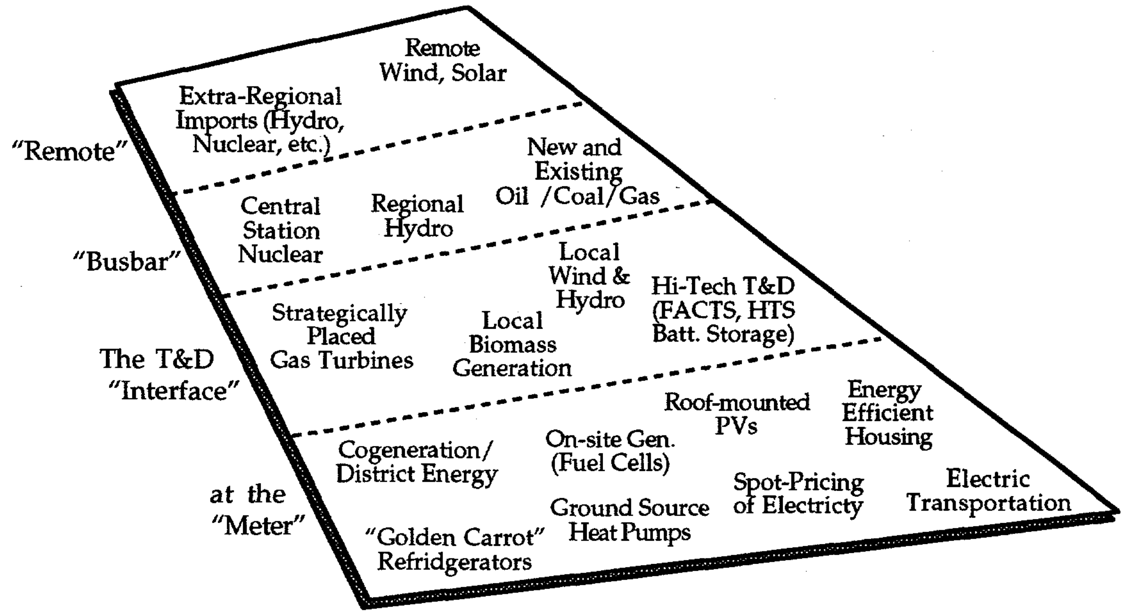
environmental retrofits on aging generation, the benefits of individual technologies can be leveraged. The above case study, as well as previous ones, have shown that failure to coordinate end-use efficiency improvements with supply-side initiatives can lead to increased utilization of older, high emissions generation resources, thereby reducing the effectiveness of DSM and other activities.

Coordination in Space and Time. While coordinating the physical installation of new resources is important from a cash flow standpoint, coordination in space and time is also important when it comes to maximizing the CO_2 reduction potentials of new resources. The real efficiency of a generation resource is a combination of it generation efficiency and the losses experienced in the transmission and distribution of that electricity. In New England, transmission and distribution losses average somewhere around 8% between central station generator and the customer, depending on location, load level, time of year, etc. Therefore, an industrial customer generating "on-site" with an equivalent technology experiences an effective 8% improvement in energy efficiency, not to mention avoided fuel costs, consumption and net emissions. The fact that the industrial customer might choose to cogenerate as well, further improves overall energy efficiency. DSM and roof mounted photovoltaics also benefit from this locationally related efficiency increase. Conversely, remote power incurs a penalty by having additional transmission losses. To attain and maintain substantial CO_2 emissions reductions, every little bit will count. Therefore, improvements to the efficiency of the transmission and distribution system should not be ignored either.

Figure Five outlines the broad range of technological responses that will need to be considered as we look at how to coordinate technologies (and their use) in order to cost-effectively reduce CO_2 emissions. The basic architecture represented in Figure Five is commonly referred to as the "Distributed Utility Concept." It recognizes that many of the new efficient technologies are small and modular, and can be "sited" either at the customer level, or at the transmission and distribution system interface. The Distributed Utility concept differs from "distributed generation" in that it recognizes that energy efficiency options, operational protocols along distribution line feeders, and consumer response to real-time spot-pricing initiatives all fall into the distributed architecture as well. In Figure Five, technologies are grouped locationally. "Busbar" refers to central station generation, where power flows across transmission lines, then distribution lines to reach the customer. Many utility peaking units are already sited at substations, the "T&D Interface," to support various parts of the grid. DSM and photovoltaics, as well as electrotechnologies and dynamic load-modification efforts take place "at the Meter." On the other end of the spectrum is "Remote" power.

As indicated in the figure, renewable energy can fall into several of these categories. Currently, to be cost-effective, wind turbines must be sited in premium wind regimes. In New England many of these sites are in remote areas such as Northern Maine. Power flow analysis shows that "remote wind" experiences sizable additional transmission losses (around 20%) if attempts are made to export

FIGURE FIVE: The Distributed Utility Concept – Coordinating Energy Technologies in Space and Time



his power out of state.[8] In contrast, photovoltaics are generally located at the customer site. In New England at least, the wind resource is skewed towards the winter, and its associated storm systems. However, New England electricity demand is highest during the summer, and concentrated in Southern New England. The fact that market prices for electricity will be highest during summertime afternoons, and environmental regulators are looking to restrict summertime NO_x emissions, makes photovoltaics a better "placed" technology in time and space than high tech wind. A alternative wind turbine technology, which can be cost-effective in lower speed, closer-to-home, wind regimes, and can feed power in at the distribution versus remote transmission system level begins to look more attractive.

Not in Figure Five are other important technological approaches to CO_2 reductions such as sequestration via improved land-use and mining practices and power plant CO_2 capture and disposal. These also factor into the technology mix but have fewer coincident benefits. More efficient energy use and generation technologies reduce all the emissions from fossil fuel combustion, not just CO_2. Given the magnitude of the CO_2 reduction efforts that may be required, these technologies should not be ignored. Cross national initiatives to facilitate CO_2 reductions, such as Joint Implementation programs also need to be evaluated in light of these multiple benefits. Will exporting efficiency saddle OECD countries with an aging and inefficient fleet of power plants? Will the multiple benefits of accepting costlier but cleaner and more efficient generation technologies make developing countries more likely to participate in Joint Implementation efforts? Attaining substantial

8 See "First Approach to Identifying Wind Generated Electricity Penetration Limits in New England: Simplified Steady-State Analysis and Economic Evaluation." by J. Lacalle-Melero, S. Connors, E. Festa, N. LaWhite, and C. Acosta-Colón. M.I.T. Dec. 1994.

long-term reductions in CO_2 and other greenhouse gases will likely require a *complete* turnover in the energy capital stock, in generation and end-use alike, including most of the building sector. The above discussions all presume that technology and equipment manufacturers have been sent the right signals such that, 1) replacement technologies *have* been developed, and 2) that such technologies are readily available for installation and use. As the electric sectors of various nations embrace competition, what structures and signals will be required so that such technological transformations can occur?

INSTITUTIONAL CHALLENGES TO REDUCING CO_2 EMISSIONS

Can the competition in the electric sector facilitate both the development and deployment of these sophisticated and highly coordinated energy mixes into the marketplace? Which direction will competition take the industry, and the environment? These are some of the issues discussed in this brief section.

Quarterly Report Lemmings and Industry Pacesetters. One of the central questions related electric industry restructuring relates to whether it will become an electricity commodity market–where every kWh is the same and spot prices rule, or whether it will become a vibrant energy services market–where cost, cost stability, reliability, quality, and environmental performance all factor into customers' decisions. Many already criticize U.S. boardrooms and financial markets for not taking the long-view. A commodity market for bulk power would invite the same mentality in the electric sector. A clearinghouse for electricity purchases and sales masks the relative environmental performance of generators, makes efforts to stabilize costs via fuel diversity almost impossible, and virtually ensures that a generic electricity, not electric service, industry will prevail. However, is cheap electricity the ultimate goal? The impetus for competition in energy, telecommunications, and transportation markets has been multi-faceted. High costs, or at least high cost differentials, have been a primary factor leading to competition in these sectors. But, competition has also been seen as a way to invite new capital investment, and new technologies, practices and products into an industry. How can the new competitive market be set up to provide the right rewards to innovators and industry pacesetters?

To invite innovation, the industry must be able to sustain market niches. Product differentiation and customer differentiation must occur. It is generally agreed that wholesale competition alone will not generate the range of market niches illustrated in Figure Five. Retail competition, with customer choice will be much better at creating such niche markets, providing initial markets for advanced energy services, distributed generation, renewable energy, energy storage technologies, and a spate of other applications. More directed efforts at sustaining research and development are being pursued. Renewable and DSM portfolio standards, systems benefits charges, and other such approaches have been promoted and in some cases approved. Customer choice and subsidies for renewables and DSM will play a key enabling role in fostering the development and initial demonstration of innovative technologies. However, several lingering concerns remain.

Promoting Environmental Responsibility. If retail competition is successful in attracting innovative technologies to the industry, will the resulting technological mix be in line with long-term environmental concerns such as climate change? How can their widespread utilization be promoted if and when large CO_2 reductions are required? These are two fundamental questions which have been effectively absent in the electric industry restructuring debate. The first question is difficult to answer with respect to market structure. As monopoly electric utilities dis-aggregate into separate operating units, they are no longer supporting basic, industry-wide research. Such long-term, strategic R&D efforts will need to be taken up by government. Just as government pursues basic knowledge-related climate change research, it needs to support basic, proof-of-concept solution oriented research. Industry-wide studies, as well as technology and science initiatives, are important as electric sector "flight simulators" to determine whether we can stay on the cost-effective emissions reduction flight path.

In the event that the electric industry must radically reduce CO_2 and other greenhouse gas emissions, environmental performance constraints on industry will play a central role. Just as competitive manufacturers must adhere to occupational health and safety regulations, a competitive electric industry will need to observe industry-wide environmental standards. "Cap and trade" systems to implement cost-effective emissions reduction strategies will be center stage. The first such system for nationwide SO_2 emissions has been operating effectively for several years. Along the eastern seaboard, an analogous system for summertime NO_x emissions is in the works. Good science to set an economically and environmentally effective emissions limits is an important topic with such initiatives. Such performance constraints can have a beneficial impact on industry, promoting a better technological balance than would exist otherwise. With the need to balance multiple emissions markets, on top of their normal competitive activities, further development of niche markets are likely to occur as consumers and suppliers seek to reduce their exposure to fluctuating emissions permit prices, or avoid the installation of multiple emissions control technologies.

PARTING SHOTS: SLOW AND STEADY WINS THE RACE

We currently do not have the requisite technologies or institutions to implement the CO_2 reductions being talked about in international negotiations by *any* deadline–let alone 2010. Performance constraints on the competitive market may well accelerate the development and introduction of some of these key technologies, but not by accident. Only with steady, continuous improvements in the efficiency of the energy infrastructure will we be able to truly implement a "no regrets" strategy.

The analysis reported on here was performed by the ANALYSIS GROUP FOR REGIONAL ELECTRICITY ALTERNATIVES (AGREA) at the M.I.T. ENERGY LABORATORY. The AGREA New England Project was sponsored by the New England electric utilities, BOSTON EDISON, CENTRAL VERMONT PUBLIC SERVICE, COMMONWEALTH ELECTRIC, NEW ENGLAND POWER SERVICE, NORTHEAST UTILITIES and UNITED ILLUMINATING, with supplemental support from the NATIONAL RENEWABLE ENERGY LABORATORY and the U.S. DEPT. OF ENERGY. Results and their interpretation are the author's and do not necessarily reflect the opinions of the sponsors. Additional assistance from the planning division of the NEW ENGLAND POWER POOL, NEPLAN was also greatly appreciated.

Opportunity Knocks

The Sustainable Energy Industry and Climate Change

By: Bob Price and Pat Keegan
International Institute for Energy Conservation, Washington, DC

Key Words: climate change, efficiency, developing countries

Abstract:

Climate change mitigation, if intelligently undertaken, can stimulate economic growth. The main tools available for this task are energy efficiency, renewable energy, and clean energy technologies and services, which are collectively known as sustainable energy. To unleash this potential, the US and other governments need the full cooperation of the sustainable energy industry. This industry knows more than most other about turning energy-related pollution prevention into profits. If engaged, they can help:

1. Identify the economic benefits of greenhouse gas mitigation;
2. Identify barriers to the implementation of greenhouse gas mitigation projects;
3. Develop policies and measures to overcome these barriers; and
4. Implement greenhouse gas mitigation projects.

THE SUSTAINABLE ENERGY INDUSTRY AND CLIMATE CHANGE

The Third Conference of the Parties (COP-3) to the Framework Convention on Climate Change will take place in December 1997 in Kyoto, Japan. The decisions taken at COP-3 could have a profound effect on the future of climate action. Ultimately, the most important factor in determining what commitments are made in Kyoto is the perceived cost of reducing greenhouse gas emissions. If national governments and international negotiators believe that mitigating climate change will spur economic growth (or, at least, will not hurt economic growth), they will be more likely to commit to the aggressive reduction of emissions. If they believe that such actions will retard economic growth, however, they will be unlikely to adopt measures in Kyoto to mitigate emissions.

Since energy consumption accounts for roughly 90 percent of global greenhouse gas emissions, it is the cost of reducing these energy-related emissions that is of greatest concern. According to the Intergovernmental Panel on Climate Change, energy efficiency measures could cut energy consumption—and hence these energy related emissions—by 10 to 30 percent at zero or negative economic cost. Implementing all economically beneficial renewable energy and clean energy (including efficient generation technology) projects could reduce energy-related emissions even further. For all countries, even the most technically advanced, it makes sense to use these *no regrets* measures as the first line of defense on global climate change. The task for the US and other governments is to remove the barriers that hinder the private sector from turning this hypothetical potential into real projects.

Governments need not proceed blindly in this task. The sustainable energy industry—comprised of firms that manufacture or provide energy efficient, renewable energy, and clean energy products and services—can give significant assistance in the development of market based solutions. This industry has first hand knowledge of the market barriers to the implementation of technologies and techniques that can mitigate climate change. Parts of this industry are already engaged in the climate change debate and are looking for cost-effective means to reduce the threat of climate change. Bringing the rest of this industry into the debate will help uncover the full potential for no regrets climate change mitigation. To do this, it is first necessary to understand what companies constitute this industry.

DEFINING THE SUSTAINABLE ENERGY INDUSTRY

The growth of sustainable energy business associations in the US and in Europe is evidence that the industry is developing an identity. In general, the industry can be broken into two groups:

1. Firms that manufacture technologies or develop projects that generate clean or renewable energy; and
2. Firms that provide energy efficient products and services.

Firms that manufacture, distribute, or develop projects that use biomass, fuel cells, geothermal, hydropower, natural gas, photovoltaic, solar thermal, and wind power components or systems compose the former group. As for the energy efficiency industry, a large portion is composed of producers of advanced, energy-efficient lines of products traditionally associated with other established industries, including the automobile, motors, lighting, and appliance industries. High technology and services firms—specializing in computer hardware and software, energy engineering, project finance, demand-side management consulting, and advanced building materials—represent another segment of the energy efficiency industry. The sustainable energy industry components are described briefly below, and in detail in Appendix A.

Renewable Energy and Clean Energy

Several renewable and clean energy technologies are already mature and cost-competitive with conventional energy sources. Many, however, are still evolving, improving, and dropping in price. For a large number of these technologies, one of their most salient features is that they are small and modular, allowing systems to expand piecemeal as energy demand grows. Moreover, a number of renewables technologies can provide extremely cost-effective energy for locations were grid interconnection does not yet exist.

Efficient Demand-Side Technologies and Services

Industrial, commercial, and residential end-use technologies consume roughly two-thirds of the world's energy (the transportation sector accounts for the remainder). Much of this energy is used much less efficiently than it could be, especially by developing and transitional economy consumers. Using more efficient lighting, motors and other end-use equipment could cut these losses by as much as 75 percent.

Efficient Supply-Side and Distribution Technologies

Independent power producers are aggressively entering emerging markets, realizing that it is in these countries that the growth of their industry lies. Most of these firms come in selling the coal or natural gas plants that they are accustomed to building domestically. High-efficiency supply-side power (cogeneration) and distribution technologies (transformers and wiring), however, could be a large part of the solution for developing countries needing to meet 10 percent annual energy demand growth.

Efficient Transportation Technologies and Services

In the industrialized world, the private sector is already responding to growing opportunities in the marketplace for "green" transport technologies. Much of this transportation technology and skill could be adapted for developing countries, where the transport sector requires urgent attention. Efficient transport products and services present a significant opportunity for developed country exports and joint ventures with host country firms.

BRINGING THE SUSTAINABLE ENERGY INDUSTRY TO THE DEBATE

Any new international commitments to mitigate greenhouse gas emissions will require governments around the world to develop and implement policies and measures that encourage energy users to adopt sustainable energy solutions. As a result, the firms that provide these products and services have a large, if yet largely unrecognized, stake in promoting aggressive climate change action. Nonetheless, climate change remains a nebulous concept for most of the industry. To get their attention, the industry must be shown how climate action could effect their business prospects.

As a first step, it will be necessary to determining the monetary value of the no regrets potential. A rough estimate shows that it is potentially huge. Using the lower end of the Intergovernmental Panel on Climate Change's estimate for the no regrets energy efficiency investment of 10 percent, the size of the investment in the US alone could approach $250 billion.

This estimate is based on the fact that the US spends roughly $500 billion per year on energy. Reducing energy use by 10 percent would reduce annual energy expenditures by $50 billion. Assuming these measures have a 5 year payback, the required initial investment in energy efficiency products and services would be $250 billion. Using the upper end of the IPCC's estimate, the required initial investment would total $750 billion. To put this in perspective, annual sales by the energy efficiency industry currently stand at roughly $40 billion.[1] Incorporating all the renewable and clean energy no regrets investments would drive the overall required investment in sustainable energy in the US even higher.

Macro-economic numbers, however, will do little to encourage the sustainable energy industry to devote time and resources to the climate change debate. Individual firms will only be interested in how climate action will effect their specific technologies and services. For this reason, the analysis of the no regrets potential must take a bottom-up approach. Once the industry understands how climate action could benefit them, they will be prepared to help governments develop the necessary market mechanisms to implement climate change mitigation projects.

THE CASE FOR CLIMATE ACTION IN DEVELOPING COUNTRIES

Getting the sustainable energy industry engaged in climate change mitigation in the developed world is only a first step. The convergence of rising energy demand, the growth of international trade, and energy sector deregulation (which has reduced energy subsidies) has created new opportunities for sustainable energy investments in the emerging markets of Latin America, Asia, Southern Africa, and Central and Eastern Europe. The International Institute for Energy Conservation and a dozen partnering organizations are making these and other arguments to the sustainable energy industry through the Opportunity Knock campaign. These conditions in emerging markets and their implications for no regrets sustainable energy investments are explored further below.

Rising Energy Demand

Developing and transition countries promise to be the largest energy markets of the 21st century. The OECD has been the world's largest market in the past, and will continue to be in the near future. However, the developing world—with population, economic, and energy demand growth that far outstrips the current growth of industrialized countries—will soon be the world's largest energy market.

Developing country energy consumption has grown by an average of over 5 percent annually since the 1970s. Annual energy consumption growth in developed country averaged less than 1 percent during that period. In coming years, developing countries' rate of energy demand growth is predicted to more than double that of OECD countries, 3.7 percent to 1.7 percent.[2] The implication? If projections hold, annual energy consumption of the developing world is expected to grow by 110 quadrillion Btus over the next 20 years. This is equivalent to the annual output of over 5,000 large coal, nuclear, or hydro plants. OECD energy consumption over that period, in contrast, is expected to grow by only 50 quadrillion Btus. Meeting the explosive demand for energy services in emerging markets will place a tremendous amount of strain on local capital markets and the local environment.

To meet the projected growth, the World Bank estimates that developing countries will require investments of over $100 billion per year for the next thirty to meet electricity needs alone.[3] Foreign exchange will be needed to pay for 40 percent of this total ($40 billion per year). Yet, only $10 billion to $12 billion per year is expected to be available from the multilateral and bilateral lending agencies that currently provide 80 percent of the foreign exchange for power sector investments.[4] While commercial banks are rapidly becoming important sources of capital for developing countries, it is unlikely that these institutions will be able to supply the nearly $30 billion annual shortfall. Since sustainable energy projects often have lower life-cycle costs than their conventional energy counterparts, these technologies and services are likely to be in high demand once policy makers, planners, and customers are familiar with their cost and performance characteristics.

Meanwhile, unchecked growth in fossil fuel consumption is fouling local air and water, and threatening the global climate through increased concentrations of greenhouse gases (GHG) in the atmosphere. Local actions in developing and transitional countries to reduce the health threats posed by air and water pollution are already providing increased impetus for sustainable energy projects.

The Growth of International Trade

International trade in both products and services grew by almost 9 percent in 1995 and by 7 percent in 1996. It is expected to grow by 8 percent per annum in the coming years.[5] This dramatic growth is being fueled in part by the rapid expansion of international trade agreements. The completion of the Uruguay Round of the General Agreement on Tariff and Trade in 1994 is perhaps the preeminent piece in these developments, but it is not the only one. The European Union, the North America Free Trade Agreement (NAFTA), Mercosur, and the Asia Pacific Economic Council's trade initiative represent only a handful of the regional initiatives underway. Many of these agreements are relatively new and are continuing to increase in scope.

The faltering infrastructures of Central and Eastern Europe and the former Soviet Union provide a perfect example of the opportunities for profitable investment in improving the efficiency of the energy sector created by the expanding international trade. Transmission and distribution losses in these countries amount to over 0.5 billion tons of oil equivalent (btoe) out of an overall production of 1.5 btoe.[6] That means more than one-third of the energy generated does not reach end-users; in other words, it is wasted. In sharp contrast, losses in Western Europe, Japan, and the United States amount to less than 20 percent of raw energy production. Bringing the former Eastern Bloc up to Western power plant and transmission and distribution standards would save energy equal to the annual production of all nuclear reactors in North America.

As new energy resources are needed, it is likely that efficiency projects designed to retrieve lost energy will be among the most cost-effective options. Until recently, however, most of these efficiency projects have not been developed only for lack of access to Western technologies. As the former Eastern Bloc opens its markets and joins the world trade regimes, these are increasingly attractive markets for Western firms. European industrial giants, like Landis & Gyr, are already poised to land several hundred million dollars of deals in the region to simultaneously reduce energy consumption and improve energy services through efficiency improvements.

Energy Sector Deregulation

For decades, governments throughout the world have subsidized energy consumption, either directly or indirectly. Government intervention has been especially common in the developing world; in the late 1980s, consumers there paid an average of 60 percent of the real cost of the energy they received.[7] While the reason for the subsidies was admirable—ensuring access of all citizens to affordable energy services and encouraging key strategic development sectors—the subsidies discouraged investment in efficient technologies and practices. In the drive for economic efficiency and international competitiveness, however, many governments are dismantling these outdated policies.

Dozens of countries from China to Chile to the Czech Republic are loosening government control; some are going so far as to seek private investment in the energy sector. In Chile, for example, the formerly state-owned owned utilities were transferred to a public company, ENERSIS. Subsequently, ENERSIS, is being sold to the private sector and residential electricity prices have risen to as high as 11 cents per kilowatt-hour. As subsidies disappear and energy prices move closer to market prices, newly cost-conscious consumers are looking for the least expensive means to meet their energy needs. Where deregulation includes the opportunity for private power producers to sell power to the grid, it also makes investment in renewable and clean energy technologies economically attractive.

How to Seize the Opportunity

Sustainable energy firms interested in entering—or deepening their engagement in—developing or transitional country markets, do not need to proceed blindly. There is an enormous amount of information and other forms of assistance available from public, non-profit, and private sources on developing and emerging country markets. To put any of this information to use, however, companies that do not currently have a department or individual responsible for international marketing must be willing to make that commitment. Further, success often requires the establishment of a local presence and a willingness to work through initial in-country difficulties. While it is possible that overseas project leads will arrive unannounced, the effort needed to find international opportunities for products is just as difficult—and often more so—than finding opportunities at home.

RECOMMENDATIONS

To help identify and implement the global no regrets potential to mitigation climate change, governments from the industrialized world should:

1. *Estimate their countries' no regrets potential for climate change mitigation measures.* It will be much easier to build enthusiasm in the energy efficiency and clean energy industries when this value is known. Developing estimates of the no regrets potential will not require significant new data gathering or analysis. The extensive assessments of greenhouse gas reduction measures that countries have already conducted should prove sufficient for this task. Their best partner in developing these estimates is the sustainable energy industry itself. The assessments should be broken down by industry subsector.
2. *Aggressively disseminate estimates of this potential to the sustainable energy industry.* The buy-in of the entire sustainable energy industry is crucial to mitigate climate change. The industry needs to guide policy makers in developing measures that will permit project implementation and to, ultimately, implement those projects. This commitment will only be forthcoming if individual firms understand the benefits that climate action holds for them.
3. *Inform policy makers of the economic benefits of greenhouse gas mitigation.* At present, in few if any countries do all the relevant ministries understand that climate change mitigation need not be a costly undertaking. To ensure passage of the necessary policies and measures to realize the no regrets potential, a much larger group of policy makers must be convinced of this potential.

4. *Develop policies and measures to permit immediate implementation of no regrets projects.* The sooner the barriers to energy efficiency, clean energy, and renewable energy projects begin to fall, the easier it will be to develop sustainable energy projects. This, in turn, will provide concrete evidence of no regrets measures and thereby encourage other countries to follow suit. Different measures will probably be necessary for each industry subsector.
5. *Assist developing and transition countries estimate their potential.* Developing countries are posed to drive global greenhouse gas emissions in the 21st century. Long-term solutions to climate change, requires immediate action by industrialized countries to identify and help implement no regrets measures in the emerging markets of Africa, Asia, Central and Eastern Europe, and Latin America.
6. *Target Kyoto and beyond.* In Kyoto, the signatories to the FCCC will attempt to agree on legally binding commitments for greenhouse gas emission reductions after the year 2000. The economic ramifications of this decision will be an important factor in influencing each country's position. This, however, is a long-term effort. After Kyoto it will continue to be important to clearly demonstrate the economic benefits possible from reducing greenhouse gas emissions, governments can provide a powerful argument for aggressive action to reduce greenhouse gas emissions.

To fulfill their role as the climate action implementors, the sustainable energy industry should:

1. *Help governments quantify the no regrets potential for greenhouse gas mitigation, and then help identify the measures necessary to implement this potential.* The industry has more experience than any other group in evaluating the markets for its products and services. It must use this expertise to assist governments in quantifying the potential size of their business (a good proxy for the no regrets potential) if government action causes market barriers to fall.
2. *Explore opportunities to market products in emerging markets.* The world's emerging markets are likely to hold the largest potential for no regrets climate change investments. To accustom policy makers, planners, and customers of the cost-effectiveness and performance characteristics of their products and services, the sustainable energy industry needs to increase its marketing efforts in these countries. Only when they are comfortable with the sustainable energy solutions will these countries be willing to implement the necessary policy reforms to reduce the barriers to their implementation.

The rest of the business community can play a constructive role too. They need to commit to the implementation of all no regrets measures. Undertaking these measures will provide positive financial returns to business. Moreover, by aggressively moving on no regrets solutions to climate change, businesses can avoid the threat of mandatory (and potentially draconian) measures being taken in the future.

ENDNOTES

[1] Hagler Bailly Consulting, Inc., 1995.

[2] Energy Information Agency, *World Energy Use, 1996* (Washington, D.C.: U.S. Department of Energy, 1996).

[3] World Bank Industry and Energy Department, "Capital Expenditures for Electric Power in Developing Countries in the 1990s, Working Paper #21" (Washington, D.C.: World Bank, February 1990).

[4] Michael Philips, *The Least-Cost Energy Path for Developing Countries: Energy-Efficient Investments for the Multilateral Development Banks* (Washington, D.C.: International Institute for Energy Conservation, 1991).

[5] OECD, Washington Center World Wide Web Page (http://www.oecdwash.org), 1996.

[6] Richard House, "Saving on Demand," *Infrastructure Finance* (December/January 1996), p. 42. House actually considered all the 0.5 btoe "wasted energy," and used for comparison the whole of the OECD's annual nuclear energy generation.

[7] U.S. Congress, Office of Technology Assessment (OTA), *Fueling Development: Energy Technologies for Developing Countries* (Washington, D.C.: OTA, 1992), p. 8.

APPENDIX A

Renewable Energy[1] and Clean Energy

Biomass

Biomass energy is either steam or electricity resulting from the combustion or anaerobic digestion of organic material or wastes. In the US, wood waste is used to fuel utility power plants as large as 80 megawatts. Biogas, with quality comparable to natural gas, is being collected at over 120 landfills. And there are more than 60 ethanol-manufacturing facilities.

Fuel Cells[2]

Fuel cells provide both hot water and electricity by combining hydrogen with oxygen in the presence of certain materials. When the electricity and hot water are used together, the units can achieve efficiencies of 80 to 90 percent. Today, the market niche for the fuel cell is most apparent as a provider of on-site electric power and hot water to hospitals, public buildings, and other large facilities. One of the most attractive features of the technology is that additional cells can be added incrementally as a facility's energy needs grow.

Geothermal

Geothermal energy is the natural heat energy of the earth contained in underground rocks and fluids that can be tapped for heat or electrical generation. In the US, over 100,000 separate facilities use geothermal heat for residential, industrial and commercial applications, including 63 power plants providing 2,780 megawatts.

Hydropower

Hydropower harnesses the energy of falling water in a generator to produce electricity. Ten percent of the US electricity supply, or 94,000 megawatts, comes from hydropower. Hydropower facilities also provide irrigation for farmers, supply water to villages and cities, control flooding, and increase and protect navigation.

Natural Gas

Natural gas is one of the leading fuels consumed throughout the world. It is used mainly for industrial process steam and heat production, for residential and commercial space heating, and for electric power generation.[3] Compared with coal, it is a relatively clean-burning fuel. Moreover, natural gas-fired power plants using combined cycle turbine technology can operate at efficiencies approaching 60 percent. Almost twice the efficiency of state of the art coal-fired plants.

Photovoltaic Power

Photovoltaic (PV) cells convert sunlight directly into electricity using a thin layer of semiconductor material attached to metal contacts. The fast-growing markets for PV systems include utilities, rural electrification, telecommunications, lighting and military applications. The US leads the world in the manufacturing of PV technology. Since the early-1980s, the US private sector has invested more than $2 billion in research and commercialization.

Solar Thermal

Solar Thermal energy uses the heat of the sun to heat water or air, or to make electricity. Parabolic troughs or dishes and central receivers (currently providing over 400 megawatts) can furnish electricity for a broad range of sizes and temperatures, and parabolic troughs can be used for industrial process heat and steam.

Wind Power

Wind energy conversion systems (WECS) convert the kinetic energy of wind into electric power. More than 16,000 utility-intertied WECS have been installed in California since 1982, with an installed capacity of 1,700 megawatts. Other applications include wind/diesel hybrids and rural electrification systems for village power, water pumping, desalination, telecommunications, and refrigeration.

Efficient Demand-Side Technologies and Services

Energy Service Companies

Energy service companies (ESCOs) provide a range of services to implement energy efficiency projects. Services include engineering, financing, project construction, project management, and maintenance requirements to identify, implement, and maintain efficiency projects. While various types of companies make up the industry, engineering experience anchors these enterprises. The ability to identify opportunities for cost-effective energy efficiency investments, to utilize myriad energy efficiency producers and technologies, and to manage their operations, makes these engineering services essential to the success of an energy efficiency project. ESCOs make use of all the energy technologies listed in the following sections.

Building Environment Controls

Building environment controls regulate one or more of a building's heating, cooling, lighting, and security needs. By turning off (or powering down) systems when they are not needed, building controls can save considerable energy.

Heating, Ventilating, and Air Conditioning (HVAC) Equipment

For commercial facilities, HVAC often accounts for most of the energy load; as a result, efficient HVAC equipment significantly reduces energy consumption. HVAC equipment can be sold as modular units, but it is most often sold as combined systems that can be integrated into a building energy management system to allow for automatic control. The various components of an HVAC system include: air conditioners, heat pumps, liquid chillers, thermal storage equipment, furnaces, and boilers.

Lighting

Lighting is one of the easiest places to achieve significant energy savings. Upgrading incandescent light bulbs to compact fluorescents reduces energy consumption by up to 75 percent. Meanwhile, replacing energy-hungry magnetic ballasts with their high-efficiency electronic counterparts can reduce energy consumption by 25 percent. The technologies that define the lighting industry are not limited to lamps and ballasts. High-efficiency fixtures, luminaires, reflectors, and control systems are integral components in energy-efficient lighting systems.

Household Appliances

The appliance industry includes manufacturers of standard and solar domestic hot water heaters, room air conditioners, dehumidifiers, ranges and ovens, microwave ovens, refrigerators, freezers, laundry equipment, dishwashers, compactors, disposers, and temperature sensors. As a whole, appliances account for the bulk of residential energy use. Most have potential for significant efficiency improvements. For example, moving from a standard efficiency, 18 cubic-foot refrigerator to the highest efficiency model available on the market would reduce annual energy consumption by 75 percent (from nearly 1000 kWh to less than 200 kWh).

Building Materials

Proper insulation of walls reduces thermal transfer, conserving energy and thereby reducing pollution and operating costs. It minimizes heat loss from conduit and building shells, maintains proper operating temperatures in industrial equipment, and protects workers from high temperature surfaces. Meanwhile, the installation of windows with the correct insulation, radiance, and insolation properties can improve the overall thermal efficiency of a building. Together, the use of proper insulation and windows can cut energy bills for facilities of all types.

Industrial and Process Controls

The industrial and process controls industry covers a range of equipment such as sensors, transducers, signal transmitters, and actuators and controllers. The main tasks of these products are starting, regulating, stopping, and protecting electric motors. The controls are highly adaptable and their exact use and arrangement are based on the production requirements for a specific product. These instruments often interface with a computerized energy management system, allowing operators to control energy consumption and analyze energy use and loss patterns.

To achieve higher efficiency levels, the controls industry constantly updates information technology components. Manufacturers either develop their own microprocessor-controlled instruments, networks, and data management systems or work with computer and software firms to create the necessary technology. In addition, new communications software permits plant-floor control systems to communicate with centralized control systems, allowing for greater control of industrial processes and higher efficiency levels.

Motors and Adjustable Speed Drives

Motors are the primary consumers of electricity in the industrial sector of developed countries and are often the largest overall energy consumer in developing countries. Motors usually fall into two categories: fractional horsepower—less than one hp—and integral horsepower—one hp or greater. Fractional horsepower motors drive systems ranging from compressors in residential refrigerators to components of air handling systems in large industrial facilities. Integral horsepower motors are used almost exclusively by the commercial and industrial sectors.

In the past, end uses that required motors to operate at differing speeds employed high-cost, inefficient, and relatively unreliable controls. Today, industry increasingly uses electronically controlled adjustable speed drives (ASDs) to vary alternating current motor speed to match process requirements. ASDs, when applied appropriately, improve motor energy-efficiency and prolong the life of the motor. However, ASDs are not appropriate for use in all motors.

Efficient Supply-Side and Distribution Technologies

Cogeneration

At its simplest, a cogeneration system takes some of the heat that would normally be wasted in the generation of electricity and uses it to satisfy some or all the facility's thermal requirements. Using "waste energy" to perform useful tasks is what makes a cogeneration unit different from other forms of power generation. In typical power plants, roughly two-thirds of the heat content of the fuel is lost as waste heat. Cost-competitive, high-efficiency cogeneration plants are capable of capturing and using 75 percent of the waste heat, bringing the plant's overall efficiency to 80 percent or higher.

Transformers

Virtually all electric power passes through at least two transformers before it is converted to mechanical power, light, or hear, and each transformer loses some of its input power to internal inefficiencies. Efficiency in standard distribution models range from around 96 to 98.5 percent. High performance units are commonly 98 to 99+ percent efficient. While this may seem like a small efficiency spread, the sheer number of units and their high duty factor make distribution transformers a large source of cost-effective energy and capacity savings. In the US, these systems have paybacks of one to four years.

Cabling and Wiring

Largely invisible in most applications, cabling and wiring plays an important role in the overall energy efficiency of a given system. Even more so than transformers, minute improvements in efficiency of these ubiquitous products can produce dramatic savings since all electric power must pass through them on the way to its destination. In many applications significant improvements in cabling and wiring efficiency can be effectuated simply by increasing the gauge of the wire. In others, even large gains can be achieved by switching from an inefficient and dangerous conductor, aluminum, to one with superior cost and safety features, copper.

Efficient Transportation Technologies and Services

Electric Vehicles

An electric car or bus is powered by motors fed by electricity stored in on-board batteries. Electric vehicles (EVs) are highly reliable, require little maintenance, and, with the right source of electricity, generate almost no pollution and few greenhouse gas emissions compared to conventional internal combustion engines. EVs, of course, are not a panacea—they have drawbacks as well. These include higher price tags, shorter ranges, and longer refueling times than their conventional counterparts. Some of the components necessary to deliver an EV are: batteries, battery chargers, lightweight composite materials, controllers, and motors.

Mass Transit Planning

Along with technologies, a wide range of technical support services enhances transport efficiency. As all levels of government try to address transport-related problems, these services, provided by private sector firms, are increasingly in demand. Transit services include the following:

1. Comprehensive economic analysis and evaluation of planned transport projects, allowing countries to make well-informed investment decisions in transportation infrastructure.
2. Innovative financing arrangements to develop light rail, such as "joint development" in which government and private sector partners jointly plan light rail infrastructure and associated commercial and residential development. Private developers gain because the rail system delivers a clientele directly to their door. The government gains because its share of the project cost drops, capital-intensive investment in auto-based infrastructure is deferred, and inner-city access to high-quality transportation is improved.
3. Public participation programs designed to create sustainable transport systems and livable communities. These programs teach the sponsors of transit projects how to build a coalition of concerned, well informed, and committed stakeholders from every relevant background and perspective to help the process succeed.

ENDNOTES

[1] All the descriptions of renewable energy technologies were excerpted from the US Export Council for Renewable Energy's World Wide Web page (http://www.crest.org/renewables/usecre/benefits.html) on April 30, 1997.

[2] US Business Council for Sustainable Energy (US BCSE), *Changing Tide: Tomorrow's Clean Energy—Today* (Washington, D.C.: US BCSE, 1996).

[3] Ibid.

TOWARD CLEANER, QUIETER SKIES: AN INTERNATIONAL DEBATE

Howard Aylesworth, Jr.
Director, Airworthiness and Regulation
Aerospace Industries Association of America

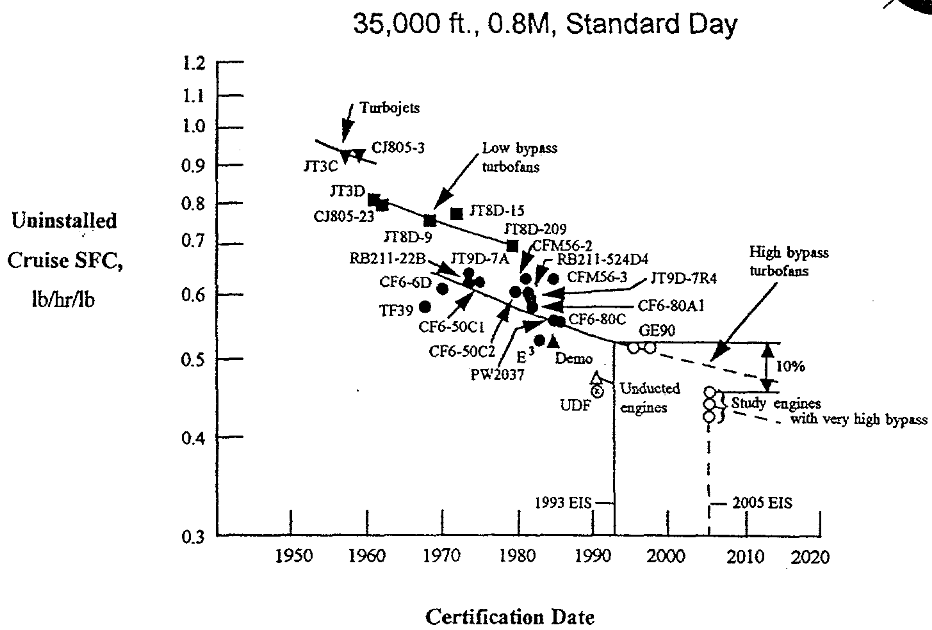
World air traffic has grown at a rate of 5 to 6 percent per year during the decade as more and more countries benefit from economic development and integration into the global economy. Civil aviation is projected to grow at a 5.5 percent annual rate over the next decade, and at 5 percent per year over the next twenty years. Airports and the air traffic control system will need added capacity and greater efficiency to accommodate increased reliance on air transportation services, and airlines will be required to expand well beyond the current commercial fleet.

With the growth of civil aviation and increased public awareness of the impact of human activity on the environment have come efforts to counter real and perceived threats of aircraft noise and engine emissions. Increasing concern over the possibility of adverse global climate change has focused attention to the potential effects of aviation to the atmosphere. The aerospace industry believes environmental problems must be addressed aggressively and impartially, and has a long history of work to reduce the environmental impacts of aviation.

The aerospace industry has achieved significant reductions in aircraft noise and engine emissions during the past four decades. Manufacturers and operators continue to devote considerable resources to further the substantive environmental gains achieved today. Although the aerospace industry works continuously to apply all available technology to achieve the quietest, cleanest aircraft possible, there are limits to what any given level of technology can contribute. Figure 1 shows gains in specific fuel consumption (SFC) efficiency. These benefits have been achieved through introduction of new technologies and through further developing current technologies, and, ultimately, by constantly upgrading the commercial fleet.

Figure 1 further illustrates that further noise and emissions reductions from existing technology produce only marginal benefits, albeit at great cost. Effective land-use planning and air traffic measures produce far greater benefits at affordable costs.

Figure 1 ***State-of-the-Art Subsonic Engine SFC***



A key question is whether existing international noise and emissions regulations will be universally adopted and uniformly applied.

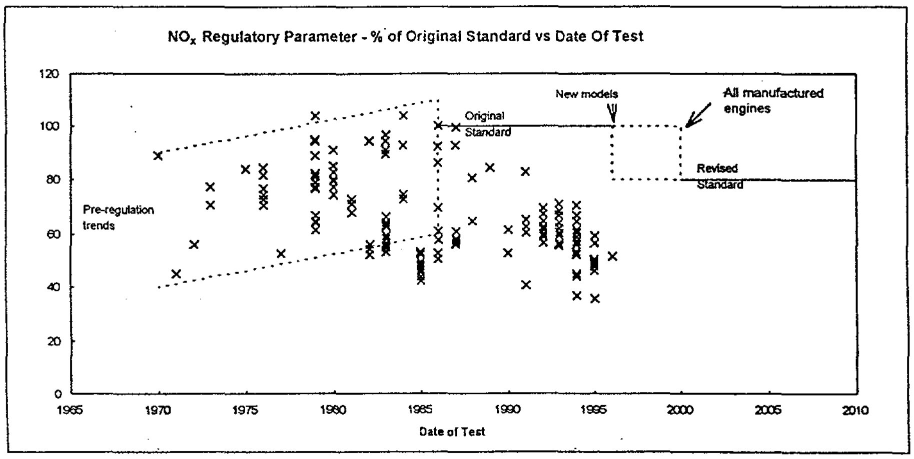
Aviation Productivity and Growth

Environmental pollution seems to the average person to have grown exponentially with the mechanization of modern society. A common argument for focusing on aviation in the Global Warming debate is that aviation's carbon dioxide emissions will grow at a rate higher than any other industry sector. Yet, this is not the case.

While total air traffic is projected to grow robustly over the next two decades, this will not necessarily translate into an equal rate of growth in aircraft emissions. Past history suggests that aviation emissions have grown less rapidly than air traffic, and there is no reason to believe this pattern is likely to continue in the future. Three factors help explain why this is true.

The most straight forward means to abate emissions is to reduce the amount of fuel consumed. Figure 1 shows how aircraft have become more fuel efficient due to advancing technology, and figure 2 shows how this and other factors have reduced engine oxides of nitrogen emissions. At the same time, developments in air traffic control technology have led to improved operational efficiency which, in turn, has led to reduced fuel consumption on a per flight basis.

Figure 2 ***Aircraft Engine NO_x History***



Second, airline operators have become more effective in obtaining more passenger miles from a given aircraft movement. Rising load factors (passengers per available seats), larger average airplane size, and developments in aircraft air traffic management technology have increased the productivity of the commercial fleet. Finally, aviation has grown in part because it is a viable substitute for other modes of transportation. These three factors indicate fuel consumption will increase at a lower rate than the growth in demand for aviation services.

Trends and Trade-Offs in Aviation Emissions

There is a growing consensus that the principal environmental impact of civil aircraft today is the emission of greenhouse gases at cruise altitude. By mass and lifetime, the most significant of these gases appears to be carbon dioxide. Carbon dioxide is not the only greenhouse gas emitted by civil aircraft, however. Nitrogen oxides, water vapor, soot and aerosols may also play a role.

The chemistry and physical modeling of these emissions are complex and there is as yet no consensus on the relative significance of the various gases to climate change. Forcing the improvement of one greenhouse gas at the expense of fuel efficiency, or loss of total ground level emissions performance are outcomes to be avoided. Developing scientific consensus over the relative significance of specific greenhouse gases can only speed industry progress in reducing the environmental impacts of aviation.

Advancing engine and aircraft design technology, coupled with improved air traffic management both on ground and in the air, hold the key to resolving potentially conflicting goals. These measures alone, however, are inadequate to meet the environmental challenge. Developing a proper and viable institutional framework to insure universal acceptance and implementation of aviation standards and recommended practices is also necessary. The regulation of noise is an instructive case in point.

Figure 3

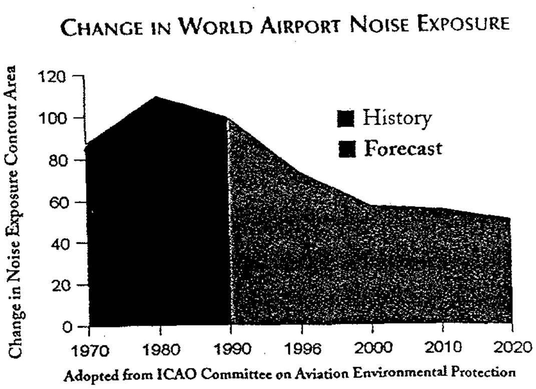


Figure 3 illustrates changes in the accepted aircraft noise contour area at airports. The contour area serves as an effective noise boundary for airport communities. A percentage increase indicates that the surface noise area is expanding, a decrease means the contour is shrinking. The shape of the noise exposure line demonstrates the potential gains from, and limitations of technology improvements.

The Federal Aviation Administration (FAA) implemented the first national noise limits for certifying commercial aircraft in the late 1960's. These *Stage 2* requirements paralleled advancements in aircraft aerodynamics and engine technology. By the late 1970s more stringent requirements were possible and applied to new airplane designs. These U.S. *Stage 3* requirements were the product of further technology development and use of noise mitigating operational procedures.

Figure 3 shows a rapid expansion in the noise contour area from 1970 to 1980, due largely to growth in civil aviation and the large number of what is now old technology *Stage 2* aircraft then in use. From 1980 to the present, the noise contour area has decreased as newer technology *Stage 3* aircraft, both new and retrofitted, have entered the fleet. These substantial benefits have been achieved while airlines have been expanding their fleets to meet the growing demand for air travel. This bodes well for the future.

The deadline for all U.S. commercial operators to meet *Stage 3* standards is the year 2000. Countries belonging to the European Union and Australia must meet similar requirements by 2002. Figure 3 forecasts the complete phase-out of *Stage 2* aircraft will dramatically reduce noise exposure to airport communities.

Contrary to the common wisdom, the combination of "technology push" and "fleet pull" produces continuing, yet diminishing, reduction of the noise contour area. The *Stage 3 requirements now in effect, combined with the phase-out of Stage 2 aircraft and noise* abating operating procedures, provide substantial noise reduction around airports. A similar pattern emerges when engine emissions are considered.

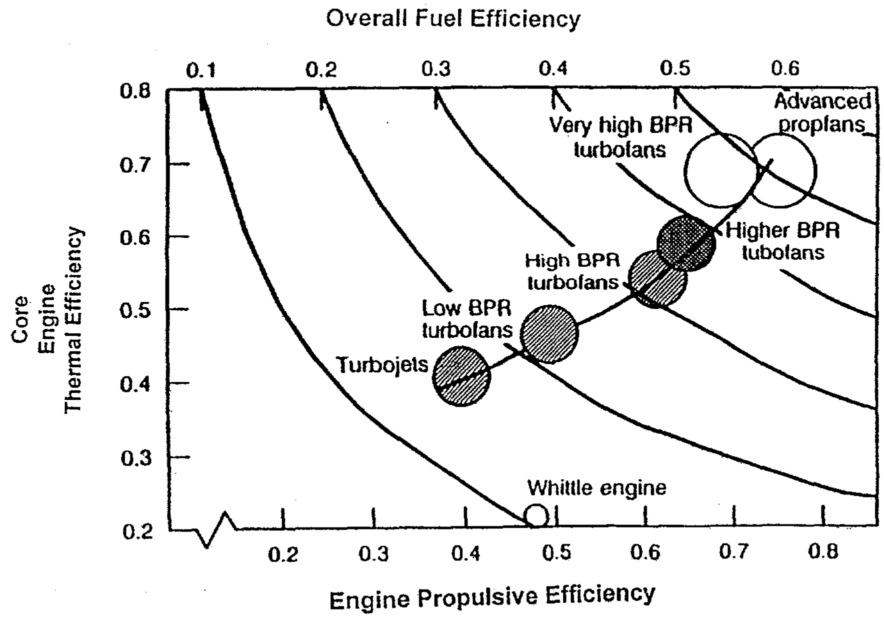
Aerospace Continues to Pace Change

Reduced fuel consumption and greater engine efficiency shown in Figure 4 have led to substantially lower emission levels. The Figure illustrates how fuel saving and efficiency gains have been achieved both within a given level of engine technology and between differing engine technology levels.

Emissions of greatest interest to policy makers are carbon dioxide (CO_2), water vapor and oxides of nitrogen (NO_X). Emissions are created by different fuels at differing rates and in varying amounts. There are no practical alternatives to kerosene as an aviation fuel.

Aircraft Turbine Engines--Fuel Efficiency Trends

Figure 4



Engine emissions are the natural by-product of combustion. Water vapor and carbon dioxide are produced at specific unvarying rates, while production of other emitants may occur at differing rates. Manufacturers have concentrated on improving the engine, airframe and operational capabilities of the aircraft to reduce aircraft fuel burn, and hence all aviation emissions.

The rate of production of oxides of nitrogen emissions are dependent upon the pressure, temperature and length of time at which combustion occurs. Although the only way to decrease the emission of CO_2 and water vapor is to reduce fuel burn, improvements to fuel efficiency also lead to reductions in all emissions including NO_x. In addition to gains from better fuel efficiency, NO_x emissions have been reduced through improved combustion technology.

Figure 4 shows that overall fuel efficiency has increased substantially as engine efficiency has been improved through introduction of new technologies and development of existing technology. Roughly half of these gains are attributable to the airframe, with engine technology accounting for the other half. Improved operational measures have also contributed significantly to overall fuel efficiency.

Emission standards are focused to engine technology. Specific to aircraft design, fuel burn may be improved by reducing aerodynamic drag, airframe and engine weight, and reducing the specific fuel consumption of the engine. Specific fuel consumption (SFC) measures the amount of fuel consumed per pound to thrust, and is the a common measure for comparing the fuel efficiency of all engines used in aviation regardless of thrust rating. The diminishing specific fuel consumption trend shown in Figure 4 has been achieved through advancements in engine efficiency. The Figure demonstrates these gains have been made both within an engine type and through fundamental changes in engine design. This is consistent with Figure 1.

Attainment of higher pressure and temperature ratios, achieved through improved cooling and combustor design, produce greater thermal efficiencies. This has allowed attainment of higher thrusts required by larger aircraft and has reduced engine fuel consumption per pound of thrust. NO_x reduction attained through increased thermal efficiency, however, can be accompanied by comparatively slight increases in CO_2 if a fuel penalty is incurred. Figure 4 anticipates that continued improvement in thermal efficiency holds promise for further SFC reduction in the long run. Further advances today, however, are limited by current available technology.

Greater propulsive efficiency has been achieved through increased movement of air. Moving a large mass of air slowly is more efficient than moving a small mass of air quickly. This is represented in Figure 4 by the evolution from the turbojet, through the low by-pass engine, to the development of the high by-pass ratio engine family. There is, however, a limit to the size of the by-pass ratio which can be practically used. Greater engine diameter leads to increased weight and drag. For this reason, Figure 4 anticipates diminishing returns by this means in the future.

Although every aircraft engine must meet many regulatory and non-regulatory requirements, aviation noise and emissions technologies are highly independent of one another. Yet, as pointed out in the International Coordinating Council of Aerospace Industries Associations *Aircraft Noise Design Effects Study*, "[A] general rule of thumb is that a 3 decibel noise reduction at Flyover, (where the noise rewards are greatest) would, on average, increase fuel burn and hence emissions by the mid-range value of some 5%."

Aircraft manufacturers and airlines have provided, and will continue to provide, aircraft fleets that use all available noise and emissions reduction technology. Although research continues, no breakthroughs in either noise or emissions technology are in sight. Yet, other, non-regulatory means are available to achieve these ends.

Aerospace Has an Established Institutional Structure

The focus of industry's environmental activity is the International Civil Aviation Organization (ICAO) and its Committee on Aviation Environmental Protection. This body is responsible for establishing world air transport environmental standards and recommended practices. Current international noise and emissions standards offer substantial protections and must be fully accepted and implemented on a worldwide basis.

The Committee on Aviation Environmental Protection (CAEP) serves as a forum for ICAO member states to address aviation environmental matters and to cooperate with national and other world bodies on these issues. Significant environmental standards have been established through the CAEP process, including *Stage 3* requirements and phase-out of *Stage 2* aircraft, and present emissions standards. Figure 2 illustrates that ICAO standards have paced industry efforts to reduce nitrogen oxide emissions.

ICAO's Committee on Aviation Environmental Protection last met in December 1995 (CAEP/3) to determine if further actions to reduce airplane noise and engine emissions were warranted. A cost-benefit analysis prepared by CAEP, in concluding that stringency increases would provide negligible benefit to society at great cost to industry, supported maintaining both standards at their present levels. By maintaining ICAO noise and emissions standards at their present level, attention is now focused the need for CAEP to work toward their uniform, worldwide adoption.

Regulation of noise and emissions through application of aircraft and engine technology has led to over reliance on this means to the exclusion of other available measures to achieve the same ends. Breaking this mold, CAEP has now directed its efforts to consistent land-use planning, more efficient operational measures and preservation of the asset value of the fleet to complement present ICAO standards and practices.

Effective land-use planning measures would preserve the noise contour area reductions anticipated through the achievement of all-*Stage 3* fleets. ICAO projections indicate that noise levels for communities near airports will be reduced substantially by the year 2002. At best, current technology can contribute only marginal further reductions at unwarranted expense. The most effective method for further reducing noise levels in communities around airports is to completely and consistently implement current ICAO requirements and to preserve the gains already made and those anticipated in the future.

Employing advanced operational measures to reduce fuel consumption, particularly universal use of the global positioning system (GPS) and modernization of European Air Traffic Control (ATC), will reduce greenhouse gas emissions in excess of what greater oxides of nitrogen stringency alone could bring. Fuel is a substantial component of the costs airline operators incur in providing air transportation services. Fuel savings translate into an airline's ability to purchase newer fuel efficient aircraft, and to retrofit existing aircraft to reduce emissions.

At the April 1996 Symposium on the Global Effects of Aviation, industry presented an estimate of the potential environmental gains adoption of GPS and ATC modernization in Europe would bring. The range of annual NO_X reduction was between 2.6 to 18 times greater than the practical regulatory solutions considered at CAEP. In addition, 31 million metric tons of CO_2 per year would not be emitted into the atmosphere if these measures were adopted. The CAEP proposals did not consider any reduction in carbon dioxide. If other operational measures were considered, these order of magnitude estimates would be meaningfully larger.

The International Air Transport Association estimates the international airline industry earned $5.2 billion in 1995. Cost saving from the fuel reduction arising from GPS and a modern ATC system in Europe at least matches this amount. These monies could be used for fleet modernization which would bring further fuel savings and, perhaps, further improve noise contours.

Concentrated effort must now be forthcoming to achieve these important objectives. ICAO's full potential cannot be realized, however, without uniform adoption of its standards. Enactment of differing national standards is at cross purposes with the development of a truly international transportation network. Yet, today, consensus on this long-established ICAO principle seems to be in question.

The United Kingdom is attempting to reduce the noise limit for London airports below the internationally agreed upon ICAO standard. Such actions run counter to global standardization necessary for efficient air transportation. The Orient Airlines Association commented, "[A]irlines have planned their fleet development and invested millions of dollars [to achieve all-*Stage 3* fleets]. Further domestic regulations which impose lower limits than ICAO [standards] are simply arbitrary and unjust. "

Similarly, the Swiss are nearing completion of a rule which employs ICAO-based emissions certification standards to penalize users of selected compliant aircraft. This proposal, which undercuts the ICAO principle of global cooperation, is being looked to for possible use as a European standard to increase emissions stringency. Proliferation of uncoordinated national and regional noise and emissions initiatives has a chilling effect on the entire civil aviation system as a whole.

ICAO has played a leadership role in regulating aircraft emissions since 1977. ICAO, with 185 members, is considered one of the United Nation's largest and most successful specialized agencies. ICAO has the sole responsibility for meeting aviation safety, performance, and noise and emissions requirements. Further, it must establish a consistent body of international aircraft standards to meet these varying objectives. To its credit, It has established international standards and practices for aircraft operations, safety of flight and the environment for more than fifty years.

The aerospace industry is committed to the CAEP process, and encourages all interested parties to take advantage of the ICAO framework to achieve uniform, worldwide implementation of these standards. Industry believes it would be a costly mistake not to take every opportunity to address environmental matters through ICAO. Avoidance or circumvention of this established body only delays achievement of truly effective and meaningful environmental protection.

CONSIDERATIONS IN FORECASTING THE DEMAND FOR CARBON SEQUESTRATION AND BIOTIC STORAGE TECHNOLOGIES

Dr. Mark C. Trexler
President, Trexler and Associates, Inc.[1]

Introduction

Current international policy, as expressed by the United Nations Framework Convention on Climate Change (FCCC), is to stabilize anthropogenic CO_2 emissions at levels that do not threaten global ecosystems. The Convention calls on Parties to reduce sources and enhance "sinks" of greenhouse gases (GHGs). The Intergovernmental Panel on Climate Change (IPCC), the Convention's scientific advisory body, has specifically identified forestry and other land-use based mitigation measures as possible sources and sinks of greenhouse gases. Such measures can slow carbon emissions to the atmosphere by reducing rates of deforestation and forest degradation while increasing the incremental uptake of carbon by terrestrial biota through means such as reforestation, regeneration, and agroforestry.

Carbon losses from deforestation and other land use changes continue in both temperate and tropical zones. Tropical deforestation accounted for an estimated 20 percent of all anthropogenic CO_2 emissions to the atmosphere in 1990. In many tropical countries, forest loss continues to be the dominant source of CO_2 emissions from human activities. Vast stretches of forest, currently storehouses for hundreds of billions of tons of carbon, remain threatened by deforestation or degradation. Hundreds of millions of additional hectares of once-forested land could in principle be reforested in both temperate and tropical zones. Even more land could support additional biomass if degraded vegetation were brought back to health or if supplemental tree cover were integrated into current land uses.

Several experts have suggested that major reductions in tropical deforestation and large-scale reforestation in the tropics could significantly slow CO_2 accumulation in the atmosphere. In *Minding the Carbon Store,*[2] Trexler estimated that forestry and related land-use measures could reduce net U.S. emissions by 10 to 15 percent. Some early studies even suggested that large-scale reforestation could remove more than five billion tons of carbon from the atmosphere every year, thus offsetting current energy-related emissions. As prominent environmentalist Norman Myers stated, "one of the

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[1] Trexler and Associates, Inc. is an energy and natural resources consulting firm specializing in the provision of climate change mitigation services to private- and public-sector clients. TAA can be reached at: 1131 S.E. River Forest Road, Portland, OR 97267; phone: 503-786-0559; fax: 503-786-9859; e-mail: taa@teleport.com; Internet site: www.teleport.com/~taa/.

[2] Trexler, M.C. *Minding the Carbon Store: Weighing U.S. Forestry Strategies to Slow Global Warming*. World Resources Institute, Washington, D.C. (1991).

most cost-effective and technically feasible ways to counter the greenhouse effect lies with grand-scale reforestation in the tropics as a means to sequester carbon dioxide from the global atmosphere -- provided, of course, that the strategy is accompanied by greatly increased efforts to slow deforestation."[3] At the international level, the Noordwijk Declaration of December 1989, signed by 68 environmental ministers from around the world, proposed increasing global forest cover by 12 million hectares per year (starting in 2000) to help slow climate change.[4]

In recent years, forestry proponents have moderated the dramatic claims appearing in the early literature as the implementation realities of large-scale forestry initiatives and the difficulty of accomplishing even small-scale initiatives have sunk in. Growing world populations are straining many forestry and land resources, and increasing pressures will be difficult to reverse. Yet forest losses and other forms of land degradation impose tremendous economic, social, and environmental costs on the people and resource bases of many tropical countries. Slowing forest loss and land-use degradation, and reforesting cleared land where practical, can often advance sustainable development, energy production, and environmental goals. At the same time, carbon is preserved in or added to terrestrial carbon stores, thus mitigating climate change. Billions of carbon offset and joint implementation dollars could in principle become available in the foreseeable future for forest protection, forest management, reforestation, and biomass energy programs that would advance both sustainable development and climate change mitigation objectives.

The net effect is that there are several reasons to pursue forestry and other biotic measures for climate change mitigation purposes:

- biotic carbon offsets can effectively advance other policy objectives at little or no additional cost, including biodiversity conservation, rural economic development, and watershed management;
- land-use based mitigation measures can be among the most societally cost-effective climate change mitigation options;
- the potential of land-use and other biotic mitigation measures to avoid future carbon emissions or to incrementally sequester carbon in new biomass is very large, easily exceeding a billion tons per year.

There is therefore little doubt that land-use based mitigation measures in both tropical and temperate zones could play an important role in future climate change mitigation efforts. Yet forestry should in no way be portrayed as "the" answer or even the primary answer to potential climate change. It can -- and should -- be an integral component, however, of a societal climate change mitigation

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[3] Myers, N. In *Global Warming: The Greenpeace Report*. Leggett, J., ed., Oxford University Press (1990).

[4] Ministerial Conference on Atmospheric Pollution and Climatic Change. *The Noordwijk Declaration on Atmospheric Pollution and Climatic Change* (1990).

portfolio. With significant effort, forest conservation and reforestation efforts could keep tens of billions of tons of carbon out of the atmosphere over the next several decades. Biomass energy programs, particularly based on biomass energy crops, could significantly expand this contribution.

Implications of a Competitive Mitigation Marketplace

Biotic mitigation options are just one part of a much larger set of mitigation options that will be available to governments and industries under a future GHG emissions reduction regime. As a mitigation technology, carbon sequestration in its various forms will need to compete with these other technologies for funding in a competitive marketplace. It will no longer be enough to know that forestry-based options exist, or that their technical potential is large; it will be a matter of determining how effectively these biotic options can respond to the needs of mitigation services purchasers, how well they can adapt to the eventual market for GHG emissions reductions, and whether they can cost-effectively compete with other mitigation technologies.

This makes it important to think about the specific characteristics of sequestration and biotic storage technologies as they relate to the future market for mitigation services. These characteristics include the cost, timing, persistence, risk, quantifiability, leakage potential, and sometimes additionality of the mitigation services provided by the forestry and other biotic sectors. This paper represents an initial attempt to look at biotic options in the context of future mitigation markets. It draws tentative conclusions regarding the future demand for sequestration technologies.

Carbon Sequestration as a Mitigation Technology

Although no widely accepted definition of a climate change mitigation technology yet exists for purposes of future mitigation markets, many observers have proposed criteria for defining what can make a mitigation measure successful for climate change mitigation. The carbon offset, JI/AIJ, and the developing GHG trading literatures all provide examples of suggested criteria. Given the diversity of the interest groups participating in the debates and their very different perspectives, not all criteria currently being discussed are necessarily internally consistent, nor will all of them guide development of future markets. Criteria commonly raised in today's discussions of climate change mitigation efforts include:

Cost: Project costs are generally expressed as the cost of a measure in \$/ton of CO_2, but costs can reflect the full cost of pursuing a measure or some increment of funding required to make the measure viable. The costs of mitigation measures are often highly sensitive to how the time value of carbon is treated, *e.g.* through annualization of costs and benefits or the possible discounting of future CO_2 benefits.

Timing: Timing depends on when the CO_2 benefits associated with the technology occur. Although CO_2 benefits for biotic projects can occur in the near term (*e.g.*, through fast-growing biomass or protection of existing forest), they often occur many years in the future (*e.g.*, through the planting of long-rotation tree species). The same can be said of many other mitigation measures, although their CO_2 benefits are often more evenly distributed over time.

Persistence: Persistence is a function of the permanence of the CO_2 benefits associated with the technology once they occur. Although a residential lawn can be (and has been) characterized as a CO_2 sequestration mechanism, its benefits are transient at best. Other biotic mitigation measures may persist for decades, and sometimes even permanently. The persistence of the CO_2 benefit may also depend on the disposition of biomass in economic markets, *e.g.*, through conversion of living trees to long-term wood products.

Leakage: Leakage is a function of the boundaries drawn around a particular mitigation measure and the market or biological feedbacks that may counteract or dissipate the measure's calculated benefit. The more closely linked a mitigation measure is to a functioning market, the higher the potential for market leakage. This conclusion applies to the full range of energy and biotic mitigation measures. A climate change effort to grow short-rotation tree species for the pulp market, for example, may have little net effect if the demand for pulp is not affected and other providers compensate by reducing their growing of similar trees. Leakage, however, can occur over short-, medium-, or long-term periods. In some cases, near-term leakage may be reversed over time. This could occur with a forest protection project that may simply displace localized pressures on the forest (arguably creating leakage), but which ultimately results in protection of forest parcels where ultimately no forest might have remained.

Risk: Risk is a function of physical, economic, and political variables that can interfere with the anticipated CO_2 benefits of mitigation measures.

Quantifiability: The quantifiability of a project is a function of the accuracy with which the CO_2 benefits of a mitigation measure can be projected, as well as the ease and accuracy with which CO_2 benefits can be monitored and verified as they accrue.

Additionality: Additionality is a function of the ease and reliability with which a "but for" project baseline can be established. Although not a significant issue within a closed-loop trading system, it can be important for mitigation programs that precede closed-loop trading or for opting in to such trading systems.

Ancillary benefit: This will be a function of the environmental, economic, and social benefits other than climate change mitigation associated with implementation of a climate change mitigation measure.

In considering these potential parameters of the benefits of a particular climate change mitigation measure, what immediately becomes evident is that there is no such thing as a single carbon sequestration or carbon storage technology. There are numerous distinguishable approaches to climate change mitigation through biotic means and each can be characterized differently, using these and possibly other criteria. This implies that it is inappropriate to group all biotic mitigation technologies under the same tent for purposes of embracing or dismissing their climate change mitigation potential. Each biotic technology may ultimately have to compete independently in the climate change mitigation marketplace.

An Overview of Sequestration and Biotic Storage Technologies

A variety of land-use and other kinds of biotic measures have been proposed for climate change mitigation purposes. In the following discussion, several of the more commonly discussed measures are briefly assessed in light of the criteria introduced in the previous section.

Reforestation and afforestation: Forestry and other experts have proposed many reforestation options for climate change mitigation. These options include pasture, cropland, degraded or arid land reforestation, reforestation of recently harvested stands, planting along highway rights-of-way and riparian corridors, and planting in windbreaks and other agroforestry applications. Large amounts of land are potentially available for reforestation in temperate and tropical zones. Reforestation is the sequestration technology most commonly discussed in the biotic climate change mitigation context. The U.S. Climate Change Action Plan proposed, for example, to support the planting by the U.S. Department of Agriculture (USDA) of over 800,000 acres of trees on non-industrial private forest lands by the year 2000.

Reforestation approaches can vary widely in their performance under the criteria introduced above. Sequestration benefits of reforestation can be relatively easy to measure and verify, and the credibility of reforestation has been well-documented. The persistence of the CO_2 benefit can vary widely for different kinds of reforestation, as can the timing of the benefits. Reforestation programs can also further multiple environmental goals, *e.g.,* reduced soil erosion, watershed conservation, regional economic development, and habitat development. On the other hand, some categories of reforestation, including replanting of recently harvested stands, can raise significant questions of net CO_2 benefit.

Forest protection: Because of the magnitude of the ongoing threat of deforestation, there is little doubt that slowing tropical forest loss offers a tremendous opportunity to reduce anthropogenic GHG emissions. Because protection of threatened forests can serve many environmental, economic, and social interests, forest protection may offer one of the most societally cost-effective mitigation technologies. Yet forest protection has received considerable negative publicity from some interest groups and developing countries. These groups argue that it is hard to establish a "but for" case for such projects, that leakage is a major problem, and that the projects are very risky. Some of the concerns commonly raised in the context of forest protection projects are probably best dealt with at a policy rather than at a project level, and can be successfully addressed. In addition, attention to project selection and design can help overcome these challenges.

Biomass energy: Biomass energy is more appropriately considered as an energy supply mitigation technology, but there are sequestration elements involved. A 50 MW closed-loop biomass project being proposed in Honduras, for example, will involve planting 25,000 acres of bamboo. Although project proponents will harvest the bamboo at regular intervals, a significant increase will occur in the average carbon storage on the planted lands. This element of a closed-loop biomass energy project in effect becomes a reforestation project.

Urban forestry: Expansion and better management of urban forests is commonly discussed as one way to combat climate change. Trees can directly shade houses and small buildings from the sun, reducing the cooling load. A tree located in the right urban area can be up to 15 times as effective at "reducing" atmospheric CO_2 as a rural tree. Most of the benefit of this approach, however, is better characterized as a demand-side management technology rather than a sequestration technology. The sequestration element of this approach in effect becomes another kind of reforestation project, but one with very different characteristics than rural reforestation projects.

Forest management: The U.S. Office of Technology Assessment estimated several years ago that 30-40 percent of U.S. timberlands could be brought under more intensive management, increasing carbon sequestration by tens of millions of tons per year. Management measures discussed both domestically and internationally include increasing productivity of poorly stocked timberlands, thinning overstocked stands where growth is being impeded, harvesting and regenerating over-mature timber, delaying harvest of other stands, using conservation easements to modify management and harvesting practices, and managing more actively to protect against fire, insects, and disease.

As climate change mitigation technologies, forest management approaches can pose a number of difficulties. First, carbon sequestration is often just one of several objectives being pursued, and often not the most important one to project developers. At the same time, carbon sequestration and economic management objectives do not always overlap. Forest management techniques, for example, are often used to replace non-commercial species with commercial species on an "under-productive" stand. While economically worthwhile, there may be no associated carbon benefit. Second, the CO_2 benefits associated with forest management projects can be very difficult to monitor and verify. For some management initiatives, careful project design combined with active monitoring and verifying should be able to overcome this challenge.

Reduced impact logging: Reduced impact logging (RIL) is a specific form of forest management that may yield significant CO_2 benefits. It is estimated that damage to the forest during harvesting can be reduced by as much as 50 percent in some regions of the world by taking basic steps such as removing vines before cutting, directional tree felling, and better planned extraction of timber on properly constructed and utilized skid trails. These measures can reduce CO_2 emissions associated with forest damage, although calculating and monitoring these reductions can be quite difficult. On the other hand, RIL can have significant ancillary benefits in promoting sustainable forestry practices and preserving biodiversity, reducing soil erosion, and protecting water quality.

Soil carbon enhancement: Soil loss and degradation is a particularly serious global environmental problems. Once lost, soil recovery is slow. It takes 200-1,000 years to restore one inch of top soil. Today, no-till or low-till cropping systems are gaining increasing favor as a way to reduce soil erosion, increase the organic content of soils, and reduce fertilizer and other inputs. Conservation tillage is an interesting biotic mitigation option because it could be pursued over such large areas and result in other economic and environmental benefits. At the same time, it is difficult to monitor and verify carbon accumulation in the soil, and the prospect of an economically motivated return to conventional tillage practices would reverse much of the benefit in a relatively short period.

Other sequestration and storage technologies: Other biotic options that have been brought up in the climate change mitigation context include prairie restoration, agroforestry, protection and restoration of coral reefs, and anti-desertification projects, among others. Some of these measures have not yet been thoroughly investigated.

Comparing Carbon Sequestration vs. Other Mitigation Technologies

What quickly becomes clear in the above review is the variety of biotic mitigation technologies and the diversity of their ability to compete in the developing mitigation marketplace. Without undertaking a comprehensive performance ranking of biotic mitigation measures based on the above criteria, and without systematically comparing biotic mitigation measures to other mitigation measures, one can safely conclude that carbon sequestration and biotic storage mitigation technologies have advantages and disadvantages for climate change mitigation:

- Many biotic technologies can be deployed and the overall CO_2 sequestration and storage potential is very large.

- Biotic technologies can result in significant ancillary benefits associated with soil conservation, watershed management, biodiversity conservation, and sustainable rural development.

- While biotic technologies are often perceived as relatively low-cost, this cost-effectiveness varies widely among the different technologies and can be sensitive to the treatment of carbon flows over time.

- Like many other mitigation technologies, biotic technologies vary widely in their quantifiability. Some are highly quantifiable, other remain in the realm of applied research.

- The CO_2 benefits of biotic technologies are often less persistent than the benefits of other technologies that result in emissions reductions. For some technologies, the CO_2 benefit is long-term if not permanent; for others, it is transient at best. A disadvantage of many biotic mitigation technologies is that CO_2 benefits in any given year cannot be seen as independent from CO_2 benefits in other years. Loss of a biotic mitigation project in any given year could potentially invalidate previous years' benefits, although development of a ton-years measurement scale might successfully address this problem.

- Biotic mitigation technologies are subject to many of the same risks as other mitigation options. Some biological risks are unique to biotic mitigation measures, although certain financial risks may be much less prevalent in biotic mitigation projects.

- Biotic technologies are subject to many of the same leakage concerns as other mitigation measures, although the perception of leakage as a problem is much higher for biotic technologies due partially to the political context surrounding the climate change mitigation debate.

Arriving at these general conclusions is not particularly difficult. What will be much more difficult is to carefully differentiate and assess individual biotic technologies according to these and potentially other criteria. To take advantage of the benefits that biotic technologies have to offer, it will often be necessary to identify the extent to which technical challenges asserted to be associated with these technologies can be overcome. Ongoing political and policy processes associated with design of a future climate change mitigation regime are focusing on these challenges; they include the timing, persistence, susceptibility to risk, and quantifiability of the mitigation services offered by many biotic technologies. In many cases, it should be possible to overcome these challenges, but a great deal of policy and technical analysis will be required to do so effectively. A policy project currently underway, the Land Use and Biotic Mitigation Policy Project, has this objective.

Forecasting the Supply and Demand for Sequestration Technologies

The future market demand for mitigation technologies will depend on many variables associated with an eventual mitigation regime. Variables that will affect the demand for mitigation measures and the likely competitiveness of different mitigation measures within the larger grouping of mitigation technologies will include:

- severity of the emissions reduction mandates;
- national and international mechanisms used to achieve the required reductions, potentially including GHG trading, new source offset requirements, and taxes;
- scope of the emissions reduction mandate (*e.g.*, across the board, limited to specific sectors, or limited to specific gases), and the flexibility available to emitters to comply with the mandate (*e.g.*, on-system reductions, offsets limited by greenhouse gas or geography, or greenhouse gas trading).

The form in which these variables are combined into an eventual mitigation regime will significantly influence the general market for mitigation measures and the relative strength of markets for specific mitigation technologies. Several potential approaches that are still on the table as international negotiations progress are briefly introduced below. These approaches may end up being mixed and matched in many ways to form a regulatory system in which a variety of domestic approaches can be integrated into a system of internationally binding emissions targets and timetables. From the standpoint of biotic mitigation technologies, the choice of vehicle may prove particularly relevant.

Domestic compliance with international targets, based strictly on fossil fuel emissions: To the extent that any national target is specifically based on fossil-fuel based emissions, it will obviously be difficult for biotic mitigation technologies to compete.

Domestic compliance with international targets, using a basket or net approach: To the extent that national compliance with an international target is based on the use of a basket of gases, or to the extent that the target can be met based on national emissions net of sources and sinks, opportunities for biotic mitigation technologies are far greater. These technologies would still have to compete for mitigation dollars domestically; their ability to do so would depend on a number of variables related to the criteria previously discussed.

Governmental-level trading of CO_2: CO_2 trading has been receiving a great deal of attention recently. One option is to have governments that exceed their national target able to market "excess" CO_2 to other countries on a simple transactional level. If this trading is based on the domestic targets themselves, it may or may not allow extensive participation of biotic mitigation technologies. CO_2 trading between governments on the basis of fossil fuel emissions targets, for example, would probably not provide for deployment of biotic technologies.

A GHG-trading system with private-sector participation: A CO_2 trading system based on industry-to-industry trades, albeit with government approval of international transactions, may pose particular challenges for biotic mitigation technologies. Financial instruments commonly associated with other trading systems (*e.g.*, options, puts, calls) may begin to develop for a CO_2 trading system. It will be challenging to conform the services provided by many biotic mitigation technologies to these kinds of instruments. Several mechanisms may be available to help overcome this challenge, including the use of different credit valuation measures such as ton-years rather than tons.

Joint implementation: Joint implementation (used synonymously here with activities implemented jointly) in the form that it has been applied up to this point is quite consistent with utilization of biotic mitigation technologies. Even here, however, formalization of mitigation criteria will require that biotic technologies show themselves able to meet those criteria in order to compete in the marketplace.

Conclusions

It is not yet possible to conclusively answer the question of what the market demand for biotic mitigation technologies will be and how successfully different biotic mitigation measures will be able to respond to that demand. Several policy and practical conclusions, however, can be reached:

- Biotic mitigation technologies are a legitimate and potentially important part of a societal mitigation portfolio as a result of their relatively low costs, ancillary benefits, and climate change mitigation benefits. The very fact that a billion tons or more of carbon are released to the atmosphere each year through forest loss should make the importance of forestry-based mitigation clear.

- The mitigation services provided by many biotic mitigation technologies do not perfectly match the common idealized definition of a mitigation measure. Issues of CO_2 benefit persistence, risk, timing, and quantifiability will have to be addressed in order for many biotic mitigation technologies to effectively compete in the future mitigation marketplace. At the same time, biotic mitigation measures can have significant advantages with respect to ancillary benefits, cost-effectiveness, and the ease with which any required additionality showing can be made.

- The policy playing field is becoming increasingly biased against biotic technologies, regardless of the merits and the relative quality of the mitigation services they can offer. Biotic options have not had the representation in the policy process that other options have.

Often, critics focus on the perceived shortcomings of biotic mitigation options, while ignoring the fact that many energy mitigation options suffer from similar shortcomings.

- Biotic mitigation technologies have become embroiled in political debates over North-South financial assistance, technology transfer, and joint implementation. Due to the technical challenges associated with many biotic mitigation technologies, they have been an easy target for critics seeking to achieve agendas in which biotic measures have little role to play.

Extensive policy and technical work will be required in order to preserve the role of biotic mitigation technologies as regulatory policy develops. Between the technical challenges popularly associated with such technologies and the relative absence of the forestry and other communities at the policy negotiating table, biotic technologies face major hurdles. The ability of proponents of biotic technologies to convincingly show that these technologies can yield valuable climate change mitigation benefits may ultimately prove as important to the future of these technologies as policy and regulatory developments at the national and international levels.

REDUCTION OF RUMINANT METHANE EMISSIONS --
A "Win-Win-Win" Opportunity for Business, Development, and the Environment

Global Livestock Producers Program
Appropriate Technology International
1828 L Street, NW, Suite 1000, Washington, D.C. 20036

Introduction

Since 1978, Appropriate Technology International (ATI) has gained experience in over 350 projects and activities in more than 40 countries promoting economic development. Emphasizing commercialization of appropriate technologies through small scale enterprise development, ATI has aided small-producers at all levels of the value chain, from production to consumption by working in a targeted number of economic subsectors. ATI carries out its responsibilities from a home office in Washington, D.C. and has ten field offices located throughout the world.

The Global Livestock Producers Program (GLPP) within ATI is a leader in establishing self-sustaining enterprises which supply cost-effective technologies (i.e., animal nutrition and genetic improvement) and reduce global methane emissions, in a number of developing world nations. This approach helps ensure the sustainability of livestock production and farming systems, and generates additional income for the small-scale farmers. The GLPP has a highly qualified technical staff to initiate projects with, but not limited, to cattle, sheep, goats, swine, and poultry. The GLPP has lent its expertise in livestock feeding and ruminant methane mitigation to various projects sponsored by the U.S. Environmental Protection Agency (US EPA), ICF Incorporated, the US Country Studies Program, and private companies. In addition, the GLPP was involved as accredited observers with the US delegation to the Rio Earth Summit, the Berlin Conference of the Parties, and other international climate change conferences.

With the assistance of the US EPA, the GLPP expanded its portfolio to include researching ruminant methane emissions with its traditional development work. The US EPA funded several prefeasibility studies to examine the possibilities of reducing ruminant methane emissions in India, Tanzania, Bangladesh, and Brazil. The results from the studies show a couple of points. First, many developing countries production systems are inefficient. Second, great potential exists for decreasing global methane emissions through increasing animal productivity. From this effort, the GLPP has established livestock development projects in India, Zimbabwe, and Tanzania. Several additional projects are in the process of being developed for Bangladesh, Nepal, and Brazil. Through diligent research and application, the GLPP has developed a proven methodology for assessing ruminant methane and incorporating methane emissions monitoring into viable projects. In addition to ruminant methane, strategic nutritional feeding and other improved management practices are the focal points of GLPP projects.

Ruminant Methane

Domesticated ruminant animals, such as cattle, buffalo, and goats, are the second largest source of anthropogenic methane, accounting for 20-25 percent of annual global methane production. The Food and Agriculture Organization (FAO) statistics indicate that the developing countries of the world contain more than half the world's cattle, yet account for less than 15 percent of the global meat/milk production. In these less developed countries, approximately 30 percent of global methane emissions come from large ruminants when it is exhaled as the animals remasticate their feed. The level of methane production from the rumen is inversely based on the quantity (energy value) and quality (digestibility) of the feed an animal consumes. As the amount of feed consumed increases, the energy available to be converted into methane also increases. If the feed is poor quality, rumen fermentation is inefficient and more methane is emitted. However, as the digestibility of the feed increases, the percentage of the energy converted to methane decreases.

In many developing countries, animal diets consist mainly of low quality forages, such as rice, straw, or sugarcane tops and lack the daily nutrients for efficient digestion. These poor diets produce substantially higher methane yields per unit of production, when compared to ruminants fed adequate diets. The US EPA estimates that various options -- such as changes in feed characteristics through supplementation -- can reduce developing country livestock methane emissions by 25 to 75 percent per unit of product, and thereby cut global methane emissions from ruminant livestock by up to 12 percent.

Measuring Methane Emissions

Methane emissions from ruminant livestock can be reduced by improving the efficiency and productivity of the animals, i.e., by reducing emissions per unit of product. This is particularly relevant for developing countries where demand for livestock products and livestock population is increasing. Meeting the expanded demand will require an increased number of animals and/or a more productive national herd. Expansion of the herd is considered the less desirable option, as an increased number of animals would strain already limited feed and fodder availability, resulting in greatly increased production of ruminant methane.

The logical solution to meeting an increased demand is to increase the per animal productivity of the existing herd, thus enabling the livestock producers to maintain smaller herds. This is the approach employed by the GLPP and the US EPA, under rationale that if the constraints to enhancing per animal productivity can be diminished, then a larger percentage of the animal product demand can be met by higher producing animals. The approach for measuring the amount of methane emitted in proportion to levels of animal production accepted by the various international bodies, and actively applied by the US EPA is to calculate the methane emissions per unit of product.

The technique for measuring per unit of product, SF_6 tracer technique, was developed by scientists at Washington State University (WSU) with a grant from the US EPA. The technology can detect methane emissions from livestock using a scientific measuring method in terms of methane per unit of product. The first methane monitoring laboratory outside the United States was established by ATI in India. Currently, there are several universities and research facilities perfecting the technique throughout the United States.

Strategies for Improving Livestock Productivity

There are many strategies for reducing methane from ruminant livestock. Although the options may be country specific, the common factor among them is increasing animal productivity. Ruminant animals in poor production systems (limited feed resources and lack of improved management practices) produce higher amounts of methane, especially relative to the amount of milk/meat production. By increasing animal productivity, methane emissions per unit of product will decrease. The rate at which the decrease in methane occurs depends on the option implemented. The strategies include the following:

1. Improved nutrition through mechanical and chemical feed processing and/or range management (ammonia treatment/chopping of low digestibility straws).
2. Improved nutrition through strategic supplementation (molasses-urea multi nutrient blocks, bypass protein supplements).
3. Improved animal health (disease control, vaccinations).
4. Improved genetic characteristics (cross breeding).
5. Improved reproduction (artificial insemination, embryo transfer).
6. Improved grassland and rangeland management.

Benefits of Livestock Projects

Livestock projects are unique in their significant environmental and developmental benefits. Research shows that there is potential to provide increases in small-scale producers' incomes, as well as enormous global environmental benefits, by offsetting thousands of tons of methane emissions per year. Specific areas of impact of projects to increase livestock productivity while reducing methane include:

Economic: Five interdependent economic benefits arise from these projects:

1. Improved nutrition of ruminant livestock.
2. Increased animal productivity and draft power on small-scale farms.
3. Greater disposable income for small-scale producers.
4. Increased crop value for producers and processors of livestock feed supplements.
5. Reduced animal product imports which drain a country's foreign exchange resources

Social: These projects bring income-generating opportunities to small-scale producers, allowing them to move beyond subsistence level agriculture. In addition, such projects promote:

1. The development of sustainable institutions through which disadvantaged groups gain greater access to resources, fostering a social fabric that encourages poor people to participate more actively in their communities.
2. Women are often the major caretakers of livestock and represent an often marginalized sector of the community. They will particularly benefit from increased standards of living.

Environmental: Projects contribute both globally and locally to:

1. Improved feed efficiency and consequently a reduction of global methane emissions per unit of product.
2. The reduction in levels of land degradation from overgrazing.

Livestock Methane Mitigation Project Design

The assessment and development of ruminant livestock projects for methane mitigation requires consideration of both traditional livestock development criteria, as well as issues related to greenhouse gas mitigation. Some of these issues include baseline assessment and methane emissions monitoring.

Criteria for Livestock Projects

When addressing whether or not a livestock project will benefit the small scale producers in a developing country, there are several criteria to consider. These criteria are helpful for the successful implementation of ruminant methane mitigation projects in a country. They include:

1. Large numbers of ruminant livestock with inadequate feeding systems (low production efficiency).
2. The significance of the livestock sector in the agricultural and national economy, and the importance of agricultural products to the farmer's income.
3. Unmet/increasing demand for livestock products.
4. Presence of physical infrastructure and market links (domestic and international).
5. Availability of local resources and services - animal feed (by-products and markets) and the environment (domestic and international) must support livestock development and greenhouse gas mitigation.

Measuring the Baseline for Livestock Projects

The baseline data for a project is generated through a survey designed to characterize trends and conditions in the project area prior to project intervention. The results of the survey aid in the identification of project targets and performing cost/benefit analysis. The survey examines:

1. Livestock demographics - population, herd size, makeup of the target herd, i.e., male/female ratio, average age, distribution characteristics, etc.
2. Production indicators - calving interval, milk yields (daily and per lactation), annual grazing and supplementary feeding levels, access to technology and veterinarian services.
3. Socioeconomic data - education, family income, percent income from targeted activity, division of labor (by time and gender).
4. Methane emissions assessments - information on level of methane emissions per animal and per unit of product using accurate methodology.

Monitoring Greenhouse Gas Mitigation

Monitoring methane emissions reduction in livestock projects involve the tracking of the relationship between animal feed and management practices, and milk/meat/draft power production and methane generation. The digestibility of feed and the quantity of animal production are affected directly and indirectly by a wide range of variables. The key elements of a livestock project monitoring system include:

1. Gathering baseline data on "with" and "without" project scenarios.
2. Data collection to review and monitor on a biannual basis the impact per animal unit, production unit, and unit of milk produced

3. Data on the impact on national and regional milk production to estimate the overall impact of the project on methane emissions.
4. Data on the social and economic benefits generated by the project.

Activities related to this data collection include:

1. Short Term Feeding/Production Trials.
2. Baseline Survey and Control Group.
3. Long Term Feeding Trials for Animal Production and Methane Monitoring.
4. Methane Mitigation Projections overtime using an Econometric Model.

Country Case Studies

Using the project design outlined in the above section, the GLPP has several projects which are operating and/or in the process of being developed. They include:

- ***India.*** In Gujarat state, India, the GLPP is administering a dairy feeding initiative which promises to improve the milk yields — and incomes — of hundreds of thousands of dairy producers while showing significant positive environmental impacts. The initiative is promoting the private sector manufacture and distribution of molasses-urea feed supplements which improve the digestive efficiency of ruminant livestock. This improved digestive efficiency is expected to reduce ruminant methane production by up to 20 percent while increasing milk production and butterfat by 20 percent. Ruminant methane emissions can potentially be reduced by approximately 200,000 tons annually. Over 30 million metric tons of carbon equivalent will be reduced over the life of the project. This reduction will be accomplished at a cost of less than US$ 0.20 per ton of carbon.

  Using a strong private sector financial backing, ATI and the GLPP are working with prominent local partners in India — such as India's National Dairy Development Board and the Self-Employed Women's Association — to design and integrate a profitable new supplement component into the country's existing dairy market systems. The GLPP redesigned a molasses-urea processing enterprise and developed an improved product, a molasses-urea block. Preliminary indications of market success are very positive as approximately 100,000 molasses-urea blocks have been sold in nine months with demand continuing to increase. The GLPP team expects that after 10 years, 50 supplement manufacturers will be selling the new product to hundreds of thousands of small-scale dairy producers eager to increase their livestock's milk production and their own profit margin while reducing methane emissions.

- ***Bangladesh and Nepal.*** Building on its experience with molasses feed supplements in Southern Asia, the GLPP is initiating pilot-scale technology demonstration projects in Bangladesh and Nepal with assistance of the US EPA. The projects will demonstrate to small scale livestock producers and agricultural development organizations that production and dissemination of molasses-urea products will result in improved productivity of draft and dairy animals and increased incomes for small-scale farmers, while reducing methane emissions.

  The majority of Bangladesh dairy cattle methane emissions fall in the range of 77 to 340 grams of methane produced per liter of milk. This compares to more efficient production practices in other countries that result in 17 to 20 grams of methane produced per liter of milk. By completion of the project's 30 year monitoring life the estimated total greenhouse gas offset will be over five million tons of carbon equivalent.

The GLPP will modify the molasses-urea product formulation according to the nutrient needs of the cattle and establish a cost-effective processing facility in each country. The projects will begin July 1997. The grant awarded to ATI by the US EPA is "seed money" which will allow ATI to initiate research and demonstration activities. Additional investors are required to turn these demonstration initiatives into successful agribusinesses.

- ***Zimbabwe and Tanzania.*** In Zimbabwe and Tanzania, the GLPP has begun a collaboration with Britain's Natural Resources Institute and the US EPA to analyze the nutritional value and methane-reduction potential of the seed cake byproduct of oilseed processing when used as a feed supplement for ruminants. The initiative will focus its study on seed cake generated by users of the ram press, a manual oilseed press invented and promoted by ATI in East and Southern Africa. Rich in nutrients, seed cake has been shown to improve digestive efficiency in livestock, increasing small producers' milk and meat yields while potentially reducing animal emissions of methane. As part of the program, the GLPP will produce training and extension materials discussing how best to use the seed cake. The GLPP will also assist in the commercialization of seed cake-based rations. This initiative could ultimately raise the incomes of thousands of small-scale oilseed producers and livestock herders throughout East and Southern Africa.

- ***Brazil.*** The GLPP is developing a project to improve the sustainability of small-scale dairy businesses in southern Brazil. Potential areas for intervention include forage production, genetics, milk cooling, and long-term financing. Preliminary indications show great promise for success. A business plan is being developed as potential investors have expressed interest in the project. To increase the productivity of dairy cows and decrease methane yields the GLPP will facilitate the exchange of appropriate technologies and related knowledge which already exist in-country from dairy cooperatives, private dairy companies, non-governmental organizations, research facilities, government agencies, and private agribusiness companies to assist small-scale dairy producers. It is estimated that over 100,000 tons of methane will be offset per year at project completion. Additionally, the total offset is over 15 million tons of carbon equivalent during the 30-year monitoring period. The cost of the project on a per carbon ton basis is less than US$ 0.40.

Path Forward

The addition of a methane analysis and evaluation component onto a livestock project greatly increases the cost of achieving the targets. This fact is coupled with the lack of funding available for livestock projects. Ruminant mitigation projects are highly cost-effective in reducing global methane emissions and appear to be one of the cheapest carbon offset possibilities available today. The estimated total cost of the projects already implemented and proposed on a per carbon ton basis is less than US$ 0.50. This cost is based on a 30 year period (the typical life of a power plant).

ATI views the reduction of greenhouse gases as an important global issue and has worked in a concerned manner to develop methane mitigation projects since the initial work with the US EPA. By using the value chain approach to development, the GLPP has developed a proven methodology for methane mitigation work, and has designed projects in several different developing country environments that demonstrate the potential to reach thousands of beneficiaries by the end of the decade. In the future, the group will continue to focus on increasing animal productivity and incomes of small scale producers in developing countries. The team is expanding aggressively to other regions where dairy animals suffer low productivity due to poorly-balanced feed rations. In the coming year, the team expects to add beef and draft cattle production to its portfolio with possible entry into the livestock subsector in South Africa, Indonesia, and China.

A "Win-Win-Win" Scenario

Through ruminant methane mitigation projects, ATI provides developing countries the most cost-effective ways of reducing greenhouse gas emissions (carbon equivalent) globally and offering an important new opportunity. This opportunity links ruminant emissions with sustainable development projects in the agriculture sector, which employs millions of poor people worldwide. Successful commercialization of this approach can offer significant global environmental and developmental benefits in the coming years.

Ruminant methane mitigation projects represent a "win-win-win" opportunity -- a "win" for the global environment as methane emissions are reduced or avoided, a "win" for small producers as their incomes are increased, and a "win" for local consumers in the project areas as the quality and quantity of milk, meat or draft power available to them increases as well. The GLPP has designed projects in several different developing country environments that have demonstrated the potential to reach hundreds of thousands of beneficiaries by the end of the decade. These projects will provide, in the aggregate millions of dollars, an increase in income for small-scale livestock producers, and enormous global environmental benefits by offsetting thousands of tons of methane per year.

ABSTRACT

Energy Conservation and Technological Change as Factors in Climate Change - A Pulp and Paper Industry Example

Allen M. Koleff
Vice President
Energy, Environment, and Process Technology
Stone Container Corporation
Tucker, Georgia

The Pulp and Paper Industry in the United States is one of this country's most energy intensive industries with energy generally being the second or third largest direct operating expense in mill budgets. As such, the industry has long had an effective energy conservation program and has recorded impressive reductions in energy use. It is also one of the two most capital intensive industries in the United States and has a long capital investment cycle, which can be estimated by various techniques at between 20 and 30 years.

This paper discusses the estimated impact of the industry's energy conservation achievements on long term emission reductions of greenhouse gases and will show how technological changes within the industry have impacted past emission reductions and the prospects for continued progress through emerging technologies.

The importance to the global competitiveness of the industry of implementing technological change designed to reduce the emission of greenhouse gases within the industry's normal investment cycle will also be reviewed.

FOREST AND WOOD PRODUCTS ROLE IN CARBON SEQUESTRATION

R. Neil Sampson
Senior Fellow, American Forests

The Forest Resources of the United States

There are 737 million acres of forested lands in the United States, of which about 2/3 is defined as timberland, that is, land capable of growing 20 ft^3 of merchantable wood per acre per year, and not reserved for other uses (Powell et al. 1993). The area of forest land has remained relatively stable since 1950 (Table 1), but the area of timberland has diminished about 19 million acres since 1952 with additions to wilderness and park areas, as well as urban development and fragmentation (Table 2).

Table 1. Major uses of land in the United States at selected years

Land use	1950	1969	1987
	Million acres		
Cropland	409	384	464
Pasture and Range	701	692	591
Forest	721	723	731
Other	442	465	479
Total Land Area	2,273	2,264	2,265

Source: Frey and Hexem, 1982; Daugherty, 1989.

Table 2. Trends in Timberland in the United States at selected years

	1952	1977	1992
	Million acres		
National Forest	95	89	85
Other Public	51	49	47
Industrial	59	69	70
Non-industrial private	304	285	288
Total Timberland	509	492	490

Source: Powell et al. 1993.

The woody materials in forests are about half carbon on a dry weight basis (Birdsey 1996a). In total the organic carbon stored in the vegetation; litter, humus, and woody debris; and soils of U.S. forests amounts to 60 billion tons (Birdsey and Heath 1995). This stored carbon amounts to about 40 times the Nation's annual carbon emissions of around 1.5 billion tons (Marland et al. 1994). The largest part of the stored carbon, some 61 percent, is found in the forest soils. About 29 percent of the stored carbon is in the trees, and the remaining 10 percent is in the woody litter, debris, and humus on the forest floor as well as the understory vegetation.

The Current Role of Forests & Forest Products in Mitigating C Emissions

Regional Differences

There are big differences in the amount of carbon stored in the major forested regions of the country. Some 25 billion tons, 41 percent of the total, is stored in the forest ecosystems of the Pacific Coast, mostly in Alaska. About 25 percent is stored in the forests in the North, 14 percent in the Rocky Mountains, and 21 percent in the South (Hair et al. 1996). These regional differences reflect differences in climate and in the age and density of the forests. The cool climates of the Pacific Coast and North slow the oxidation of carbon in the soils, in dead trees, and in the woody materials on the forest floor. The Pacific Coast region has big areas of old, undisturbed forests that contain large volumes of carbon.

Carbon storage in forests is constantly changing in response to land clearing; tree planting on lands that have been used for crops and pastures; timber harvesting; and the natural regeneration, growth, and death of vegetation. In recent decades, carbon storage has been rising because timber growth has been higher than the total of harvest removals and mortality, with a consequent increase in timber inventories. Between 1952 and 1992, for example, carbon storage on forest lands in the conterminous United States increased by 12.4 billion tons—about 25 percent (Birdsey and Heath 1995).

Timber growth is substantially above removals in the hardwood forests, and carbon is accumulating in the major hardwood regions. The largest increase is in the Northeast, but there are also big increases in storage in the Southeast and on the Pacific Coast. In some areas in the South Central region, removals are above or close to growth, and the carbon accumulation is quite small.

Mortality increased by 24% between 1986 and 1991 in all regions, on all ownerships, for both hardwoods and softwoods (Powell et al. 1993). Obviously, the continued increase of carbon storage in U.S. forests is not assured if increasing mortality rates are experienced in the future.

Managing Carbon Balances in Forests

Carbon accumulates within a forest over time, as the forest changes due to tree growth and ecological succession. Over many years, the Forest Service has measured the growth of different tree species and forest types on different soil types. These growth and yield models have now been converted to carbon accumulation models (Birdsey 1996b).

Two examples illustrate the use of these tables. In loblolly pine plantations of the South, there are two significantly different growth yields. One is the estimate of managed yields — the yields that good managers consistently achieve. The second is the inventory yield — the yield that is realized over the average of all ownerships and managers. The difference, which can be as much as 60% over an 80-year rotation, is important. For individual projects on good sites, where management is assured, the high estimate of carbon sequestration is reasonable. For national policy, where we ask what the general achievement will be, the lower estimate is most reasonable (Hair et al. 1996).

Another example might be the old growth Douglas-fir stands of the Pacific Northwest. These forests have enormous stores of carbon on site, and while the accumulation is slow because of the maturity of the trees, it continues to occur. If our goal is to retain stored carbon for the next few decades, we protect these forests. Harvesting them, and removing all the dead wood from the site without using it to offset fossil carbon, would result in a net loss of carbon that would take decades to recover. If our object is to increase carbon storage over time, however, then harvest and replanting becomes the best option (Row 1996).

The reason for this somewhat counter-intuitive conclusion is found in the research that has tracked the fate of forest carbon following harvest. This has demonstrated that a significant amount of the carbon remains in terrestrial storage, often as products in use or in material that is retained in landfills or dumps (Row and Phelps 1996). Another significant percentage is utilized to replace fossil fuels as an energy sources. As long as this comes from forests that are managed sustainably, it represents a short-term recycling of carbon in and out of the atmosphere, replacing an emission from the stored fossil sources, so it is a net replacement in terms of carbon emissions (Hair et al. 1996).

The effect is that, if we study the effect of long-term forest management schemes on carbon balances, the managed forest, with products utilized for long-term storage, continues to build terrestrial carbon storage rotation after rotation, as the amount of products continue to reside for significant periods of time in storage. This can be illustrated by looking at the probable effects of different management schemes on several different forest types (Row 1996).

Potential for Increasing Carbon Storage in United States Forests

Converting marginal crop and pasture land

An estimated 116 million acres of land that was biologically suited to growing trees was being used as marginal crop and pasture land in 1982. (Parks et al. 1992). About half was in cropland and half in pasture at the time, and it was equally nearly divided in terms of its suitability for softwood and hardwood forests (Parks et al. 1992). The total opportunity it offered was between 1.5 and 5.2 billion cubic feet of wood a year, which would have been somewhere in the range of 36 and 131 million tons of carbon added to the forest inventory (Hair et al. 1996). Some of that opportunity—4 to 5 million acres—has been captured by tree planting under the Conservation Reserve Program since 1985, but there are over 100 million acres still available for trees if the appropriate incentive to landowners can be created.

Increasing timberland growth

Even larger opportunities exist in increasing timber growth and inventories on timberland (Vasievich and Alig 1996). These opportunities exist on over 200 million acres, and could add up to somewhere between 152 and 210 million tons of carbon storage per year (Hair et al. 1996). Changes in storage that would result over time from implementing these opportunities will depend on the timber growth or yields that could be expected in the future. These will vary with geographic location, species or forest type, management practices, and climate change.

It is clear that there are very large opportunities to increase carbon storage on marginal crop and pasture lands and on timberlands. But in time, if trees are left alone, carbon storage will tend to stabilize as sites and species reach the stage where trees begin to die and decay or when they are burned in fires. However, if the trees are harvested sustainably and converted into products or used for fuel, storage can be increased through many forest rotations.

Reducing wildfire losses

That illustrates the quandry faced in many areas as forests without active management begin to reach conditions where destructive wildfires are virtually assured. In the western United States, a large area of forests that were historically disturbed by frequent, low-intensity wildfire have been without fire's effect for a century or more (Covington et al. 1994). The result, as biomass levels have built up, are forests that are so heavily laden with flammable fuels that today's wildfires are larger and hotter than those of the past. Table 3 illustrates the average annual wildfire experienced in the 11 western United States in recent decades. The annual averages shown are the average of the 10 years in each decade, which helps reduce the variability experienced from year to year because of annual weather conditions.

Table 3. Average annual wildfire, 11 Western United States, by decade.

Years	1940-49	1950-59	1960-69	1970-79	1980-89	1990-96
Average acres burned per year	825,348	476,920	463,871	765,948	1,553,142	1,872,353

Source: USDA Forest Service (1940-1990); National Interagency Fire Center (1990-96)

These wildfires are increasingly costly, both in terms of suppression costs and resource damage. In the ten years 1985-1994, the Forest Service reported expenditures of over $4 billion in fire suppression costs, not including the costs incurred by other federal, state and local agencies, nor the amount spent on post-fire watershed or forest restoration. Much of the suppression money was spent protecting homes and other structures adjacent to wildland areas. In 1994, $250-300 million was spent in urban-wildland areas (USDA/USDI 1995).

Wildfires emit enormous amounts of C, but estimates are difficult to derive because fuel consumption estimates for wildfires are seldom available. In one assessment of two large (120,000 acres) 1994 wildfires in the Boise National Forest, Neuenschwander and Sampson (in press) estimated that the average fuel consumption was 47.2 tons per acre, equivalent to 21.4 tons of carbon per acre. These fires, which burned at mixed intensities in ponderosa pine forests, consumed more fuel than average for western wildfires, many of which burn in grass and brush fuels. Average wildfire emissions are on the order of 10 tons C per acre burned (Sampson, in press). That puts the average emission impact in the range of 15-20 million tons C per year from the western wildfires. This is somewhat higher than the estimates used in recent climate modeling exercises, perhaps because wildfires have increased over the last few decades, and the models were based on historical averages (USEPA 1993). Auclair and Carter (1993) noted a correlation between the recent wildfire increases and recent atmospheric CO_2 levels.

The challenge for forest managers is to reduce available fuels in the most dangerous situations, and introduce managed fire under cooler conditions that restore ecosystem conditions without destructive effects (USDI/USDA 1995; Covington et al. 1997). That is a formidable task, due to the large areas involved and the lack of markets for the smaller material that needs to be removed from many sites. Research in an Arizona ponderosa pine forest found, for example, that 37 tons of thinning slash and 21 tons of surface duff per acre needed to be removed prior to a restoration burn (Covington et al. 1997). A biomass market for this material, so that it could be burned cleanly for energy production, would be welcomed by forest managers, but is currently not competitive with natural gas generation (Sampson, in press). Between the estimated 47 tons of biomass burned per acre in the recent Boise National Forest fires (above) and the 58 tons of excess that Covington found, it appears that the surplus biomass in overcrowded ponderosa pine forests, were it to be made available for energy production, could be in the range of 50 tons per acre over 20 million acres. (There are around 29 million acres of ponderosa pine forests in the west; most are in dense structures that need thinning (Oliver et al. 1997)). That's roughly 1 billion tons of biomass, and while it took 100 years or so to accumulate on these sites, there is no assurance that it will remain in its current unstable condition for much longer without burning in an unwanted wildfire. One estimate suggests that only 10-15 years remain before most of it burns (Covington et al. 1994). Removing this biomass through planned thinnings, and burning it for energy within the next decade, would require the burning of 100 million tons of biomass a year from the ponderosa pine forests alone. Other western forests, primarily mixed conifer and lodgepole pine types, would add to that total. The treatment of ponderosa pine alone would result in an average offset in the range of 50 million tons C emissions per year, which could be proposed as a high estimate of the opportunity. The low estimate is zero, because of the current lack of an opportunity for biomass generation near the affected forests.

<u>Changing timber harvest methods</u>

A related opportunity exists through changing timber harvest methods. Timber harvest is, except for intense wildfire, the most disruptive event in the forest life cycle. Attention to the effects of forest harvest methods on carbon sinks will lead to methods that:

* Leave enough canopy cover to shade the soil and keep soil temperatures reduced;
* Leave foliage and small branches on-site to minimize nutrient export;
* Burn slash carefully, and leave adequate snags and large woody debris as a carbon legacy for the ecosystem; and,
* Minimize soil disturbance and movement, through mechanical activities or erosion, to prevent export of soil carbon or accelerated organic decomposition due to aeration (Sampson, 1995) .

The practice of clearcut harvesting attracted negative public reaction to its appearance and effect on the forest, and foresters failed to convince the public that it is a necessary and useful practice. In 1992, the Forest Service declared a new policy to minimize the use of clearcutting as a harvest method wherever other methods are available (Robertson, 1992). The Sustainable Forestry Initiative encourages industrial foresters to voluntarily limit the size of clear-cut (some states also have enacted size limits). Reports by participating members of the American Forest and Paper Association indicate that the average size of industry clear-cut was 61 acres in 1996, down from 66 acres in 1995 (AF&PA 1997).

This should be a positive change in terms of carbon sinks and the effects of forest harvest upon them. Particularly in its most extreme forms, where the slash, stumps, and debris were piled and burned, the volatilization of carbon, both in the debris and the soil, was maximized. Although little evidence of site deterioration has been found, it seems inconceivable that interrupting the normal cycles in such an aggressive fashion would go without impact (Sampson 1995).

Potential for Using Forest Products to Reduce or Offset Carbon Emissions

Post-harvest carbon flows

The fate of carbon as it flows from forest through processing, end use and final disposition back to the atmosphere is an important aspect of the carbon question. A computer model called HARVCARB produces an estimate of the various routes and fates of harvested carbon through the current U.S. economy (Row and Phelps, 1996). This model allows a test of the implications of different forest management strategies, changes in wood-using technology, and differences in disposal methods.

In tracing the flow of carbon that results from a timber harvest, it is important to recognize that, in addition to the major products involved such as lumber, plywood and paper, there is a constant stream of by-products that can be burned, with or without energy recovery, or simply left to decompose on the land or in landfills. In evaluating how effective the trees and forests that we plant or manage today will be in altering the global carbon balance in the future, we must make some assumptions about the fate of those trees and forests, and the use of the biomass produced. The more biomass that is constructively utilized, in long-lived products or to replace fossil fuel energy, the more effective the forests will be as a carbon sink.

Using a southern pine stand as a test case, Row and Phelps (1992) demonstrated that there are significant differences in carbon flows depending upon the management regime chosen for the forest . The differences were created mainly by the fact that longer-rotation trees are utilized in different product mixes (more solid wood products) than when the trees are harvested at a younger age.

Wood products and environmental impact

There has been considerable debate and positioning between industrial sectors over the most "environmentally-friendly" ways to meet our need for industrial products. Increasingly, consumers indicate preference for "green" products, even at somewhat higher costs (NEETF 1996)

In the main market for wood products — building materials — the competition comes largely from the steel and masonry industries. The steel industry has developed framing materials that compete well in price and performance for use in homes and other building applications, and that out-compete wood when timber prices rise. Its claim to being a "green" product lies in its high degree of recycling. Concrete and brick make much of their local abundance in many areas, and long life in use. Wood counters with its claim of renewability (Meil 1994).

The question of total environmental effect is a complex one, and several parameters need to be considered. One of the measures relevant to the climate policy debate is total energy expended in the life cycle of the product. This estimates the relative amount of energy involved in extracting the basic material, processing or manufacturing the product, fabricating the building, occupying it, and disposing or recycling the material at the end of its useful life (Meil 1997).

Table 4.—Estimated emissions from alternative building materials used to frame new residential construction in the U.S., based on 1995 construction estimates.

Framing Option	CO_2 Emissions	C Emissions
	(Million tons)	
All-wood framing	1,488,534	405,964
95% wood; 5% steel	1,686,759	460,025
75% wood; 25% steel	2,479,661	676,271
All-steel framing	5,453,042	1,487,193

On this measure, wood competes well. An interior wall constructed with steel studs is 3 times more energy intensive than its wood counterpart, meaning that the CO_2 emissions are also 3 times as great (Meil 1994). If the analysis is extended to an exterior, load-bearing wall, the wood advantage increases to something on a 1:4 energy and CO_2 ratio with steel, even where 50% recycled steel is assumed, because of the thicker steel needed for structural strength (Meil 1994). On another environmental parameter — water consumption — steel assembly requires some 25 times more water than its wood counterpart (Meil 1994). This increases the polluting effluents associated with industrial water use, so if either water shortages or pollution control costs are a locally-important environmental issue, this is a factor to consider.

While the relative environmental advantages of wood over steel seem significant, the total annual climate impacts are modest by comparison with many of the other forestry-related opportunities to affect CO_2 emissions. The life-cycle model results reported by Meil (1994) indicate that, for an interior wall, wood construction results in about 0.35 tons of CO_2 emissions per 1,000 ft^2 of wall while steel results in about 1.07 tons. Comparable estimates for exterior walls are 0.44 tons CO_2 per 1,000 ft^2 for wood and 1.76 tons for steel. In 1995, U.S. housing starts were around 972,000, with the average house utilizing around 4,260 board feet of framing lumber to construct an average of around 1,600 ft^2 of interior walls and 2,170 ft^2 of exterior walls (NAHB 1996). These estimates can be used to test the potential CO_2 effect of the steel industry's goal of achieving 25% of the U.S. market for framing materials in housing construction (Meil 1994). Table 4 indicates the impact of options for using wood and steel. The difference between all-wood and all-steel—about 1 million tons C per year in terms of CO_2 emissions— is only a partial measure of the climate impact of the two competitors, because it does not account for the wood wall's value in storing C for many years, which would increase the wood's advantage.

There would appear to be a significant opportunity to increase carbon storage, as well as achieve other environmental goals, by using wood more effectively. This would include substituting wood for more environmentally-damaging products, recycling wood and paper products extensively, and improving the efficiency of wood use in buildings and other products. Research by the USDA Forest Service indicates that the average annual impact of increased recycling of paper and wood products could result in from 8 to 44 million tons of additional carbon stored in forests each year (Skog et al. 1996).

A major question to be answered by those proposing to "save forests" by substituting other products for wood in the name of environmental impact is "what will we do with all that wood?" Forests are valued for many things besides wood products, and many forest lands are managed with timber as a secondary product, or with no timber harvest at all. That does not stop the forest from growing a surplus of biomass on most sites that, if not harvested and used, needs to be recycled somehow. It cannot build up endlessly on the site and, if it builds up over threshold levels for a particular site, the system can become unstable and subject to extreme disturbances such as uncharacteristically hot or large wildfires (Binkley et al. In press). If the answer, in the name of environmental protection, is "let it burn," which is sometimes heard, the implications for destructive ecosystem impacts, watershed deterioration, and human health (air quality) effects need to be considered (Sampson et al. In press).

The total potential for growing wood in the United States, on both existing forests and marginal lands that could grow forests, is in the range of 35 billion ft^3 per year (up from an estimated 22 billion today (Hair et al. 1996). We currently utilize about 24 billion ft^3 in industrial products, indicating that if forests were producing to their potential, we would have some 11 billion ft^3 added to the inventory each year unless it were harvested and burned as fuel (Hair et al. 1996). The reality of the situation is that there are environmental tradeoffs to be made with every aspect of forest management and product use, and a careful accounting of the net effect often comes out to favor the sustainable use of forests for wood products.

Biomass energy crops

Substituting woody biomass for fossil fuels results in a net reduction of fossil fuel burning and, consequently, a net reduction in the amount of net CO_2 added to the atmosphere. Planting woody crops that grow rapidly, are harvested on a 4-12 year cycle, and re-sprout after cutting, can meet energy needs, reduce fossil fuel use, and build new income-producing options for farmers (Wright and Hughes, 1993). Because of intensive management such as maintenance of high fertility rates, irrigation, and weed control, the technology is more related to agriculture than to forestry.

Land availability for short-rotation woody crop (SRWC) production is more a function of economic opportunity and technological development than of biological capacity. Of the 422 million acres of U.S. cropland, about 307 million have the combination of fertility, rainfall, and slope to be suitable for SRWC (Wright et al. 1992). In addition, over 85 million acres of pasture and forest land are estimated to have good to moderate potential for conversion to cropland. Most of the suitable lands are in the North Central states. Of these lands, about 225 million acres have the capability to yield 5 or more tons of standing dry biomass per acre per year under current technology (Wright and Hughes, 1993).

Increasing the Use of Energy-Conserving Trees

In urban situations, properly placed urban trees can have a significant impact on atmospheric carbon buildup through energy conservation. Studies in the U.S. indicate that the daily electrical usage for air-conditioning could be reduced by 10-50% by properly located trees and shrubs (USEPA, 1992). Savings of 1,351-1,665 kWh per year for a 137 m^2 house have been recorded (McPherson and Woodward, 1990). On the other side of the calendar for energy conservation, properly placed trees can also reduce winter heating costs by 4 to 22 percent (De Walle, 1978).

Sampson et al. (1992) have proposed a goal for a 10-year program aimed at increasing the canopy cover by 10% on residential lands, and 5-20% on other urban lands in the U.S. They estimate that the effect of such an improvement program on U.S. urban forests could result in sequestration of 3 to 9 million tons of

Table 5. Forest Opportunities to Increase Carbon Sequestration or Reduce Carbon Emissions in the United States.

Type of Opportunity	Low Estimate	High Estimate
	Million tons C per year	
Converting marginal crop and pasture land to trees	36	131
Improving growth and yield of timberlands	152	210
Reducing wildfire losses*	5	15
Substituting wood for steel in housing construction (Emissions reduction effect only)	0	1
Biomass energy from surplus forest biomass	0	50
Biomass energy from woody crops	100	199
Energy-saving trees around homes and communities	13	45
Increased wood substitution, efficient buildings, recycling*	8	44
Total annual impact on C emissions	314	695
Total impact as a percentage of annual C emissions (1.5 billion tons/year)**	21%	46%

* This is an estimated savings in addition to the biomass energy estimated below.
** These percentages are slightly higher than reported in Hair et al. (1996) due to the addition of quantitative estimates for wildfire, excess biomass in western forests, substitution, and recycling.

C per year in trees and soils, and an added 7 to 29 million ton reduction in C emissions due to energy conservation from improved shading, increased evapo-transpiration, and reduction of the urban heat island, along with wintertime heat savings. Methods of achieving these reductions have been well developed (USEPA 1992). Windbreaks and shelterbelts add another 3 to 7 million ton potential (Brandle et al 1992).

Adding up the Forest-Related Opportunities in the United States

In total, the opportunities to increase carbon storage and reduce carbon emissions could offset somewhere between 20 and 40 percent of the carbon being emitted annually into the atmosphere in the United States (Table 5). The broad range in these estimates is a measure of the uncertainties with these calculations, which are based on many data sources of variable quality and on relationships between tree and forest growth and carbon impacts that have had only limited scientific study. In one sense, the estimates are conservative, because they are based on current technology. On the other side of the ledger, they are also based on a continuation of recent climate trends.

Despite the uncertainties, there are major opportunities to use forests, trees, and wood to mitigate carbon emissions and to ameliorate adverse effects that might come from global warming. With the necessary investments, trees and forests can make substantial contributions in any comprehensive program to mitigate climate changes resulting from the buildup of carbon dioxide in the atmosphere.

Uncertainties Facing Forest Managers

Adapting forests to an uncertain climate

The calculations above are based on the assumption that climate conditions for forest growth and management will remain roughly the same in the future as in the recent past. Whether that is a sound assumption or not is open to considerable conjecture, but lacking any reliable data upon which to provide an estimate of future climate trends, it seems logical to use it.

What we realize, however, is that changing climate may impose significant new challenges for forest managers, particularly if it changes faster than the average life span of planted trees or the migration rate of natural forest species (Sommers 1996).

If, as some evidence indicates, unstable climate regimes also result in an increase of extreme climate events such as droughts, floods, or hurricanes, that also spells difficulty for forest managers. Forests that are affected by large-area disturbances such as these put large and unplanned "lumps" of wood on the market in the affected regions, stretching industrial capacity and resulting in additional waste in some instances.

Resource managers, both public and private, will be tested with new challenges if climate events or trends begin to adversely affect forests. The net effect of increased mortality will be to move many forest regions toward younger stands and earlier-successional forests. Whether managers can adapt to these changes, particularly in remote areas, remains a major question.

Overcoming Political and Economic Barriers

The barriers against implementing all or most of the foregoing opportunities include a major need for increased investment in forest management. One estimate suggests the need for an additional $10.9 billion invested in timberland opportunities alone, mostly on the private forest lands of the South (Hair et al. 1996). Investments of this type will only be made when investors believe the policy climate is favorable and stable for the investment future of 1-3 decades. This means that incentive programs, and tax treatment, as the two most visible policy instruments, must appear to be favorable. The fact that there are massive opportunities in today's situation, in spite of the fact that many of them would pay an economic return of 4 percent or more above inflation, suggests that landowners either aren't aware of the opportunities, or don't believe them to be attractive enough.

On public lands, the increasing opposition to intensive forest management and its impact on other forest values signals a less-active timber program in the future. The challenge on many of these forests, particularly those that are fire-adapted, will be to manage biomass so as to minimize the ecological, economic, and public health damage from the fires that will recycle the biomass if it is not intentionally removed and either used for wood and paper products, or burned for energy. The challenge of having fairly large populations, sprawling urban-wildland intermixes, and greatly increased smoke emissions from fires is not one that will be easily resolved, but it is the reality facing much of America today.

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LIFE CYCLE INVENTORY ANALYSIS OF REGENERATIVE THERMAL OXIDATION OF AIR EMISSIONS FROM ORIENTED STRAND BOARD FACILITIES IN MINNESOTA – A PERSPECTIVE OF GLOBAL CLIMATE CHANGE

by

William J. Nicholson
Potlatch Corporation
San Francisco, California

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I. Executive Summary

Life cycle inventory analysis has been applied to the prospective operation of regenerative thermal oxidation (RTO) technology at oriented strand board plants at Bemidji (Line 1) and Cook, Minnesota. The net system destruction of VOC's and carbon monoxide, and at Cook a small quantity of particulate, has a very high environmental price in terms of energy and water use, global warming potential, sulfur and nitrogen oxide emissions, solids discharged to water, and solid waste deposited in landfills. The benefit of VOC destruction is identified as minor in terms of ground level ozone at best and possibly slightly detrimental. Recognition of environmental tradeoffs associated with proposed system changes is critical to sound decision-making. There are more conventional ways to address carbon monoxide emissions than combustion in RTO's. In an environment in which global warming is a concern, fuel supplemental combustion for environmental control does not appear warranted. Consideration of non-combustion approaches to address air emission issues at the two operations is recommended.

II. Introduction

Environmental life cycle inventory analysis (LCIA) is a systematic accounting of environmental impacts caused by the inputs and outputs required to operate a device or process. In the case of this specific analysis, the device is a regenerative thermal oxidizer (RTO) installed to combust certain criteria pollutants, principally volatile organic compounds (VOC), and secondarily, carbon monoxide (CO), and particulate matter (PM). The inputs to the RTO are electricity and fuel and the outputs are carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x) and water. There is no real fuel value in the stream to be treated. The LCIA process quantifies the net result of the inputs and outputs. The environmental impacts required to collect, convert, and deliver energy and ceramic media are the inputs to operate the RTO, the environmental emissions and discharges are the outputs. The net result of the inputs and outputs defines a price for the presumed benefits of the process in question. This price is stated in terms of natural resource use and emissions/discharges rather than economic terms. The price can then be related to unit benefits.

Ideally in the analysis of a proposed change being made for environmental reasons, this form of analysis should be made before any economic consideration. This form of analysis provides a basis to make a judgment regarding whether a change is environmentally beneficial and to describe the magnitude of the benefit. This technique is not an analysis of specific environmental impacts of the identified emissions, discharges, benefits of the process change, and the natural resource use because the analytical capability to correctly identify all those factors does not exist.

If the judgment from this analysis is that there is no net environmental benefit from a proposed environmental change, there is no reason to proceed to an economic analysis of the change. If the environmental situation is made worse by the change, the economic cost thereof, no matter how low, does not offset the environmental damage. Under a no-net-environmental-benefit conclusion, the change should not be made. If there is judged to be a net environmental benefit to the change, then both the environmental cost/benefit and the economic cost of the change become relevant and both an environmental and an economic price per unit of environmental benefit can and should be developed. With these unit prices for the change, a judgment can be made if environmental and economic costs of the environmental benefit are beneficial. If the environmental and economic prices are acceptable, the change should be made.

The issue before a regulatory agency or other body making such an evaluation whether the analysis demonstrates a net environmental benefit is that a tradeoff of natural resource use and additional emissions and discharges against the presumed environmental benefit is the likely result. In simplistic terms, the elimination of a pound of emission X is or is not deemed beneficial if the cost is Y pounds of discharge A and use of Z pounds of natural resource B. In reality the tradeoffs are much more complex. There are usually multiple natural resource uses and many additional emissions and discharges, and they may not be easily equatable. In addition, these resource uses and emissions and discharges may not occur at the site of the benefit or even within the jurisdiction of the decisionmaker. Over time the decisionmaker will develop a pattern of acceptable prices in terms of environmental emission and discharges and natural resource use that can be used by many to assess particular circumstances. If life cycle inventory analyses are made of a series of changes over time, conclusions also can be drawn about the quality of environmental decisions.

This particular analysis applies life cycle inventory technique to the addition of regenerative thermal oxidation (RTO) technology at Potlatch Corporation's oriented strand board plants at Bemidji (Line One) and Cook. The analysis focuses only on the environmental tradeoffs associated with the RTO's; no consideration is given to any environmental cost of the manufacture of the capital equipment, which would only make the technology less environmentally attractive. Environmental prices for the application of the technology using two different fuels, natural gas at Bemidji and propane at Cook, are determined and a perspective of the implications of the prices given.

III. Methodology and Results

The calculated benefits of the addition of RTO's to Bemidji (Line 1) and Cook are shown in Table I. The emissions for particulate focus only on the RTO, as the bulk of the particulate is caught in the already existing secondary cyclones and wet electrostatic precipitators (WESP).

The emissions and discharges and natural resource use associated with the operation of an RTO firing natural gas at Bemidji (Line 1) are shown in Table II. These quantities are determined based upon the annual quantities of natural gas, electricity, and ceramic media used and the conversions developed in the 1995 Scientific Certification Systems' report, "Environmental Characterization of Inputs to a Regenerative Thermal Oxidation Unit in the Forest Products Industry."[1] Some of these emissions and discharges, such as some NO_x emissions and the ceramic that is discarded which occur at the Bemidji site, do not change, but much of the resource use and other emissions and discharges occur off site at such locations as coal mines, electric power generating stations, petroleum and natural gas fields, and along natural gas pipelines. In general, these locations are in North America, primarily in the United States and mostly in the northern Midwest.

Table III contains the information for an RTO at Cook comparable to the information given in Table II for Bemidji (Line 1). Note that the principal difference is that propane is used as fuel at Cook, while natural gas is used at Bemidji.

IV. Analysis

The net environmental cost of operation of RTO's at Bemidji (Line 1) and Cook, as measured in terms of natural resource use, emissions, and discharges is summarized in Table IV. Table IV is developed by subtracting the benefits from Table I from the environmental costs at Bemidji (Line 1), shown in Table II, and Cook, shown in Table III. Benefits are shown in parentheses.

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[1] See reference at end

The use of propane to fire the RTO at Cook uses about five percent more energy than use of natural gas at Bemidji. Two thirds more water is used in the case in which propane is fired. Because more and higher carbon content energy is used in the propane firing facility about 18% greater CO_2 emissions, potentially contributing even further to global warming, are associated with the propane firing facility. An interesting difference in the two cases is that for the Bemidji case the system is a net emitter of particulate; in the Cook case there is a small amount of particulate destroyed. The difference in particulate in the two cases is related to higher particulate emissions associated with production and delivery of natural gas, as identified in the Scientific Certification Systems' report in Table 6.26 on page 13. [2] Many other comparisons between the Bemidji (Line 1) and Cook cases can be made.

The cost-benefit ratios in environmental terms are another form of comparison. The benefits identified for RTO operation, two for Bemidji and three for Cook, are summed. Under these assumptions the net environmental benefits of RTO operation are

	CO + Hydrocarbon + Particulate = Total
Bemidji (Line 1)(lbs)	1,144,392 + 41,156 + 0 = 1,185,548
Cook (lbs)	965,848 + 313,762 + 4,426 = 1,284,036

1,185,548 lbs of pollutants destroyed at Bemidji (Line 1) and 1,284,036 lbs at Cook.

Using these totals as the denominator, a series of environmental prices for operation of RTO's at Bemidji (Line1) and Cook may be calculated. These prices, shown in units per ton of benefit, all of which must be paid by the environment, are shown in Table V. The presumption that all emissions are equivalent based on weight is very simplistic and certainly not scientific, but it is a gross indicator.

The use of RTO's as pollution controls for the destruction of VOC's was developed for a process emitting high concentrations of VOC's in low volumes of air. This situation, typical of a painting activity, allows self-sustaining combustion. Additional sources of fossil fuel are not required. Additionally, the low volumes of air require only a small amount of electricity to drive the fans moving the VOC-laden air to the RTO's. The environmental price for use of RTO's in a painting activity, drawn in the form of Table V, should be far lower than for the application at oriented strand board facilities, where VOC's are in low concentrations in high volumes of air in a moisture saturated condition. Burning fuel in wet air is particularly fuel consumptive. The absence of fossil fuel use and the lower amount of electricity use in a painting activity makes all the difference.

[2] See reference at end

The location of the Bemidji and Cook facilities are in an environment naturally rich in volatile organic compounds, the forest. Trees naturally give off VOC's. These areas are also short of NO_x, the other input to generation of ground level ozone, the real environmental indicator of concern. The use of fossil fuel combustion technology, the RTO, to destroy VOC's while producing NO_x as an emission in a VOC-rich environment as summarized in Table I, strongly suggests that the result may be an increase in ground level ozone associated with the control technology. The amounts of ozone involved relative to that produced by natural VOC levels and other available sources of NO_x likely are small. The environmental modeling of ozone plumes suggests changes of a magnitude far less than is measurable. From an ozone perspective the use of RTO's in these cases is ineffective, seems purposeless, and may be slightly detrimental.

The major benefit of the RTO technology appears to be destruction of carbon monoxide. Carbon monoxide is usually an indication of incomplete combustion. Adding a complex combustion unit, such as an RTO and large amounts of fossil fuel, to address an issue of incomplete combustion appears to be technology overkill with a high environmental price. A more attractive focal point for effort may be the combustion that provides heat to the dryers at the facilities. It is likely that this combustion is the point of generation of carbon monoxide and thus an attractive point for investigation.

The issue faced by the environmental decisionmaker is whether the destruction of CO, VOC's, and at Cook a small amount of particulate by RTO's is worth the environmental and natural resource use price indicated in Table V. The issue is complicated by the likelihood that the destruction of VOC's has little, no, or even a possibly detrimental effect on the generation of ozone and that an RTO is not the logical choice for eliminating carbon monoxide.

In evaluating the environmental prices identified in Table V, the energy equivalent of the 350 MMBtu/ton used at Cook is 2800 gallons of gasoline/ton. In terms of manufacturing processes the RTO requires takes seven to ten times the energy needed to manufacture a ton of paper from delivered wood. The evaluation of the other factors is more conventional – NO_x and SO_x are conventional pollutants. Carbon dioxide is, however, becoming a major policy issue because of its global warming potential. Given the broad concerns that are arising about this issue any pollution control technology based on fossil fuel combustion will be suspect, particularly if there are alternative ways of addressing the issues.

V. Conclusion and Recommendations

A life cycle inventory analysis of the operation of RTO's at the oriented strand board facilities at Bemidji (Line 1) and Cook identifies a relatively high environmental price per ton of pollutants destroyed. The process uses large amounts of fossil-based energy, which leads to the emission of large quantities of carbon dioxide, the gas related to global warming. In addition to the energy use and the global warming potential related to RTO's, there are significant emissions of SO_x and NO_x, considerable water use, and discharges to water and land. Payment of this environmental price eliminates some VOC's, but with little, no, or a slight detrimental effect on ground level ozone. Carbon monoxide, which is likely easier to address by focus upon the combustion in the dryers, is also destroyed. In the Cook case some particulate is destroyed.

All of these characteristics of the operation of RTO's at Bemidji and Cook lead to the conclusion that RTO's are an inappropriate technology for the intended purpose, particularly if there are any alternatives for addressing the issues. From a purely environmental perspective, there is logic to reach the conclusion even to do nothing. At most an investigation should be made to evaluate technical alternatives to address the carbon monoxide issue.

These results are developed from a life cycle inventory analysis of a proposed regulatory change designed to enhance the environment. Typical analysis focuses on emissions to one media at one location. LCIA addresses emissions to all media at all locations relevant to the system involved. This form of energy and environment tradeoff analysis should be made as part of development of information for regulatory decisions. In an environment in which global warming is a concern, this tradeoff analysis is particularly important.

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TABLE I

Annual Quantities of Pollutants Destroyed by RTO's (1)(5)
(lbs/yr)

	Bemidji (Line 1)	Cook
Volatile Organic Compounds	401,540 (4)	401,540 (4)
Particulate (2)	92,639 (4)	92,639 (4)
Carbon monoxide	1,156,440 (4)	1,156,440 (4)
NO_x (3)	(30,940)	(30,940)

(1) Source: 1993 BACT emission rate, 8112 operating hours, permitted control efficiency.

(2) Particulate (11.42 lbs/hr) destroyed by the RTO's. The vast proportion of the particulate is caught by the secondary cyclones and the WESP.

(3) NO_x emissions increase, but these amounts are incorporated in the NO_x emissions shown in Tables II and III.

(4) Environmental benefits of RTO operation.

(5) Bemidji (Line 1) and Cook are nearly identical plants constructed in the early 1980s.

TABLE II

Natural Resource Use, Emissions, and Discharges for an RTO at Bemidji (Line 1)

Input to RTO Units	Natural Gas (Mcf)	Electricity (kwh)	Ceramic Media lbs	Annual Total
Annual quantitiy used	109,616	5,737,500	336,000	
		Raw Material Resources required		
<u>Resources</u>				
Water (gallons)	negligible	1,721,250	48,384	1,769,634
Petroleum (MMBtu)	negligible	5,738	411	6,149
Natural Gas (MMBtu)	118,824	745	484	120,052
Coal (MMBtu)	negligible	85,000	291	85,291
		Emissions to Air (See Table 6.2b)		
<u>Compounds</u>				
CO_2 (lbs)	13,525,163	14,040,488	222,227	27,787,878
CO (lbs)	76	11,890	81	12,048
SO_x (lbs)	4,326	175,822	2,444	182,593
NO_x (lbs)	194,297	53,126	1,482	248,905
Hydrocarbons (lbs)	354,037	5,237	1,111	360,384
Particulate (lbs)	21,146	82,219	741	104,105
		Emissions to Water (See Table 6.3b)		
<u>Compounds</u>				
Total Solids (lbs)	negligible	1,733	31,793	33,526
Hydrocarbons (lbs)	negligible	negligible	1	1
Phenols (lbs)	negligible	negligible	1	1
		Solid Waste Emissions (See Table 6.4b)		
Total Solids (lbs)	negligible	1,733	336,001	337,374

References are to tables in the Scientific Certification Systems' report.

TABLE III

Natural Resource Use, Emissions, and Discharges for an RTO at Cook

Input to RTO Units	Propane (gallons)	Electricity (kwh)	Ceramic Media lbs	Annual Total
Annual quantitiy used	1,191,478	5,737,500	336,000	
<u>Resources</u>		Raw Material Resources required		
Water (gallons)	1,191,478	1,721,250	48,384	2,961,112
Petroleum (MMBtu)	126,637	5,738	132,786	6,149
Natural Gas (MMBtu)	4,330	745	5,558	120,052
Coal (MMBtu)	1,082	85,000	291	86,373
		Emissions to Air (See Table 6.2b)		
<u>Compounds</u>				
CO_2 (lbs)	18,731,522	14,040,488	222,227	32,994,237
CO (lbs)	178,621	11,890	81	190,592
SO_x (lbs)	36,775	175,822	2,444	215,042
NO_x (lbs)	231,156	53,126	1,482	248,764
Hydrocarbons (lbs)	31,430	5,237	1,111	87,778
Particulate (lbs)	5,254	82,219	741	88,213
		Emissions to Water (See Table 6.3b)		
<u>Compounds</u>				
Total Solids (lbs)	negligible	1,733	31,793	33,526
Hydrocarbons (lbs)	252	negligible	1	253
Phenols (lbs)	252	negligible	1	253
		Solid Waste Emissions (See Table 6.4b)		
Total Solids (lbs)	negligible	1,733	336,001	337,374

References are to tables in the Scientific Certification Systems' report.

TABLE IV
Environmental Net Cost of Natural Resource Use, Emissions and Discharges
for RTO's at Bemidji (Line 1) and Cook

	Bemidji (Line 1) (3) (natural gas)	Cook (4) (propane)
Resources		
Water (gallons)	1,769,634	2,961,112
Petroleum (MMBtu)	6,149	132,786
Natural Gas (MMBtu)	120,052	5,558
Coal (MMBtu)	85,291	86,373
Air Emissions		
CO_2 (lbs)	27,787,878	32,994,237
CO (lbs)	(1,144,392)	(965,848)
SO_x (lbs)	182,593	215,042
NO_x (lbs)	248,905	285,764
Hydrocarbons/VOCs (lbs)(1)	(41,156)	(313,762)
Particulate (lbs) (2)	11,466	(4,426)
Water Discharges		
Total Solids (lbs)	33,526	33,526
Hydrocarbons (lbs)	1	253
Phenols (lbs)	1	253
Solid Waste		
Total Solids (lbs)	337,374	337,374

(1) Volatile organic compounds destroyed by the RTO's are offset by emissions of hydrocarbons off site.

(2) The bulk of the particulate is captured in the secondary cyclones and WESP. The RTO's destroy 11.42 lbs/hr of particulate which in 8112 hours of operation amount to 92,639 lbs/yr.

(3) Calculated by subtracting benefits on Table I from the total environmental costs in Table II.

(4) Calculated by subtracting benefits on Table I from total environmental costs in Table III.

TABLE V

Environmental Prices for Operation of
RTO's at Bemidji (Line 1) and Cook (1)
(units per ton of pollutant destroyed) (2)

	Bemidji (Line 1)	Cook
Water (gallons)	2,985	4612
Energy (MMBtu)	356.7	350
CO_2 (lbs)	46,877	51,391
SO_2 (lbs)	308.1	334.9
NO_x (lbs)	419.9	445.1
Particulate (lbs)	19.3	-
Solids to Water (lbs)	56.6	31.9
Solids to Land (lbs)	569.1	525.5

(1) If the environmental emissions and discharges are summed only to gain a general sense of the magnitude of the issue, there are about 24 tons emitted per ton of pollutants destroyed in the Bemidji (Line 1) case and 26 tons in the Cook case, not considering natural resource use.

(2) The pollutants destroyed are carbon monoxide, VOC's and particulate as shown in Table I.

POST-HARVEST CARBON EMISSIONS AND SEQUESTRATION IN SOUTHERN UNITED STATES FOREST INDUSTRIES

Clark Row
Row Associates

Summary

Whether the forest industries in the southern United States are net emitters or sequesters of carbon from the atmosphere depends on one's viewpoint. In the short-term, the solid-wood industries--lumber, plywood, and panels--appear to sequester more carbon than is in the fossil fuels they use for processing. The paper industries, however, emit more carbon from fossil fuels than they sequester in the pulp and paper they manufacture.

This viewpoint is quite limited. If one considers the life-cycles of solid-wood and paper products from seedlings to landfill, these industries sequester more carbon than they emit from burning fossil fuels.

These industries also generate large amounts of energy by replacing fossil fuels with biofuels from processing residues, and wood-based products produce more energy from incineration and landfill gases. Use of the carbon in these biofuels in effect keeps fossil fuel carbon in the ground, considering that at least that amount of carbon would be emitted in producing alternative materials. Another way of looking the emission balances is that wood-based materials, pound for pound or use for use, are the most "carbon efficient" group of major industrial materials.

Background

What happens to the carbon in forest harvests and its role in mitigating global climate change has been one of the last pieces in the global carbon cycle to be understood. The earliest analyses of greenhouse gases in global climate change emphasized the role that loss of forest cover has played since the industrial revolution in generating the observed buildup of carbon dioxide in the atmosphere. Later analyses incorporated the regeneration of forest biomass in second growth temperate forests as a modest mitigating flow of carbon from the atmosphere to terrestrial carbon sinks. But until several years ago, most analyses made the convenient assumption that once cut and processed, the carbon in forest harvests immediately returned to the atmosphere. Though an obvious gap, no studies had quantified the complex flows carbon from wood products or how long the carbon remained in terrestrial wood product sinks.

Studies of post-harvest carbon flows and sinks by Row and Phelps (1990, 1996) described these flows for the U.S., and other researchers have made more limited studies for several other nations. Row and Phelps developed and used a simulation procedure called HARVCARB. This presentation uses that simulation procedure, but it incorporates:

- Estimates of fossil fuel use in each phase of forest and forest product processing.

- More current information on forest growth and harvesting from the U.S. Forest Service's 1992 update of forest survey statistics (1994, 1995).

- Estimates of carbon flows only from harvests in the 12-state southern region from Virginia to Texas, and extending north to Tennessee, Arkansas, and Oklahoma.

The southern U.S. region was chosen because most of the opportunities to increase sequestration are in that region (Sampson and Hair, 1992 and 1996), even though the latest forest statistics show that regional harvests plus losses roughly balance forest growth (thus net <u>forest</u> sequestration is minimal). In addition, the regional forest industries are more modern and probably "emission efficient" that in other regions. They perhaps better illustrate developing trends, both in the U.S. and worldwide.

Thus the region shows how that sustained management of second growth forests, with the sequestration of as much as a third of the harvested carbon in long-term man-made sinks, and the use of another third to replace fossil fuel energy, may be a significant means to mitigate global climate change.

The carbon life-cycle of forest and forest products

Figure 1 shows a general scheme of how the carbon accumulated in forests after harvest flows from one carbon sink to succeeding ones--round-wood raw materials and finished wood products temporarily, then into wood products in use, then into disposal products. During each transformation, some of the product returns to the atmosphere while the rest goes to another sink.

While this conception is useful, it is not complete. Each transformation requires energy for processing, and many steps in processing generate residues that are used as biofuels. These effectively reduce the requirements for energy from fossil fuels. (Though some electrical energy is generated from hydroelectric, nuclear, solar, and other energy sources, the marginal energy in the U.S. economy comes from fossil fuels). Figure 1a shows this complete conception of the forest/forest product carbon cycle.

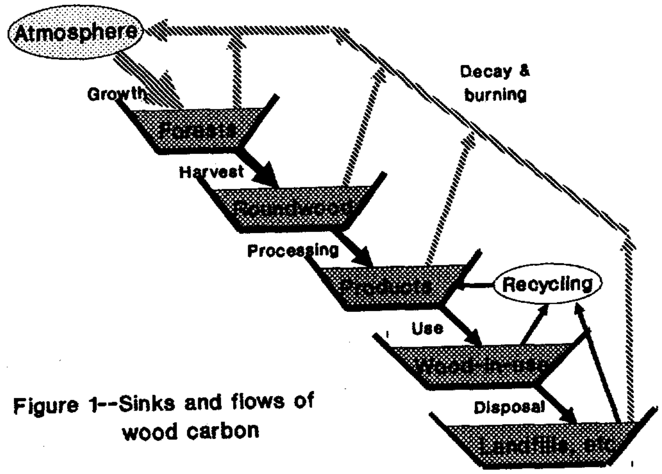


Figure 1--Sinks and flows of wood carbon

Greenhouse gas and global climate change studies did not neglect the energy used by the forest product industries. The main IPCC study points out that the paper manufacture, in particular, is one of most energy-intensive industries worldwide. But analyzing both the wood and energy carbon flows together is necessary to assess the net impact of the industry and its products on greenhouse gas emissions.

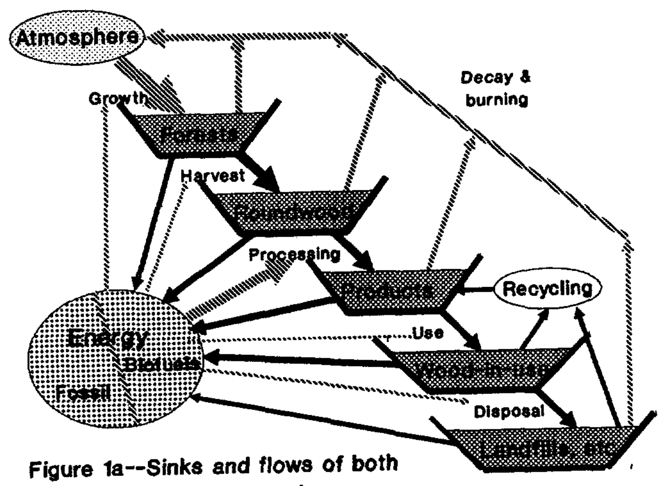


Figure 1a--Sinks and flows of both wood and energy carbon

A brief look at forest carbon flows and sinks

Large amounts of carbon flow into and out of forests, day by day and season by season. Much of the carbon does not stay, but long-term forest carbon accumulation is wood growth, less harvest, losses, and changes in soil carbon. Figure 2 shows a rough schematic of long-term flows. In the southern U.S., the latest estimate (1991) of current wood growth of 195 million metric tons a year about balances the harvest of 150 million tons and losses from mortality of 45 million tons. Uncertainties of computation are perhaps plus or minus 10 million tons. This is a change from the situation estimated 5 years earlier, which showed a significant net increase of forest carbon in the region.

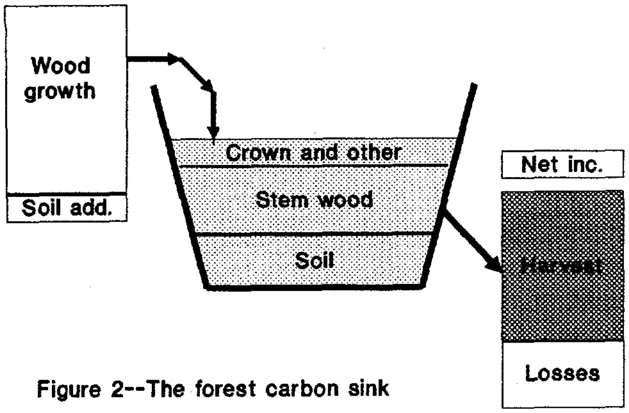


Figure 2--The forest carbon sink

The switch ends a 60-year period of rebuilding forest inventories after widespread logging early in 20th century.

This change appears to have resulted from a combination of higher than usual losses from storm and insect infestations, together with heavy cutting by forest industry on their own lands. Many companies have been converting from naturally regenerated forests to pine plantations with shorter rotation periods.

The total forest sink in the South is about 5.3 billion metric tons of carbon in trees and about 5.0 billion metric tons in the soil.

Changes in soil carbon are quite hard to quantify. Soil carbon increases significantly when cropland or pasture is planted to pine. But once pine plantation canopies close, soil carbon accumulation slows. Some soil carbon appears to be temporarily lost when stands are harvested, but is regained subsequently.

Carbon accumulates fastest in young, moderately stocked pine forests, and are increased by genetic improvement, stocking control, and protection. Carbon does not accumulate rapidly in overstocked, or poorly regenerated stands. Losses from fire, storm, and insect epidemics are greatest in stands grown too dense. Roughly half of forests in South are in need of one type of timber standimprovement, almost all of which would be good investment. Figure 3 lists factors that alter the rates of forest carbon sequestration.

Figure 3--Actions affecting forest carbon balances

- Plus
  - Planting additional area
  - Improving timber stands--thinning, culling
  - Planting genetically improved trees
  - Regenerating promptly
- Minus
  - Letting stands become overstocked
  - Fires, storms, insects, and diseases
  - Converting lands from forests to other use

Carbon in tree harvested is converted to roundwood and products

Once cut, trees are converted to roundwood products--sawlogs, veneer logs, pulpwood, and round fuelwood--either in the woods or increasingly at special facilities that optimally cut tree-length logs into the best combination of products (Figure 4). These products then go to either solid-wood (lumber or plywood) mills or pulp mills. Up to this stage, energy use is modest (5 million tons), largely equipment fuel.

At both types of mills, both wood carbon and energy carbon have significant roles. At both types of mills, four general processes take place, each requiring significant energy. Logs must be debarked, if not already done; the wood must be processed into smaller pieces (at pulp mills into fibers); the resulting wood or fiber may be treated; the product finally formed and dried.

In solid-wood mills the energy requirements (figure 5) are much less than in pulpmills (figure 6), which require massive amounts of energy to digest pulpchips and to form and dry the paper sheet, and also to bleach the fibers if the products produce require bleaching.

In each type of processing the reduction in carbon in the product is somewhat more than half. But in solid-wood product mills much of the residue is chips that are utilized by pulp mills. In most southern mills relatively little residue is not used either for product or burned for energy. In particular, pulp mills recover both energy and chemicals by burning the spent digesting liquor, which then contains much of the lignins and other carbon chemicals of the wood. This energy

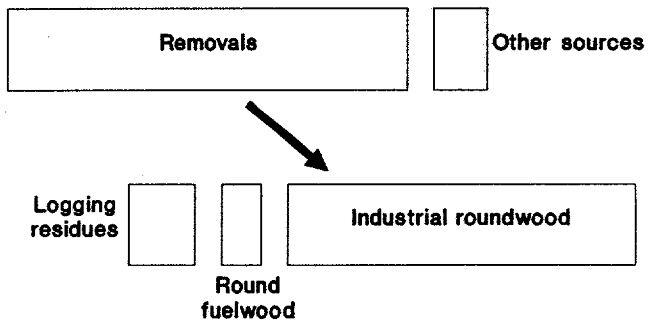


Figure 4.--Carbon flows from forests to mills

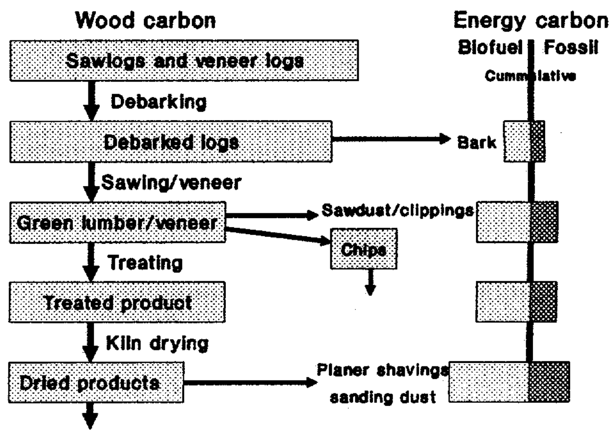


Figure 5.--Carbon accounts for solid-wood processing

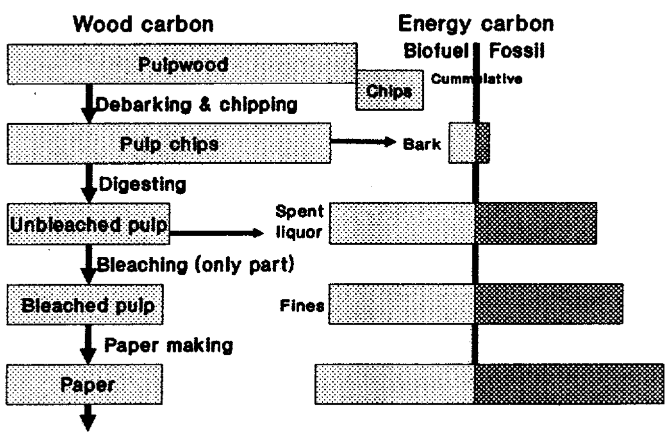


Figure 6--Carbon accounts for paper processing

replaces carbon in purchased fuels and electricity, also produced predominately from fossil fuels. Some byproducts are rosins and other wood chemicals for use in various wood and non-wood materials, a pathway for carbon sufficiently significant to be tracked.

If recycled fiber is used as part of a paper mill's raw material, it also goes through three phases--breakdown into fiber, treatment--usually de-inking and bleaching, and mixing with other fiber before being made into paper. About 15 percent of recycled fiber is lost, mostly through breakage. But relatively little residue is produced for biofuels. Thus recycled pulps require substantial additional energy.

Figure 7 lists some of the major factors affecting the efficiency of carbon utilization in forest product mills. Improvements in energy efficiency are often costly, as mills replace boilers and processing equipment, which often has 30 or more years of useful life.

It is now technologically feasible to build a completely energy self-sufficient forest product complex, or at least one thatachieve balance in energy bought and sold.

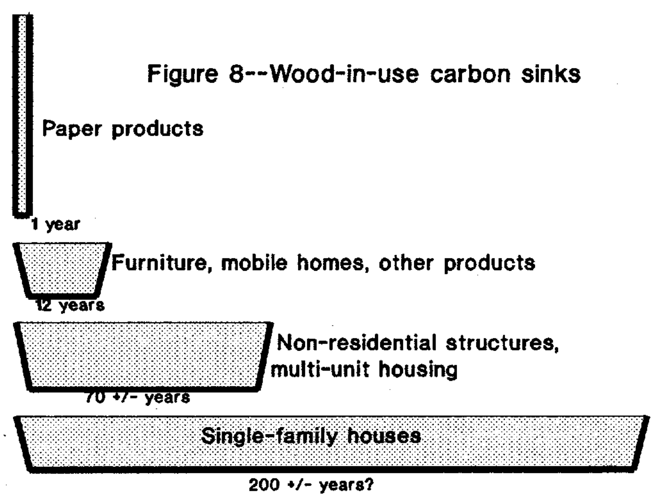
Figure 7--Factors affecting processing carbon balances

- Plus
  - Integrating solid-wood, paper, and power facilities
  - Completely using waste wood for biofuel
  - Improving processing yields
  - Recovering all possible energy in processing
- Minus
  - Drying and rewetting market pulps
  - Procrastinating equipment replacement
  - High use of recycled fiber

Carbon accumulates in wood product-in-use sinks

Once wood-derived products are in use, they add to man-created wood sinks of varying importance and average period in which the carbon remains in the sink (Figure 8). The period for all types of paper other than printing and writing is probably less than a year, and thus the paper sink is quite limited even though the amount of carbon flowing through it is great.

Figure 8--Wood-in-use carbon sinks



Solid wood products largely go into building construction, furniture, or fixtures, all with decades-long life. Since about 1950, carbon in residential housing, now largely in land-use restricted developments, is being lost as if houses had lives of 200 years. The carbon in an average house is increasing. And also the carbon in an average house built in a given year actually increases as it gets older, because of additions and alterations, and adding decks and sheds.

Replacement of some pre-World War II housing, especially in older, inner city areas would save carbon emissions, since they are hard to insulate and inefficient to heat or air-condition. Figure 9 lists additional factors that affect wood-in-use sinks.

Figure 9--Factors affecting wood-in-use sinks

- Plus
  - Improving packaging technology--safety
  - Zoning land uses, especially for housing
  - Greater use of decay-resisting treatments
  - Increasing size of average homes
- Minus
  - Replacing wood by steel, aluminium, cement, plastics
  - Use of microfilm, mag tapes for libraries, records

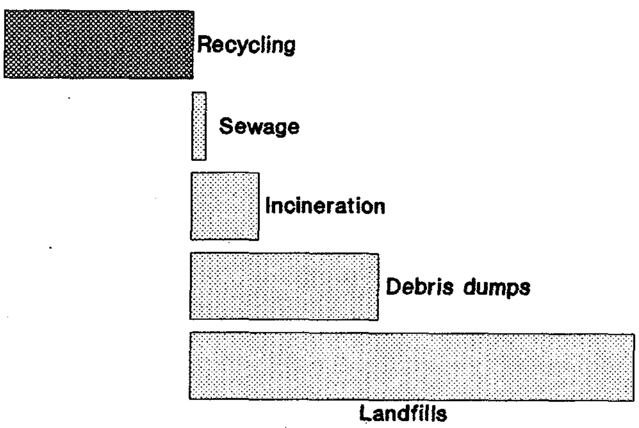


Figure 10--Product disposal after use

Part of carbon in discarded products remains in landfills and dumps

On discarding from use, some products are recycled, some burned, but most go to landfills or debris dumps. Figure 10 shows the amounts of products from current southern U.S. harvests likely to go to each disposal mode.

Over 40 percent of paper products are collected for reuse or export, up from 25 percent only several decades ago. The practical economic limit is thought to be about 50 percent. Some collected paper may have more value as biofuel than for recycling.

Despite opposition, the quantity of refuse burned is increasing. Most opposition is now against the traffic nuisance rather than the smoke emissions. Most new incinerators burn waste for energy. Recycling non-wood products makes incinerators more efficient and safer.

The major fate of most wood products is landfills or dumps. Re cent regulations will insure that decomposition is relatively slow, or regulated for production of methane gas for energy.

Figure 11--Factors affecting carbon disposal balance

- Plus
  - Applying new landfill regulations
  - Increasing trash incineration
  - Recycling (keeping toxics out of landfills)
  - Recovering methane from landfills for energy
- Minus
  - ?

It appears that less than half of carbon from wood products deposited in landfills will ever return to atmosphere. Lignin in wood or paper does not decompose well in anaerobic conditions. Many coatings of products and landfill environment conditions act to retard decomposition. Figure 11 mentions factors that increase or decrease emissions from disposal of carbon from wood-derived products.

Tracking both carbon in wood products and in energy through life cycle is needed

Once harvested, a large part of the carbon in forest removals returns to the atmosphere over the next century, but through quite complex paths. Nevertheless, it can be estimated with objectivity and some validity. The rate and the ultimate proportion that returns has been generally overestimated in climate change models.

Recent trends indicate that the rate and proportion returning will probably decrease with technological progress, environmental controls, and economic progress. The proportion of the carbon in wood harvested that will be burned for energy, and thus replace fossil fuels, will also increase. On the grounds that this fossil fuel carbon replaced will remain in the ground, this offset should be recognized.

To analyze the role of forest management and forest product manufacture and use in reducing atmospheric carbon emissions requires accounting for both product and energy carbon. This accounting should recognize that individual aspects will have dissimilar accuracy, but that realistic and perhaps conservative estimates will have to be made.

A final accounting, in total and in units of production

Of the 170 million tons of carbon per year in the recent timber harvests and other sources in the South, about 2/3 will be used either for products or for biofuels. Its disposition, at various lengths of time after harvest, is shown in Figure 12. The analysis indicates that the amount of carbon that is still in terrestrial carbon sinks after 100 years slightly exceeds the carbon in the fossil fuel used to produce it. Within the accuracy of the procedures used in the analysis, it is about the same.

But the equivalent carbon in the energy produced from fuelwood, residues, and disposal products is of an additional similar magnitude as the fossil energy used. There are two interpretations possible: first, that forests and forest products are net sequesters of carbon relative to other basic materials, or that wood-based products are among the most carbon-emissions efficient materials.

Though the long-term trend of forest sequestration among all forestland owners is likely to decline, the carbon efficiency of post-harvest forest product production and use is likely to improve in future decades. Among them are the continued concentration of production in mills with modern processing and energy recovery equipment, technological improvements, and recovery of energy from discarded wood-based products.

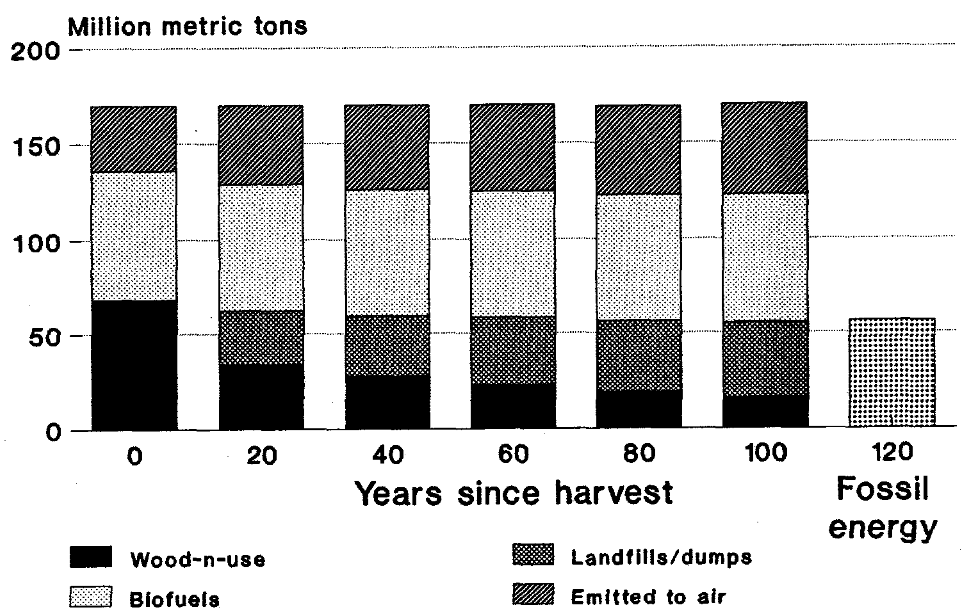


Figure 12--Post-harvest distribution over time

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Technologies for improved soil carbon management and environmental quality

D.C. Reicosky[1], Soil Scientist, USDA-Agricultural Research Service, North Central Soil Conservation Research Lab, 803 Iowa Avenue, Morris, MN 56267

Introduction

The possibility of greenhouse warming due to increased CO_2 is receiving attention, (Wood, 1990) and (Post et al., 1990). This concern is warranted because of potential climatic changes that could result in increased temperatures and drought over present agricultural production areas. Agriculture's role in sequestering C is not clearly understood. Thus, there is a need for direct measurements to quantify CO_2 fluxes as impacted by agricultural management practices (Houghton et al., 1983).

Soil organic matter or soil carbon (C) is one component of mineral soils that makes plant growth possible and is one of the most important natural resources. Minimizing agriculture's impact on the global increase of carbon dioxide requires that we sequester carbon and maintain high levels of organic matter. Information is needed on the variation and magnitude of carbon loss from the soils and the interaction of tillage on various soil types.

Soil organic C is the foundation of sustainable agriculture and is highly dependent on management decisions that influence the intensity of tillage and the amount and placement of crop residues. Agriculture and intensive tillage have caused between 30 and 50% decrease in soil C since many soils were brought into cultivation over 100 years ago (Schlesinger, 1985). Thus, there is a need for a better understanding of the tillage processes and the mechanism leading to carbon loss and how this C loss would link to soil productivity, soil quality and carbon sequestration. Understanding these processes as part of the food production process will lead to enhanced soil management techniques and new technology for increased efficiency with minimum impact on environmental quality.

Objective

There is a need to maintain resource quality (soil, water, and air) for the long-term production of food and fiber because our global resources are finite. The objective is to create an environmental awareness and to provide insight into the future balance of environment and economic issues in developing new technologies that benefit the farmer, the public and agricultural product sales. Agricultural impacts of tillage-induced CO_2 losses will be addressed along with new and existing technologies to minimize tillage-induced flow of CO_2 to the atmosphere. Emphasis will be placed on the carbon cycle and the cost of environmental damage to illustrate the need for improved technologies that lead to business ventures to reduce environmental impact. New technologies and concepts related to methods of tillage and stover management for C sequestration within the agricultural production systems will be presented.

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[1]All programs and services of the U.S. Department of Agriculture are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, age, marital status, or handicap.

Carbon cycle in agricultural ecosystems

The carbon cycle, in addition to the water and nitrogen cycle make up the three major nutrient cycles in agricultural ecosystems. These three cycles are intertwined in a very complex dynamic system where numerous processes are occurring. Nitrogen fixation and mineralization take place as part of the N cycle that is tied in with the carbon cycle. In the hydrologic cycle, rainfall and evaporation occur with runoff and infiltration as the major modes of chemical transport within the soil system. The C cycle plays a critical role in plant photosynthesis and respiration and organic matter decomposition that releases CO_2 to the environment.

The C cycle begins when plants combine solar energy, CO_2 and water to form carbohydrates through photosynthesis, the basic food supply of all life. We remove the grain as our primary food source, but another important form of carbohydrate as stover (often referred to as plant residue) remains. Plant stover is a major source of C input into the soil system and plays a very vital role as nourishment for the soil microbial population. Our human bodies require energy input to perform such activities as walking, lifting, and other bodily functions. So it is with soil. Soil needs energy input in the form of stover (residue) so that all biological components can function properly and produce the necessary output for the nutrition of agronomic crops. The C input through the crop residue from the grain production contributes to the cycle of life where it is placed on the soil and performs the necessary function for biological processes. This C is regenerated through the process of photosynthesis and supplied to the soil as the cycle continues.

While these crop materials are the primary energy source, the simple end product is CO_2 and water with a few other mineral elements. Carbon dioxide is the end product of the decomposition of soil organic matter and apparently interacts and plays a critical role in plant nutrition. Thus soil organic matter plays a critical role in many of the soil processes because of its impact on the physical, biological and chemical properties important for crop production.

One example of what intensive tillage in agricultural production systems has done to soil organic C is illustrated in figure 1. These data illustrate the long-term trends in soil C at the Morrow plots in Champaign-Urbana, Illinois (Odell et al.1984, Peck, 1989); and Sanborn Field, the experiment station of University of Missouri at Columbia, Missouri (Wagner, 1981, 1989). Both locations show similar decreases in soil organic C over the last 100 years. Interestingly, the continuous corn treatments, which presumably, had a large amounts of crop residue returned to the soil surface at both locations had the lowest organic C after 100 years of cultivation. Different cropping rotations or systems yielded a difference in soil organic matter which suggests management options for controlling soil organic matter. These rotations may not be th emost profitable but can result in improved in soil carbon levels. The only phenomenon common to these two locations was the moldboard plow used to till the experimental plots. These results suggest the large decline in soil organic matter was a result of tillage-induced C losses caused by the moldboard plow and disk harrow. An alternate interpretation may be the soil C inputs from annual species used in the cropping systems are substantially different from that of perennial prairie grass species before the land was brought into production. Differences in soil organic matter accumulation may be a result of the differences in root biomass. Thus, the long-term decline in soil organic matter in the corn belt can be attributed to the combination of intensive tillage and a change to annual species in the cropping systems.

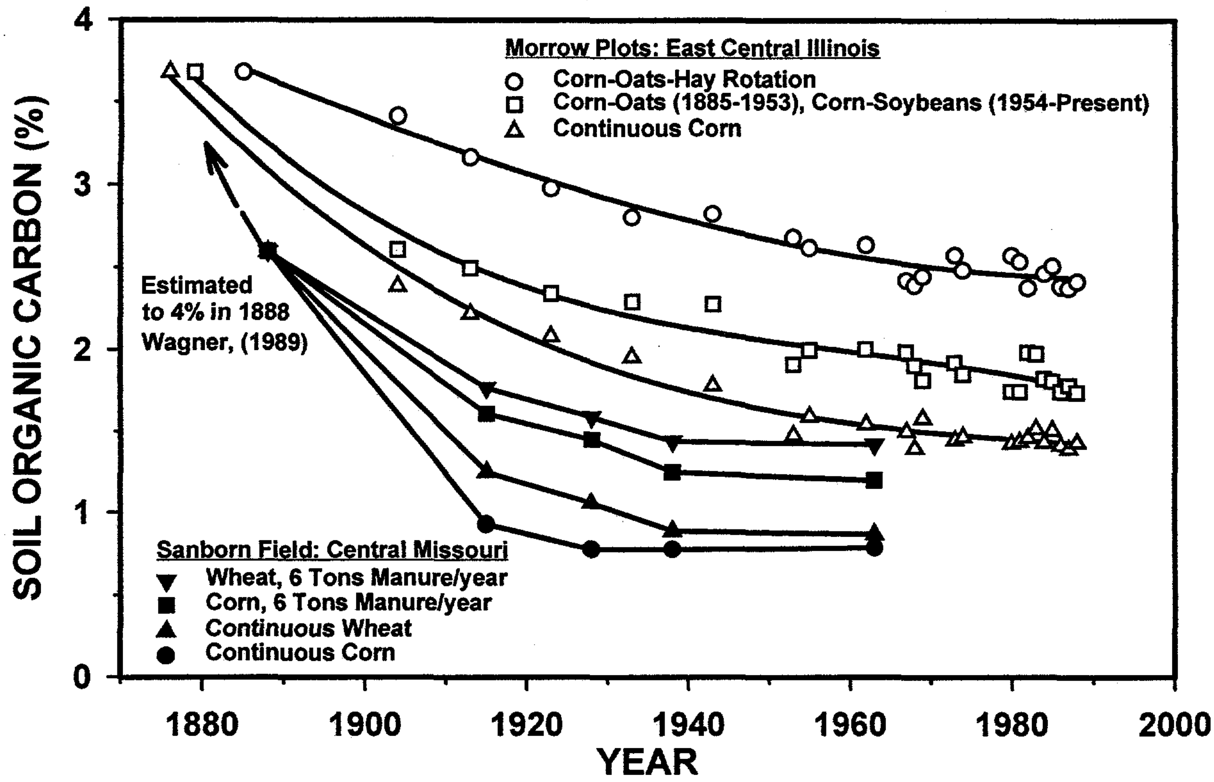

Figure 1. Long-term effects of tillage and crop rotations on soil carbon.

Soil quality/resource quality

Resource quality must be maintained for sustainable food and fiber production. Our global resources are finite in that we have limited soil for crop production. The concept of soil quality draws attention to a critical understanding the soil system. Karlen et al. (1997), loosely defined soil quality as the capacity to function. An expanded definition presents Soil quality as " the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation." The definition of soil quality emphasizes soil resource maintenance and identifies an interaction between soil and air that is critical with respect to the greenhouse gas emissions. Just as water quality is important to us, air quality is associated with soil quality through biological CO_2 produced in the soil system. Thus, maintaining resource quality with emphasis on the soil requires C sequestration to enhance the soil physical properties which increase infiltration and decrease erosion and serve as an energy source for the soil organisms. This maintenance of soil quality will result in improved air quality when C is sequestered in the soil and CO_2 emissions are minimized in the agricultural production systems. Our soils are the fundamental foundation of our economy and our life. Soils, along with the air and water resources used in food production, must be maintained. We are the stewards of these resources and we must manage the C to maintain the system at optimum efficiency if we are to continue to feed the increasing world population.

Tillage-induced CO_2 losses

Soil, which represents the outermost layer of the earth's crust, is a dynamic and complex mixture of organic and inorganic constituents that support human and animal life as we know it and regulates the environment. This functional definition states two primary functions of the soil within the terrestrial ecosystems: regulating the gaseous concentrations in the atmosphere, primarily through the C cycle; and water quality through the hydrologic cycle which affects the earth's climate and biodiversity. These important and interdependent feedback mechanisms need to be managed closely in agricultural production systems. Practices that minimize the risk of soil degradation and enhance productivity also reduce the risks of environmental degradation. Practices with beneficial impact on the environment also control soil erosion, increase soil organic matter content and biomass carbon, enhance soil structure and improve soil fertility in agronomic productivity. Thus the soil is an important part of our ecosystems and must be properly managed to minimize the impact on the environment.

Recent studies involving tillage methods indicate major gaseous loss of C immediately after intensive tillage (Reicosky and Lindstrom, 1993). Reicosky and Lindstrom measured the effects of fall tillage methods on CO_2 flux from a Hamerly Clay loam in the northern cornbelt, comparing moldboard plow, moldboard plow plus disk harrow, disk harrow only, chisel plow and an area not tilled (Figure 2).

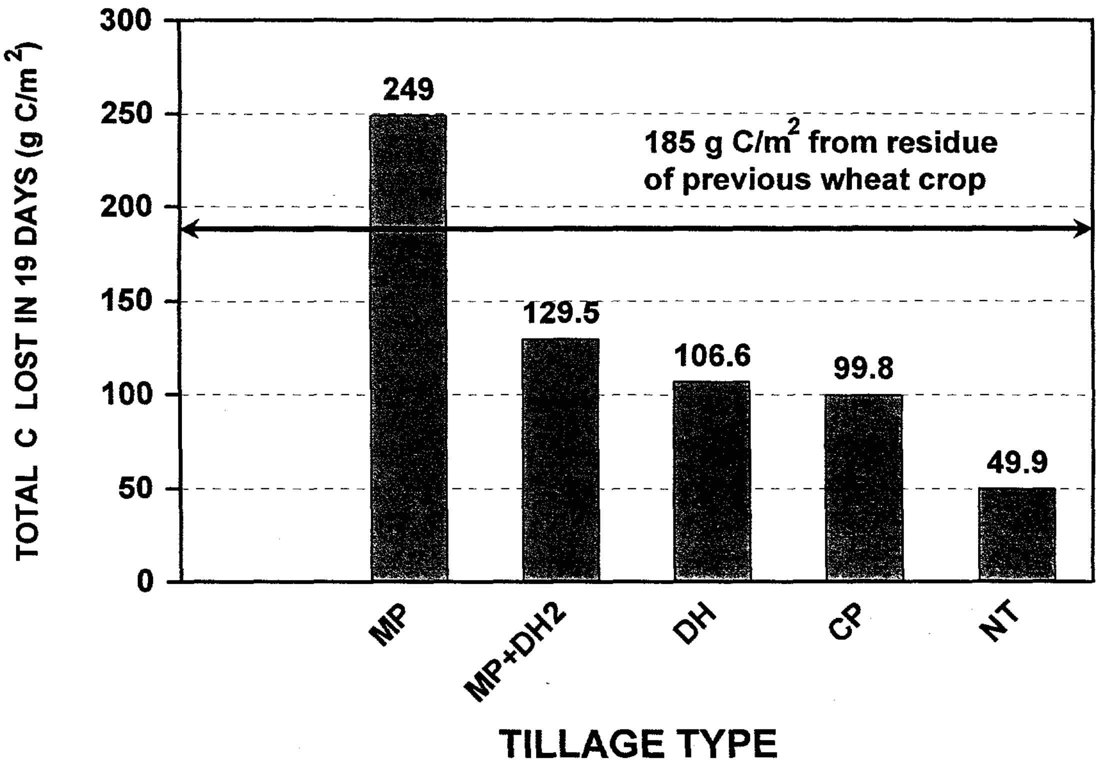

Figure 2. Tillage-induced CO_2 loss and current crop residue 19 days after tillage.

Measurements taken immediately after tillage and continuing intermittently for 19 days showed differences of CO_2 losses related to tillage intensity (soil fracturing) that facilitated the movement of CO_2 out of and oxygen into the soil. The moldboard plow treatment buried nearly all the residue and left the soil in a rough, loose and open condition and resulted in maximum CO_2 loss. The initial CO_2 fluxes showed a large and rapid decline within the first hour after the plowing. The moldboard plow had two major effects: 1) loosened and inverted the soil to allow rapid CO_2 loss and oxygen entry and 2) incorporated and mixed residues for enhanced microbial attack. The amounts released can be compared with the equivalent C in the tops and roots of the previous wheat crop, (Reicosky and Lindstrom, 1995). With moldboard plowing, the CO_2 loss was greater than the equivalent C input from the previous crop. The CO_2 released during the 19 days following the tillage treatments MP, MP+DH2, DH, CP and NT would account for 134, 70, 58, 54 and 27% respectively of the C in the current year's crop residue.

Considerably more C was lost as CO_2 from the plowed plots than from the area not tilled. The effect of plowing and incorporating fresh crop residue on biological oxidation of residual soil C can be viewed as analogous to opening the air supply and stirring the kindling into smoldering coals of a camp fire. In both cases, oxidation is accelerated by improved oxygen supply and accessibility of new, easily oxidizable material resulting in further oxidation of the residual C within the soil system. Management decisions that affect tillage intensity and amount and placement of residues have a significant effect on soil C. There is a definite need to develop new technologies that can minimize tillage intensity and maximize efficient use of residue placement to result in soil C sequestration that minimizes the impact on environmental quality.

Stover (residue) management

The management of croplands has a large impact on the quantity and quality of food and fiber production and on soil, water, and air quality which act together to influence environmental quality. Management of the non-harvested plant tissue, such as leaves, stems, branches and roots, (often referred to as crop residues) also referred to as litter, stover or stubble are important in maintaining environmental quality. These materials constitute one of the important components in maintaining agricultural productivity via nutrient availability and nutrient cycling. The soil C cycling, as discussed above, is one of the major processes. These residues provide opportunities to control dust in the air and sediments and nutrients in the water through the control of wind and water erosion. Furthermore, these materials are the primary energy source for the dynamic biological system that utilizes this material to build up soil C and partially removes it from the C cycle.

Crop materials are often regarded as "waste" that require disposal before producing a new crop. However, as more information becomes available, these materials are essential and a vital resource for enhanced and continued crop production. From the conservation perspective, crop residue management is the proper use of the residues for soil protection and improvement. These residues are important for enhancing and maintaining soil quality in that they increase the soil C and contribute to the biological, physical and chemical processes vital for crop production.

The equilibrium organic matter content of the soil depends on the amount of organic material added and the soil environment. Larson, et al. (1973) indicated rational use of crop residues, either incorporated in the soil or placed on the soil surface, can maintain adequate infiltration rates, prevent soil surface crusting, improve soil aggregation and modify the transport and retention of water, heat and air in the soil. Proper use of crop residues is the most powerful tool available for reducing runoff, erosion and transport of sediment to streams. Crop residues have a further benefit that they contribute soil C that enhances soil quality. The manipulation of crop residues and C provides opportunities for relatively easy management over large areas. Systems which remove crop residues must be carefully designed to prevent serious consequences, i.e., loss of productive capacity as well as environmental degradation of runoff waters.

Crop residue management as a new technology requires some ingenuity; however, it does require appreciation of the value of crop residues. One example of real world experiences is described by Crovetto (1996), a farmer from Chile. Crovetto first farmed with traditional methods using the moldboard plow until excessive soil erosion became such a serious problem that he realized his life on the farm was in jeopardy. He then developed a new philosophy and strategy, "Make the best use of the land within its capabilities and achieve an economic return." He had a strong desire to improve soil quality and to leave the land better than when he obtained it. Thus, his improved residue management techniques resulted in improved soil quality while providing economical returns in an environmentally sound manner. He has accomplished real ecosystem management. In fact, the conservation system implemented has resulted in approximately 1 mm of organic material or soil development annually as a result of the leaving the stubble on the soil surface. He truly lives his philosophy that "The grain is for the farmer and the stubble is for the land." The importance of enhanced residue management and what it can mean for soil quality as well as improved environmental quality cannot be over emphasized.

Cover Crops

Cover crops in agroecosystems can be a cost-effective way of maintaining environmental quality. The recent interest in cover cropping is mainly a result of economic and environmental concerns. Traditionally, cover crops have been used to protect and cover the soil during the off season, primarily for erosion control. Simply holding the soil in place is the most obvious way that cover crops can reduce erosion. The cover crops also absorb the impact of raindrops which is notable when heavy rains fall on sloping soils that have poor infiltration.

Renewed interest in cover crops comes from their capacity to enrich the soil with organic matter and to improve water infiltration into the soil. However cover crops function in the same manner as agronomic crops and generally are not intended to be harvested for feed or for sale. The primary interest is in improving soil conditions for succeeding crops. Cover crops are beneficial in maintaining resource quality. They can partition the energy input into the soil that enables some climate control that may affect global circulation. Cover crops enable maximum energy utilization throughout the season to maximize C fixation during the off season. Cover crops are important in maintaining water quality as scavengers for excess nutrients and control infiltration with enhanced evapotranspiration. The enhanced evapotranspiration results in evaporative cooling and the cover crops can serve to decrease blowing dust as a result of wind erosion. Cover crops can further impact air quality through the fixation of CO_2 and sequestering carbon to decrease the greenhouse effect. In addition, through the process of photosynthesis, oxygen is released to the atmosphere. More important is the impact of cover crops on soil quality. The C input for sequestration, increased soil aggregation, increase in infiltration and decrease in erosion are critical functions of the cover crops. Cover crops also serve as a food source for soil organisms and are critical in maintaining the soil ecosystem from the physiological standpoint. Selected cover crops can serve as nitrogen fixers that also contribute to the overall nutrition of the soil. Thus, cover crops are very critical to agricultural ecosystems and help maintain resource quality.

Long-term projections of the impact of a cover crop are presented by Lee et al (1993). They used the EPIC model predictor for a typical "cornbelt soil" and evaluated changes in soil carbon for 100 years in the 0-15 cm depth. With current tillage methods, primarily conventional tillage, there was a 0.4 t ha^{-1} net loss in C. However, with increased no-till and increased no-till plus a cover crop, there was twofold increase in soil C attributed to the cover crop. Thus cover crops can contribute substantially to the long-term carbon input, particularly when the growing season is sufficiently long to allow adequate growth.

In most situations, annual cropping requires cover crops to be planted on an annual cycle. Information is coming to light about the relative proportion of the below-ground biomass in grasslands as opposed to those of the annual crops. Lindstrom et al. (1997) demonstrated the below-ground biomass for an alfalfa-bromegrass mixture sampled in the spring was higher than the above-ground biomass. Their results suggest a substantial amount of root biomass available in the grass species that may contribute to soil organic matter increase. Thus, the difference between annual and perennial crops suggests alternate methods for enhancing soil organic matter sequestration. The differences between annual and perennial crops in their distribution of the biomass needs to be further evaluated to determine the most efficient way to increase soil organic C using cover crops.

New Technologies for Tillage and Planting

New technologies for conservation tillage and "no-till" are currently being developed and recommended primarily for erosion control. Conventional tillage methods using the moldboard plow are declining due to energy costs and potential soil erosion. There is little information on the degree and extent of soil mixing by new conservation tillage tools that may affect soil C and soil CO_2 release. More information is needed on new conservation tillage tools primarily designed for residue management to meet conservation compliance. Conservation tillage tools, also referred to as combination implements, encompass many types of tillage and planting techniques that maintain at least 30% or greater residue cover after planting. These conservation tillage tools consist of a wide variety of basic components commonly found as part of other tillage implements mounted on toolbars that are adjustable to vary the residue cover left after tillage. Combination implements are often used for one pass tillage and chemical incorporation. Most operate in heavy residues without clogging and often require larger horsepower available in modern tractors. Reicosky et al. (1994) reported CO_2 losses following several different kinds of conservation tillage tools compared with the moldboard plow summarized in figure 3.

They found that the average cumulative CO_2 loss for five hours after tillage for four conservation tillage tools was only 31% of the moldboard plow. The moldboard plow treatment lost 13.8 times as much CO_2 as the area not tilled that compared to 4.3 times for the conservation tillage tools, excluding the Paraplow[2]. These results suggest progress in developing conservation

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[2]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

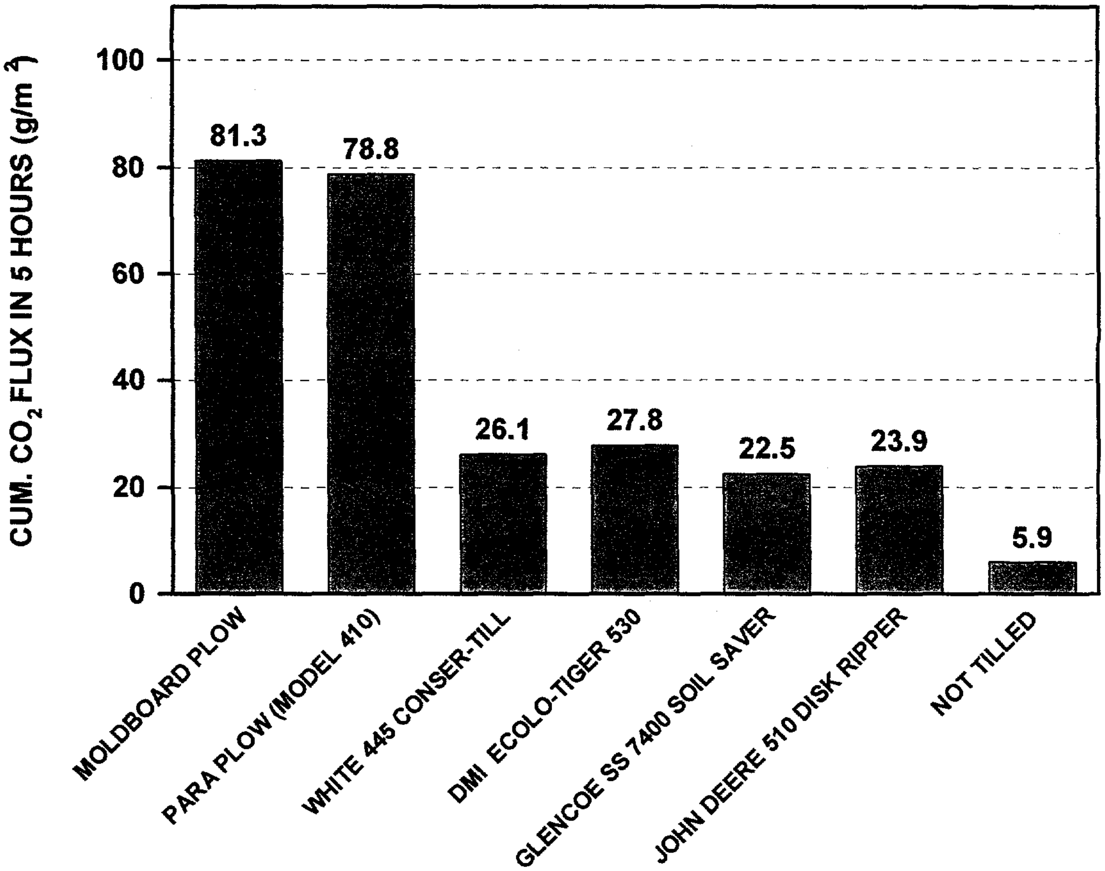

Figure 3. Tillage-induced CO_2 loss after various conservation tillage tools[2].

tillage tools for enhanced soil C management as well as leaving crop residue on the soil surface. New technologies currently being used by farmers show merit for improvement of soil quality and minimizing environmental impact through decreased CO_2 loss.

Environmental Costs

Society incurs some environmental costs in food production that are not reflected in the present economic balance sheet. So far we have not adequately charged ourselves for damage to the environmental quality with specific examples representing soil erosion, water quality issues and now more recently air quality issues. Because our soil, water and air resources are finite, we must always consider environmental costs in every decision that we make. Decreasing the impact on the environment now will provide value added as the cost of future remediation may be impractical or impossible.

Opportunities for new technologies

Environmental quality is directly linked to soil quality through soil organic C. The natural C cycle continues in agricultural production systems, but now we must learn to manage it in a "natural" way without perturbing the ecosystem. We must understand how we can manipulate the C cycle for our benefit in food and fiber production and still have a minimum impact on the environment.

There are numerous business opportunities for developing new technology that will protect and preserve the environment. New tillage equipment and concepts for minimizing tillage intensity will be beneficial in decreasing CO_2 release to the atmosphere. Examples are the Rawson Zone® till concept and strip tillage. Strip tillage concepts have been around for years, but now are becoming economically and environmentally more acceptable as pressures for conservation are applied. There are numerous opportunities for niche markets to make minor modifications for various kinds of tillage equipment around the U.S., because the conditions required for tillage in the southeast Coastal Plains are different from the northern Cornbelt and different in the Great Plains' area. Each area has its own special requirements that enable niche markets to develop. The development of direct seeding or no-till planters have come a long way in recent years and have provided opportunities for crop establishment with less tillage. While these have been accepted and have shown marked improvement in total production, we still have room for improvement.

Opportunity exists in the breeding of agronomic crops for more cold tolerance, disease tolerance, and generally higher yield. These breeding programs can also enhance the total C input and is a viable option for seed companies. Increasing the photosynthetic capacity of existing varieties would go a long way to enhance C input to the soil. Expanded efforts are required for cover crop development with emphasis on the root system as a form of C input. One need is to have annual cover crops with root morphological characteristics of perennial crops. A relatively larger root system would be beneficial in addressing environmental concerns with respect to erosion and infiltration and soil C buildup. Much of the emphasis of the breeding program has been on yield and economic return and now must start to shift toward maintaining a balance between direct economic benefits and environmental benefits. These opportunities for developing new technologies will help protect and preserve our soil, water and air resources for sustainable production in the years to come.

As opportunities for new technology and new business develop, we must learn to sell our products for what they do good for the environment. This will not only help the environment and the farmers, but will help everyone. Our clients are more than just farmers because we all require food to eat, water to drink and air to breathe. The goal is to educate both the farmers and the consumers on the need for new technologies for profit and yet protect the earth's limited resources. Thirty years ago one farmer fed 35 people, today one farmer feeds 129 people who take food security for granted. They, the consumers, however, are aware of the environment and must understand the environmental risks and costs in the production of food and fiber. These 129 consumers carry more votes than one farmer when it comes to policy decisions relating to the environment. Thus it becomes imperative that we all understand the political implications when making farm management decisions as they affect the environment.

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J.M. Libre, Elf-Atochem, SA, Central Research & Development, Paris.

HFCs contribution to the Greenhouse effect.
Present and projected estimations.

Abstract: This paper will review available data that can be used to calculate HFC contribution to the greenhouse effect and compare it to other trace gases contributions. This has been done for present time and also projections have been made to the horizons of 2010 and 2100 on the basis of available emission scenarios. Also industrial judgement on the likelihood of those scenarios is developed. Calculations can be made in two different ways: from GWP (Global Warming Potential) weighted emissions of species or by a direct calculation of the radiative forcing (energy captured by the molecule in w/m^2) based on measured and projected atmospheric concentrations of compounds.

Results show that HFCs corresponding to commercial uses (excluding fugitive or incidental emissions related to other processes) presently have a negligible contribution to the greenhouse effect in comparison with other trace gases like CO_2, N_2O and CH_4; 134a is about 0,014 % of the total.

The projected contributions are also very small even if very high emission scenarios are maintained for decades. In 2010 this contribution remains below 1%. Longer term emissions projections are difficult. However, based on the IPCC scenario IS92a, in spite of huge emissions projected for the year 2100, the HFC contribution remains below 3%. Actually many factors indicate that the real HFC contribution to the greenhouse effect will be even smaller than presented here. Low emissive systems and small charges will likely improve sharply in the future and have drastically improved in the recent past. HFC technology implementation is likely to grow in the future, reach a maximum before the middle of the next century; the market will stabilise driven by recycling, closing of systems and competitive technologies. This hypothesis is supported by previous analysis of the demand for HFCs type applications which can be represented by "S" type curves and by recent analysis indicating that the level of substitution of old products by HFCs is growing slowly. On the basis of those data and best industrial judgement, the contribution of HFCs to the greenhouse effect is highly likely to remain below 1% during the next century.

1-HFCs definition.

The HFCs (hydrofluorocarbons) are molecules containing carbon, hydrogen and fluorine. These compounds do not contain chlorine and therefore are not ozone depleter. Owing to the presence of hydrogen atoms in their structure, HFCs react with the OH radicals in the troposphere and are removed.

The focus of this study is HFC use in commercial products, with the major applications being refrigeration and air conditioning.

HFC-23 is not included in this study because it is a by-product of HCFC-22 production. Its emissions are controlled by production and demand for HCFC-22, a substance controlled by the Montreal protocol and various national regulations. HFC-23 emissions are also controlled by national regulations which prohibit venting. Perfluorocarbons (PFCs) are not HFCs. Their atmospheric behaviour is totally different because they do not degrade in the troposphere and show a very high stability and therefore cannot be considered in the same way as HFCs. Most PFCs are by products from other industrial processes .

Although HFC-23 and PFCs can be used in very special applications (very low temperature refrigeration) this remains a negligible use in comparison with HFCs applications.

2-Calculation methods of product contribution to the greenhouse effect.

2-1- Limitations of the GWP indices.

The GWP used alone is not an adequate tool to represent a product contribution to the greenhouse effect. These indices reflect intrinsic properties of the compound like its lifetime, its spectroscopic properties in the Infra Red spectrum and its molecular weight. It does not reflect the contribution of a given species to the greenhouse effect. To derive the real contribution of a compound to the greenhouse effect one needs to calculate the corresponding additional radiative forcing produced by that compound which depends on its real atmospheric concentration or the real quantities which are emitted to the atmosphere.

The radiative forcing in W/m^2 is indeed the key quantity to consider because it is at the origin of potential climate change.

2-2-Calculation method of radiative forcing.

The relationships described in (ref.1) between atmospheric concentration and the radiative forcing for a given species can be used to calculate its contribution to the greenhouse effect. This gives the real time contribution of species to the greenhouse effect because it calculates the amount of energy which is directed toward the earth surface by each compound as a function of its atmospheric concentration.

2-3-Integrated calculations of radiative forcing.

Calculations can be done on the basis of GWP weighted emissions of trace gases. Table (1) shows a GWP weighted emission calculation for CO_2, CH_4, and N_2O. This calculation takes into account the future impact of species on the greenhouse effect because GWPs are calculated by integrating the radiative forcing produced by compounds on a period of 100 years and are taken from (ref.2) and (ref.3).

Molecule	Emissions in kt/year	GWP_{100}	Emissions in 10^3·GWP.tonnes
CH_4	375 000	21	7 875 000
N_2O	8 950	310	2 776 000
CO_2	26 030 000	1	26 030 000
CFCs	354	6386*	2 260 780
HCFCs	273.3	1392*	380 610
		Total :	39 322 390

Table (1): Caculation of GWP weighted emissions for the greenhouse gases on the basis of emissions data coming from (ref.3) and (ref.5) in the case of CFCs and HCFCs.(*The GWP values in the case of CFCs and HCFCs are average values of the mixture of compounds émitted to the atmosphere)

It is important to realise that both methods of calculation consider HFCs which are either present in the atmosphere or emitted to the atmosphere. This varies from production data which do not reflect the quantity of product which is emitted to the atmosphere. In the case of HFCs which are being developed this can only be an upper limit of emissions.

3-Current HFC contribution to the greenhouse effect.

* Calculation on the basis of measured atmospheric concentrations.

HFC-134a is the major HFC currently contributing to the greenhouse effect. Its atmospheric concentration has been recently measured and is in average 2 pptv (ref.4). The corresponding HFC-134a radiative forcing is 0,0003388 w/m^2.

Current anthropogenic radiative forcing for other trace gases (CO_2, CH_4, N_2O and CFCs) is 2.45 w/m^2 (ref.2).

ThereforeHFC134a contribution in present days is about 0,014 % of those trace gases.

* Calculation based on production data taken as an upper limit.

The major HFC which is produced in 1995 is HFC-134a and the production reported by AFEAS is 73.7 kt for that year (ref.5). The corresponding atmospheric emission still needs to be determined and is far below production reported. Calculation of an upper limit can be based on the production number.

The GWP of HFC-134a being 1300 (ref.2) this corresponds to a total of 95810 10^3 GWP.tonnes.

HFC-134a upper limit contribution is therefore: 95810/39 418 200 = 0.243 %.

* Calculation on the basis of atmopheric emissions.

The United Nation Framework Convention on Climate Change (UNFCC) (ref.6) has issued numbers on 1994 HFCs emissions:

Molecule	Emissions in kt/year	GWP100	emission in 10^3 GWP.tonnes
HFC-134a	11.191	1300	14 548
HFC-125	1.141	2800	3194.8
HFC-152a	1.582	140	221.5
		Total :	17964.3

Table (2): HFCs GWP weighted emissions for 1994 using UNFCC data (ref.6).

This corresponds to a HFC contribution of 17964.3/39 340 354 = 0.0457 %

Based on these analysis, current HFC contribution to the greenhouse effect is negligible in comparison with other trace gases. As stated above production numbers which can be taken as an indication do not reflect the real situation of emissions to the atmosphere and resulting atmospheric concentrations. Results can be summarised as follows:

Present HFCs Contribution	
Calculated From Atmopheric Measurements	0.014 %
From estimated emissions	0.0457 %
Maximum possible from production	0.243 %

4- 2010 projected HFC contributions to the greenhouse effect.

Emission scenarios have been established to try to project the future contribution of HFCs to the greenhouse effect. USEPA has developed a scenario for HFC-134a up to 2010. They estimate a 134a emission for the year 2010 of 220 kt/year . On the basis of this emission scenario calculations of atmospheric concentration give an average value of 85 ppt (ref.8) for the year 2010. 85 ppt of HFC-134a correspond to a radiative forcing of 0.0144 W/m^2.

Other emission estimations developed by McCulloch (ref.7) give a value of about 160 kt of 134a emission in 2020.

134a and a variety of blends will be used in refrigeration and air conditioning equipments in 2010-2020. The HFCs blends are R404A, R410 and R407C. The HFCs used to constitute these blends are HFC-134a, HFC-143a, HFC-125 and HFC-32. The production corresponding to the use of blends and HFC-134a as foreseen are exposed in table (3).

Presuming steady state production increase through 2010, atmospheric concentrations of HFC-125, HFC-143a and HFC-32 can be calculated using a single box model (ref.9). The radiative forcing can be calculated using coefficients from (ref.2). Calculated concentrations and corresponding radiative forcing are listed in the table (3).

	Poduction Estimations for 2010*	Expected Atmospheric concentration to the year 2010, pptv	Corresponding radiative Forcing in W/m^2
HFC-134a	190 kt	75.9	0.0128
HFC-143a	13 kt	6.9	0.00096
HFC-125	30 kt	10.6	0.00212
HFC-32	20 kt	9.7	0.00107
		Total:	0.01695

Table(3): Calculations of radiative forcing on the basis of projected HFCs atmospheric concentrations in 2010.(*estimations for world wide HFC production based on future market needs, an Elf Atochem study).

Calculations have been conducted by IPCC on the basis of different emission scenarios. The average scenario of IPCC is called "Business as Usual" or IS92a. CO_2, N_2O, CH_4, CFCs, and HCFCs radiative forcing amount to about 3.29 w/m^2 in 2010 on the basis of the IPCC IS92a scenario. Contributions of each species are detailed in the table (4). Thus one can compare the different projections of HFCs radiative forcings with the radiative forcing projected for the year 2010 for other trace gases. The results summarised below show that the contribution of HFCs to the greenhouse effect, projected to the year 2010 is still very small and is of the order of 0.5 % .

Trace Gase	Corresponding Radiative Forcing, w/m^2 for the year 2010.
CO_2	2.23
N_2O	0.2
CH_4	0.56
CFCs and HCFCs	0.3
HFCs	0.02
Total:	3.31

Table (4), Calculations of radiative forcing of trace gases due to anthropogenic activities in 2010 on the basis of the IS92a IPCC scenario.

	Projected HFCs contribution for the year 2010, in %
134a, EPA Concentrations Scenario	0.435
HFCs from table (3)	0.51
EPA emission scenario	0.6

In conclusion in spite of rather large hypothesis on future HFCs emissions up to the year 2010, their contribution to the greenhouse effect remains negligible in comparison with other trace gases.

5-Long term HFCs projected contribution to the greenhouse effect.

There are no industry published estimations of long term HFCs scenarios i.e. up to 2100. This is because industry rather foresees a stabilisation of HFC demand before the middle of the next century as described further below. However, IPCC has developed long term scenarios for all

Trace Gas	Projected concentration in 2100 from IS92a (ref.2).	Corresponding Radiative Forcing in W/m^2 since preindustrial times.
CO_2	710 ppmv (approx.from (ref.2))	5.9
CH_4	3616 ppbv	1.054
N_2O	417 ppbv	0.510
CFCs		0.09
	Total:	7.55
HFC-134a	860 ppt	0.1457
HFC-125	262 ppt	0.05187
HFC-152a	82 ppt	0.00884
	Total :	0.206

Table (5). Calculations of HFCs contribution to the greenhouse effect in comparison with other important trace gases in 2100 on the basis of the IPCC scenario IS92a.

trace gases in order to calculate their contributions to the greenhouse effect. These projections seem very large given historical market patterns. Emissions of the HFC-134a, are projected to be of the order of 1000 Kt. The relative HFCs contribution in 2100 can be derived from the corresponding radiative forcing, as shown in table (5) which are calculated on the basis of the atmospheric concentrations resulting from the IS92a scenario of IPCC.

The HFCs contribution in 2100 is 0.206/7.76 = 2.65%.

The figure (1) also shows how that contribution evolves between 1990 and 2100.

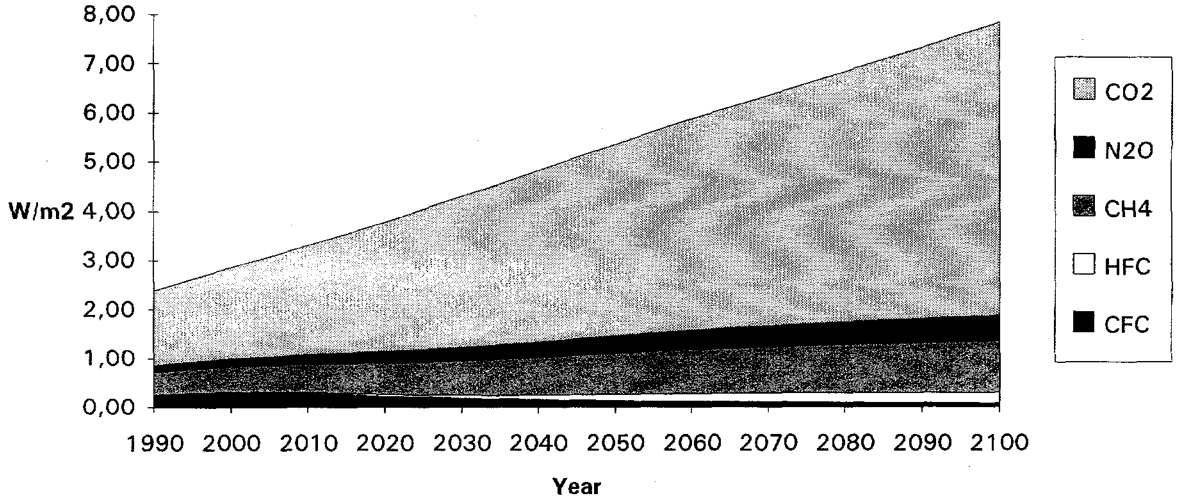

Figure 1: Anthropogenic trace gases contribution to the greenhouse effect on the basis of scenario IS92a from IPCC (ref.2).

The HFC emissions projected in 2100 by the IS92a scenario are very large and unrealistic. Present atmospheric concentration of HFC-134a is 2 pptv whereas the IS92a scenario of IPCC calculate a value of 8 pptv in 1995 which is 4 times larger than the real situation. Estimation of future HFCs demand on the basis of an analysis of CFC-12 production has been done by McCulloch (ref.7). It shows that the demand in the refrigeration and air conditioning applications should evolve as an "S" type curve of the following relationship:

$$\log_{10}P = \log_{10}A + k^i \cdot \log_{10}B .$$

Where P is the demand for CFC-12 for the year i, year zero being 1946, A value is 616, k is 0,965 and B is 0,0115.

According to this equation the demand for CFC-12 and consequently, corresponding HFCs applications, levels out at a little bit more than 600 kt and a probable emission much lower than that number. This tendency should result from several factors among which strong improvements in technology containment, smaller charges of fluids and competition with other technologies should play a very important role. This needs to be compared with a total HFC emission of about 1.8 million tonnes as foreseen by the IS92a scenario. In terms of emissions it is more than 3 times larger than industrial projections. Larger scenarios for HFCs emissions for the year 2100 have been published (ref.10) with a number of 4.048 million tonnes. This is about 6 times larger than the expected production from calculations described above and also appears to be unrealistic. Recent estimation of historical emissions in European Union suggests a level of substitution of the old products of about 5% in the case of HFCs which is smaller than what could have been expected (ref.11). This tendency seems also to confirm the different factors described above which are in favour of limited levels of emissions. In conclusion, long term projections still show a small contribution of HFCs to the greenhouse effect in comparison with other trace gases at the end of the next century. This contribution is below 3%. Long term market based projections show less than 1% contribution.

6-Comparison of HFCs contributions to the greenhouse effect with other radiative forcing.

The calculations done in previous sections compare the HFC radiative forcing contribution to the greenhouse effect with other direct contributions of the main trace gases: CO_2, CH_4, N_2O and CFCs. A broader, global perspective is also useful to compare HFCs radiative forcing contribution with other forcings.

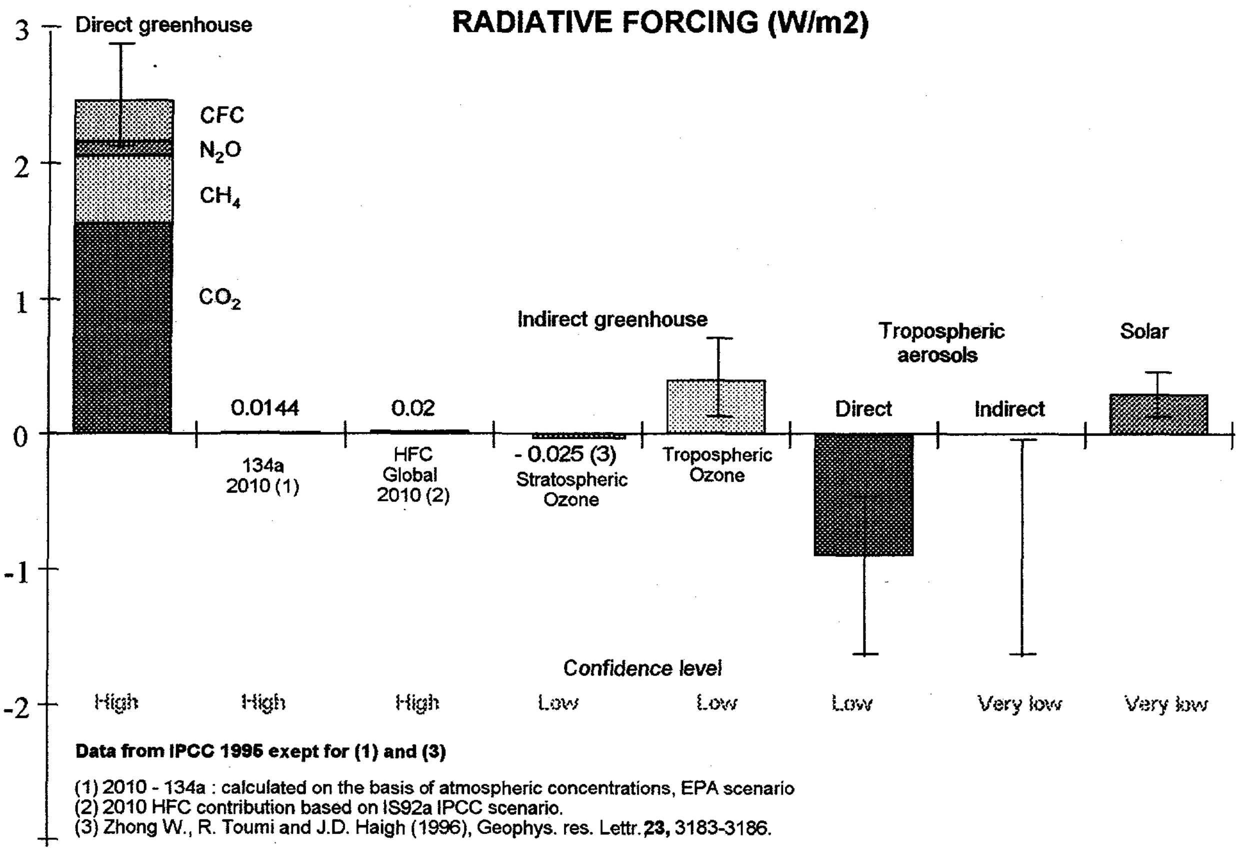

Figure 2. HFC greenhouse effect contributions projected for the year 2010 and compared with other contributions.

The figure 2 shows the status of knowledge from the 1995 IPCC scientific report regarding the different contributors to the greenhouse effect calculated from atmospheric concentrations in the case of trace gases. These are the present days contributions. The current HFC contribution is so small that it would not be visible on that scale. The HFCs projected contributions to the year 2010 continue to show negligible contributions both in comparison with other trace gases but also with other studied effects like for example tropospheric ozone effect. Another important conclusion which can be derived from this analysis is that the HFCs contribution to the greenhouse effect should remain below the present contribution of the CFCs even taking into account the indirect cooling effect of ozone depleting substances produced by the ozone depletion.

7-Conclusion: Present HFC contribution to the greenhouse effect is negligible. Projections to 2010 indicate that HFC contribution should be below 1%. Existing long term projections suggest small contributions through 2100 of less than 3% in spite of unrealistically huge emission scenarios. Industrial considerations based on passed demand for HFC type applications, improved technology and competition with future new technology suggest a significantly lower contribution. The contribution of HFCs to the greenhouse effect is therefore very likely to remain below 1%.

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Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies: TEWI-III

J. R. Sand S. K. Fischer V. D. Baxter

Oak Ridge National Laboratory
Building Equipment Technology Program
Oak Ridge, Tennessee

ABSTRACT

The use of hydrofluorocarbons (HFCs) which were developed as alternative refrigerants and insulating foam blowing agents to replace chlorofluorocarbons (CFCs) is now being affected by scientific investigations of greenhouse warming and questions about the effects of refrigerants and blowing agents on global warming. A Total Equivalent Warming Impact (TEWI) assessment analyzes the environmental affects of these halogenated working fluids in energy consuming applications by combining a ***direct effect*** resulting from the inadvertent release of HFCs to the atmosphere with an ***indirect effect*** resulting from the combustion of fossil fuels needed to provide the energy to operate equipment using these compounds as working fluids. TEWI is a more balanced measure of environmental impact because it is not based solely on the global warming potential (GWP) of the working fluid. It also shows the environmental benefit of efficient technologies that result in less CO_2 generation and eventual emission to the earth's atmosphere. The goal of TEWI is to assess total global warming impact of all the gases released to the atmosphere, including CO_2 emissions from energy conversion.

Alternative chemicals and technologies have been proposed as substitutes for HFCs in the vapor-compression cycle for refrigeration and air conditioning and for polymer foams in appliance and building insulations which claim substantial environmental benefits. Among these alternatives are:

- Hydrocarbon (HC) refrigerants and blowing agents which have zero ozone depleting potential and a negligible global warming potential,
- CO_2 as a refrigerant and blowing agent,
- Ammonia (NH_3) vapor compression systems,
- Absorption chiller and heat pumping cycles using ammonia/water or lithium bromide/water, and
- Evacuated panel insulations.

This paper summarizes major results and conclusions of the detailed final report on the TEWI-III study.

INTRODUCTION

The concept of total equivalent warming impacts, or TEWI, was developed to combine the effects of the direct emissions of refrigerants and polymer foam insulation blowing agents in end use applications with the indirect effects of energy consumption from the combustion of fossil fuels and generation of electricity used for heating or cooling. Direct contribution to TEWI is based on the use of the global warming potentials (GWPs) developed by the Intergovernmental Panel on Climate Change (IPCC) that use carbon dioxide (CO_2) as a reference gas (GWPs of CO_2 = 1.0 regardless of time horizon). TEWI provides a measure of the environmental impact of greenhouse gases from operation, service and end-of-life disposal of equipment. TEWI is the sum of the ***direct*** contribution of greenhouse gases used to make or operate the systems and the ***indirect*** contribution of carbon dioxide emissions resulting from the energy required to run the systems over their normal lifetimes.

The TEWI concept provides a useful tool in the assessment of various competing technologies. However, it is only one of many criteria that must be considered. Safety, health, and other environmental concerns, system initial and operating costs, regional energy considerations, and ease of maintenance are among other important factors that must be evaluated in the selection of the "best technology" for any given application.

The Alternative Fluorocarbons Environmental Acceptability Study (AFEAS)[1] and the U.S. Department of Energy (DOE) undertook this current study to assess the significant developments that have occurred in HFC blends and the application of non-fluorocarbons like HCs, CO_2 and NH_3 as refrigerants or foam insulation blowing agents. New data on the thermal performance of these compounds made it possible to perform an objective evaluation of the energy and global warming impacts of these "third generation" refrigerants and blowing agents. Refrigerant and equipment manufacturers have also made significant advances in the use of high pressure blends of HFCs as alternatives to HCFC-22 in both refrigeration and air conditioning applications. Analytical and experimental results are available to perform quantitative comparisons between HFC blends and the application of hydrocarbons, ammonia, and carbon dioxide as refrigerants. Additionally, new technologies for gas-fired air conditioning systems are being commercialized and operating data are available. This paper summarizes the major findings of this third study (Sand, et al. 1997)

The study focuses on evaluating the energy and global warming impacts of refrigeration and air conditioning technologies that could be commercialized during the phaseout of HCFCs. These alternatives include HFCs, hydrocarbons, ammonia, and carbon dioxide as refrigerants in conventional (and transcritical[2]) vapor-compression equipment, absorption chillers and heat pumps, and evacuated panel insulations for refrigerator cabinets.

As with the previous studies, analyses for end use applications in North America, Europe, and Japan account for cultural and technical differences in each region. The differences included such things as the ambient room temperatures and internal compartment temperatures for refrigerator/freezers, the sizes of refrigerators and thicknesses of insulation used, annual driving distances for automobiles, fuel types used for generating electricity, and climate differences for building heating and cooling loads. The results in this paper expand the work in the initial studies and indicate important regional differences in TEWI for some applications.

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1 AFEAS is an international consortium of fluorochemical manufacturers

2 The term transcritical is used to describe a vapor compression (reverse Rankine) cycle in which the working fluid is heated above its critical temperature in the compression step, and is cooled by ambient conditions prior to throttling and evaporation rather than being condensed to a liquid in a condenser as in a normal reverse Rankine cycle.

Analysis Limitations

TEWIs are calculated using "published" values for power plant emission rates. The heat content of various fossil fuels, regional generating capacities, plant efficiencies, and electric distribution efficiency are not used for a calculation of a value for kg CO_2/kWh of electricity delivered to the end-user. TEWI calculations have become widespread enough that good published data are available in the open literature for regional and national power plant emission rates. Slightly different trends are observed or conclusions can be drawn when calculations are performed using low regional emission rates as compared to the national averages. The range of rates is important for setting and achieving national CO_2 emission goals.

It is difficult to calculate an *absolute* value for TEWI. Most of its value comes from using it as a *comparative* tool for meeting a given refrigeration or air conditioning need under a standardized/controlled set of assumptions. A minimum of ±20% uncertainty exists for the GWP values assigned to refrigerants and blowing agents by the Intergovernmental Panel on Climate Change. These uncertainties, when taken in combination with the other estimates and assumptions of the analysis, make TEWI differences of ±10% statistically comparable. In many cases, established technologies with far fewer uncertainties and variables are being compared to systems under development for which significant uncertainties exist. When TEWI values are within 10% of each other, the technologies which show better energy efficiency should be favored as long as safety and environmental considerations are adequately addressed and costs are reasonable.

TECHNICAL EVALUATIONS

Alternative and Next Generation Technologies

Several alternative technologies for the conventional vapor compression (reverse Rankine) cycle employing halocarbons were identified in the Phase II (TEWI-2; Fischer et al. 1994) report that had been laboratory tested or had been developed to a point where they were considered as potential alternative technologies for those currently used. For example, employing CO_2 in a transcritical vapor compression cycle or using a high efficiency absorption cycle heat pump showed sufficient promise that they were revisited as potential alternatives in this study. Additional development work has occurred on triple-effect, direct-fired absorption chillers and absorption heat pumps for residential or light-commercial applications so that estimates of TEWI for this equipment are included in the appropriate sections of this paper. Alternative technologies which showed little near-commercial promise in the TEWI-2 report, such as thermoelectric cooling, magnetic heat pumps, thermoelastic heat pumps, etc., are not considered here.

Engine Driven Systems. Engine driven chillers and heat pumps are considered which employ the same reverse Rankine cooling cycle as conventional electric powered systems, but the electric motor is replaced by an internal combustion engine. This change has very little or no effect on the *direct* contribution to TEWI resulting from inadvertent releases of the working fluid to the environment, but it can change the *indirect* contribution associated with CO_2 emissions. Factors affecting the *indirect* contribution result from the primary energy source used to drive the cycle and any inherent differences in cycle efficiencies such as changes in part load efficiencies or waste heat recovery, resulting from this substitution. Thermally driven air conditioning and refrigeration equipment allows consumers to select natural gas as the primary fuel source in situations where there are significant differences in energy prices, utility rebates, prohibitive peak charges, or an opportunity for waste heat recovery. These opportunities have prompted considerable support for research and development (R&D) at HVAC manufacturers and other organizations for gas-driven technologies and have resulted in the commercial availability of packaged, natural gas engine-driven chillers and residential heat pumps. Since this equipment does represent a significant departure from conventional practices, TEWI calculations are presented for gas engine-driven chillers and heat pumps for comparison with electric-driven technologies.

Absorption Chillers. Absorption chillers are commercially available and represent a major share of the commercial air conditioning market in Japan and a portion of the market in the U.S. Absorption equipment is often used in "hybrid" plants working together with electric centrifugal chillers to reduce electric peak demands and utility demand charges. Even though absorption chillers generally have lower cycle efficiencies than electric chillers, absorption equipment is an effective component for managing utility demand charges and customer energy costs. Single-effect absorption chillers are also used in applications powered by waste heat, in which case the lower efficiency is not important. Direct-fired, double-effect chillers can simultaneously provide chilled water for air conditioning and hot water for cleaning or space heating thereby alleviating some requirements for a boiler. Gas fired single- and double-effect absorption chillers have higher TEWI than electric driven centrifugal chillers. Triple-effect absorption chillers are under development which will be 50% more efficient than current double-effect equipment.

Absorption Heat Pumps. Absorption heat pumps are under development for heating and cooling in residential and light commercial applications. One or two manufacturers have prototype units undergoing laboratory and field testing in 1998, with a goal commercialize this technology in the 1999-2000 time frame. Seasonal performance data are available for these prototype units. Compared to current electrically driven heat pumps, these systems have a slightly lower TEWI in areas where heating load dominates, but show larger TEWIs in areas where cooling loads dominate.

Advanced Vapor Compression. Conventional vapor compression technologies continue to be improved and efficiencies of refrigeration and air-conditioning equipment will be higher in the future. Developments leading to these improvements include the use of higher efficiency motors and compressors, more effective heat exchangers, and adaptive controls. Refrigerant losses from applications such as automobile air conditioning and supermarket refrigeration have been, and will continue to be, reduced. Supermarket equipment now under development and entering the market, such as systems that circulate a chilled secondary fluid or distributed compressor rack designs, show promise of dramatically reduced refrigerant charge and emissions. Regulations and refrigerant costs provide an incentive to reduce emissions of refrigerant by eliminating intentional venting during servicing, improving maintenance practices and procedures, mandating charge recovery and recycling, and minimizing leaks.

Compression systems will continue to improve, but it is not known how quickly or how significant these improvements will be. TEWI calculations for fluorocarbon compression systems summarized in this paper are based on demonstrated production, modeled efficiencies, historically verified refrigerant loss rates, or proven performance from R&D research laboratory tests (which would probably show different efficiencies than optimized production designs). Refrigerant loss rates used in the two previous studies in the series (Fischer et al. 1991, Fischer et al. 1994) were from a time when it was standard practice to simply vent the refrigerant charge during servicing.

These practices are now prohibited in the United States and elsewhere and it is clear that historical emission rates are no longer appropriate. Current and projected refrigerant make-up rates based on information from industry were used for cases presented in the third study (Sand et al. 1997).

TEWIs of viable, commercially available compression systems are compared in some cases to estimated TEWIs for emerging technologies which have not been developed beyond laboratory prototypes. In these instances the best available laboratory or computer modeled performance data are used for new technologies. While helpful in identifying future technologies that may have lower global warming impacts, the reader must be careful not to attribute too much significance to comparisons with minor differences in TEWI because of the more speculative nature of the data used for these non-commercialized, emerging technologies.

Evacuated Panel Insulation. Evacuated panels which can be used to improve appliance and building insulations have very low thermal conductivities. Thin, flat panels are constructed using a filler material such as aerogel, diatomaceous earth, or glass fibers enclosed by one or more plastic or metal membranes under a vacuum. "Total panel" thermal conductivities are usually significantly higher than the "center-of-panel" measurements usually cited, because heat transfer through the plastic or metal membranes along the surfaces and near the edges of the panel is enhanced. Evacuated panels, at last report, are being used by a Japanese refrigerator-freezer manufacturer for a commercial product. While evacuated panel insulation could be an effective means to reduce TEWI especially for refrigerator-freezers, these panels are quite expensive compared to the foamed polyurethane insulations usually used. There continues to be doubt that panels used for cabinet insulation will retain a vacuum and maintain high thermal resistances over the 15-20 year lifetime of an appliance. Such panels could be used in conjunction with blown foam insulation to improve the thermal properties of appliance cabinets or to achieve comparable performance using thinner walls, thereby permitting more usable internal volume.

Refrigerator-Freezers. The latest available published information indicates no significant difference between the measured energy efficiency of refrigeration circuits utilizing HFC-134a or Iso-butane (HC-600a) as the refrigerant despite ideal cycle calculations which show a 2 to 5% thermodynamic efficiency advantage for HC-600a depending on specific operating conditions.

Insulating foams blown with cyclopentane or pentane isomers consistently show higher thermal conductivities than HCFC-141b blown foams; refrigerators produced with these HC foams would have 8 to 10% higher energy consumption assuming the same foam thickness. Most of the R&D work for this application has centered around finding an alternative for HCFC-141b, which is scheduled for a 2003 phaseout date in the United States. Current data shows HCFC-141b blown foam has the lowest thermal conductivity and highest insulating value of the foam blowing agents investigated, which results in the lowest energy consumption for the refrigerator design when equivalent wall thicknesses and internal volumes are assumed. Optimized HFC-245fa or HFC-365mfc blown foam is expected to show similar conductivity and insulating values. Vacuum panel technology can further improve cabinet thermal performance but with significantly increased costs. Designs consistent with the "average" models prevalent in each region were postulated based on data from manufacturers and industry associations and consistent assumptions on components, wall thicknesses, and internal volumes were applied.

The direct contribution of HFC-134a and the various halocarbon blowing agents range from 8% to 15% of the TEWI for refrigerator-freezers in North America. Only one-tenth of the

TEWI of refrigerators using HFC-134a as the refrigerant and HCFC-141b as the blowing agent is due to fluorocarbon emissions. Almost all of the direct effect is due to the foam blowing agent. Mandatory refrigerant recovery results in a 1 to 2% decrease in total lifetime TEWI (direct and indirect).

The direct contribution due to fluorocarbons in European refrigerator-freezers is about 19% of TEWI, primarily because their refrigerators are smaller and have lower annual energy use. The lower CO_2 emissions rate for electric power generation in Europe, which has a higher percentage of nuclear and hydroelectric power generation than North America, is also a factor.

In 1996 hydrocarbon refrigerators were available in both manual and automatic defrost models in parts of Europe, particularly Germany. Iso-butane (HC-600a) frost-free refrigerator designs which incorporate a foamed-in evaporator and explosion proof electrical devices or switches located outside of the food compartments are now being built and sold. These additional safety precautions and system components have resulted in higher manufacturing, purchasing, and servicing costs for refrigerators using HCs. Flammable refrigerants are not used in United States or Japanese refrigerators because the associated safety risks are considered unacceptable.

Unitary Air Conditioning Equipment. HFC mixtures and hydrocarbons have been proposed and tested as substitutes for HCFC-22 in unitary equipment. Building codes and safety concerns in most developed countries limit the use of hydrocarbons in applications where a refrigerant leak could result in explosive mixtures at atmospheric conditions. These restrictions apply to air-to-air heat pumps and air conditioners in North America and Japan (90-95% of the approximately 214 million unitary heat pumps and air conditioners in the world). Hydrocarbon refrigerants might be able to satisfy safety requirements for the air-to-water or water-to-water unitary systems used in Europe where the entire refrigerant charge remains outdoors, but leakage rates for these hydronic units are typically small, therefore any refrigerant choice results in a small direct TEWI effect.

Comparisons were made for HCFC-22 and two non-flammable HFC mixtures identified as likely HCFC-22 replacements in the Air-Conditioning and Refrigeration Institute (ARI) HCFC-22 Alternative Refrigerants Evaluation Program (AREP). The direct TEWI effects for both HCFC-22 and HFC alternative mixtures are a small fraction of the total in each case. Energy efficiency is very important for this application and contributions to global warming from energy usage with HFC blends are about the same as current technology air conditioners using HCFC-22; engineering optimization is expected to reduce energy use and resultant CO_2 emissions with the mixtures in future systems. Propane's performance as a refrigerant for air-to-air equipment was degraded by assuming an intermediate heat transfer loop was needed to keep this flammable refrigerant out of the occupied space. Compared to conventional, electically-driven heat pumps, engine driven heat pumps and Generator Absorber Heat Exchange (GAX) absorption heat pumps give lower TEWIs in areas where heating loads predominate and larger TEWIs in cooling-dominated regions.

Refrigerant make-up rates and end-of-life losses assumed in this study for 1996 vintage equipment were suggested by industry experts in each region and are the same as those used for the 1994 study; a 4% annual make-up rate and 5% loss of charge upon equipment decommissioning.

Supermarket Refrigeration Systems. These systems have historically used large refrigerant charges and experienced high leakage rates. The current high costs of refrigerants and environmental regulations are resulting in better efforts at refrigerant containment and lower loss rates. The most likely substitutes for CFCs and HCFCs in supermarket refrigeration are mixtures of HFCs, although use of ammonia chillers with indirect heat transfer loops is seeing some use in Europe. Alternative refrigerants and technologies are considered as replacements for R-502 in low temperature refrigeration (e.g. freezers and ice cream display cases) and HCFC-22 in medium temperature refrigeration (e.g. meat, fish, and dairy cases). The alternatives include HFC mixtures in direct expansion systems using remote and distributed compressor racks and HFC mixtures or ammonia in secondary loop refrigeration systems.

Secondary loop systems are a means of reducing refrigerant charge and controlling leakage and emissions, albeit with first cost and efficiency penalties. This approach to commercial refrigeration avoids long, field erected refrigerant lines which run to individual cases in the store and confines the refrigerant charge to a smaller, more leak-tight refrigeration circuit in the store's equipment room. The secondary loop approach must operate over a larger temperature lift to accommodate the intermediate level of heat exchange and has an additional parasitic load associated with a fluid circulating pump. Building codes in many countries make it expensive, or in some cases prohibitive, to use ammonia in most supermarkets because of the public safety risks in the densely populated areas near the stores. When ammonia is used, secondary loops are usually mandatory so that the refrigerant lines do not enter the retail sales areas of the building .

Another alternative commercial refrigeration design, usually referred to as the *distributed system* approach, moves the compressor with its associated high pressure liquid and suction gas lines as close as practical to the case evaporator loads and utilizes a closed-loop, water circuit to reject the heat of condensation. The distributed system with compressors located near or in the refrigeration cases requires a larger number of smaller compressors located throughout the store. It, too, has a parasitic load associated with the heat rejection water loop and pump albeit smaller than for the secondary loop system. Both the distributed system and secondary loop approaches drastically reduce the refrigerant charge (by as much as 75-90%) and make it more practical to minimize refrigerant leaks and maintain system efficiency.

Chillers. The air conditioning loads of larger commercial buildings are generally met with water cooled chillers which use cooling towers for condenser cooling and distribute chilled water or a water/antifreeze mixture to building fan coil units. Centrifugal or screw compressors are used for larger, 350 to 75,000 kW (100 to 10,000 ton), chillers because of the high volumetric flow rates of refrigerant required. Replacement of CFC refrigerants in chillers with HCFC and HFC alternatives has had the most significant impact on the direct contribution for this equipment. An increased awareness of the environmental impact of refrigerants, recently enacted legislation which requires extensive record keeping, increasing refrigerant prices, and improved equipment designs have all served to dramatically reduce refrigerant loss rates from chillers. Typical annual loss rates of low pressure refrigerant from new centrifugal chillers has been reduced more than 50- fold in seven years. New systems are equipped with electronic alarms alerting operators to the first indications of leaks or unusual purge pump operation. Refrigerant leak and annual make-up rates have been improved to the point where the GWP of all chiller refrigerants has very little effect on the total TEWI.

The TEWI of chillers has been reduced through remarkable improvements in chiller efficiencies as well. Rating point COPs for new electric chillers have increased by about 30% (from 5.0 to 7.0) over the last ten years which has resulted in a proportional decrease in the indirect contribution from CO_2 emissions. Market competition and a greater emphasis on lower life cycle operating costs, as opposed to governmental legislation, are responsible for these dramatically improved efficiencies. Even with these improved efficiencies, lifetime energy consumption is the predominant factor influencing TEWI for this equipment. The direct contribution to TEWI for fluorocarbon-based technologies is less than 6 to 7% of the total (less than 1% for the HCFC-123 machines) even when the maximum annual leak/make-up rate is assumed.

Efficiency of natural-gas-engine-driven chillers and of absorption chillers has also been improved. Gas-powered chillers are sometimes used together with electric chillers to decrease peak electrical demand and lower building operating costs. TEWI results for gas-engine-driven and electric-driven chillers are essentially equal when the CO_2 emission rates from electric power plants are in the 0.60 to 0.70 kg CO_2/kWh range. Gas-fired absorption chillers (double- and triple-effect) continue to have TEWIs 25 to 50% higher than comparable vapor-compression technologies. The decision to utilize absorption chillers is based on operating costs when favorable conditions exist.

TEWI calculations were made for both vapor compression and absorption chillers of two discrete capacities - 1,200 and 3,500 kW (350 and 1,000 tons) - in North America. These calculations were based on the use of Integrated Part Load Values (IPLVs) and annual operating hours for an Atlanta, Georgia office building. Direct contributions to TEWI were computed for centrifugal and screw chillers using HCFC-123, HFC-134a, HCFC-22, and NH_3 as refrigerants for a range of annual make-up rates up to 4%. 1993 vintage CFC-11 and CFC-12 machines were included for comparison purposes. Similar computations were made for 1,055 kW (300 ton) chiller options in Japan. In this case, rated full-load performance data and associated annual operating hours for a Tokyo location were used. Vapor compression chillers using HCFC-123 and HFC-134a and direct- and indirect-fired absorption chillers were considered.

Automobile Air Conditioners. Automobile air conditioning was identified in the two previous studies as one of the few applications in which the direct contribution of fluorocarbon refrigerant emissions was a significant fraction of total TEWI. While the conclusion has not been contested, the approach taken in those studies has been criticized because of reliance on efficiency data at a single design point coupled with estimates of equivalent full-load operating hours. These two assumptions greatly simplified the analysis but cannot account for varying performance over a range of operating conditions or the effects of different climates. The present analysis addresses these concerns by incorporating efficiency differences across a wide range of operating conditions, regional variations in ambient temperature, and changes in air conditioner on-time with ambient temperature.

Three fundamentally different cooling systems were considered; a conventional HFC-134a-based system, an HC-600a-based system, and a transcritical vapor compression system using CO_2 as the refrigerant. The hydrocarbon system in this study includes the use of a secondary heat transfer loop to isolate the flammable refrigerant outside the passenger compartment. This essential safety feature reduces cycle efficiency relative to direct expansion systems, adds parasitic energy consumption due to the fluid pump, and increases overall system weight.

Though the analysis includes much more detailed information than the earlier studies, it relies on the same approach of evaluating energy use for operating and transporting the air conditioner and the direct contribution of refrigerant emissions. Results are computed for thirteen different countries. Depending on the location and assumptions about lifetime refrigerant emissions, the alternative systems show some potential for lower TEWI than the HFC-134a system. Prototypes of both alternatives are being studied by manufacturers (the CO_2 system to a much greater extent than the HC system), however more extensive prototype and field trial testing will be needed before fully developed, reliable commercial designs will be available.

Conclusions

Several broad conclusions can be drawn from the study.

TEWI evaluations emphasize the combined environmental effect of the direct emission of greenhouse gases with the indirect effects of CO_2 emissions from energy use by equipment using these fluids as refrigerants or blowing agents. This is only one criterion in selecting technologies to meet any given application. System costs, operating costs, regional energy costs, ease of maintenance, etc., are equally important factors to consider in selecting the most appropriate technology for any specific application.

Reductions in TEWI through the use of ammonia or hydrocarbons as refrigerants are insignificant for refrigeration systems with low emissions and may lead to an increase in energy use when applications must meet the same safety design criteria currently defined as acceptable for fluorocarbon refrigerants.

The direct effect of HFC refrigerant and blowing agent emissions in refrigeration and insulation applications appears greater when 100 year GWP values are used in calculating the TEWI (the 100 year GWP values are approximately three times the 500 year values used in the 1991 report).

Non-fluorocarbon technologies may penetrate into mainstream refrigeration and air condition application areas, but it appears unlikely that this penetration will be significant in the near future.

Alternative/non-fluorocarbon technologies need to compete with improving energy efficiencies of conventional refrigeration, air conditioning and insulation technologies. Both electric and gas-driven technologies will continue to improve. Efficiencies of conventional technologies are likely to increase as equipment and foam formulations are further optimized for replacement refrigerants and blowing agents.

Innovative design and modifications of standard practice can lead to significant reductions in TEWI for refrigeration systems using ammonia, fluorocarbon, or hydrocarbon refrigerants. These include mandatory refrigerant recovery and recycling, distributed refrigeration systems, charge reduction, elimination of flared fittings and fewer brazed connections, highly efficient purge units, improved heat transfer surfaces, high-efficiency compressors, etc.

Average annual CO_2 emissions from electricity generation vary over a wide range for individual regions and countries -- from 0.0 to over 1.0 kg CO_2/kWh compared to the 1993 World average of 0.58. Emission rates also vary with season and time of day depending on how the generation fuel mix changes. Overall TEWI values in any particular location will be peculiar to the local electrical power generating efficiency and generating characteristics. The direct contribution can range from all (or nearly all) of the TEWI for all applications in areas with low CO_2 emission rates [using mostly nuclear or hydro power] to a minor fraction of total TEWI for areas with high rates [using coal].

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LESSON LEARNED CASE STUDY: WHAT THE HISTORY OF OZONE DEPELTING CHEMICAL PHASEOUT MAY TEACH US ABOUT HOW TO APPROACH INTERNATIONAL CLIMATE CHANGE POLICY

Steven E. Younis
Conceptual Engineering Group, Inc.
Crofton, Maryland

Dr. Daniel P. Verdonik
Hughes Associates, Inc.
Baltimore, Maryland

Abstract

The world approached the production phaseout of ozone depleting chemicals (ODCs) in a conservative manner when the Vienna Convention was convened. The initial task was to not only recognize the problem within the small select science field, but make the world's political leaders and people aware that the problem of ozone depletion existed and was a very real threat to the Earth's environmental stability.

Several years later, Meetings of the Parties to the Montreal Protocol to Protect the Stratospheric Ozone Layer, began occurring on a regular basis. Long term goals on production reduction levels of chlorofluorocarbons (CFCs) and Halons were set. As time proceeded and support increased, rapid acceleration in production phaseout dates were implemented worldwide. This greatly impacted industry's plan to research, develop, and implement replacements for these agents. It also effected the user, who needed to analyze alternatives, develop implementation schedules, and account for economic support to change their uses of these chemicals. The impacts were widespread from small cleaning processes to the defense of countries. We use CFCs and Halons in every aspect of today's life and replacing them, though possible, needed sound long term implementation and economic planning. The trials and tribulations that industries such as the foam, refrigeration, air conditioning, fire protection, and manufacturing industries have gone through to meet the accelerated challenges are great. This fight is not yet over. Alternatives have yet to be fully implemented, long term effects analysis are not yet completed, budgets have not caught up with the rapid phaseout, and supplies of ODCs are dwindling quickly, as well as increasing in cost at a rapid rate. This is being felt from car owner all the way up to the national defense of countries.

The paper will briefly describe the historic events and developments that occurred to industry and the users, from a political, environmental, and business perspective. From this, valuable lessons can be learned and we can plan for the future well in advance, in order that we are not caught off guard again. A very real environmental problem exists with global climate change. This is being increasingly recognized by both political leaders and citizens alike. From what we have seen with ODC phaseout, we can potentially project what course the future

holds, its direction and impacts on International Climate Change Policy, and use it to our advantage. The problem is real, the policy and groundwork are set, the world is becoming more aware and concerned, and now we must learn from the recent past to set environmental, social, business, and economic directions for the future. The correlation is there, and we will attempt to show how it can be used to the benefit of all. In the long run, it not only is sound environmental protection to plan ahead, but for many concerned, it is a combination of sound economics and good business practice.

Ozone depleting chemical phaseout

Prior to the Montreal Protocol, Halon was specified as part of many fire protection building and special fire protection systems. Halons, which are extremely effective fire fighting agents and the worst of the ozone-depleters, became the cure for many fire protection needs, prescribed rightly and wrongly, but they became a victim to their own success. The ironic part is no one knew then, or completely understands now, why Halon works.

As the Montreal Protocol took hold and the fire protection community realized its fix-all agent may be removed, it reacted like any others, denial. The fire protection industry and users alike, all set their minds to the fact that Halon could not be replaced. It was critical to save lives, became their battle cry, but the international community was convinced that alternatives were available. A small group within the community realized that if you weren't part of the solution, you were part of the problem, and developed methodologies that could be used to perform an orderly phase-out of Halons, if required. In 1990, the Parties voted to cease the production of all CFCs and Halons, by the year 2000. The production phaseouts were then accelerated again during the Parties' 1992 meeting in Copenhagen, Denmark. This meeting accelerated the phaseout dates to January 1, 1994 for Halons and January 1, 1996 for CFCs. Other ODC communities that were not prepared had to play catch-up. The Halon sector started to become the model for all of the ODC sectors within the Montreal Protocol assessment process.

Once panic receded, the masses within the fire protection community mobilized and developed responses in tune with the times. They set out to comply with this environmental requirement, like so many had done before them, their goal was to control and minimize the environmental impacts, not solve them. They developed research programs that would take years to accomplish and cost tens to hundreds of millions of dollars. It was another search for the holy grail, the son of Halon. A gas that had all of the firefighting capabilities of Halon, without the environmental problem of ozone-depletion.

As each new agent of the month failed for one reason or another, the realization set in that this goal might not be the best one. This is especially true in light of the fact that no one fully comprehends why or how Halon works in the first place. We were left with trial and error, with only a very basic scientific understanding to go on. Each failure brought us closer to the final realization that we were going nowhere fast, but and its a big but, some of us were learning that the performance parameters of a material can not be separated from the environmental parameters. They need to be considered together. Slowly the philosophy moved away from just finding Halon replacements to where it should have been all along, to fire protection because that is the real need.

The same can be said of the other ODCs. The requirement wasn't to replace CFC-113 or TCA as a solvent, it was to clean and degrease, or better yet remove the need to clean and degrease in the first place. The ODC community had a revelation. The answer to replacing Halon isn't to find a replacement for Halon its to find other ways to meet the fire protection requirements and that must come from the fire protection experts. To replace CFCs, we needed new ways to meet air conditioning & refrigeration requirements or foam blowing requirements and that must come from the experts. The code had been broken and the solutions to ODC problems began to surface.

The key was to be active in search of solutions to the problem, not replacing the chemicals. In most cases, ODCs are the most effective performance agent and provide the most optimum result for the application. Now came the logic of addressing the applications, not the agent equivalents. By bringing the problem back to the originator of the requirements, most of the problems found solutions, but not all. In essence, utilizing system engineering. This engineering requires the understanding and development of what your requirements are, not just addressing a direct replacement agent or process. It requires analysis of operations, goals, impacts, and economics, all as one system. The driver may be the agent replacement, but the alternative has to have a corporate, industry, or application wide perspective.

The refrigeration and foam industries found and implemented replacements. The solvent industry worked towards the critical deadline of January 1, 1996 phaseout and has delivered many products and methodologies to the market. Some still need to be evaluated for efficiency or toxicity over the long term, but many industries have replaced solvent needs with the new processes or agents. The cleanliness requirements dictated the alternative, not the performance against the previously used ODC solvent. The users of Halons, determined what their fire protection requirements were and determined that Halon was the only solution for some of them for the present time. How much? About 5% require Halon in new designs and 25% continue to need to use Halons in existing designs. Unfortunately this represents some of the most difficult, expensive and critical uses of Halons, such as commercial and military aircraft, commercial and military ships, ground combat vehicles, oil and gas pipeline works, etc. This was not unexpected and the solution to these problems again came from the fire protection community in the form of banking, where less important uses of Halons were discontinued, generally by attrition, and the Halon placed in a reserve to support the uses of Halons where they were required. The needs of these critical applications are being met through the banking systems established in private industry and government departments all governed by market forces with very little regulation. Availability of reserve supplies fluctuate, but are limited over the long term.

Don't take that to mean that this was done in spite of the EPA, it wasn't. It was done with a EPA, who had the forethought and insight to see what could potentially happen. They became a partner for example, with the fire protection community, in working with consensus standards generating bodies, like the National Fire Protection Association (NFPA), the American Society for Testing and Materials (ASTM), and building/fire code generators, in enabling new technologies, as they did with all industries involved. The EPA also helped to maintain an even keel on the international front. Time and time again, EPA fought back the urges of the environmentally extreme groups in the international community, that were fighting for more regulatory controls. They kept in mind that there is a balance between environment and business functions, which in turn, keeps the process moving at a level of reality that all parties may be satisfied by. This partnership has worked well and results speak for themselves. The U.S. has re-asserted itself as the global leader in specialty hazards fire protection technologies. The majority of new technologies that are gaining global, wide-spread acceptance are from U.S. companies. Similar results are happening in other ODC sectors.

In terms of evaluation of success, the Montreal Protocol is generally viewed as an environmental success, but the real impacts are much further reaching. For example, within the fire protection community this new philosophy is really taking hold. We are taking a hard look at fire fighting techniques, agents and training to see where the environmental impacts can be lessened. U.S. manufacturers are introducing their environmentally safe line of fire fighting agents, marketing them not as environmental technologies, but as fire protection technologies that are better for the environment. These are some of the very positive outcomes from the Montreal Protocol. They are having profound effects on the fire protection community, and will probably also have, profound effects on the future of environmental protection in the U.S.

But the whole picture isn't rosy. In addition to the normal turmoil associated with change, there are specific challenges to be overcome, both technical and programmatic, with the Montreal Protocol. One area that needs to be emphasized again, is the EPA's role in keeping the Montreal Protocol process from degrading into a regulation match where each Party tries to out green the next. The EPA has been successful so far, but they will need to continue to fight and will need the weight of the whole U.S. behind them.

Another high impact area is in the phase-out for Article V countries. We, in the Article II phase-out countries, have made great strides that can be completely wiped-out if the Article V countries emissions can't be controlled during their 10 year grace period. The lessons that we have learned in implementing the Montreal Protocol should not be ignored. The process right now is degrading into what some call an environmental welfare state. Instead of paying these countries to not grow wheat we can assist them with fire protection. We need to advocate having fire protection engineers solving fire protection problems in the Article V countries just as we have done, and are continuing to do in the Article II countries. There are huge opportunities to improve environmental performance of fire fighting in these countries but just as importantly, the U.S. can assist them in increasing their fire protection performance as well. The benefits to the U.S. and other Article II countries can not be just measured environmentally. The country or countries that assist or lead in solving this problem with the Article V countries, will have the competitive edge.

Other factors have played roles in the still developing scenario of ozone depleting chemicals. Several foreign governments have imposed stricter laws controlling ODCs.

Countries such as Australia, in response to the seriousness of ozone depletion over that sector of the world, and the epidemic rate of increase of skin cancer in that country, has imposed use phaseouts. The German government has also imposed use restrictions across the board for all CFCs and Halons. Both countries have also restricted HCFC use, taking into early consideration the whole scope of both Class I & II ODCs. The German government has also taken steps to review and has begun controls on HFCs. Scientific correlations connecting ozone depletion and global warming, previously unrecognized, are now becoming more prevalent and accepted.

The laws and regulations put into place by both of these governments give us a clear picture of what is happening or will happen eventually on the international scene. Subsequent meetings of the Parties have led to debate and decisions geared toward addressing the next step in the phaseout process, use restrictions and phaseout. The steps are being addressed and implemented in a gradual, methodical process. Items such as listing of applications and voluntary use restrictions are leading us in the direction down the path toward overall use restrictions, and eventually, total use phaseout of ODCs.

In summary, the status, results and impacts of the Montreal Protocol need to be looked at from a larger scope than just ozone-depletion and the environment. For fire protection, as well as the refrigeration, foam, and solvent industries, it has provided the impetus needed to again begin to make technological advances. There is still much to do. CFCs and Halons are still required in some applications. We are on the right road and inevitably will find solutions.

<u>What should we learn from ODC phaseout?</u>

The major lessons that should be extracted from examining the history of ODC phaseout, are forethought, planning, and the use of system engineering. They should be used as one integrated package.

Each industry or user should develop a methodology for analyzing applications. The system should not be chemical requirement oriented in its analysis. The methodology should analyze and develop a plan to optimize the function of the application, as the driving requirement. There is a distinct, but subtle difference. The original use of the chemical, in this case, ODCs, may have been over specified for the application; Halon 1301 may not have been required to protect many areas; TCA may have cleaned the quickest, cleanest, and most inexpensive, but was it necessary; CFC-12 cooled efficiently across the board, but at what costs. There are replacements for these agents, for most applications. Costs may be more expensive, but none the less, the options have been found and are being implemented. Some applications remain, but will eventually have replacements. Class II ODCs are scheduled for production phaseout, and in all eventuality, will probably face acceleration of production phaseout, as did the Class I ODCs before them. Following this will be a move towards use restrictions and finally use phaseout. This is where users and industry must keep an eye towards the future. Plan and realize now to stay in line with what is to come, take the systems engineering approach.

The systems engineering approach should

1. Develop the users short and long term requirements,
2. Develop the users short and long term economic impacts,
3. Analyze worker health, safety, and toxicity parameters,
4. Analyze environmental impacts,
5. Analyze current and future trends in environmental regulations,
6. Develop the short and long term impacts to the application,
7. Set effectiveness and use criteria,
8. Set a schedule for R&D, T&E, and implementation,
9. Develop the budget to accomplish the process,
10. and Constantly be reviewed and updated during the process.

Many thought ozone depletion was environmental babbling and that the supposed problem and its subsequent regulations would get lost or buried in the shuffle. They were wrong. Though it was initially an environmentally driven problem, it became a politically recognized issue, driven by economic, business, and social impact problems. The more it was recognized to impact economy, business, and life in general, the more reality struck and the more the users realized what they had to do address the problem.

How do we use this to plan ahead for International Climate Change Policy?

Many of the lessons that need to be drawn on, if we are to successfully face other major international efforts such as the International Climate Change Policy, have been presented in the ODC phaseout framework . While many are skeptical of the global climate change and greenhouse effect problems, as they were with ozone depletion, the problem is now in the political forefront and is likely to follow the same track as ozone depletion and its regulation trail. Users and industry alike, must recognize now that the regulations are being developed and the foundations are in place. Now is the time to sit, look, and **learn** from the mistakes made and decision processes developed during the ODC phaseout process.

Approach climate change from the same framework of systems engineering used to assess ODC replacement. Use the ten step procedure described previously and learn from what has just transpired over the last decade. Major corporations already recognize the potential impacts that climate change regulations will have on users and industry alike. The impacts are far reaching and will conceivably be more widespread than ozone depletion regulation impacts. At first, it does not appear this way, but a deeper analysis shows that these regulations will have an impact on everyone.

The answer is simple. Start with the basic concept behind business - planning and analysis. Get into the mode now of **acting instead of reacting**. This will assure a much smoother, more economically based transition away from chemicals and processes that contribute to climate change potential. Inevitably, this will help the user and industry alike, contribute to a sound economic future for themselves and to a more healthy environment for the planet and future generations, or to quote, we must, "Think globally, act locally."

THE U.S. CEMENT INDUSTRY

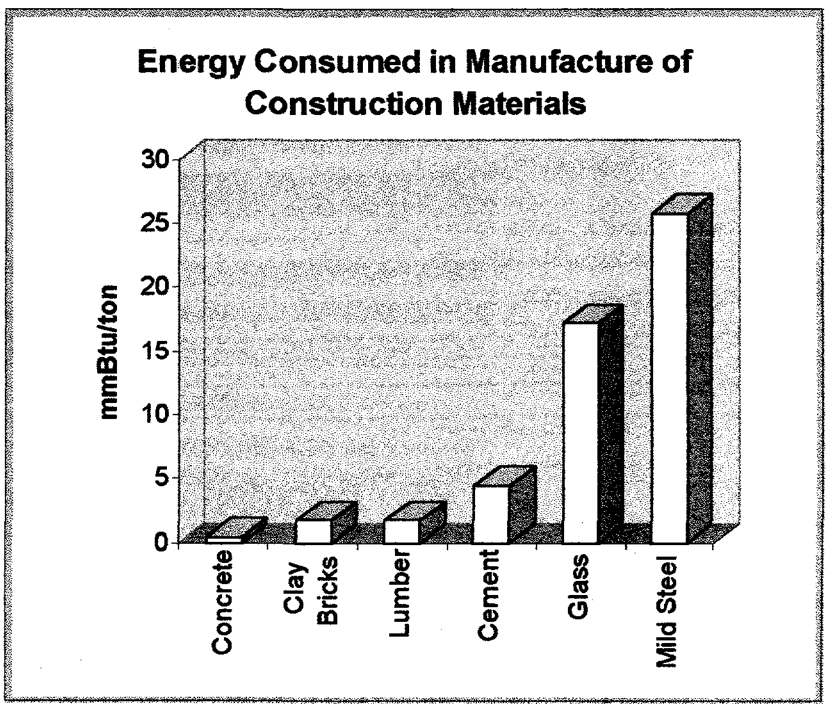
Michael A. Nisbet, JAN Consultants, Montreal, (514) 931-6272, jancon@vir.com

Cement and Concrete

Portland cement is a gray, finely-ground manufactured mineral product that, when mixed with water, sand, gravel and other materials, forms concrete, the most widely used construction material in the world.

The raw materials are primarily limestone, shale, clay, and silica sand which are usually quarried within 1 to 3 miles of the cement plant. They are crushed, proportioned to give the required chemical composition and ground. Small quantities of iron oxide and alumina may be added to adjust the chemistry of the raw mix. The mixture is heated to about 2700 ^{o}F (1500 ^{o}C) in large rotary kilns. The clinker, a hard granular intermediate product is discharged from the kiln, and is finely-ground with the addition of about 5% gypsum to give cement. Cement manufacture is relatively energy intensive, requiring an average 4.7 million Btu per ton of product.

Concrete contains 10 - 15% cement, the remainder being crushed stone, sand or gravel and water. The cement reacts with the water to bind the mixture into a hard, durable mass. Because of the relatively small cement content, concrete is not energy intensive compared to other construction materials. For example, the data provided by the U.K. Institute of Concrete Technology indicates that manufacture of one ton of concrete requires 0.42 mmBtu while one to of mild steel requires 25.8 mmBtu.



Source: U.K. Cement Manufacture and the Environment, Institute of Concrete Technology, April 1993

Profile of the U.S. Cement Industry

The U.S. cement industry consists of 47 companies operating 118 plants in 38 states. Ranked on the basis of cement grinding capacity, the 10 major producing states account for 65% of capacity. U.S. cement plants are large scale. Average capacity in 1993 was about 700,000 tons of cement per year. The largest plant has grinding capacity of 2.3 million tons per year. The manufacturing process is continuous with the kilns operating 24 hours per day for approximately 330 days per year. Except for occasional process upsets or equipment failure, the downtime is scheduled and is used for major maintenance.

U.S. annual production capacity is close to 85 million tons, making it the third largest cement manufacturer with 5.8% of the total world production of 1.4 billion metric tons. China is the major producer with 390 million tons of capacity or 27.3% of world production. As a point of comparison, about 80% of Chinese production is from mini-plants of less than 100,000 tons per year capacity.

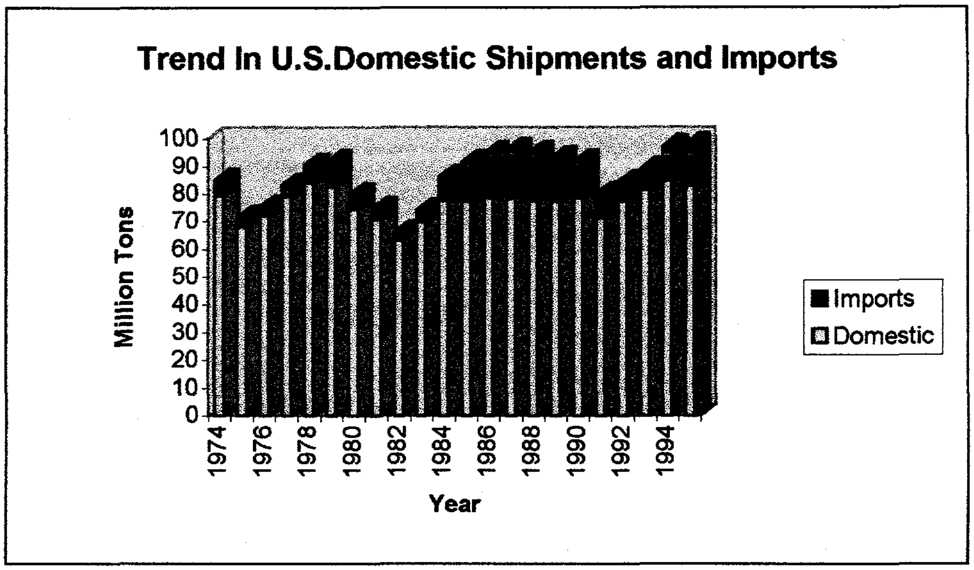
The cement industry is regional with about 60% of shipments being to destinations within 150 miles of the plants. Plants are located to minimize transportation of raw materials and finished products. In most cases this has meant construction of plants adjacent to a suitable limestone deposit and as close as possible to major markets. However, if it is sited on navigable water, a plant can receive raw materials by water from remote quarries and can distribute its products by vessel to a more widely dispersed market.

There are five main categories of products which are used in different applications. Of these, general use and moderate heat of hydration cements account for 87.5% of the market. All the products are made in rotary kilns with the different properties resulting primarily from changes in the composition of the raw mix and the fineness of the finished cement. With the exception of masonry cement which consists of up to 50% interground limestone, all have similar energy requirements.

The primary customer, accounting for 60% of shipments, is the ready-mix concrete industry which supplies concrete to construction sites. Other major customers are the concrete products manufacturers, building material dealers, government agencies and contractors. About 70% of cement is shipped directly from the plant to the customer. The remainder is distributed though terminals which are supplied from cement plants primarily by rail, or barge and boat.

Clinker production capacity in 1994 was 82.9 million tons this is 8% below the 1974 level. Between 1974 and 1994 the number of operating kilns dropped from 432 to 207 which is an indicator of the trend towards larger more efficient units. Increasing unit size has led labor productivity rising from 1.3 tons per employee hour in 1974 to 2.5 tons in 1994, a 92% improvement. Because production capacity has not increased, employment has dropped from 32,000, in 1974, to its current level of 18,000.

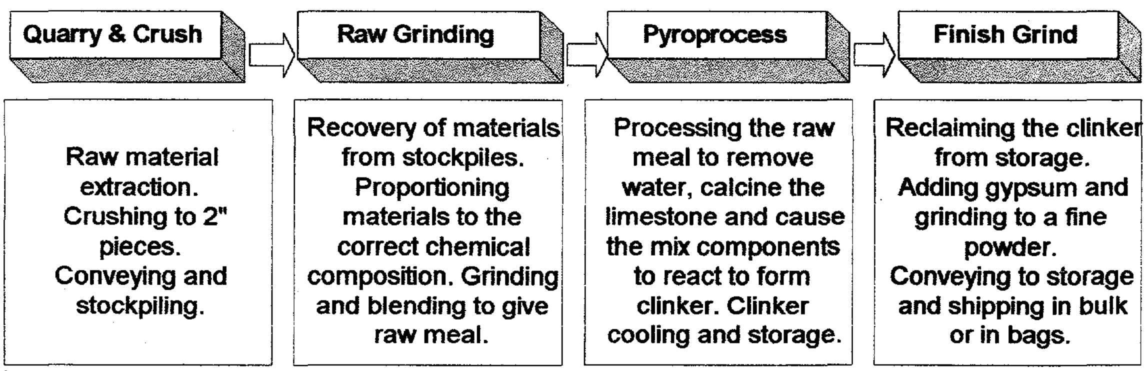
U.S. cement consumption, estimated to be 94.6 million tons in 1995, has grown modestly over the last 20 years with an average annual growth rate below 1% per year. Consumption shows a strongly cyclical pattern concurrent with the business cycle. Imports of clinker and cement, primarily from Canada, Latin America and Europe, were 15.2 million tons in 1995 which is approximately 16% of U.S. consumption. Import volumes follow a clear pattern, increasing in periods of strong demand and dropping when demand weakens. The accessibility of the U.S. market to offshore cement makes the U.S. cement producers vulnerable to any type of unilateral regulatory or tax burden which would increase their costs but not those of the offshore producers.



Source: PCA Economic Research Dept. U.S. Cement Industry Fact Sheet, Fourteenth Ed

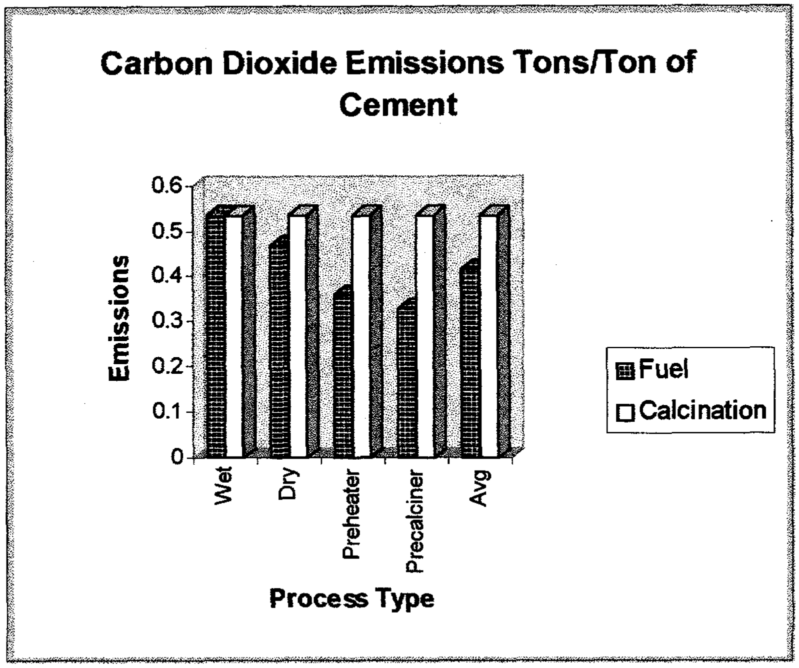
The Cement Manufacturing Process

The cement manufacturing process consists of four main steps.



There are four main process types: wet, dry, preheater and precalciner. They all use similar raw materials and can produce the same products. They differ in energy efficiency because of the method of grinding the raw meal, or in the configuration of the pyroprocessing step. The modern, more energy efficient plants are equipped with preheater and precalciner systems which heat and calcine the raw meal before it enters the kiln.

The primary greenhouse gases of concern are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane. Cement manufacture produces relatively minor amounts of N_2O and CH_4 but emits CO_2 from combustion of fossil fuel and from calcination of the limestone in the raw material. Emissions from calcination are constant at about 0.54 tons of CO_2 per ton of cement while emissions from fuel depend on the type of fuel being burned and fuel efficiency of the process. The less efficient wet process emitted an average of 0.56 tons of CO_2 per ton of cement in 1994; the most efficient technology, precalciners, emitted an average of 0.35 tons per ton of cement. Total CO_2 emissions, therefore, range from about 1.1 to 0.89 tons of CO_2 per ton of cement depending on the process type.

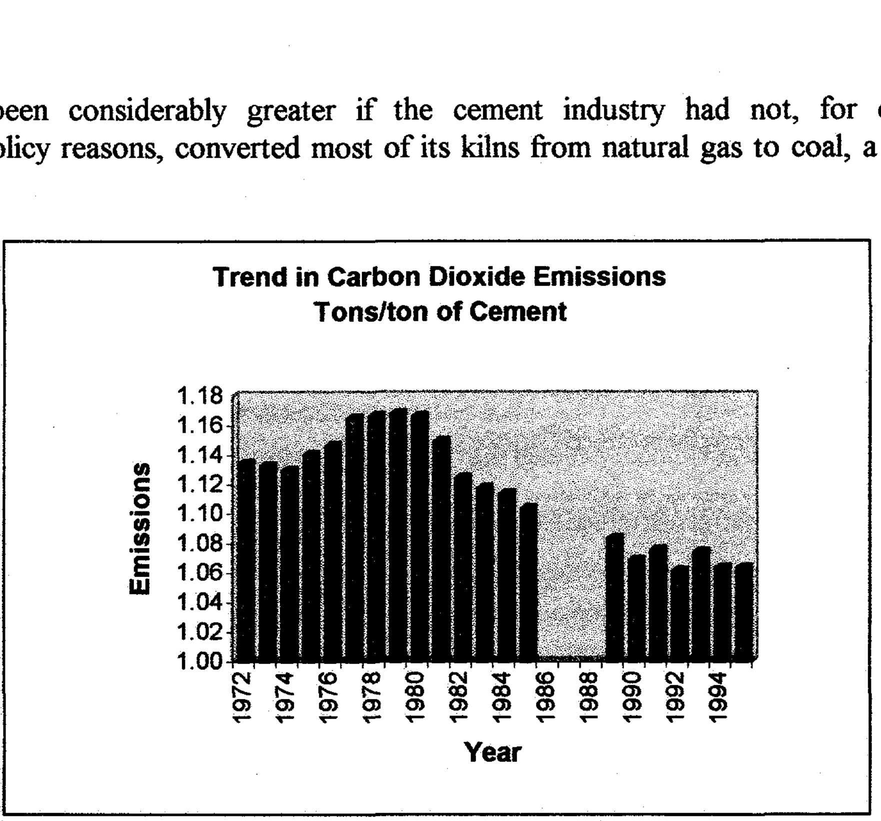


Energy use by the Cement Industry

The energy price increases resulting from the oil crisis in the early 1970s, triggered a drive by the cement industry to reduce fuel costs by becoming more energy efficient and by switching away from petroleum products and natural gas. The gains in energy efficiency ware achieved by shutting down older, primarily wet capacity kilns and replacing them with modern dry process units. The extent of this replacement is evident from the fact that in 1974 wet process kilns accounted for 58% of capacity but only 29% in 1994. In addition, a general upgrading of existing plants made further improvements in energy use. The result has been to reduce average energy input per ton of cement from 6.64 mmBtu in 1974 to 4.73 mmBtu in 1994, a reduction of 29%.

In parallel to the reduction in energy consumption, the cement industry also reduced energy costs by installation of fuel grinding equipment in order to burn coal and petroleum coke. The trend towards cheaper fuels has resulted in natural gas dropping from 45% of the fuel mix in 1972 to 7.2% in 1994. Over the same period coal and coke rose from 36% of fuel to 74%. Petroleum products represented 12% of fuel in 1972 and are currently at 1%

The cement 20-year trend in CO_2 emissions per ton of cement shows a drop from an average of 1.099 tons in 1974 to 1.03 tons in 1990, an improvement of 6.3%. The decrease in CO_2 emissions would have been considerably greater if the cement industry had not, for economic and government policy reasons, converted most of its kilns from natural gas to coal, a higher carbon fuel



Note: no energy survey was conducted in 1986 and 1987.

A further cost reduction initiative, started in the early 1980s, is the use, as kiln fuels, of selected waste materials such as spent solvents, paint residues, used oil and scrap tires The high temperatures in cement kilns have been shown to assure effective combustion of the wastes while et the same time recovering the energy value of these materials, which otherwise might have been landfilled or incinerated without energy recovery. Waste fuels in 1994 was accounted for 7.4% of the industry's energy requirements. This percentage has been relatively unchanged since 1990.

Energy Mix
Percent Based on Btus Consumed

	1972	1994
Natural Gas	45.1	7.4
Coal & Coke	36.1	74.2
Petroleum Products	12.2	1.1
Wastes	0	7.2
Electricity	6.6	10.1

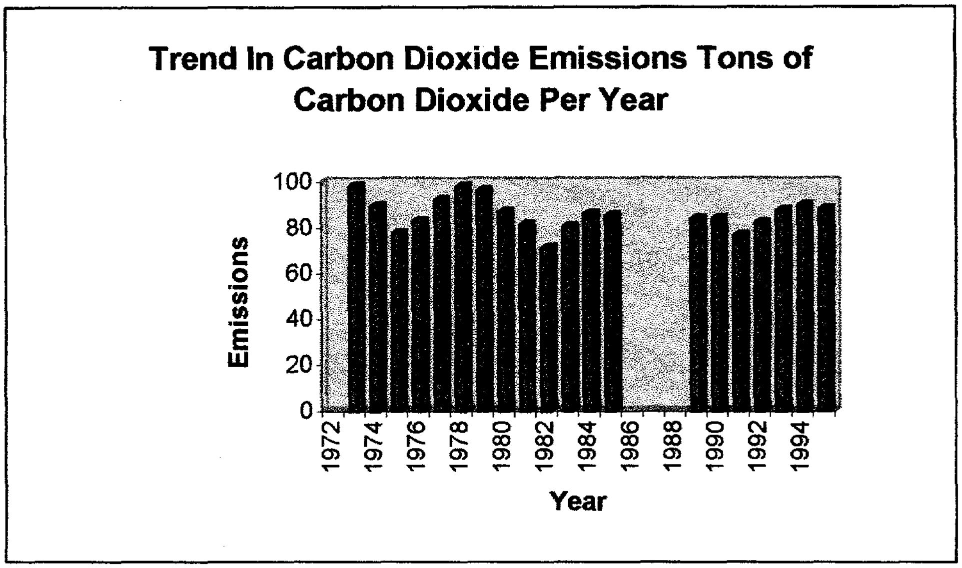
Source: PCA Economic Research Dept. U.S. Energy and Labor Survey 1995.

Carbon Dioxide Emissions and the Cement Industry

Total U.S. CO_2 emissions in 1995 are estimated to be 5,098 million metric tons. Cement industry CO_2 emissions, in 1995, from energy consumption are estimated to be 36.2 million metric tons. Emissions from calcination of limestone are 38.3 million metric tons. Total CO_2 emissions from cement manufacture in 1995 were 74.5 million metric tons or 1.5% of total U.S. emissions.

The FCCC set 1990 as the base year by which to measure future greenhouse gas emissions. The original treaty called for a reduction of emissions to the 1990 level or below by the year 2000. Cement consumption is cyclical, thus selection of any single year as a base poses difficulties. The cyclicality also means that, at the peak of the business cycle, cement industry CO_2 emissions may exceed targets but this will be offset during the troughs when emissions are below the target level.

The single greatest factor in determining the amount of CO_2 emitted by the industry is the level of cement shipments by domestic producers. Total industry CO_2 emissions since 1974 have fluctuated from a high of 94.9 million tons in 1978 at the peak of the business cycle to a low of 68.4 million tons during the poor business conditions of 1982. Emissions in 1990, the base year, were 77.6 million tons



Potential Impact of an Energy tax

An energy tax, or some other form of economic instrument aimed at reducing CO_2 emissions, imposed on the U.S. cement industry but not on other countries would have a negative impact. Cement is widely traded, and product from one source can readily be substituted for another, provided it meets the appropriate standards. The product has a low price elasticity meaning that changes in price do not alter demand significantly. However, it has a relatively high elasticity of substitution which means the change in relative share resulting from a 1% change in relative price. The United States International Trade Commission in 1990, when addressing the issue of gray portland cement and clinker from Mexico suggested an elasticity of substitution between 5 and 10. The example below uses a value of 7.5, which implies that for a 1% drop in the relative price of cement imports, the relative share of imports will increase by 7.5%.

If an energy tax, expressed as $/million Btu, is imposed on U.S. cement producers but not on countries that export cement to the U.S., then the impact under the following set of assumptions can be estimated for a range of taxation levels:

- average energy used in cement production — 4.7 mmBtu/ton of cement,
- range of energy tax — $0.50-4.00/mmBtu,
- import market share before imposition of tax — 16%,
- average cement price — $72.00 per ton,
- elasticity of substitution — 7.5.

In making the estimate it is assumed that the manufacturing cost increase is passed on to the consumer as a price increase on cement from domestic sources. Imported cement from producers not subject to a tax, would not increase in price. Under these conditions, market share of imported cement would rise to 25% if an energy tax of $1.00/mmBtu was imposed, and 47% if the tax was $4.00/mmBtu.

If import market share were increased from 16 to 47% and the U.S. cement industry had the same parameters as it has today, the result would be to:

- increase cement imports from 15.2 to 44.6 million tons per year,
- reduce domestic cement shipments by 29.4 million tons per year,
- shut down 27.9 million tons of domestic clinker capacity,
- cause the loss of 5,500 jobs.

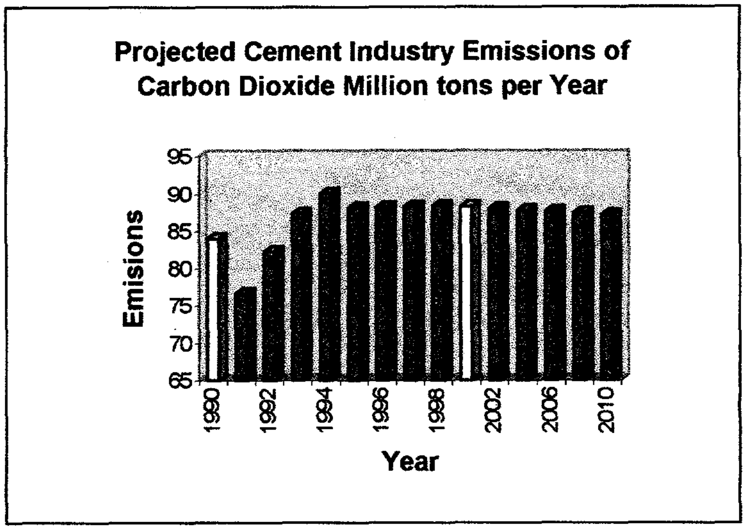
Opportunities for Reducing Carbon Dioxide Emissions

Improving Energy Efficiency

The industry will continue to upgrade its production capacity by modernizing its plants primarily by replacing older, less energy efficient kilns with precalciner units. This type of investment is driven by economics and is linked to capacity increases. Cement manufacturing is very capital intensive and replacement of an old kiln with a new one solely for the purpose of energy saving does not provide a reasonable return on investment.

A long term projection of CO_2 emissions assumes that cement consumption will grow at an average of 1% per year. Domestic shipments, and thus installed capacity are projected to grow at 0.5% annually. The remainder of the cement supply will be from imports. It also assumes that the energy mix will remain constant. The projected energy consumption per ton of cement drops from 4.51 mmBtu in 1990 to 4.33 mmBtu in 2000 and 4.02 mmBtu in 2010.

This reduction of 4.0% in energy consumption will result in a reduction of 2.0% of CO_2 emissions per ton of cement since improving energy efficiency only impacts CO_2 from combustion and does not affect CO_2 from calcination. Domestic shipments are projected to grow by 7.4% between 1990 and 2000 which will leave the industry's total CO_2 emissions at 82.6 million tons which is 5 million tons or 6.4% above the 1990 level. Beyond 2000 it is projected that the continued improvement in energy efficiency and the projected slow growth of domestic shipments will keep average total emissions relatively constant. However, energy efficiency gains alone will not be sufficient to reach the 1990 target and other action will be needed to achieve a further reduction in industry CO_2 emissions.



Fuel Switching

Switching from coal and coke to natural gas would result in a substantial decrease in CO_2 emissions per ton of cement. Combustion of industrial coal releases 0.095 tons of CO_2 per mmBtu while natural gas, because of its lower carbon content, releases 0.054 tons per mmBtu. In 1994 coal and coke accounted for 74.2% of the energy consumed in cement manufacture. If the industry switched all its coal and coke consumption to natural gas, emissions would be reduced by 0.13 tons of CO_2 per ton of cement or about 12%. This course of action would enable the industry to match its 1990 emissions by 2000. However, since cement manufacturing is much better suited to burning coal because of process conditions and pollution control equipment, than for example the residential or commercial sectors, switching the cement industry to natural gas could represent misallocation of a valuable resource.

Waste Derived Fuels

Burning hazardous waste as kiln fuel results in a net decrease in CO_2 emissions compared to incinerating the wastes without energy recovery. Use of hazardous wastes by the cement industry while being environmentally sound, is not expected to increase substantially above current levels primarily because of the difficulty, cost and uncertainty in the permitting process. Scrap tires which are generated at the rate of approximately one tire per person per year, represent a large energy resource. Tires have a relatively high carbon content and technical factors normally limit their use to 10 - 15% of energy input. Thus using them as a fuel to replace coal would not achieve a significant reduction in CO_2 emissions.

Refuse derived fuel (RDF) consists of a combustible fraction of municipal waste. Landfilling of municipal wastes and the resulting decomposition liberates approximately equal amounts of CO_2 and methane. One metric ton of municipal waste is estimated to release the equivalent of 3.8 metric tons of CO_2 over a 50 year period. Use of RDF to provide 10-15% of kiln fuel requirements is technically possible and would result in considerably less emissions than the landfilling option. However, the lack of economic incentive and difficulties in both preparing and use of the RDF has lead to uncertainty about its potential use by the U.S. cement industry.

Limestone addition

Intergrinding moderate amounts of limestone with clinker has no detrimental effect on performance and may even improve some product characteristics. Countries such as Germany, France, Canada, Japan, Russia and Brazil allow up to 5% limestone to be incorporated in portland cements. In the U.S., the Standard Specification for portland cement, does not allow addition of limestone. If the standard were changed, addition of 5% limestone to cement would reduce the proportion of clinker in cement from about 95% to 90% resulting in a decrease of about 5% in CO_2 emissions per ton of cement.

Supplementary Cementitious Materials

Cementitious materials by themselves, show limited activity as binders in concrete but, in the presence of portland cement, they contribute to the concrete's performance. Materials of this type which are widely available include fly ash and blast-furnace slags.

Approximately 85% of the CO_2 emissions embodied in concrete result from the manufacture of portland cement. If the amount of cement in the concrete can be reduced while maintaining the performance of the product, then the embodied CO_2 emissions will decrease proportionately. In recent years, driven by economic considerations, fly ash, blast-furnace slag and silica fume have found increasing use in production of concrete. All three can be interground into the cement to give a blended product or they can be added at the concrete mixing stage. Blended cements are used in Europe but have not yet gained acceptance in the U.S. Introduction of blended needs the support of additional technical development work and demonstration of the performance of such products in the U.S. market.

Alternative Raw Materials

Calcium carbonate is the most readily available naturally occurring compound that can be used in cement manufacture. Not only does calcium carbonate emit CO_2 when calcined, but the calcination process also requires energy resulting in emissions from fuel combustion. There are a number of industrial by-products such as waste lime from the production of acetylene from calcium carbide, whose, use would avoid the calcination step, but the available quantities tend to be too small to have a significant impact on CO_2 generation by the cement industry. Slags from steel making, unlike blast-furnace slags, are not used in blended cements or as a replacement for portland cement in concrete. Of the approximately 5.7 million tons per year of steel furnace slag, 2 million tons are recycled. Most of the remainder is used as concrete aggregate. This type of slag could be used an alternate raw material. The quantities that could be used would be limited by the chemical composition of the slag.

Alternative clinkers

Cement composition varies in a relatively narrow range. However the trend has been towards an increase in the limestone content in the raw meal and higher lime content in the product. Research indicates that suitable performance can be achieved in cements with lower lime contents. However, the reduction in CO_2 emissions from this course of action is marginal.

Other research initiatives aimed at new cementitious products, for example geopolymers or artificial mineral glasses from basalts may in the long term result in products with a lower embodied CO2 content. But for an alternative to be viable it will have to be based on inexpensive and readily available raw materials and be manufactured at low cost on a large scale using commercially available equipment.

Conclusions

The U.S. cement industry is well positioned to meet a 1990 emission target in the year 2000. The key factor in determining CO_2 emissions is the level of domestic production. The projected improvement in energy efficiency and the relatively slow growth in domestic shipments indicate that CO_2 emissions in 2000 should only be about 5% above the 1990 target. But, because of the cyclical nature of cement demand with pronounced peaks and troughs occurring on a 5 - 7 year cycle, emissions will probably be above the target levels during peaks. This, however will be offset during troughs when emissions will be below the target.

Opportunities for the cement industry to achieve the target CO_2 emission lie in a number of specific areas.

Action	Carbon Dioxide Reduction	Comments
Improved energy efficiency	0.5% for 1% gain in efficiency	Reduces combustion CO2 only
Fuel switching	Depends on fuel selection	Reduces combustion CO2 only
Limestone addition	1% for each 1% limestone added to cement	Reduces fuel and calcination CO2
Blended cements	1% for each 1% material added to cement	Reduces fuel and calcination CO2
Additions to concrete	1% for each 1% cement replaced in concrete	Reduces fuel and calcination CO2
Alternate raw materials	Relatively small impact	Sire specific opportunities
Modified clinker	Relatively small impact	Requires further research
Credits for using wastes	Potentially large impact	Requires policy on waste credits

The 1990 target could be met if the industry were to switch from coal to natural gas, however, because of their pollution control equipment and burning conditions, cement kilns are better suited to use coal that the commercial and residential sectors. Using natural gas as kiln fuel might represent a misallocation of a valuable resource.

The industry is seeking agreement on replacing up to 5% of the clinker in portland cement with interground limestone. This has been done successfully in Europe and Japan in some cements without affecting product performance It will also continue development of blended cements containing cementitious materials such as, fly ash or slags. Using alternative raw materials that liberate less CO_2 in cement manufacture offer site specific opportunities but will not have a major impact on overall industry emissions. Modifying the composition of clinker so that its production uses less limestone is theoretically feasible but would also result in a small reduction in CO_2 emissions. The industry will continue its research in both these areas.

The industry currently uses about 7% waste derived kiln fuels but does not get credit for the emissions which would occur if these materials were landfilled or incinerated without energy recovery. The industry is well suited to use larger amounts of such fuels given an incentive, such as CO_2 credits, for recycling and resource recovery from wastes and by-products.

GM's PICOS Initiative on Resource Conservation and Pollution Prevention: Greening the Supply Chain

Terry Pritchett
General Motors Corporation
Public Policy Center
3044 W. Grand Blvd.
MC 482-112-157
Detroit, MI 48202
(313) 556-7566
(313) 556-2644 Fax

Terry Pritchett is Manager of Corporate Affairs - Public Policy Center of General Motors Corporation in Detroit. Terry has been with GM for over 27 years and is currently involved in environmental and energy initiatives related to GM's suppliers, global climate change issues and GM's energy policies. General Motors' manufacturing operations and suppliers provide billions of parts to a corporation that produces vehicles in 25 countries and sells them in over 170 countries around the world, so you can see why GM has a special interest in environmental and energy issues. Mr. Pritchett is a Certified Hazardous Materials Manager and a registered Professional Engineer with a M.S. Degree in Environmental Engineering from the University of Tennessee.

THE GREEN BUSINESS Letter

Washington, D.C.
October 1996

THE HANDS-ON JOURNAL FOR ENVIRONMENTALLY CONSCIOUS COMPANIES

SUPPLY-SIDE ECONOMICS

How General Motors Cuts Costs by Making Its Suppliers Leaner and Cleaner

The idea of a company prodding its suppliers to reduce their products' environmental impacts is not new. For years, customers have asked—or demanded—that suppliers eliminate wasteful packaging, toxic ingredients, and other factors that burden them with costs and liability. The tales have been well told of companies using the power of the purse to push environmental improvements up the supply chain.

But what about environmental impacts that don't necessarily show up in the products directly, but which can still cost customers plenty? That's the focus of an effort launched earlier this year but publicly unveiled this month by General Motors Corp. The goal: To reduce the automaker's costs and boost its competitiveness by helping its thousands of suppliers harness environmental improvements to become more efficient and productive.

It's not a new idea for GM. Since 1992, through a trademarked program called PICOS, the company has unleashed teams of engineers to help suppliers find faster, lower cost, and more efficient ways of getting GM the parts it needs for the 8.567 million vehicles it builds each year. PICOS has helped GM keep up in the fiercely competitive automobile industry, where every few cents shaved off a part's price can make a big difference.

Recently, PICOS added environmental considerations—energy efficiency, waste minimization, and pollution prevention—to the tools it offers suppliers. In the process of promoting environmental excellence to its supplier network, GM has become one of the world's leading champions of industrial eco-efficiency.

The seeds of the PICOS Initiative on Resource Conservation and Pollution Prevention, as the program is formally called, were planted last year, when GM signed on to the federal government's Climate Wise program, a voluntary initiative to

(Continued on page 6)

INSIDE

GM

(Continued from page 1)

help companies reduce greenhouse gas emissions (see box, below). Climate Wise members are required to prepare an "action plan," mapping a strategy to increase energy efficiency, reduce pollution, and achieve cost savings. As part of its plan, GM committed to a regional workshop for 30 to 50 key suppliers on environmental issues. That simple plan quickly expanded into a much bigger idea: to integrate environmental issues into the existing PICOS program. "We didn't want a one-shot meeting that would simply become the program of the month," says James P. Olson, GM's manager of supplier development.

A Peek Into PICOS

In many ways, the environment was a natural fit for GM's corps of PICOS engineers, who are based around the world. (GM does not disclose the number of engineers, the number of suppliers they visit, or the total number of GM suppliers, though previously published estimates of suppliers have ranged from 7,000 to 30,000.) Suppliers get involved with PICOS for any of a variety of reasons. They may be seeking to raise prices, for example, or having trouble meeting production volumes or schedules, or having quality problems. Not all PICOS visits stem from supplier problems, however.

In a typical weeklong supplier workshop, PICOS engineers hold a succession of training modules with plant personnel, each followed by time spent on the shop floor focusing on one or more processes to identify opportunities to reduce waste. "Waste," under GM's definition, represents far more than what goes down a drain, up a stack, or into a dumpster. The company counts seven categories of waste: inventory, overproduction, correction, material and information movement, processing, waiting, and motion.

After the walk-throughs and discussions, a team of PICOS engineers and plant personnel develop a strategy to make improvements.

Olson explains that attacking any of GM's seven categories of waste can yield environmental benefits. For example, he says, by optimizing a stamping press operation by 50%, the result is that "the time actually forming parts is increased and the time sitting there idle, using lubricants and electricity, is vastly decreased."

Another example: "We just completed a workshop at a supplier where, because of their operating practices, they had an offsite warehouse," says Olson. "We changed their methods in order to 'lean out' their system. We anticipate that in a very short period of time they won't be needing that extra warehouse." That, he says, will eliminate the energy costs of running the warehouse, and the emissions and energy associated with a truck traveling back and forth continuously between the two facilities.

Along with their new environmental marching orders, PICOS engineers have been equipped with an expanded set of tools devised for them through a collaboration involving GM; Climate Wise; the Business for Social Responsibility (BSR) Education Fund, a nonprofit organization that works cooperatively with the Climate Wise program to recruit new compa-

How Climate Wise Helps

General Motors' PICOS effort to help suppliers reduce their environmental impacts began as a part of its commitment to the Climate Wise program. The two-year-old initiative, sponsored by the U.S. EPA and Energy Department, helps industrial companies identify and implement energy-efficiency and pollution-prevention projects that lower operating costs while reducing emissions linked to global climate change.

Under the voluntary program, companies draft a "pledge" in which they commit to specific measures and goals. Climate Wise supports them by providing technical assistance and working with financial institutions to help with funding.

Among the resources available to Climate Wise companies:

- ***Opportunities Assessment Guide*** and ***Case Study Compendium***—reference materials published by Climate Wise.
- **Industrial Assessment Centers**—30 university-based centers that provide detailed recommendations to small and midsize manufacturers.
- **National Laboratories**—five federal labs providing technical expertise.
- **NIST Manufacturing Centers**—funded by the Commerce Department to provide technical assistance on efficiency measures.

"Climate Wise can help companies identify cost savings they might not have thought about," says EPA's Pamela Herman, a Climate Wise co-director. "We help companies work with the assets they've already got for the greatest advantage."

In addition to GM, Climate Wise's more than 120 member companies include AT&T, Dow Chemical, DuPont, Johnson & Johnson, Louisiana Pacific, and a host of smaller and midsize firms.

For more information :

- Pamela Herman, U.S. EPA, 401 M St. SW (22126), Washington, DC 20460; 202-260-4407; 202-260-0512 (fax)
- Amy Manheim, U.S. DOE, Off. of Industrial Technology, 1000 Independence Ave. SW (EE-1), Washington, DC 20460; 202-586-1507; 202-586-1605 (fax).

nies and provide technical assistance; and the Industrial Assessment Centers (IAC) at Rutgers University, an Energy Department-funded program that provides energy-efficiency and waste-minimization assessments for small and midsize manufacturers. Together, the group collaborated on an assortment of resources, including:

- a Quick Scan, designed to easily assess opportunities to target waste-reduction efforts;
- a waste education module, describing root causes and symptoms;
- a supplier checklist to identify areas of opportunity and create a plan for improvement;
- case studies from GM and supplier facilities, highlighting dollar savings from conservation measures; and
- "rules of thumb" to estimate cost savings (see box).

In addition, GM is helping to promote Climate Wise to suppliers it believes can benefit from the program.

Seemless Integration

Partners in PICOS' environmental effort—Climate Wise, BSR, and IAC—all view GM's initiative as a significant attempt to integrate environmental considerations seemlessly into company operations. "Most companies send environmental questionnaires to their suppliers, but they don't work closely with them," says Rebecca Calahan Klein, who directs BSR's environmental program. "GM is bringing some valuable resources to the table, which is unique. They are helping their suppliers reduce their environmental impacts and do well by doing good."

"One of the things I like best about the program is that GM is instituting a corporate structure that will continue into the future, whatever happens to Climate Wise," says Pamela Herman, a Climate Wise co-director. "This is an asset GM is building for itself."

Dr. Michael R. Muller, DOE's IAC regional director at Rutgers, believes the real strength of the GM effort lies in the quality of the PICOS engineers. "They're an extraordinary bunch," says Muller, who has worked or consulted with several of them. "They are very talented in their ability to walk into a plant, bond with people, but push them in a positive way. In a couple of days, they've got to turn a supplier's head around 180 degrees. I think they deserve quite a bit of praise."

GM, for its part, isn't ready to deem the initiative a success. PICOS engineers have just begun to incorporate the new environmental program in their work, and measurable results can take months. "Our operating philosophy is 'Judge us by what we are doing, not by what we say we are going to do,' " says Terry E. Pritchett of GM's corporate affairs department, part of the PICOS development team. Though the PICOS initiative is consistent with GM's environmental principles, the company has been reluctant to promote the program outside its walls. "We wanted to wait until we could say 'This is what we have already accomplished and here is what we still need to do,' " says Pritchett.

However reluctant, a company as big as GM, and whose impact extends to such a large supplier base, won't likely be able to keep the PICOS environmental program quiet for long. If it succeeds in engendering measurable waste, energy, and emissions reductions—and, given PICOS' track record of fomenting supplier efficiencies, it stands a good chance of doing so—it may well become a model for other manufacturers. There's already a precedent: WE CARE, GM's program to reduce pollution and waste inside its own operations, has become a model for both Ford and Chrysler's eco-efficiency efforts.

GM doesn't intend to turn PICOS into a green-marketing tool, but consumers' environmental concerns are never far from the company's thinking. Sandra Brewer, project manager for resource conservation and pollution prevention strategy, says the pressures to reduce the company's environmental impact come from everywhere, including kids. "We're aware that as they grow up and are old enough to buy cars, it's going to be important to be environmentally conscious in their eyes."❖

Rules of Thumb

To assist suppliers in reducing waste and costs, GM's PICOS engineers provide suppliers with a range of informational and resource tools. Among them is a series of "useful rules of thumb," compiled by Mike Muller of the Industrial Assessment Center at Rutgers University. The rules, says Muller, are intended to help plant managers estimate the potential savings from waste minimization and pollution prevention measures.

A few examples follow, based on national averages and typical operating scenarios. All numbers are stated on an annualized basis.

- **Cost of low-pressure steam leaks:** \$30 to \$110 per leak per shift.
- **Cost of high-pressure steam leaks:** \$150 to \$500 per leak per shift.
- **Cost of compressed air leaks:** \$30 to \$90 per leak per shift.
- **Operating cost of a typical motor:** \$62 per horsepower per shift.
- **Cost of heat lost through hot, uninsulated pipes:** \$375 to \$515 per 100 feet per shift.
- **Cost savings for demand reduction** (shifting an operation to off-peak times): \$75 per horsepower.

Ambassador Program Awards Suppliers with Great Opportunities

Pg. 4

Global News

GM WORLDWIDE PURCHASING
SUPPLIER NEWSLETTER

Volume 2, No.2 Fall/1996

Harold Kutner
Vice President, Worldwide Purchasing, Production Control, and Logistics

Paradigm Shift in Quality
Standards in the Pharmaceutical Industry Inspire GM and Suppliers

GM's success as a company relies on our ability to provide products that consistently exceed customers' expectations. In today's extremely competitive and global market, our key aspect for customer satisfaction is quality. Considering the fact that everything a customer touches or experiences in our vehicles comes either directly or indirectly from you, our suppliers, we absolutely must have the best quality. I refer to this as "Quality in—Quality out."

To this end, I am declaring a full-blown paradigm shift when it comes to quality in the automotive industry. I want us to design defects out of existence—to reduce them to the point that every part is flawless. The idea is to strive for zero PPM defective, and it can be done if we begin to adopt the "pharmaceutical mentality."

In the pharmaceutical industry, only perfection is acceptable. When I take aspirin to relieve a headache, I never think, "I hope this is not one of the 25 out of every million tablets that are defective." That's because every aspirin must be capable of tackling an adult headache.

(Continued on page 4)

***1995 SUPPLIER OF THE YEAR ***

Award-Winning Suppliers Visit with GM Leaders and Earn Year-Long Rewards

(See related article on page 8.)

Suppliers representing 158 companies received rave reviews and several honors from GM top leaders at the corporation's fourth annual international Supplier of the Year Awards ceremony held in Vienna, Austria. Winning a 1995 Supplier of the Year award is an "awesome achievement," Harold Kutner, vice president for Worldwide Purchasing (WWP), told award recipients, "because you exceeded the expectations of your toughest customers–GM buyers, GM engineers and GM plants".

At gatherings during the weekend event, Tribute '96–the Art of Perfection, suppliers had an opportunity to visit with GM officials and gain new insight into corporate strategies. This kicked-off a year-long commitment from GM to enhance its relationship with award-winning suppliers.

GM leaders who spoke to suppliers at the Vienna business meeting were: Dick Donnelly, president of GM Europe; Eddy Geysen, vice president GM Europe Supply; Louis Hughes, president of GM International Operations (GMIO); and Rick Wagoner, president of North American Operations (NAO).

Enhanced communications between GM and the award-winning suppliers will continue during the year through the GM Supplier Ambassador Program. (Refer to article on page 4 for details.)

Cosma Body and Chassis Systems, a division of Canadian supplier Magna International Inc., won the top honor—Corporation of the Year—for the second year in a row. Twenty-four companies won the Supplier of the Year title for the fourth consecutive year.

The Suppliers, representing 25 countries, received global recognition for their achievement in a full-page ad that ran in well-known publications. The ad also appears on the back page of this newsletter.

GM hosted celebrations at the wine-

(Continued on page 4)

IN THIS ISSUE:

PICOS Branches Out to Improve Environmental Performance

PICOS is branching out into new territory as it begins to offer suppliers around the world an enhanced process to improve on environmental performance while becoming more profitable. The PICOS Initiative on Resource Conservation and Pollution Prevention provides GM supplier development engineers with tools to work with suppliers on projects that can reduce costs, minimize waste generation and lower energy use.

This initiative supports the GM environmental principles and complements GM's voluntary commitment to the Climate Wise Program, which is jointly managed by the United States Department of Energy and United States Environmental Protection Agency, in partnership with the Business for Social Responsibility Eduction Fund Environment Program. The Climate Wise Program is a non-regulatory program that focuses on manufacturing companies committing to and achieving reduced greenhouse gas emissions. GM, the first automotive OEM to participate in Climate Wise, has chosen to work with its suppliers as one of its actions.

The PICOS workshop provides practical information, case studies and resources to suppliers. New tools include:

- An Opportunity Assessment "Quick Scan," designed to quickly assess opportunity areas to target, ranging from improving energy efficiency, reducing water usage, and minimizing waste generation to utilizing cleaner fuels;
- An expanded PICOS Waste Module, including environmental and energy root causes and symptoms;
- A comprehensive Supplier Checklist to identify areas of opportunity and set an action plan for improvement;
- Case studies from GM and supplier facilities highlighting the dollar savings as a result of resource conservation and pollution prevention initiatives;
- Rules of thumb to estimate cost savings and useful energy and environmental conversion factors, and
- A Resource Guide with a directory of United States federal and state programs to obtain additional information and assistance.

Suppliers are also encouraged to incorporate several key initiatives into their operations. Activities range from obtaining management support of environmental stewardship and practicing resource conservation (energy efficiency, water and materials conservation), to designing products and production processes with energy efficiency and environmental performance in mind.

"We have created a methodology in which GM and the supplier community can work together to identify, analyze and implement resource conservation and pollution prevention projects around the world to improve environmental performance while reducing total cost," said Jimmy McDonald, director, Supplier Development.

APO *continued from page 13*

Corporation (SAIC). The W-Car (NAO Buick midsize) will be assembled at approximately 150,000 units per annum, including engine and transmission manufacture.

SAIC is among China's most profitable automotive companies because it established an initial scale of economy in sedan and component supply systems manufacturing. APO WWP has been actively working with the SAIC partners to develop a sourcing process that meets mutual requirements. There has been a high level of activity from a joint APO/NAO team. Key actions of the team include identifying local raw material and steel products which will support the joint venture.

Indonesia

Founded in 1993, GMBI is a joint venture between GM (60 percent) and PT Garmak Motor Ltd (40 percent). It has produced the Vectra since 1994, and the Astra/Optima and Blazer since 1995. The Bekasi, West Java, assembly plant represents a $110 million investment by GM.

GMBI recently won a contract to paint the C class Mercedes in their state-of-the-art paint shop.

Japan

GM Japan is responsible for North American and Opel brand vehicle sales in Japan. In 1995, the GM group was top importer to Japan. Sales increases were led by the Opel brand, with Vita/Corsa winning three awards.

GM has a 37.5 percent equity interest in Isuzu, Japan's largest and best-selling manufacturer of truck and commercial vehicles.

Taiwan

APO continues to strengthen its Opel and North American-sourced product presence via a landmark showroom in Taipei and a network of 120 dealers. The end of 1997 will see the first J-Car assembled in Taiwan, complementing the Opel Astra, which commenced assembly in 1993.

India

GM India (GMI) is a joint venture established in 1994 between GM and the Birla group of companies to produce Opel cars for the Indian market. Production of the Astra began this year.

High import duties present a particular challenge for GMI as the resultant high local content requirement (44 percent at SOP) is a difficult task for a developing country. The crucial task of supplier development is being facilitated by the positive attitude of local suppliers who are actively pursuing a global automotive market.

A Global PICOS Process—Keeping GM and Suppliers Competitive

One tool GM uses with its suppliers worldwide to deliver customers the best in quality, service and price is PICOS.

GM has conducted approximately 7,000 PICOS workshops worldwide for close to 5,000 suppliers since its inception in Europe in 1989. Exemplifying its global nature, PICOS workshops have been held in 43 countries—on every continent except Antarctica.

Recently, GM consolidated its 35 PICOS teams into one global team led by David Brown, director of supplier development in Worldwide Purchasing. "Now we can apply the PICOS process consistently and capitalize on the creativity from teams around the world," said Brown.

The logistics of leveraging PICOS resources are also enhanced, according to Brown. "We have already conducted one multi-national workshop for a supplier with international facilities. We conducted workshops at their Germany and United States locations, and plan to reach their Brazil site soon. It has been a coordinated effort worldwide."

PICOS—More Important Than Ever

In today's fiercely competitive marketplace, Brown is convinced PICOS is "more important than ever before. We have made significant gains—but much remains to be done."

To this end, PICOS is evolving over time, continuously enhancing its scope. This year, the PICOS focus is on increasing the positive impact on quality, service and price throughout the supply chain. Additionally, three new tools have been introduced to the PICOS program: Constraint Workshop, Business Process Reengineering and Strategic Business Planning.

Constraint Workshop

Using PICOS methods, the Constraint Workshop facilitates suppliers' ability to meet GM's needs. "As we looked at the business climate and saw the auto industry rebound, we found instances where demand exceeded capacity levels, especially in the truck business," Brown said.

The workshop covers:

- managing overtime
- addressing unscheduled work
- minimizing additional investment
- removing bottlenecks in the supply chain for a smooth flow of material

Strategic Business Planning

GM is focusing on suppliers of strategic importance—based on their volume of business, technology, and/or nature of their products—to gain a complete understanding of the supplier's business and how the two organizations (GM and the supplier) can best work together.

The process begins with a "discovery phase" where GM and the supplier review, in depth, each other's methodologies and facilities. "We then evaluate the information and come to a consensus on which tools to use to pursue future opportunities," Brown said.

Business Process Reengineering

Business Process Reengineering (BPR) is a tool to seek out improvements by investigating an entire process or activity. The PICOS version of BPR incorporates the lean concepts of a formal BPR study (which typically takes over a year) to develop a game plan for a three- to six-month period. This activity is underway primarily with businesses in the health-care industry.

A Glimpse at PICOS Evolution

When PICOS was first introduced to the supplier community, the focus was on lean manufacturing and workshops were developed to help suppliers implement this practice. In 1994, the PICOS focus shifted to ensure process integrity and to expand the tools.

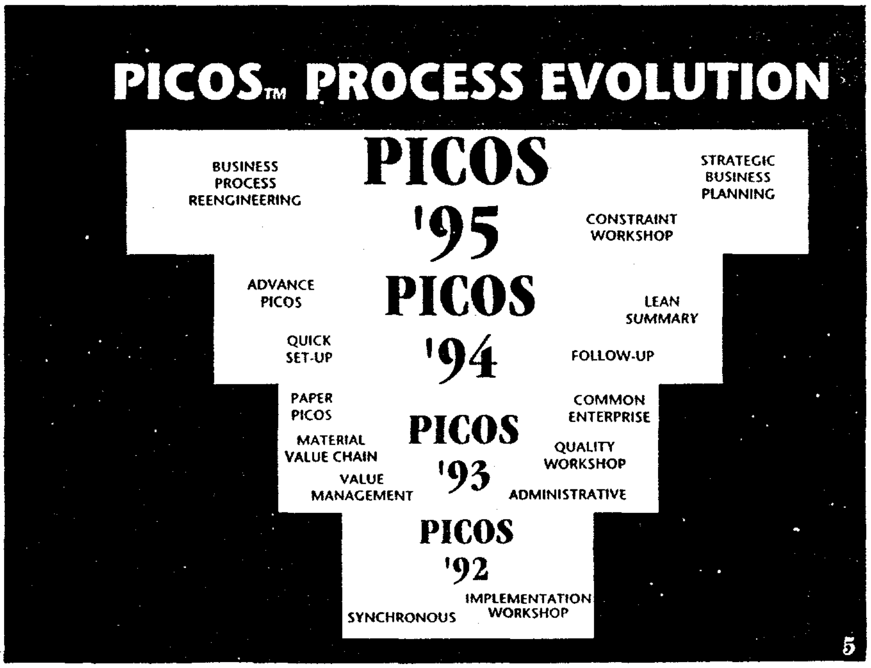
This goal was accomplished by offering several activities:

- **Follow-up Workshop**—Verifies accuracy of improvements, identifies additional areas of opportunity, and questions the expansion of the concepts beyond the original workshop.
- **Quick Set-up Workshop**—Reduces downtime due to changeovers.
- **Advance PICOS**—Investigates opportunities to implement lean concepts before the design stage.

As a result of the continued growth of the PICOS process, the ability to improve quality, service and price in the supply chain has expanded to all aspects of an organization and all areas of the supply base—whether direct, indirect, machinery and equipment, healthcare or other service industries.

"PICOS is a tool we can use to become even more efficient—to drive out every piece of waste," Brown said. "We are changing the automotive industry and supplier base to keep our business as competitive as possible."

Clearly PICOS will continue to be an important tool GM and its suppliers use as they strive to design and manufacture the best vehicles in the marketplace.



THE "CLIMATE WISE" PROGRAM

AT THE

COSMAIR, INC.

CLARK MANUFACTURING FACILITY

BY
KEN KRALY

MAJOR COSMAIR, CLARK MANUFACTURING BUILDING STATS

BUILDING SIZE: 240,000 SQ. FT.

BUILDING AGE: 35 - 40 YEARS OLD

BUILDING FUNCTION: MANUFACTURE OF HAIR CARE PRODUCTS: PACKAGING, WAREHOUSE, PROCESSING, LABS, AND OFFICES

NUMBER OF SHIFTS: THREE

FINISHED GOODS PRODUCED: 130MM/ANNUALLY

COSMAIR, INC.
CLARK MANUFACTURING'S "CLIMATE WISE" PROGRAM

EMPLOYEE INVOLVEMENT

- INTERNAL AUDITS
- TRACKING OF UTILITIES
- STEERING COMMITTEE
- SIGNAGE/PUBLIC RELATIONS
- PREVENTATIVE MAINTENANCE SYSTEM

COSMAIR
CLARK MANUFACTURING
"CLIMATE WISE" SUMMARY

	1996	TO YEAR 2000
ENERGY SAVINGS (X 10^5BTU)	167,000	1,239,000
COST SAVINGS (DOLLARS)	$332,000	$2,260,000
EMISSION REDUCTIONS (TONS)	3,260	28,540

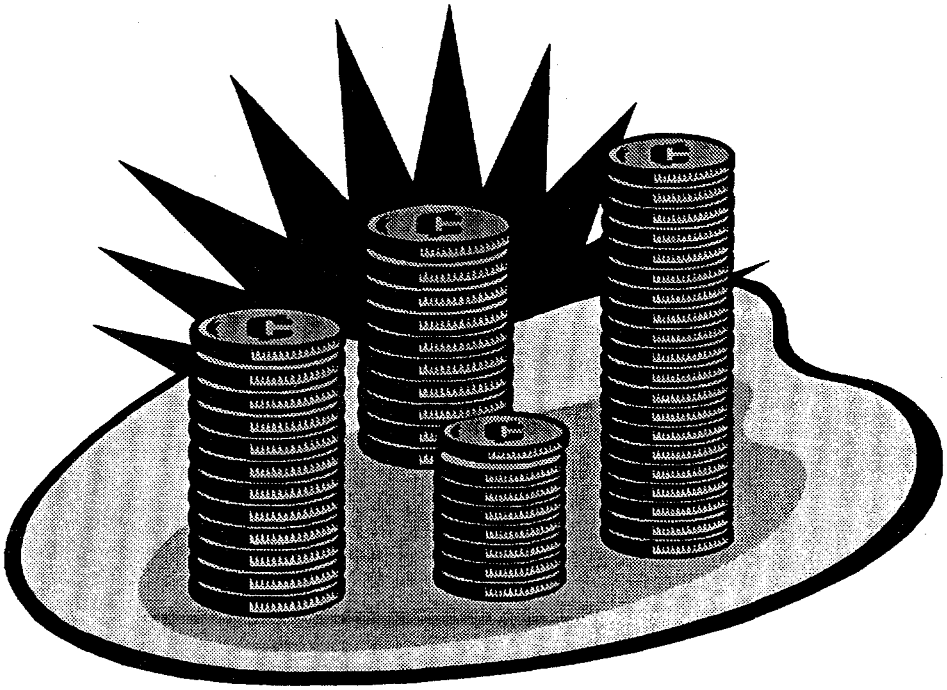
ANNUAL UTILITY SUMMARY

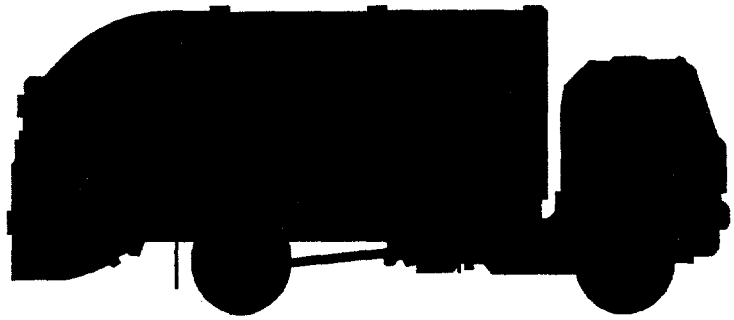
1996

TOTAL UTILITY COST - $1,340,000

OR

$13,400 SAVED FOR EACH % SAVED



SOLID  WASTE SUMMARY

1996

TONS RECYCLED/REUSED	1,368
REUSE/RECYCLE RATIO	87.0%
ITEMS REUSED/RECYCLED	20
COST OF SOLID SANITARY WASTE AND RECYCLING	$39,000
SALE OF RECYCLED ITEMS	$12,000
NET COST SOLID SANITARY WASTE	$27,000

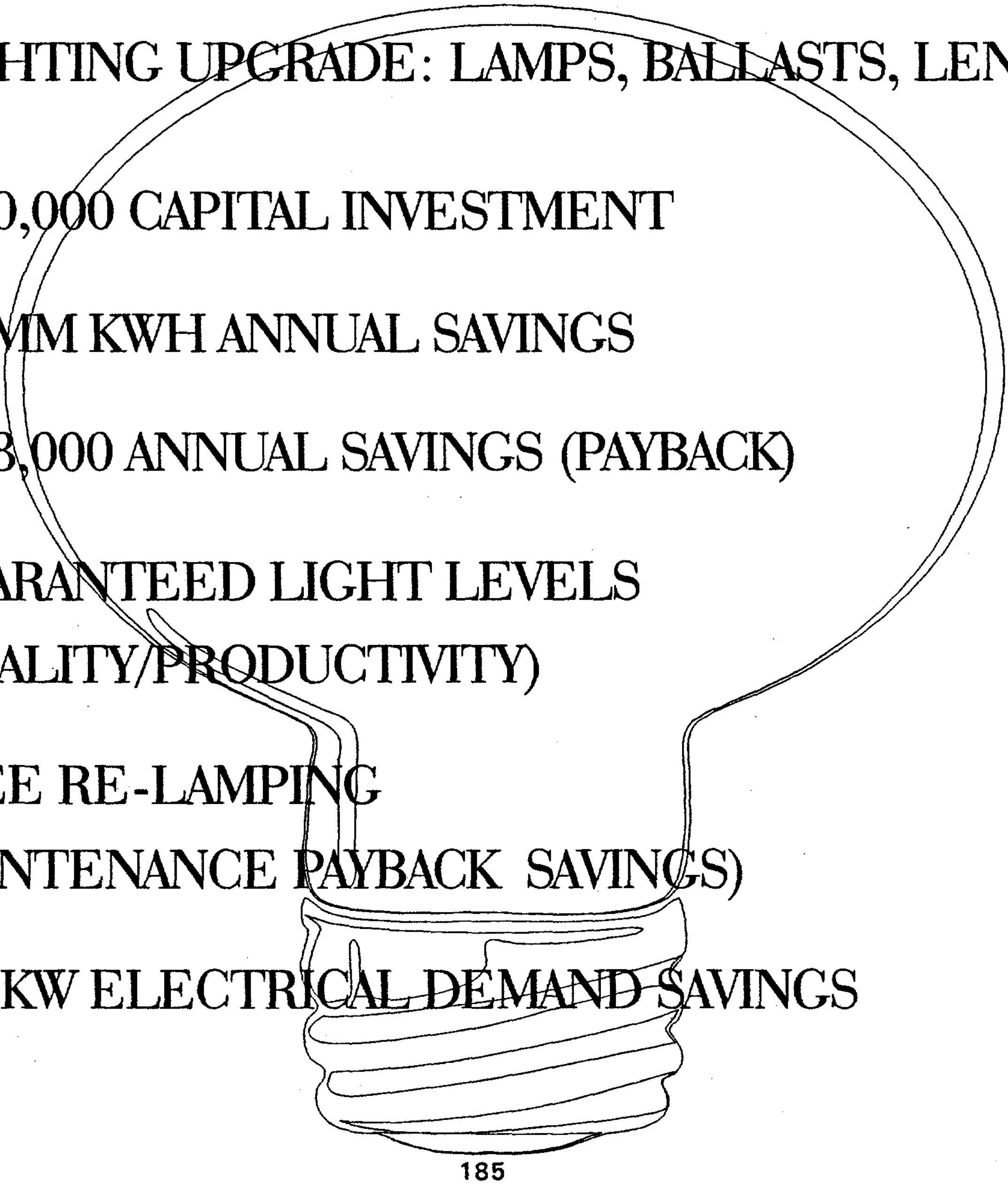
COSMAIR, INC.
CLARK MANUFACTURING
"CLIMATE WISE" PROGRAM

CHILLED WATER SYSTEM

- 500 TON RECIRCULATING SYSTEM
- 30 MM GALLONS OF WATER AND SEWERAGE SAVED ANNUALLY
- REDUCED SHAMPOO/CONDITIONER BATCH TIMES INCREASING PRODUCTIVITY AND CAPACITY
- IMPROVED FILLING (PRODUCTIVITY)
- PROCESS CONSISTENCY (IMPROVED QUALITY)
- IMPROVED PUBLIC RELATIONS

COSMAIR, INC.
CLARK MANUFACTURING'S "CLIMATE WISE" PROGRAM

EPA "GREEN LIGHTS PROGRAM"



★LIGHTING UPGRADE: LAMPS, BALLASTS, LENSES

★$180,000 CAPITAL INVESTMENT

★1.8 MM KWH ANNUAL SAVINGS

★$158,000 ANNUAL SAVINGS (PAYBACK)

★GUARANTEED LIGHT LEVELS
(QUALITY/PRODUCTIVITY)

★FREE RE-LAMPING
(MAINTENANCE PAYBACK SAVINGS)

★300 KW ELECTRICAL DEMAND SAVINGS

COSMAIR, INC.
CLARK MANUFACTURING'S "CLIMATE WISE" PROGRAM

1985 UPGRADES FOR BOILER/BURNER /STEAM

$100,000 CAPITAL INVESTMENT

NEW OIL/GAS HIGH EFFICIENCY BURNERS
(EMISSION REDUCTIONS)

STEAM LINE CROSS CONNECTS

ANNUAL SAVINGS - $100,000

SAVINGS TO DATE EXCEED $1 MM

CLARK MANUFACTURING'S ON-GOING "CLIMATE WISE" PROGRAM

HEATING/VENTILATION/ AIR CONDITIONING/LIGHTING

- COMPUTERIZED ENERGY MANAGEMENT SYSTEM
- COMPUTERIZED PREVENTATIVE MAINTENANCE PROGRAM
- BOILER/BURNER EFFICIENCY CHECKS (MONTHLY)
- INSULATION PROGRAMS
- ROOM OCCUPANCY SENSORS
- ENERGY/MAINTENANCE TOURS
- USE OF OUTSIDE AIR FOR COOLING
- VARIABLE SPEED CONTROLS
- HIGH EFFICIENCY MOTORS
- STEAM TRAP PROGRAM

SEMICONDUCTOR TECHNOLOGY
FOR REDUCING EMISSIONS AND INCREASING EFFICIENCY

by Bob Duffin and Randy Frank
Motorola Semiconductor Products Sector
Phoenix, AZ

Abstract:
The cooperation and support of all industries are required to significantly impact a worldwide reduction in gaseous emissions that may contribute to climate change. Each industry also is striving to more efficiently utilize the resources that it consumes since this is both conservation for good citizenship and an intelligent approach to business. The semiconductor industry is also extremely concerned with these issues. However, semiconductor manufacturer's products provide solutions for reduced emissions and increased efficiency in their industry, other industries and areas that can realize significant improvements through control technology. This paper will focus on semiconductor technologies of digital control, power switching and sensing to improve efficiency and reduce emissions in automotive, industrial, and office/home applications.

1.0 INTRODUCTION

The atmospheric concentrations of greenhouse gases, such as carbon dioxide (CO_2) and nitrous oxide (N_2O), have increased by about 30% and 15% respectively since 1750. These trends appear to be largely due to human activities such as fossil fuel use. The direct radiative forcing of these gases was calculated to be 1.70 Wm^{-2} in 1992. If carbon dioxide emissions remain at current levels it is estimated that atmospheric concentrations will reach about 500 ppmv by 2100, compared to 280 ppmv in pre-industrial times. Global mean surface air temperature has increased between about 0.3 and 0.6°C since the late 19th century and the best models predict an additional increase of about 2°C by 2100 [1].

The U.S. Environmental Protection agency has estimated that about 1% of current, total global warming gas emissions in the United States comes from HFC, PFC and SF_6 emissions caused by the manufacture of semiconductors and that the usage of these gases is growing due to increased product complexity and market demand. The semiconductor industry has begun an aggressive voluntary program to significantly reduce its normalized rate of emissions of these gases. Active programs are now underway in the United States, Japan and Europe, and are expected to spread to all semiconductor manufacturing nations. But use of semiconductors to improve equipment efficiency is also part of the greenhouse emissions reduction strategy of many other industries. A conservative estimate is that energy usage in the United States can be reduced by at least 25%, with corresponding cost and emissions reductions, from more efficient cars, motors and numerous industrial applications. While semiconductor manufacturing is a small part of the greenhouse gas emissions problem, semiconductor-based products can be part of a much larger solution.

2.0 SEMICONDUCTOR TECHNOLOGIES IN CONTROL APPLICATIONS

The control systems that are used to optimize the consumption of energy and minimize emissions rely heavily on semiconductor technologies. Digital control using computers, microcontrollers (MCUs) or digital signal processors (DSPs) is the basis of most modern control systems. Without microcontrollers the automotive emissions could not have been reduced from their 1960 values to the levels that are obtained today. Today's cars/light trucks emit 96/97% of the hydrocarbons and carbon monoxide and 90/89% of the oxides of nitrogen of the precontrol times [2]. However, other semiconductor technologies also play a vital role in these systems. For example, the adjustable speed drive motor control in Figure 1 requires either an MCU or DSP, efficient power switches and sensors to contribute to the EPA' plans of eliminating 6 million metric tons of carbon equivalent emissions that are generated every year by motors by the year 2000 [3]. Semiconductor power devices and smart power integrated circuits are as integral a part of these control systems as the MCU or DSP. In many systems, semiconductor sensors have provided feedback for at least one critical control parameter. The role of sensors is likely to increase as new semiconductor sensors are developed to address reliability, cost and performance issues in control systems. In addition to semiconductors for control, power and sensing, other semiconductors provide a clean power source, isolation , interface capability, memory and logic. A variety of discrete semiconductors typically complete the system. However, only the digital control, power switching and sensing will be discussed in more detail.

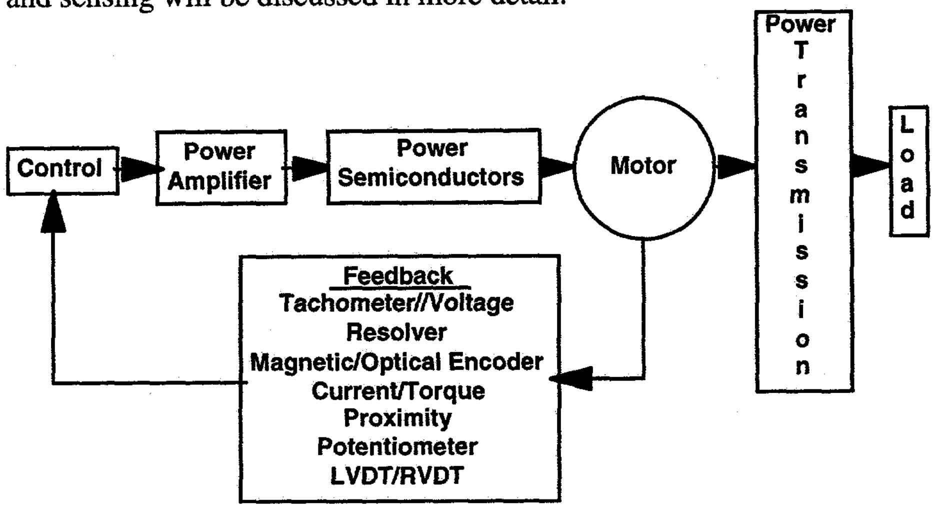


Figure 1 - Semiconductors and the elements of a adjustable speed motor control system.

2.1 Microcontrollers & DSP

Microcontrollers and digital signal processors provide the computational capability for low cost embedded control applications. The automotive emission control provided the impetus for semiconductor manufacturers to create the microcontroller - a microprocessor-based semiconductor device with enhancements specifically designed for control applications. A microcontroller is different from a microprocessor (MPU) because the MCU contains a central processing unit (CPU), memory, clock oscillator and general as well as application-specific input/output capability on a single chip. MCUs are frequently designed for higher operating temperatures than the MPU. The most popular MCU is the 8-bit unit but 16- and 32-bit units are also used in control systems. DSPs are gaining in acceptance for control systems where extensive real-time calculations are required.

MCUs have been designed for a variety of motor control applications. A motor-control specific MCU measures the speed and rotor position, calculates the resulting torque, accepts input and calculates the timing and amplitude of the current pulses that energize the windings. Digital control is an essential element of adjustable speed motor controls. Recently introduced MCUs for brushless dc motor control contain features such as: one time programmability; 8-bit, dual channel, high speed, pulse-width modulator; A/D converter for analog feedback signals; a serial communications interface; and operate at two frequency ranges (i.e., 183 to 23 kHz and 122 to 15.6 kHz). Higher frequency MCUs can also control open-loop 3-phase induction motors.

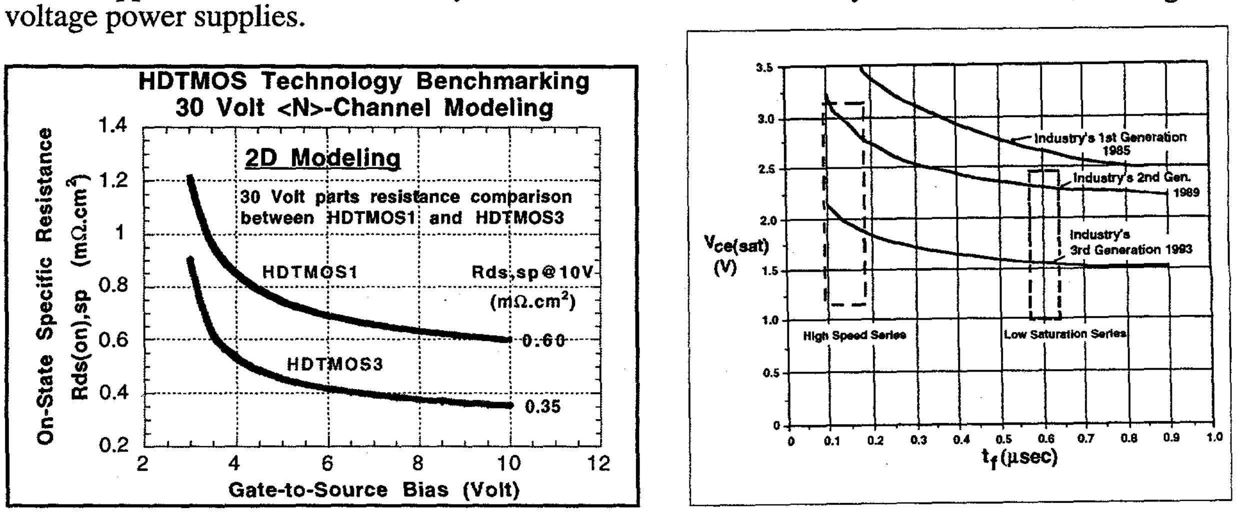
In addition to basic MCU control, more sophisticated digital control is being implemented with digital signal processing (DSP) and reduced instruction set computers (RISC). DSP techniques have been used for analog filtering, sampling and zero-crossing detectors, implementing fast Fourier transforms, spectral estimation methods, filtering and manipulation of speed-related current harmonics. Advancement in MCUs and DSPs have enabled higher complexity motor controls. The dynamic performance range is extending as these digital control devices improve.

2.2 Increasingly Efficient Power Semiconductors

Power semiconductor processes continue to evolve and achieve higher performance and greater efficiency levels than previous generations. Market- or application-specific solutions allow a semiconductor manufacturer to meet tough specifications for highly-competitive end products by optimizing production processes for performance and yield. These technologies include: silicon rectifiers, power MOSFETs in very low (<30V), low (30-100V), medium (100-250V), and high (>250V) voltage ratings and IGBTs (insulated gate bipolar transistors) (500-2000V) from a number of suppliers. More advanced technologies such as GaAs (gallium arsenide) are provided by a limited number of suppliers and meet very specific market/application requirements. Also, the addition of on-board circuitry, including smart power levels of integration, continues to provide performance advantages for many applications [4].

Power devices in industrial drives typically constitute about 35% of the cost. Motor topologies dictate the power device configuration and the supply voltage affects the choice of power devices. For example, in the low voltage area (less than 100 volts) power MOSFETs (metal oxide semiconductor, field effect transistors) or simply FETs are the current choice for power switching in digitally-controlled applications. A single direction motor driving a fan for example can be PWM (pulse width modulation) controlled from a single power FET. If the motor is grounded the FET must be a high side switch which means a P-channel FET or a N-channel FET with a charge pump to ensure the gate is fully enhanced when the FET is on. If the motor is not grounded an N-channel FET can be used. To reverse a brush dc motor an H-bridge is required with four FETs. The top two legs of the bridge have the same requirements as a high side switch - either P-channels or N-channels with charge pump must be used. Inverters for 3-phase ac or brushless dc motors use six FETs with the same high side requirements. Power MOSFETs are also used as switches for power management and in switch-mode power supplies.

Power MOSFETs are high frequency devices but lack the current density needed to make their use practical in many high voltage applications. Power MOSFETs would require a very large area to reduce the on-resistance for the power module and create serious reliability concerns due to the number of potential opportunities for failure. To provide the necessary power handling capability, IGBTs (Insulated Gate Bipolar Transistors) are the technology of choice for high voltage motor controls. IGBTs use a cell design similar to power MOSFETs but have a slightly different fabrication process. This provides a power device with the ease of drive like a power MOSFET and the area efficiency at higher voltages like a bipolar power transistor. These devices have a high voltage rating, as well as, high current capability. IGBTs are also used in lighting control applications, which currently consume 20% of the electricity sold in the U.S., and high voltage power supplies.



(a) (b)

Figure 2 - Efficiency improvement in (a) power MOSFETs and (b) IGBTS. The key steady-state improvement metric is on-resistance for MOSFETs and Vce(sat) for IGBTs.

2.3 Sensing Critical Feedback Parameters

Sensing technology has advanced considerably in the past decade based on semiconductor technology. Among the semiconductor-based sensors are sensors with micro-mechanical structures made by a batch process called micromachining. The microelectromechanical or MEMS devices provide an example of the dramatic changes that are possible using semiconductor technology. Micromachining is a chemical etching process that produces 3-dimensional mechanical structure or microstructure in silicon or other materials. Micromachining uses many semiconductor processing techniques including: photolithography, thin-film deposition, and chemical and plasma etching. Two types of micromachining are already used extensively for commercial products: bulk and surface micromachining. The bulk micromachined diaphragm in a pressure sensor is approximately 25 microns thick. In contrast, a surface micromachined accelerometer structure is only 2 microns thick and is separated by only 1 or 2 microns from the supporting substrate and the top layer [5].

One of the newest micromachined sensors is the chemical sensor. Thin-film metal oxide technology is combined with an embedded micro-heater on a thin micromachined silicon diaphragm. The small sample area of a micromachined sensor can more readily be raised to the higher operating temperature (about 450°C) that is required for detecting the presence and actual value of specific chemicals. Figure 3 shows a silicon chemical sensor made using bulk micromachining and thin-film metal deposition [6].

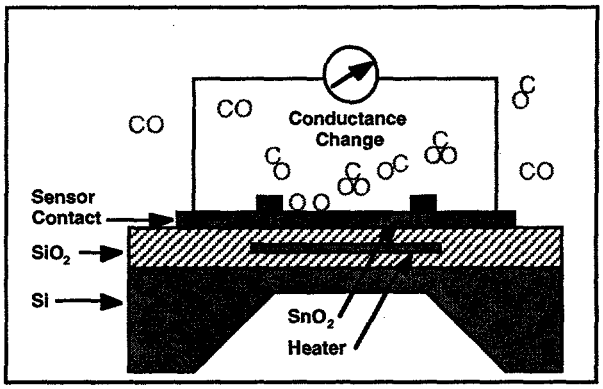


Figure 3 - Chemical sensor for detecting carbon monoxide.

Chemical sensors can be used either as a simple diagnostic or possibly in the control loop and have the potential to significantly enhance the sensed inputs in future systems. Since sensors are the means for a control system to see, feel, hear and touch its environment, the chemical sensor adds the capability for the control systems to "smell" as well. Chemical sensors have been developed for consumer and industrial applications to sense CO and methane.

3.0 AUTOMOTIVE EMISSIONS CONTROL SYSTEMS

Federal and state legislated standards for lower emissions and higher corporate average fuel economy (CAFE) have been the driving force behind increasingly sophisticated powertrain control systems. Today's more advanced powertrain control systems use 32-bit MCUs to control fuel injection, spark timing, emissions and transmission solenoids, idle speed motors, provide diagnostics and communicate with external and onboard systems. The MCU uses input from a variety of sensors including the oxygen sensor and semiconductor-based sensors such as the manifold absolute pressure to determine what actions should be taken and precisely when they should occur to minimize fuel consumption and emissions. The programs for the MCU are taking increasing amount of memory and are soon expected to exceed 1 MByte. Figure 4 provides a generic picture of the elements in an automotive control system [7].

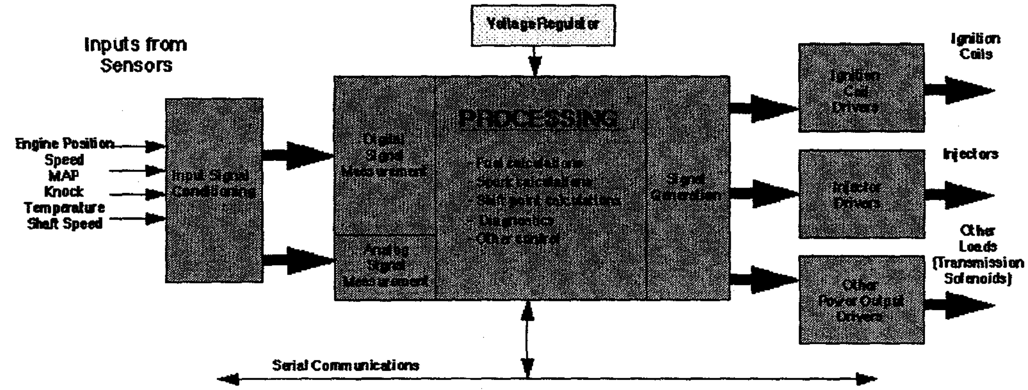


Figure 4 - Elements of an automotive powertrain control system.

The need for precise control of the spark timing, direct firing of multiple ignition coils and efficient high voltage switching has lead to the use of IGBTs for this high voltage application in vehicles. Automotive-specific IGBTs have been designed that incorporate precision output and protective gate clamps. These IGBTs are driven by a gate voltage of 5-volts allowing easy interface to the MCU [4].

Higher levels of integration in a power IC or smart power device have produced more complex products with several outputs in one package capable of driving all of the injectors for four, six, or eight-cylinder vehicles. At the same time, complex diagnostic and protection circuitry have also been incorporated. Circuitry that is integrated in multiple-output SMARTMOS™ drivers allows the independent thermal shutdown of each output device. The circuitry can include serial interfaces for communication with the host microcontroller and more complex diagnostics that can determine open load and the movement of a solenoid as the result of the device being activated [4].

Reducing the current draw of injectors through high impedance design allows the more integrated power IC to be used for more applications. Furthermore, legislated diagnostic requirements from California Air Resources Board (CARB) or the Federal government are leading auto makers to the sophisticated diagnostic capability available from a power IC design. Failure detection specified in On-Board Diagnostic II (OBD-II) legislation has been achieved by increasing the computing power and memory in most US automotive control systems

Micromachined pressure sensors have been used successfully for over a decade to provide the manifold absolute pressure and barometric absolute pressure measurements in engine control systems. Measurements in the early engine control systems were made by electromechanical devices. However, the semiconductor pressure sensors have proven to be more reliable, lower cost and easier to use in digital control applications.

4.0 INDUSTRIAL APPLICATIONS

Increased savings can result with adjustable-speed drives (ASDs) in industrial applications where dampers and vanes were previously used to control air flow. The improvement that results from replacing a valve with a variable speed drive can provide more than a 50% energy savings. With more efficient controls, motors can also be sized smaller adding to the system cost savings.

In some industrial systems the use of ASDs allows the elimination of flow control valves and reduces electrical and mechanical maintenance. The power needed to drive the pump is proportional to the cube of the speed. Therefore, a small reduction in speed can result in significant reduction in required motor output. The combination of a variable-displacement hydraulic pump with a digitally-controlled brushless motor drive allows the pump to continually operate near maximum displacement where it is most efficient [8]. This results in a 50% to 70% efficiency improvement over fixed-displacement, constant-speed systems. Figure 5 shows a comparison of energy consumption using previous versus present control techniques.

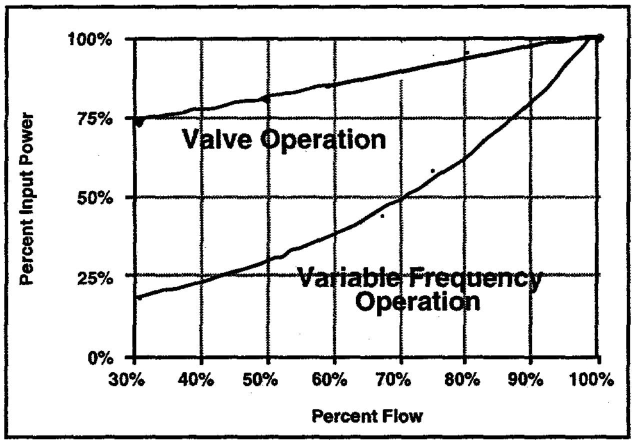


Figure 5. Energy Savings Using Adjustable-Speed Drive (Variable Frequency Operation) in Pump Application [8].

In the factory or office, chemical sensors could detect harmful or annoying levels of a variety of chemicals and, in the future, should ultimately prove beneficial as feedback elements in more complex control systems. Dampers in the heating, ventilation and air conditioning (HVAC) system could be automatically opened or closed changing the air exchange and circulation to minimize the effects of harmful chemicals or offensive odors. The combination of chemical sensor with efficient motor controls can be used to avoid sick building syndrome - a problem that occurs with highly effective sealing in new buildings.

As the number of chemicals that can be detected is expanded, it is possible that chemical sensing could be used as a process monitoring and quality control tool. Humidity sensors are among the possible sensors that could be produced by micromachining that could detect the process environment and provide comfort information for HVAC motor control systems. Humidity could also be combined with multiple chemical sensors for more complex control and reduced cost per sensed parameter in future systems.

5.0 HOME & OFFICE APPLICATIONS

Household energy use contributes 20% of all U.S. emissions of carbon dioxide [9]. The Energy Star Home Program expects that qualified homes will consume 30% less energy and save $1.8 billion in utility bills by the year 2000. Semiconductor technology is involved in more energy efficient appliance, heating and cooling equipment and lighting.

Energy efficiency and convenience are both accomplished by a network that connects the components of a smart or automated house. An example of a network system solution in home automation area is shown in Figure 6. This distributed control environment is interconnected with Neuron® ICs that allow a minimal number of wires, infrared, fiber optics, or even radio frequency transmitters to perform peer-to-peer communications between sensors and actuators via the LonTalk™ protocol. A high efficiency HVAC control strategy could be implemented in various ways. Energy management and load shedding can be built into the system.

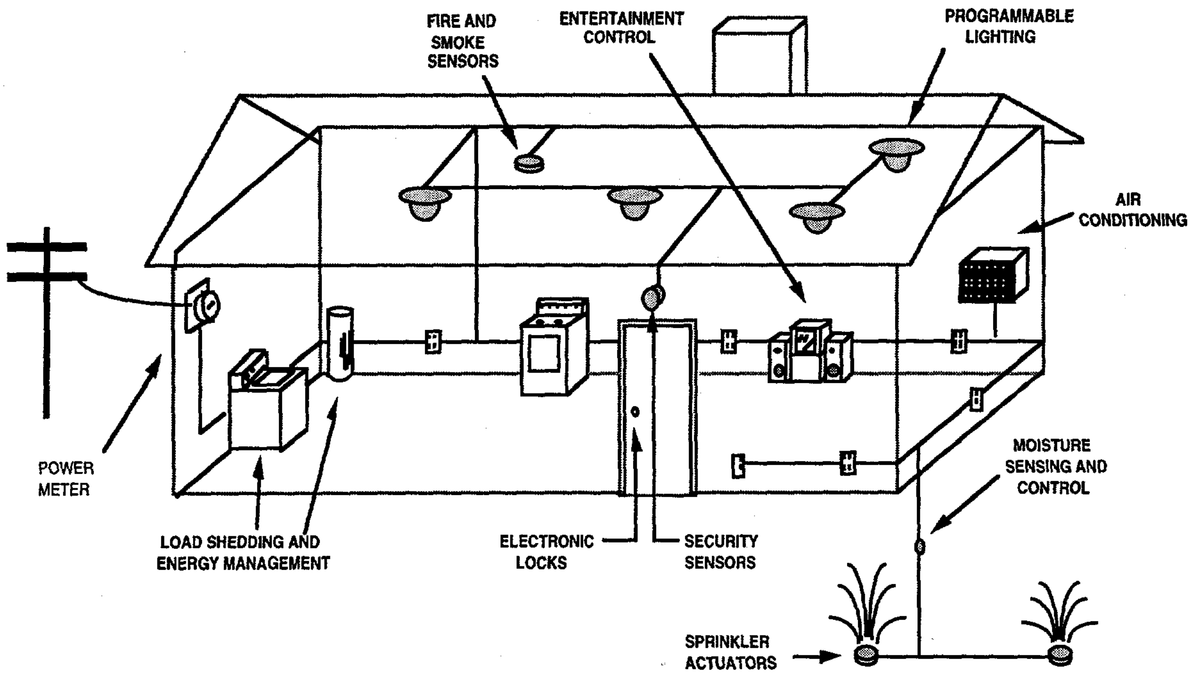


Figure 13. Home automation network.

The smart house intelligently communicates control information. For example, motors as well as lighting and solenoid controls could be connected for automatic and remote programming for improved efficiency and flexibility for different lifestyles. Safety and security can be increased in homes by sensing problems such as smoke or harmful chemicals and activating motors to restrict or increase airflow. Homes with motor-activated sunscreens can be positioned to increase or minimize heating from the sun based on sensor input to a central control system or interaction between remote smart nodes. A number of protocols have been defined and are available to address these applications in the home.

In a large office building one strategy for improved efficiency HVAC would have the ASD controlled motors in the HVAC system run at their lowest speed and only when required for minimum energy consumption. An alternate strategy could have the motor running continuously at an optimum efficiency point and directing the air flow to specific zones. A variable air volume (VAV) system controls the volume of air that is heated or cooled depending on user's demand. This reduces the amount of air that must be heated or cooled and consequently reduces energy consumption. Zoned control systems combine ASD with multistage heating or cooling elements, motors providing the air flow and the input from temperature, air flow and other sensors [5].

The fastest growing use of electricity in the United States is occurring in office buildings [10]. Over 30 billion kWh of electricity is currently consumed annual. Computers represent an area that can provide a significant energy saving with energy consumption in the 15 to 25 watt area compared to 150 watts by non-energy efficient units.

5.1 Computers

Computers represents the largest market segment for semiconductor products. The requirements are not limited to high performance computing and memory devices. Power devices are required in the power supplies and power management is an increasingly important design issue as computers exceed 200 MHz operation. Computer peripherals also require power devices to provide increased functionality. Power MOSFETs are typically used for the power management. A relatively new semiconductor technology, gallium arsenide (GaAs), is proving useful for increasing the efficiency in power supplies.

In a continuous-mode boost converter, GaAs rectifiers demonstrated the following advantages over silicon rectifiers [4]:

1. over a 40% reduction in power loss,
2. 20°C lower heatsink temperature,
3. 80% reduction in the power MOSFET's overshoot, and
4. significant reduction in total harmonic distortion and electromagnetic interference (EMI).

The GaAs rectifiers provide superior performance to silicon in 48V DC-DC converters and also have performance advantages in power factor correction circuits and as anti-parallel diodes for IGBTs in motor control applications [4].

6.0 SEMICONDUCTOR TECHNOLOGY & THE FUTURE

Semiconductor technology has made impressive advances into essentially every aspect of modern life. The learning or experience curve for this industry is typically 70%. When volume applications are identified manufacturers reduce the cost of providing semiconductor products at a rate that equals or exceeds other industries. This allows the products that use these semiconductors to become more and more affordable and find broader acceptance in the marketplace. The challenge for the semiconductor industry and its customers is defining standards that allow the volume market to be created.

Specifically, in the area of energy efficiency and emissions control, the semiconductor industry has provided the enabling technology that allowed increased vehicle production, higher corporate average fuel economy and vastly less aggregate pollution the 1990's than in 1970. Semiconductor technology is an integral part of plans to reduce energy consumption and reduce pollution for automobiles, motor controls and lighting, office buildings and homes. For an industry based on an invention that is only 50 years old this year, the expectations for the future are certainly high.

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