Tennessee Greenhouse Gas Emissions

MITIGATION STRATEGIES

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION

The purpose of this study is to present policy options and actions that could be implemented to limit the potential impact of global climate change for Tennessee and its citizens by reducing the level of Tennessee's greenhouse gas (GHG) emissions. A variety of initiatives are suggested that make progress toward our economic, energy and environmental goals. This document provides an initial resource for citizens and policy makers as they make the decisions that will shape our future.

Scientists who study worldwide climate change have raised the possibility of potential global climate change caused by the addition of greenhouse gases to the atmosphere from human activities. One major source of the primary greenhouse gas, CO_2, is the combustion of fossil fuels that supply the majority of our worldwide energy needs. Chapter 1 of this report outlines some of the science that supports global climate change concerns.

The issue of global climate change has received increased public attention and debate for only the past four to five years, while the science supporting this discussion has been under development for 40 to 50 years. The premise of global climate change has been actively monitored and researched in the scientific community for a long time relative to the period of the public debate.

While there is still much controversy associated with global climate change science, the United States has participated in a number of international agreements aimed at reducing worldwide greenhouse gas emissions. The most recent of these is the Kyoto Protocol, signed in December 1997. This document obligates the United States to reduce GHG emissions to 7 percent below 1990 levels by the 2008-2012 time frame. The agreement is not binding until the U.S. Senate ratifies it. The Senate has not taken up the issue to date.

THE REMI MODEL

The statewide macroeconomic impact of the various proposed strategies contained in this report for reducing the greenhouse gas emissions in Tennessee were generated using the Regional Economic Models, Inc. (REMI) Economic-Demographic Forecasting and Simulation 53-sector Model (EDFS-53) for Tennessee. The REMI model simulates the impact of changes in spending, both public and private, taxes, and prices on the state economy. The model is designed around the 53 sector (two digit SIC code) input-output table with endogenous final demand feedbacks. The model generates extensive numerical output allowing one to analyze in great detail the impact of a particular proposal on all affected sectors in the economy.

Potential global climate change caused by human activities is a daunting issue to consider in terms of proposing immediate policy options. The options must impact the problem without having unacceptable economic consequences. Certain new technologies are currently available that if implemented on a large scale could significantly reduce the state's GHG emissions. Tennessee can adopt an early pro-active stance relative to this issue, possibly forestalling any federal regulation at a later date.

Successfully implementing these measures designed to reduce GHG emissions will require the commitment of a large number of Tennessee citizens. Public discussion in Tennessee of these policy options and actions can also serve to further general education about the science of global climate change and the economic incentives for energy efficiency. The public policy options in this report intentionally involve voluntary and willing participants. The decision by Tennesseans to act on the policies with commitment can originate in and be influenced by open forum and debate. Thus, public awareness of the global climate change issue and policy responses that make good economic sense are critical to addressing the problem.

ES.2 BACKGROUND

An inventory of greenhouse gas emissions from Tennessee sources was conducted in 1995 for the year 1990. The year 1990 is the agreed starting point for international measurement. The inventory found that Tennessee's 1990 GHG emissions were 134.4 million tons equivalent CO_2**.** By using the term equivalent CO_2 emissions, the global climate change effects of other greenhouse gases such as methane and nitrous oxide can be included in the total by converting the amounts of those gases to an equivalent amount of CO_2. The utility and transportation sectors each represented roughly 30 percent of Tennessee's total GHG emissions, and together they accounted for 63 percent of GHG emissions. A 7 percent reduction from 1990 levels would place the targeted emission level for Tennessee at 125.0 million tons of equivalent CO_2 annually.

As part of this study to develop mitigation strategies, the emission levels for Tennessee have been projected through the year 2017, assuming that there are no concerted actions taken to reduce current long-term growth rates. The projected 2017 Tennessee emission level is 194.7 million tons of equivalent CO_2. The methodology for these projections is detailed in Chapter 2 of this report.

It is important to remember that our understanding of the global climate system is limited. As the body of evidence about the global climate system continues to grow the projected consequences of climate change will change. For example, estimates of sea level rise have gone from 10 meters to less than one meter. In addition, surprises—both good and bad that are beyond our ability to predict with current knowledge—are possible and even probable. Earth's climate, environments, and species interact and adapt in unexpected ways. Beyond these considerations are uncertainties about the rate at which CO_2 is added to the atmosphere.

Advances in combustion turbine technology, for example, have lowered CO_2 emissions per unit of electricity produced by 70 percent when compared to traditional coal fired plants. The federal government is also sponsoring research to triple the fuel efficiency of motor vehicles. The application of new technologies will at some point have a profound impact on global climate change projections. Then reported climate change projections and the consequences thereof may or may not actually occur due to the current incomplete understanding of weather systems and the unknown timing of future measures to reduce GHG emissions.

These uncertainties about the consequences of climate change create a dilemma. Years or decades may pass before all the interrelated science about climate change is resolved. Yet waiting passively risks irreversible damages while immediate action risks expenditures that may prove to be unnecessary based on climate considerations. There are several ways policy makers might approach this balancing effort. One is to consider and implement GHG mitigation measures with corollary economic benefits as insurance against uncertain risks. Following this logic results in an active GHG control program to reduce the potential risks until knowledge about climate change improves. Another approach is to invest heavily into research and development in technologies with the potential to reduce GHG emissions. A third approach is to implement only those activities that make sense for reasons beyond climate change, a "no regrets" approach. Determining the appropriate government response to climate change requires the skill of both scientists and policy writers/developers; scientists to describe the potential consequences and policy analysts to balance the potential threats and opportunities of climate change against other social needs and desires.

ES.3 PHILOSOPHY GUIDING THE DEVELOPMENT OF GHG MITIGATION STRATEGIES

The general philosophy guiding the development of policy options for the reduction of Tennessee's GHG emissions has been the following:

- Citizens, businesses and governments of Tennessee should and will voluntarily engage in activities, such as energy conservation projects, that will substantially reduce GHG emissions, or increase carbon sequestration, because of the economic attractiveness of the investment in these projects. The State of Tennessee should play a role in publicizing the return on investment commonly obtained from energy conservation initiatives. There are many new technologies currently available that when employed provide returns on investment in the 15 percent to 100 percent and beyond range. With the proper information at hand, the citizens of Tennessee will choose to participate in a plethora of energy related projects that make compelling economic sense and accomplish our environmental goals in the process. This report will present a limited number of examples of the type of projects envisioned and their economic impact statewide.

- The long term ability of Tennessee to reduce its GHG emissions to 7 percent below the 1990 levels, as has been agreed to in the Kyoto Protocol (but not yet ratified by the U.S. Senate), resides in the implementation of new technologies under development, but not currently available at an economically feasible cost. Many new technologies are close at hand that will drastically improve the efficiency of the transportation and electrical utility industries throughout this region of the country. These new technologies will penetrate the market because of their economic attractiveness, not because they are mandated by governmental action.

- Early action credits should be established immediately to encourage the implementation of existing technologies where the return on investment is well documented and the environmental benefit is not in doubt. Early action has the highest value in beginning to slow the rate of increase in Tennessee's GHG emissions. It will take time and a considerable effort to educate the citizens of Tennessee as to the economic and environmental benefits of investing in energy efficiency projects.

ES.4 TENNESSEE GREENHOUSE GAS EMISSIONS PROJECTIONS THROUGH 2017

The Phase I Tennessee Greenhouse Gas Emissions Study (Cunningham and Anderson) established the levels of greenhouse gases emitted to the atmosphere from all major sources within Tennessee for the year 1990. The majority of the GHG emitters within Tennessee produce either carbon dioxide (CO_2) or methane (CH_4). A summary of the results of the 1990 greenhouse gas inventory for Tennessee is shown in **Table ES.4.A**. The Phase II Tennessee Greenhouse Gas Emissions Study has as an overall goal the development of voluntary policy options for Tennessee to reduce GHG emissions from sources within the state. As a first step toward the completion of the Phase II study, annual emissions for Tennessee have been projected through the year 2017 assuming that no new initiatives are undertaken to reduce their growth rate.

TABLE ES.4.A: SUMMARY OF 1990 GREENHOUSE GAS EMISSIONS FOR TENNESSEE (CUNNINGHAM AND ANDERSON)

Source/Sink	Emissions (tons)	Equivalence Factor	Equivalent Emissions (tons CO_2)
Carbon Dioxide			
Fuel Combustion	122,127,302	1	122,127,302
Production Processes	1,939,663	1	1,939,663
Forest Management	(4,887,589)	1	(4,887,589)
Total	119,179,376	1	119,179,376
Methane			
Gas and Oil Systems	24,537	22	539,819
Coal Mining	39,058	22	859,273
Landfills	283,011	22	6,226,234
Animals	211,342	22	4,649,531
Manure Management	57,870	22	1,273,129
Crop Wastes	719	22	15,819
Municipal Wastewater	5,875	22	129,241
Total	622,411	22	13,693,046
Nitrous Oxide			
Production Processes	0	270	0
Fertilizer	2,834	270	765,094
Crop Wastes	44	270	11,915
Total	2,878	270	777,009
Other			
PFCs (Production of Aluminum)	145	5,400	780,516
Total			**134,429,948**

The overall projections for Tennessee's greenhouse gas emissions are summarized in **Table ES.4.B**, where total equivalent CO_2 emissions are shown for the years 1995 through 2017. The 1990 inventory found that Tennessee's emissions were 134.4 million tons of CO_2 equivalents. The inventory extension has projected Tennessee's 1995 emissions to be 161.5 million tons of CO_2 equivalents, or a 20.1 percent increase in five years. The closing year of the projections shows a total emission level 194.7 million tons of CO_2 equivalent. This represents an increase of 44.8 percent from the 1990 emission levels. **Figure ES.4.A** shows a plot of the total equivalent CO_2 emissions for the years 1995 through 2017.

TABLE ES.4.B: TOTAL EQUIVALENT CO_2 EMISSIONS 1995-2017

Year	Carbon Dioxide Emissions	Equivalent CO_2 from Methane	Equivalent CO_2 from Nitrous Oxide	Total Equivalent CO_2 Emissions
	million tons	*million tons*	*million tons*	*million tons*
1995	148.148	12.507	0.821	161.476
1996	149.568	12.586	0.846	163.000
1997	150.978	12.663	0.882	164.524
1998	152.388	12.739	0.918	166.045
1999	153.798	12.814	0.958	167.570
2000	155.188	12.885	1.003	169.076
2001	156.578	12.953	1.052	170.583
2002	157.958	13.017	1.106	172.082
2003	159.338	13.078	1.166	173.583
2004	160.698	13.136	1.233	175.067
2005	162.048	13.191	1.305	176.545
2006	163.398	13.243	1.386	178.026
2007	164.738	13.291	1.474	179.504
2008	166.078	13.338	1.571	180.987
2009	167.398	13.381	1.677	182.456
2010	168.728	13.424	1.794	183.947
2011	170.058	13.468	1.922	185.448
2012	171.378	13.511	2.063	186.952
2013	172.698	13.554	2.218	188.470
2014	174.018	13.596	2.387	190.002
2015	175.338	13.638	2.574	191.550
2016	176.658	13.680	2.778	193.116
2017	177.978	13.721	3.002	194.702

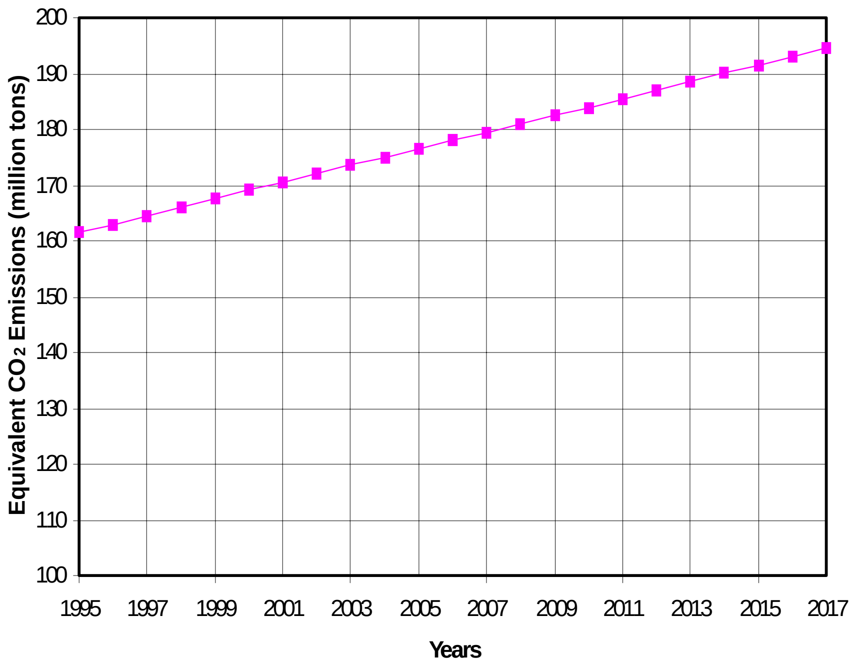


FIGURE ES.4.A: TOTAL EQUIVALENT CO_2 EMISSIONS

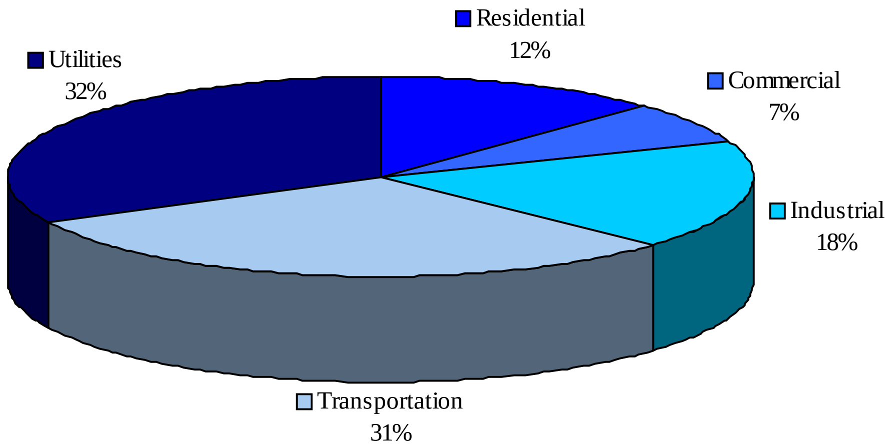


FIGURE ES.4.B: 1995 EQUIVALENT CO_2 EMISSIONS

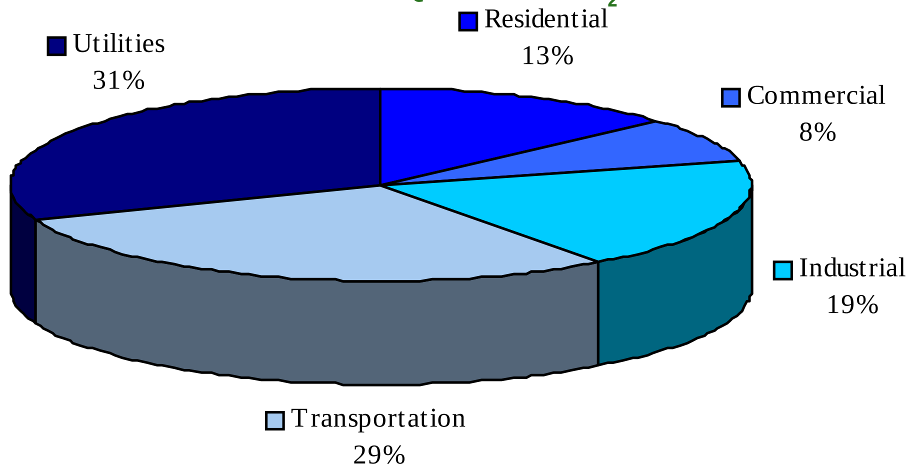


FIGURE ES-4-C: 2017 EQUIVALENT CO_2 EMISSIONS

The sector breakdown for total equivalent CO_2 emissions in 1995 and 2017 are shown in **Figures ES.4.B and ES.4.C**, respectively. For 1995 the utility and transportation sectors each represent roughly 30 percent of the total emissions, and together they total 63 percent of Tennessee's emissions. They are followed by the industrial sector at a little less than 20 percent, the residential sector at 12 to 13 percent, and the commercial sector at 7 to 8 percent. The percentage breakdown between the sectors is fairly constant between 1995 and 2017.

ES.5 RECOMMENDED POLICY OPTIONS

The statewide macroeconomic impact of the various proposed strategies contained in this report for reducing the greenhouse gas emissions in Tennessee were generated using the Regional Economic Models, Inc. (REMI) Economic-Demographic Forecasting and Simulation 53-sector Model (EDFS-53) for Tennessee. The REMI model simulates the impact of changes in spending, both public and private, taxes, and prices on the state economy. The model is designed around the 53 sector (two digit SIC code) input-output table with endogenous final demand feedbacks. The model generates extensive numerical output allowing one to analyze in great detail the impact of a particular proposal on all affected sectors in the economy.

The regional modeling exercise permits one to capture the net effects of increased spending on the following variables:

- **Employment**: measures the numbers of Tennessee workers in a given year involved in full- or part-time work.

- **Gross State Product** [GSP]: is a measure equivalent to the value of Tennessee's final goods and services produced in a year. GSP is analogous to a measure of gross domestic product on a state basis. It is measured in billions of 1992 dollars.
- **Output**: measures GSP plus the value of all intermediate goods and services which serve as inputs to production. A gauge of total annual sales revenues for final and intermediate goods and services. It is measured in billions of 1992 dollars.
- **Real Disposable Personal Income** [RDPI]: measures the after tax income in 1992 dollars that is available for consumption and savings.
- **Personal Consumption Expenditure Price Index** [PCE Price Index]: measures state-wide inflation in the consumer price index with 1992 as the base year. The PCE Price Index is reported in terms of percentage change.

This section summarizes possible policy options to reduce greenhouse gas emissions from Tennessee by sectors. While policies implemented through voluntary actions are preferred, others are included for consideration by policymakers. More detailed information on most policies is included in Chapter 3.

A quick analysis reveals that of the 194.7 million tons of CO_2 equivalent emissions projected for 2017 (without mitigating actions), about 39.5 million tons can be avoided by the implementation of the policies represented in **Table ES.5.A**. Additional annual reductions of about 30.2 million tons are needed to reach the target set by the Kyoto Protocol. At first glance this might seem like an impossible goal, but further investigation into technologies that should penetrate the market in the next 10 to 20 years leads to a more optimistic conclusion.

TABLE ES.5.A: SUMMARY OF CO_2 EMISSIONS REDUCTION FROM SUGGESTED POLICIES

SECTOR	CO_2 Emissions Reduction million tons/yr
Residential Sector Policies	2.6
Transportation Sector Policies	3.7
Commercial Sector Policies	3.9
Industrial Sector Policies	5.9
Utility Sector Policies	14.9
Carbon Sequestration Policies	8.5
Sum	**39.5**

The economic impact on the State of Tennessee of implementing the specific policy options discussed in Chapter 3 of this report has been estimated and is included in the discussion of the options where applicable. Overall, if all of the policy options were implemented they would provide a net economic boost to the state economy.

RESIDENTIAL SECTOR

The residential sector in Tennessee contributes between 12 to 14 percent of the state's total equivalent GHG emissions, depending on the year of interest. Policies to help reduce this sector's emissions have been designed to center around energy conservation measures that have a high return on investment. Thus, home owners should voluntarily participate in these activities once they are convinced of the economic feasibility.

Policy 1: **Promote the replacement of incandescent lighting with compact fluorescent lamps in existing houses and apartments in Tennessee.** New compact fluorescent lamps are currently on the market that allow 60 to 100 watt incandescent light bulbs to be replaced with 13 to 24 watt lamps. The fluorescent lamps have a 10,000 hour rated life versus 750 hours for most incandescent bulbs. Carbon dioxide reduction—1.2 million tons per year in 2017. Annual savings—$73 million. Implementation cost—$168 million. Simple payback—2.3 years.

The estimated economic impact of this proposal can be summarized by the following results that were obtained from an analysis of this proposal using the REMI model for Tennessee:

- an expected average increase in employment of 799 jobs per year
- an expected average increase in GSP (gross state product) of $37.4 thousand per year
- an expected decrease in the average price level in Tennessee by 0.04 percent per year

Policy 2: **Promote the use of fluorescent and other high efficiency lighting products for new residential and apartment construction.** Discourage the use of incandescent lighting for residential applications wherever possible.

Policy 3: **Enact new requirements on the minimum insulation levels and window types for new residential and apartment construction.** The cost of adding additional insulation during new construction is low. Insulation standards such as R-38 for cecilings, R-22 for walls and floors, and double pane windows will ensure good energy efficiency for new residential construction. Carbon dioxide savings - 0.9 million tons in 2017. Savings value - $13.7 million per year. Minimal additional cost when done with new construction.

The estimated economic impact of this proposal can be summarized by the following results. These were obtained from an analysis using results extrapolated from earlier runs on similar cases using the REMI model for Tennessee:

- an expected average increase in employment of 149 jobs per year
- an expected average increase in GSP of $6.9 thousand per year
- expected to have a negligible effect on the average price level in Tennessee

Policy 4: **Promote the use of renewable energy resources wherever their application is economically feasible.** Potential energy sources include hydro-electric generation, biomass energy, animal waste, landfill methane, garbage, geothermal energy, wind power and solar energy. New technologies are under development to utilize these energy sources in a cost effective manner.

Policy 5: **Promote the purchase of new high efficiency home appliances and home electrical and computer equipment.** These products are currently on the market and additional promotional efforts would increase their market penetration.

Policy 6: **Promote the use of low flow shower heads to reduce the amount of hot water used during bathing.** Carbon dioxide reduction —0.45 million tons per year in 2017. Annual savings $27.5 million. Implementation cost—$2.68 million.

The estimated economic impact of this proposal can be summarized by the following results. These results were obtained from an analysis using results extrapolated from earlier runs on similar cases using the REMI model for Tennessee:

- an expected average increase in employment of 301 per year

- an expected average increase in GSP of $14.1 thousand per year
- expected to have a negligible effect on the average price level in Tennessee

COMMERCIAL SECTOR

The commercial sector in Tennessee contributes between 6 to 8 percent of the state's total equivalent GHG emissions, depending on the year of interest. Policies to help reduce this sector's emissions have been designed to center around energy conservation measures that have a high return on investment. Thus, commercial business owners should voluntarily participate in these activities once they are convinced of the economic feasibility.

Policy 1: **Promote and encourage the replacement of inefficient water chillers.** In large, air-conditioned buildings and industrial facilities requiring significant refrigeration, the chiller plant is one of the major energy consumers. Consequently, the energy performance of water chillers is critical to minimizing overall operating costs. Most large water chillers in operation today are 15 years or older. The chiller efficiency improvements of recent years have made the return on investment for chiller retrofit projects very attractive, and in many cases in the 15 to 35 percent range. Along with the energy cost savings potential, the phasing out of refrigerants commonly used by older chillers gives extra incentive to the replacement of these units. The Montreal Protocol calls for the phasing out of common refrigerants such as R11, R12 and other chlorofluorocarbons (CFCs). Production of these refrigerants has been limited or stopped altogether, making their cost extremely high relative to the refrigerants used in new chillers. These older chillers will have to be replaced in the next 5 to 10 years.

New developments in commercial and industrial size water chillers have led to units that require roughly one-half of the electrical input of older units. Instead of consuming electricity at the rate of about 1.0 to 1.2 kW/ton, these newer, more efficient chillers require only 0.5 to 0.6 kW/ton. By estimating approximately 400 ft^2/ton of installed chiller capacity and assuming 50 percent of chillers could be replaced, resulting in a 50 percent reduction in electrical energy consumption, the total reduction in electrical energy use would be 2.16 billion kWh per year. This would correspond to a reduction in CO_2 output of almost 2.3 million tons. The expected cost of this project would be $784 million and, with a savings of $140 million per year in electricity bills, would result in a 5.6-year simple payback.

The estimated economic impact of this proposal can be summarized by the following results that were obtained from an analysis of this proposal using the REMI model for Tennessee:

- an expected average increase in employment of 3,758 per year
- an expected average increase in GSP of $171 thousand per year
- an expected decrease in the average price level in Tennessee by 0.05 percent per year

Policy 2: **Promote and encourage lighting retrofit projects to increase the efficiency of lighting systems.** There is a vast potential for energy savings and GHG emissions reduction by implementing current state of the art lighting technologies into the existing building stock throughout Tennessee. Estimates have been made of the square footage of facilities in 6 major classifications within Tennessee. From the square footage numbers, projections are made of the possible energy savings due to lighting retrofit projects. The building categories include public schools (K-12), medical care facilities, commercial office space, retail office space, state government owned buildings, and manufacturing facilities. Overall, it is estimated that this measure could save 1.5 million tons of CO_2 emissions annually. The annual electrical cost savings are approximately $91.7 million and the implementation cost is about $471 million. The estimated simple payback is 5.1 years.

The estimated economic impact of this proposal can be summarized by the following results that were obtained from an analysis of this proposal using the REMI model for Tennessee:

- an expected average increase in employment of 2,045 per year
- an expected average increase in GSP of $98 thousand per year
- an expected decrease in the average price level in Tennessee by 0.04 percent per year

Policy 3: **Promote efficient refrigeration systems for supermarkets.** Commercial food refrigeration systems move heat from one place to another. Energy conservation opportunities exist and include measures to improve the efficiency of these systems. Plastic strips on supermarket refrigerated display cases reduce energy use 15 to 45 percent. Glass doors reduce energy consumption 30 to 60 percent. Improvements to the refrigeration system offer large energy savings potential. The use of multiple compressors in parallel reduce energy use 13 to 27 percent (EPRI, 1992). Tuning the compressor pressure to ambient conditions (instead of for the hottest day) lowers energy demand by over 20 percent. Variable speed drives for the compressors also save considerable amounts of energy. Heat recovery devices which recover waste heat from the refrigeration system for use as space heat or for heating water also improve efficiency. One side-by-side test of conventional and advanced commercial refrigeration systems revealed a 23 percent energy savings for the advanced system. Assuming that the supermarket refrigeration retrofit program begins in 2002, the 2017 annual CO_2 emissions reduction would be about 138,000 tons. The value of the annual electrical savings in 2017 is projected to be $6.4 million and the total cumulative project cost would be about $19.4 million if implemented in 2002. Estimated simple payback—3 years.

The estimated economic impact of this proposal can be summarized by the following results. These results were obtained from an analysis using results extrapolated from earlier runs on similar cases using the REMI model for Tennessee:

- an expected average increase in employment of 171 jobs per year
- an expected average increase in GSP of $7.8 thousand per year
- expected to have a negligible effect on the average price level in Tennessee

Policy 4: **Encourage participation by the commercial sector in the US EPA's Greenlights and Energy Star Buildings programs.** Both of these programs promote energy efficiency in buildings.

Policy 5: Consider adoption of a commercial new construction energy efficiency code. Adopt a commercial building energy efficiency code, modified to account for existing commercial codes and building practices in the state. A modified ASHRAE Standard 90.1-1989 could serve as the basis for Tennessee's commercial new construction code. This code should be modified to account for existing local codes and standard building practices in the state.

ASHRAE 90.1 is a nationally recognized energy efficiency standard that applies a set of energy efficiency criteria to a building's lighting, heating, ventilating and air conditioning systems, and the building envelope. Developed by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) in cooperation with the Illuminating Engineers Society (IES), this standard is used in many states, including Tennessee, as the basis for energy efficiency codes. When modified to account for Tennessee's existing building practices, codes and standards, and current compliance issues, the ASHRAE code would be recognized as the universal minimum standard for energy efficiency in Tennessee buildings.

Policy 6: Establish an energy efficiency partnership and information clearinghouse. Through a non-profit government/industry partnership, establish an information clearinghouse and provide product information, technical assistance, and energy efficiency education services to professionals who design, build and operate commercial and industrial buildings.

An energy efficiency partnership could operate a clearinghouse to disseminate information about code requirements, high efficiency equipment, technologies, and construction practices. Initially, this information clearinghouse could receive utility support in return for delivering the educational and training components of their demand side management programs. This policy should be viewed as a long-term objective.

The energy efficiency information clearinghouse should include a telephone and Internet accessible database that addresses energy efficiency issues in a user friendly format. The database should contain information about product availability, innovative technologies, energy efficiency codes, efficient design practices, and programs and resources available to support efficiency in the commercial and industrial sectors. Other functions of the partnership include providing advice, training, and technical assistance to improve building commissioning and promoting sound energy management, energy cost accounting, and preventive maintenance procedures. The partnership could disseminate energy management protocols, energy cost accounting systems, and preventive maintenance procedures to assist building operators with monitoring and controlling energy costs. Educational materials should be developed and tailored to specific building types and energy end uses. The partnership will develop a database of governmental and private organizations, trade associations, and consumer groups that assist specific market sectors with energy management needs.

Policy 7: Continue to administer the Small Business Energy Loan Program and the Energy Loan Program for Government through the Energy Division of the Tennessee Department of Economic and Community Development. The

Energy Loan Programs provides low-interest loans for energy efficiency improvements to Tennessee small commercial and industrial business facilities and local government facilities. The program's goal is to reduce energy costs and enhance the energy efficiency of the state. The Energy Loan Program assists with identification, installation, and incorporation of approved energy efficiency measures into existing facilities within Tennessee.

INDUSTRIAL SECTOR

The industrial sector in Tennessee contributes between 18 and 19 percent of the state's total equivalent GHG emissions, depending on the year of interest. Policies to help reduce this sector's emissions have been designed to center around energy conservation measures that have a high return on investment. Thus, industries are expected to participate voluntarily in these activities once they are convinced of the economic feasibility.

Policy 1: Encourage participation by the industrial sector in federal government sponsored energy conservation programs such as: Motor Challenge, Steam Challenge, Compressed Air Challenge, Greenlights, Energy Star Program, Climate Wise Program and others as they are introduced. These programs are all voluntary and provide resources and information to assist businesses in implementing energy efficiency improving measures.

Policy 2: Promote a detailed energy efficiency enhancing program to assist Tennessee's industries in identifying and implementing energy conservation projects. A total of 22 separate types of industrial energy conservation projects are listed in **Table ES.5.B**. This list represents just some of the possible measures that have been investigated.

The estimated economic impact of the combined proposed changes in industrial energy use can be summarized by the following results that were obtained from an analysis of this proposal using the REMI model for Tennessee:

- an expected average increase in employment of 3,097 per year,
- an expected average increase in GSP of $161 thousand per year,
- an expected decrease in the average price level in Tennessee by 0.08 percent per year.

The data presented in this report are for the industries listed in **Table ES.5.C** that have been selected from the Standard Industrial Classification (SIC). These industries were selected because energy conservation data were available for analysis.

Table ES.5.C contains policies which are proposed to reduce greenhouse gas emissions from the industrial sector in Tennessee. A more detailed discussion of these policy options is included in Chapter 3.

TRANSPORTATION SECTOR

In Tennessee the transportation sector is the second largest contributor to greenhouse gas emissions, accounting for almost 28 percent (33.8 million tons) of CO_2 equivalents in 1990. Over the twenty year period from 1997 to 2017, the unmitigated levels of transportation-related CO_2 equivalent emissions will continue to rise to 58.0 million tons in year 2017. Between 1970 and 1992, the number of registered motor

TABLE ES.5.B INDUSTRIAL SECTOR GHG REDUCTION POLICIES

Policy Option	Policy Cost ($)	Annual Savings ($)	CO_2 Reduction (tons)	Cost per Ton Reduced ($)	Simple Payback (years)
Promote Heat Recovery System Improvement	8,679,141	7,873,415	471,700	18.4	1.1
Improve Steam System Operation and Maintenance	66,812	377,778	29,632	2.3	0.2
Promote Cogeneration Systems	112,652,455	40,728,705	1,392,962	80.9	2.8
Promote Boiler Equipment Upgrades	1,778,775	1,023,184	85,147	20.9	1.7
Promote Process Heat Recovery	441,784	306,544	18,673	23.7	1.4
Promote Heat Recovery from Equipment	936,080	1,230,000	48,936	19.1	0.8
Promote Refrigeration Equipment Upgrades	1,016,232	587,328	16,438	61.8	1.7
Promote Flue Gas Recuperation	8,450,841	6,747,490	554,212	15.2	1.3
Promote Improved Boiler Maintenance	2,576,144	7,117,503	824,144	3.1	0.4
Promote Steam Condensate System Improvement	355,438	432,362	26,072	13.6	0.8
Promote Improved Thermal Insulation Systems	3,508,349	4,955,122	287,770	12.2	0.7
Promote Steam System Leak Reduction Program	661,532	1,606,518	197,889	3.3	0.4
Promote High Efficiency Motor Hardware	48,838,559	25,940,691	402,966	121.2	1.9
Promote Air Compressor System Optimization	7,123,631	18,265,627	311,610	22.9	0.4
Promote Space Conditioning Control Upgrades	5,074,565	7,766,428	290,660	17.5	0.7
Promote Reduced Building Infiltration	1,704,447	1,843,488	122,571	13.9	0.9
Promote Air Circulation Hardware Improvement	2,091,700	1,820,938	62,907	33.3	1.2
Promote Mechanical Systems Design Miprovement	390,532	286,580	30,052	13.0	1.4
Promote Heating/Cooling Equipment Improvement	9,745,337	3,666,942	77,849	125.2	2.7
Promote Equipment Use Reduction	7,031,186	2,101,266	83,103	84.6	3.4
Promote Lighting Retrofit Projects	46,613,468	27,594,306	390,150	119.5	1.7
Promote Misc. Hardware Improvement	14,960,119	7,558,275	194,757	76.8	2.0
Totals	284,697,127	169,830,490	5,920,202	48.1	1.7

TABLE ES.5.C INDUSTRIAL SIC CODES INCLUDED IN THE ENERGY CONSERVATION ANALYSIS

SIC Code	Industrial Classification
20	Food and Kindred Products
21	Tobacco
22	Textile Mill Products
23	Apparel and Other Textile Products
24	Lumber and Wood Products
25	Furniture and Fixtures
26	Paper and Allied Products
27	Printing and Publishing
28	Chemicals and Allied Products
29	Petroleum and Coal Products
30	Rubber and Misc. Plastics Products
31	Leather and Leather Products
32	Stone, Clay and Glass Products
33	Primary Metal Industries
34	Fabricated Metal Industries
35	Industrial Machinery and Equipment
36	Electronic and Other Electric Equipment
37	Transportation Equipment
38	Instruments and Related Products
39	Misc. Manfacturing Industries

vehicles on Tennessee highways rose from 2,049,992 to 4,645,083 (CBER, 1994: 349). This represented a 127 percent increase over twenty-two years, or an average annual increase of about 5.8 percent, far ahead of levels of population growth.

The emissions figures reported in Chapter Two reflect the heavy environmental cost imposed by our singular reliance on passenger cars as the primary form of transportation. The fact that our dependence on cars is combined with a tendency to travel as single occupants makes the related issue of emissions reduction especially intractable. Moreover, the social costs that result from reliance on cars extends well beyond environmental problems that are narrowly conceived in terms of auto emissions alone. Rising levels of traffic congestion, noise pollution, and the worsening of already existing social inequities all exact a toll in terms of higher social costs.

The transportation-related CO_2 mitigation policies considered for the state of Tennessee—commuter rail, telecommuting, high occupancy lanes, van and carpools and emissions control and testing—draw on concrete proposals currently being either considered or implemented to some degree. There are already standard policies in many areas of the United States that are now finding proponents in Tennessee as the metropolitan areas of the State begin to experience severe problems associated with transportation by passenger car.

Policy 1: **Promote commuter rail alternatives.** The substitution of commuter rail travel for cars is a travel alternative that has received attention in the Nashville metropolitan area in recent years. As a form of mass public transport, commuter rail could be expected to relieve the congested conditions of vehicular traffic on existing roadways as well as to provide reductions in greenhouse gas emmissions.

A 1996 study titled "Nashville Regional Commuter Rail Evaluation" details the economic feasibility and environmental impact of a proposed light rail, public transportation network in the five county Nashville area (RTA et al, 1996). Five travel corridors, making use of existing or potential heavy rail facilities, were studied with respect to the projected ridership, estimated revenues, capital and operating costs, and the air quality impact that would result from decreased reliance on individual vehicular travel. The five corridors considered parallel the existing roadway commuter routes into Nashville. All ridership, cost, and environmental impact estimates were based on projections for the year 2015.

Table ES.5.D reports ridership along with estimated revenues and operating costs for the five rail corridors for the year 2015 (RTA et al, 1996: 81). Revenues reflect

TABLE ES.5.D ANNUAL OPERATING COSTS AND REVENUES FOR NASHVILLE COMMUTER RAIL IN 2015

	Northeast	East	Southeast	South	West
Rail Trips (One-way)	810,645	532,695	1,037,850	618,630	497,505
Revenues [$]	1,789,080	1,287,495	2,456,925	1,369,605	1,077,120
Total Operating Costs [$]	4,170,130	3,518,605	4,551,981	3,338,033	3,358,970
Operating Cost per Passenger Mile [$]	0.428	0.440	0.297	0.474	0.571
Operating Deficit [$]	2,381,050	2,231,110	2,095,056	1,968,428	2,281,850
Deficit per Passenger Mile [$]	0.245	0.279	0.137	0.280	0.388

Source: RTA et al, 1996:81.

projected ticket prices times one-way railtrips. Depending on distance traveled and the corridor selected, ticket prices range between $2.17 and $2.41 per trip. Operating costs per passenger mile vary across corridors. The fact that unit operating costs are lower for corridors with higher levels of ridership would indicate some economies of scale are present.

Given the proposed revenue structure, the system is projected to operate at a deficit. In the United States, public transportation operating ratios—defined as revenues as a proportion of operating costs—typically are well below one; thus implying the generation of a deficit. In most instances, this deficit is covered by local taxes on property, sales, gasoline, or downtown parking.

Significantly, the cross price elasticity of ridership demand compared to the price of daily parking was found to be highly elastic. A fifty percent rise in the price of daily parking was estimated to increase commuter rail ridership by approximately eighty-two percent, or from 7,418 trips per day up to 13,475. The high degree of cross price sensitivity to parking fees would indicate that increases in the cost of gasoline and other expenses in operating individual vehicles would be likely to induce an increased use of commuter rail. Pricing policies which promoted the substitution of commuter rail for individual vehicular travel could be anticipated, as well, to increase the operating ratio.

Apart from reducing traffic congestion on traditional commuter routes and roadways, commuter rail travel would result in the abatement of greenhouse gas emissions. The estimated reduction in CO_2 emissions from the use of commuter rail services in Nashville are reported in **Table ES.5.E.** Utilizing figures reported in the commuter rail study (RTA et al, 1996: Appendix 2), it is possible to approximate net mileage reductions in vehicular traffic across the five corridors served by commuter rail. In 2015, the substitution into commuter rail travel could diminish vehicle miles traveled

TABLE ES.5.E IMPACT OF COMMUTER RAIL

	Vehicular Miles Reduced	Tons CO_2 Reduced
Nashville Area	60,243,240	19,510
Total Tennessee*	118,377,967	38,337
*Includes Memphis area extrapolation estimate		

Source: RTA, et al., 1996: Appendix 2

by 60,243,240. As reported in **Table ES.5.E**, the conversion of this number into emissions savings indicated that 2015 commuter rail travel would result in 19,510 fewer tons of CO_2. If one assumes that Memphis could support a commuter rail service of roughly similar scale, then extrapolation estimates indicate that an additional 18,827 tons of CO_2 reductions could be attained. As seen in **Table ES.5.E**, this would result in a total projected state-wide abatement of 38,337 tons of CO_2.

Policy 2: **Promote telecommuting.** Through the use of communications technology, telecommuting permits employees to work at home instead of traveling to their employer's business location, thereby reducing the total number of vehicular miles traveled. The federal government defines a telecommuter as "anyone who regularly works at an alternate location, at least once a pay period (every two weeks) with at least one of the following outcomes: quality of life improvements, environmental benefit, customer service benefit or other form of productivity improvement such as real estate saving or worker productivity" (cited in TMA, 1998:4). In the U.S., it has been estimated that approximately 11.1 million Americans telecommuted in 1997 and that each year about one million more workers are added to the ranks of telecommuters (TMA, 1998:3,6). By the year 2002, the Federal government plans to deploy about 15 percent of its workforce in some form of telecommuting.

Environmental benefits are measured primarily in the lower levels of auto emissions and cleaner air. One study by the U.S. Department of Transportation estimated that between 5.2 percent and 10.4 percent of the country's total workforce will be telecommuting in the year 2002 with the result that total vehicle miles traveled will be between 0.7 percent and 1.4 percent lower than if there were no telecommuting. At the national level, this would mean a reduction of between 17.6 and 35.1 billion miles of vehicular travel and fuel savings that ranged from 840 to 1,679 million gallons of gasoline (TMA, 1998:16).

Environmental and economic benefits of telecommuting in Tennessee. A survey carried out among telecommuters in the Nashville region found that workers who telecommuted did so on average three days per week and realized a net reduction in travel of 355 miles per week (TMA,1998:38). By scaling national estimates of increases in numbers of telecommuters to fit Tennessee's workforce and combining these with the results of the TMA survey cited above, it is possible to extrapolate estimates and to assess the likely impact of telecommuting on travel mileage and CO_2 emission reductions over time for the State.

The results of this exercise under the assumptions of low range (5.2 percent) and high range (10.4 percent) rates of expected telecommuting in the year 2002 can be summarized as follows. By the year 2017 between 494,000 and 649,000 Tennessee workers could be expected to telecommute at least three days at week. Depending on the actual rate of telecommuting, this could mean reductions in CO_2 emissions of 2.8 up to 3.6 million tons.

Based on the findings of the Nashville-area telecommuting survey, the economic benefits of telecommuting for households, in particular, appeared to be significant. Ninety-two percent of respondents believed that their productivity had increased as a result of their telecommuting experience (TMA, 1998:28). Out-of-pocket savings to individual telecommuters averaged $49.86 per person per week in 1997. Factoring out the increased at home costs of electricity and food for telecommuters, the average, weekly net per capita savings amounted to $41.76. On an annual basis, the savings realized would be approximately $2,088 per worker (TMA, 1998: 36). As the figures cited above were based on an average of three telecommuting days per week, one could infer that even greater household savings would result were the number of weekly telecommuting days to increase.

By extrapolating from the Nashville telecommuter survey, it is possible to evaluate the compound value of the net benefits that would accrue to telecommuting households over time. Under the assumption that the cost savings were invested at current bond rates, Tennessee telecommuters could expect the future value of these savings in 2017 to be between $153 million at the low-range rate of telecommuting up to $201 million dollars at the high range. Since the Nashville-area survey did not attempt to quantify the net benefits to businesses from telecommuting, the household savings reported above are apt to underestimate significantly the overall economic gains.

Policy recommendations. Since telecommuting apparently holds out considerable societal gains, public policies promoting greater levels of telecommuting have an important role to play. Education is seen as a central element of the policy response. The Tennessee-based Transportation Management Association (TMA) has advised that Federal, State, and Local governments take the lead by expanding telecommuting opportunities among their employees (TMA, 1998:44,46). In addition, the TMA suggests that public educational efforts include the development and distribution of technical manuals on telecommuting for employers and workers as well as video presentations and speakers.

While support for telecommuting among workers is generally high—reaching 88 percent in one study—support among executive decision-makers is apparently more tepid—measuring only 16 percent (Yen el al, 1994). Significantly, the Yen et al study found that once an employer had personal contact with a telecommuting worker, employer support rose to 59 percent. This experience indicates that imperfect information—very likely associated with the costs to businesses of attaining relevant information—is responsible for notable efficiency losses. In this regard, it could be advised that the costs of educational outreach should be borne by state subsidies for educational materials and services promoting telecommuting which would be disseminated through State Energy and Transportation Departments and directed at private sector employers and employees. It has been suggested that Tennessee state policy-makers could draw lessons from the experience of California, Arizona, Oregon and Washington where educational programs to promote telecommuting have been developed (TMA, 1998:45).

Policy 3: **High occupancy vehicle lanes.** The predominant response to the problem of traffic congestion in the United States has been to expand roadway capacity. As population and vehicular traffic have increased, the expansion of the interstate system, especially in urban areas, has proceeded apace.

In spite of roadway expansion, the rapid rate of growth of vehicular traffic has run ahead of roadway capacity with the result that traffic congestion and costly time delays are an ever-present fact of urban life. The escalating economic and political cost of purchasing additional right-of-ways has forced municipalities to reexamine the forms of utilization of the existing transportation infrastructure with an eye toward enhancing that infrasturcture's efficiency. One alternative that has been considered in Tennessee and elsewhere is the use of high occupancy vehicles.

A high occupancy vehicle (HOV) is typically defined as a vehicle with more than one occupant. In some areas and on particular roadways, however, HOV travel is understood to designate vehicles that carry three or more riders. Carpools, vanpools and buses are all considered HOVs. Higher vehicle occupancy levels along a given corridor mean that a higher number of travelers can be accommodated for a given number of vehicles. In the U.S., policies which increase the incentives for HOV travel are becoming one method of managing travel demand.

The most common way of providing for HOV travel has been to designate special HOV lanes in which only vehicles with multiple riders are permitted to travel. In metropolitan areas, the fact that interstate systems generally intersect with themselves and form radial patterns that allow travelers to bypass city streets, means that HOV lanes can be readily incorporated into existing infrastructure. Once established, HOV lanes can be operated over variable time periods, running, for instance, on a 24-hour basis or functioning only during peak travel times during the morning and evening "rush hours". Enforcement of HOV lane utilization becomes a central element in assuring the success of the policy.

Nashville Tennessee's transportation infrastructure has not escaped growing problems with traffic congestion. In 1993, the Tennessee Department of Transportation, the Federal Highway Administration, and the Nashville Area Metropolitan Planning Organization began an investigation of the feasibility of HOV travel in Nashville called the "High Occupancy Vehicle Land and Improved Accessibility Study"; henceforth the HOV Study.

Based on the reported survey results it was possible to generate the estimated total daily miles traveled by HOVs. For the purpose of appraising future HOV land usage, the study operated under the assumption that in the year 2016 there would be no modal shift or vehicle mile reductions over the 1996 base year as a result of HOV travel. This assumption was considered the "worst case" scenario and was made in order to determine if HOV demand in a corridor would be sufficient given the 2016 average daily traffic estimates and the current (1996) percentage of HOV traffic in a particular corridor during peak hours (HOV Summary, 1993:p.5).

Under a "better case" scenario, it was believed that there would likely be an increase in the number of HOV vehicles in 2016 of between 20 percent and 60 percent. If one makes the additional—and conservative assumption—that there are on average only two riders in HOV vehicles, then if would be possible to estimate the likely reduction in vehicle miles traveled due to higher HOV use. This could be accomplished by multiplying the total daily miles of HOV travel found on all six corridors in the 2016 no-change-travel-mode case by the low (20 percent) and high range (60 percent) percentages of expected increases in HOV travel. Once mileage reductions were determined, it was possible to convert the effects of such mileage declines into estimates of CO_2 reductions.

TABLE ES.5.F ESTIMATED STATE-WIDE REDUCTIONS IN VEHICULAR TRAVEL AND EMISSIONS RESULTING FROM HOV TRAVEL AT LOW- AND HIGH-RANGE LEVELS

	Low Range (20% HOV Increase)	High Range (60% HOV Increase)
Miles of Reduced Travel	80,547,679	214,643,037
Tons CO_2 Reduced	25,646	76,943

Extrapolated from: HOV Study, 1993: pp.8.1-8.72.

An extrapolation of the Nashville-area study results to the state of Tennessee was made on the assumption that at least four other metropolitan areas—Memphis, Knoxville, Chattanooga, and Johnson City—would be large enough to consider employing HOV lanes in 2016.

The results of this extrapolation are reported in **Table ES.5.F**. In 2016, increased HOV ridership is calculated to reduce vehicle miles traveled by over 80 million miles at the low range estimate and by over 241 million miles at the high range. The reported drops in vehicle miles traveled translate into approximately 25,646 and 76,943 fewer tons of CO_2 emissions at the low and high range estimates, respectively. The decline in vehicle miles and CO_2 reductions should be seen as conservative estimates given the assumption that the average HOV vehicle in 2016 would carry only two riders.

Policy 4: Promote the development of complementary and emerging transportation alternatives

Park-and-Ride Lots. Park-and-ride lots are an important component in the development of alternatives to single occupant auto travel. Studies in the U.S. have shown that successful park-and-ride lots within a region are situated within travel corridors that experience high levels of traffic congestion (RTA, 1993: p.1). The vast majority of the trips that make use of currently existing park-and-ride lots are work-related. The upstream location of park-and-ride lots from areas suffering traffic congestion can often mitigate traffic problems while serving to lessen the environmental problems related to single occupancy vehicle travel. Moreover, strategically located park-and-ride lots serve as complementary infrastructure to carpooling, vanpooling, commuter bus, and commuter rail services. In locales with limited carpooling activities and no commuter transit service, park-and-ride lots can foster the development of such activities.

A study of the Middle Tennessee area developed a comprehensive inventory of existing park-and-ride lots in the five county area surrounding Nashville and identified areas where additional lots could be best located (RTA, 1993: p.1). The RTA study was carried out in order to aid traffic planning for interrelated activities such as commuter rail and to serve as an information tool for the promotion of ridesharing.

Hybrid Vehicles. Hybrid vehicles combine standard type engines with electric powered motors. In sensitive city environments where low emission or low noise requirements are the standard, hybrid vehicles permit diesel or gasoline engines to be shut off and the electric propulsion system activated. When in areas where environment regulations are less restrictive, the vehicles are powered with diesel, ethanol or biogas engines which can also be used to drive the electric motors and to recharge the batteries (CADDET, 1998: pp.4-14). Typically, hybrid buses are powered by two electric motors and a combustion engine, which are integrated into a traction hybrid system. In Sweden, where the most extensive hybrid vehicle demonstrations are being carried out, passenger vehicles as well as buses and trucks are involved. Elsewhere, Toyota has developed the first mass-produced hybrid gasoline engine/ electric motor passsenger car, the Prius. The hybrid sedan has attained a range of 28 kilometers per litre of gasoline while halving CO_2 emissions (CADDET, 1998: p.9).

New Vehicle Fuels: A-21. A-21 is a hybrid fuel that is composed of 55 percent water and 45 percent naphtha, a cheap-to-produce by-product of petroleum distillation. According to studies, A-21 not only is cleaner burning and safer than diesel fuel, but cheaper as well (Miller, 1999: p.533). The fuel has been tested primarily in bus fleets and power generators. A-21 appears especially attractive to the trucking industry which faces increasingly strict regulations on the emissions generated from diesel fuel. Tests have shown that A-21 leads to a 60 percent drop in emission levels of carbon monoxide, nitrous oxide, and hydrocarbons. The only adaption required of standard vehicles is a set of special spark plugs. Since the fuel is immune to fire and explosions, it can be stored above ground, thereby avoiding problems of leakage and groundwater contamination that is common with tanks of traditional fuels. Moreover, the use of naphtha would eliminate up to 90 percent of the air pollutants emitted by oil refineries in their production processes.

UTILITY SECTOR

In Tennessee and the wider Tennessee Valley region, the Tennessee Valley Authority (TVA) is the utility that provides electrical power. When investigating the CO_2 emissions associated with electric power generation in this region, the policies and operating procedures of TVA are central to the analysis.

TVA has 33 operating coal-fired units, located at 7 plant sites in Tennessee. The oldest such unit began operations in 1951, while the latest unit to come on line commenced electric generation in 1973. The combined capacity of the coal-fired units is 14,743 megawatts, or 57 percent of TVA's total capacity. By comparison, TVA's hydroelectric power and nuclear power units generate 4,044 and 3,282 megawatts, respectively (TVA Dams & Power Plants, 1994). TVA projects no technical problems that would preclude the continued operation of these units through the year 2020 (TVA, 1995: 4, 2-44).

TVA's existing coal-fired plants are responsible for a significant portion of the region's smog-producing and greenhouse gases through these plants' emissions of sulfur dioxide, nitrogen oxides, particulate matter, and CO_2, among others. In the TVA region, power generation activities by TVA in 1990 accounted for 73 percent of the sulfur dioxide, 33 percent of the nitrogen oxide emissions, and considerably smaller percentages of volatile organic compounds and suspended particulate matter (TVA, 1995: 3.12). TVA's current sulfur dioxide emission rate is 60 percent lower than it was 20 years ago. In the case of CO_2, TVA accounted for almost 40 percent of total CO_2 emissions in the state of Tennessee in 1990 (Cunningham and Anderson; 1995: 11).

On February 3, 1995, TVA signed a Climate Challenge Participation Accord with the U. S. Department of Energy. Under this Memorandum of Understanding (MOU), TVA committed to reduce greenhouse gas emissions by 24.9 million tons of CO_2 equivalent below the emissions that would have occurred in 2000 without the actions identified in the agreement. The Tennessee portion of these emissions reduction is estimated by TVA to be 14.9 million tons (Climate Challenge Participation Accord, 1995).

The following is a summary of the GHG reduction activities identified by TVA as consistent with the Climate Challenge Program MOU.

Nuclear Unit Operation - The operation of its Browns Ferry Nuclear Unit 2 and Watts Bar Unit 1 are expected to reduce CO_2 emissions by 10.6 million tons annually by 2000.

Biomass Cofiring - TVA has initiated a biomass cofiring test program at its fossil fueled units. The biomass used is wood waste from the wood products industry in the TVA region. Based on these tests, TVA will initiate commercial cofiring projects at various fossil plants that will result in annual GHG reductions in the year 2000 equivalent to 1.6 million tons of CO_2.

Demand Side Management (DSM) Programs - TVA has identified a number of demand side management programs that may be implemented as a result of its ongoing integrated resource planning (IRP) process. TVA expects the DSM programs to result in estimated annual CO_2 emissions reductions in the year 2000 of 0.9 million tons.

Fossil Fueled Unit Efficiency Improvements - TVA expects to continue to initiate activities to offset thermal performance degradation and to improve the efficiency of its fossil fueled generating units.

The efficiency improvement activities TVA plans to initiate in 1995 through 2000 are expected to result in additional annual CO_2 emissions reductions of approximately 0.6 million tons in the year 2000.

Transmission System Efficiency Improvements - TVA expects to continue to improve the efficiency of its transmission system and thereby reduce power generation requirements. Such improvements include replacing the conductors on existing transmission lines, constructing new substations, and replacing transformers. These activities are expected to result in the reduction of 0.5 million tons of equivalent CO_2 in the year 2000.

Hydro Modernization Activities - Activities will continue to improve the performance of the hydroelectric generating units. Upgrading turbines and generators will increase their efficiencies. These upgrade projects will produce a savings in GHG emissions of about 0.3 million tons in the year 2000.

Other Activities - Smaller reductions have been identified in the following areas: fossil fueled unit flyash sales, heat pump program activities, Utility Forest Carbon Management Program (UFCMP), CFC management activities, internal energy management activities, internal transportation efficiency improvement, forest management activities, office waste paper recycling, cogeneration, animal waste methane recovery, NO_x emissions reductions, public power initiatives. The total emissions reductions for these activities are estimated to be 0.4 million tons of equivalent CO_2 in the year 2000.

CARBON SEQUESTRATION

Policy 1: **In 1992 the U.S. Department of Agriculture Soil Conservation Service performed a National Resource Inventory and reported that Tennessee had approximately 1.86 million acres of marginal and sub-marginal pasture and cropland.** By supporting a program aimed at planting the entire 1.86 million acres with pine trees, Tennessee could sequester 3.4 million tons of CO_2 annually for the first 10 years, with that amount blossoming to 8.5 million tons annually at the end of the next 10-year period. Presumably, these trees could be harvested and replanted in a continuing cycle.

ES.6 NEW TECHNOLOGIES

Chapter 4 of this report contains information on a number of new technologies currently under development that hold the potential to drastically reduce the net equivalent CO_2 emissions from Tennessee over the next 10 to 20 years.

Transportation Sector: In the transportation sector, which represented 31 percent of Tennessee's GHG emissions in 1995 (50.9 million tons of equivalent CO_2), hybrid vehicles are available today that average 60 miles per gallon of gasoline and cost less than $20,000. Further cost reductions, technological advances and creative marketing efforts should lead to significant market penetration in the next 10 to 20 years. The potential of hybrid vehicles to reduce GHG emissions is large, if significant market penetration can be achieved.

Utility Sector: As the largest GHG emitting sector in Tennessee , the electric utility industry was responsible for 32 percent of the State's GHG emissions in 1995. This 54.3 million tons of equivalent CO_2 emissions came mostly from the combustion of coal to generate electricity. There are a number of new technologies that have the potential to significantly reduce the emission of GHGs from electric power generation. Photovoltaic (PV) systems are currently available that directly convert sunshine into pollution-free electricity. Utility applications are possible when PV systems are integrated with energy storage systems. While the technology to manufacture these cells is in place, at current production levels and costs the power produced by PV systems is not economically competitive with conventional power. PV systems are commonly installed today in remote areas where the cost of connection to the electric power grid is prohibitively high. As production levels slowly ramp-up and greater economies of scale enter the manufacturing processes, it is thought that PV systems will someday rival conventional energy sources in providing low cost power. If one adds an environmental cost to the price of electricity generated by fossil fuels, then some of the difference between the two energy sources disappears.

Many new electrical generating units are fueled with natural gas. If the electricity generated from natural gas displaces electricity generated from coal, then a reduction in GHG emissions is achieved. Not only are the new natural gas units more efficient than the older coal fired units, but the hydrogen content of the methane (CH_4) in the natural gas burns to water vapor instead of additional carbon burning to CO_2. Thus, a large scale conversion of electric generating capacity from coal to natural gas fired units would produce sizeable reductions in GHG emissions.

Eventually, new gasification combined-cycle power systems will be available that can utilize coal and reduce CO_2 emissions by 20 to 30 percent of those emitted by today's technologies. These systems would allow us to utilize the vast worldwide coal reserves for energy production while supporting the environment.

The time required for some or all of these new electric generating technologies to economically displace the current stock of electric utility generators is difficult to predict. It is likely that, within a 15 to 30 year time horizon much of the electric generating capacity of the Tennessee Valley Authority will be upgraded to new technologies. The actual timing of that replacement and the new technologies implemented are not clear at this point. With utility deregulation occurring in the next several years, accurate predictions concerning the equipment base and overall emissions levels 10 to 20 years into the future are not possible at this time.

Carbon Sequestration: Recent research just beginning to be published indicates that by the judicious selection of farming techniques and crop rotation, the soil used to grow crops can act like a giant siphon to pull in and store CO_2 from the atmosphere. Some scientists now think that with the change of a few simple farming practices applied across the United States, the nation's farms could be transformed into CO_2 sponges, sopping up millions of tons of the gas per year. A battery of recent studies has prompted national policy makers to focus on the potential of farms and new farming techniques to help fight global climate change by offsetting emissions from the burning of fossil fuels. Farmers could find themselves with a new cash crop: pollution-reduction credits that can be sold to electric utilities and others emitting greenhouse gases. The Kyoto Protocol allows for countries to create new sinks to meet part of their required emissions reductions. Thus, it may turn out to be easier and cheaper to capture and sequester carbon from the atmosphere than to prevent its release.

With the relatively large amount of farming that occurs within Tennessee, pollution-reduction credits could have a significant impact on the State's GHG emissions, as well as provide a revenue source for its farmers. These ideas are too premature for quantification at this time. As the science improves over the next 10 years the justification for specific policy options may emerge.

ES.7 CONCLUSION

A wide variety of emerging technologies possessing great potential for helping to reduce GHG emissions from Tennessee are included in Chapter 4 of this report. It is with great optimism that the authors include this information, as it and additional innovations too numerous for inclusion, represent the means by which Tennessee will be able to reach its GHG emissions target. It is not clear at this time the exact timetable for the specific emissions reductions, but within a 10 to 20 year time frame it should be possible for Tennessee to reduce its annual GHG emissions to or below the target level of 125.0 million tons of CO_2 equivalent.

CHAPTER 1

THE SIGNS OF CLIMATE CHANGE

It is important to remember that our understanding of the global climate system is limited. Thus, the projected consequences of climate change presented in this chapter are speculative and will change in the future as we learn more about the global climate system. For example, estimates of sea level rise have gone from 10 meters to less than one meter. In addition, surprises—both good and bad that are beyond our ability to predict with current knowledge—are possible and even probable as climates, environments, and species interact and adapt in unexpected ways. Reported climate change projections and the consequences thereof may or may not actually occur due to the current incomplete understanding of weather systems and the unknown timing of future measures to reduce GHG emissions.

These uncertainties about these possible consequences of climate change create a dilemma. Years or decades may pass before the uncertainties about climate change are resolved. Waiting passively risks irreversible damages while immediate action risks large expenditures to mitigate emissions that may prove to be inconsequential. The remainder of this chapter presents basic information concerning the possibility of global climate change brought on by human activities. The scientific community has many supporters of this viewpoint as well as many who believe that any climate change experienced in recent years was caused completely by natural processes. The remaining portion of this Chapter is taken from Climate Change: State of Knowledge, Office of Science and Technology Policy, October 1997.

1.1 INTRODUCTION

Burning coal, oil and natural gas to heat our homes, power our cars, and illuminate our cities produces CO_2 and other greenhouse gases as by-products. Deforestation and clearing of land for agriculture also release significant quantities of such gases. Over the last century, we have been emitting greenhouse gases to the atmosphere faster than natural processes can remove them. During this time, atmospheric levels of these gases have climbed steadily and are projected to continue their steep ascent as global economies grow.

Records of past climate, going as far back as 160,000 years, indicate a close correlation between the concentration of greenhouse gases in the atmosphere and global temperatures. Computer simulations of the climate indicate that global temperatures will rise as atmospheric concentrations of CO_2 increase. The 1995 report of the Intergovernmental Panel on Climate Change (IPCC), which is the most comprehensive and thoroughly reviewed assessment of climate change science ever produced, concluded that change is already underway. The IPCC, which represents the work of more than 2,000 of the world's leading climate scientists, concluded that Earth has already warmed about 1° F over the last century, and that "the balance of evidence suggests that there is a discernible human influence on global climate."

The IPCC estimates that global surface air temperature will increase another 2 - 6.5° F in the next 100 years. The difference in temperature from the last ice age to now is about 9° F. Their "best guess" is that we will experience warming of about 3.5° F by 2100, which would be a faster rate of climate change than any experienced during the last 10,000 years, the period in which modern civilization developed.

Warming of this magnitude will affect many aspects of our lives as it changes temperature and precipitation patterns, induces sea level rise, and alters the distribution of fresh water supplies. The impacts on our health, the vitality of forests and other natural areas, and the productivity of agriculture are all likely to be significant. As the risks of global climate change become increasingly apparent, there is a genuine need to focus on actions to reduce our greenhouse gas emissions and minimize the adverse impacts of a changing climate.

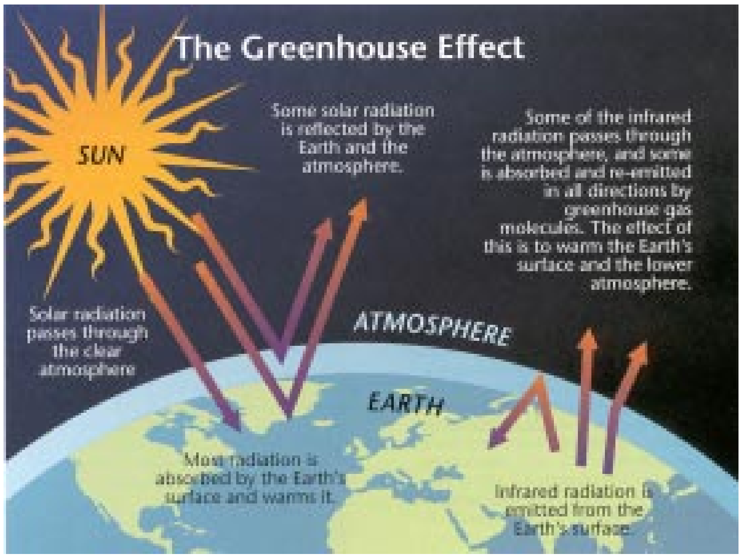


Figure 1.2.A: The greenhouse effect naturally warms the Earth's surface. Without it, Earth would be 60° F cooler than it is today - uninhabitable for life as we know it.

1.2 THE GREENHOUSE EFFECT AND HISTORICAL EMISSIONS

Life as we know it is possible on Earth because of a natural greenhouse effect that keeps our planet about 60° F warmer than it otherwise would be (Figure 1.2.A). Water vapor, CO_2, and other trace gases, such as methane and nitrous oxide, trap solar heat and slow its loss by re-radiation back to space. With industrialization and population growth, greenhouse gas emissions from human activities have consistently increased. These steady additions have begun to tip a delicate balance, significantly increasing the amount of greenhouse gases in the atmosphere, and enhancing their insulating effect.

A wide variety of activities contribute to greenhouse gas emissions. Burning of coal, oil, and natural gas releases about 6 billion tons of carbon into the atmosphere each year worldwide. Burning and logging of forests contributes another 1-2 billion tons annually by reducing the storage of carbon by trees.

The result is that the atmospheric level of CO_2, the most important human-derived greenhouse gas, has increased 30 percent, from 280 to 360 parts per million (ppm) since 1860 (Figure 1.2.B). Over the same time period, agricultural

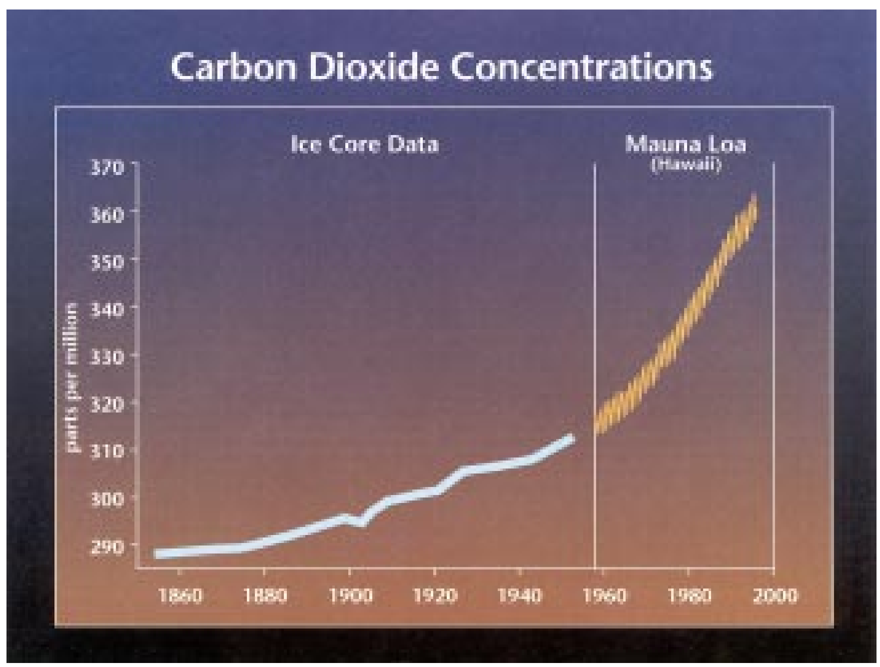


Figure 1.2.B: Since the beginning of the Industrial Revolution in the middle of the 19th century, the concentration of carbon dioxide ($C0_2$) in the atmosphere has steadily increased. Beginning in 1957, continual measurements of atmospheric $C0_2$ concentrations have been made by scientists at an observatory in Mauna Loa, Hawaii. The seasonal cycle of vegetation in Northern latitudes can be seen in this record: each spring the vegetation "inhales" and absorbs $C0_2$, and each autumn most of that $C0_2$ is released back to the atmosphere.

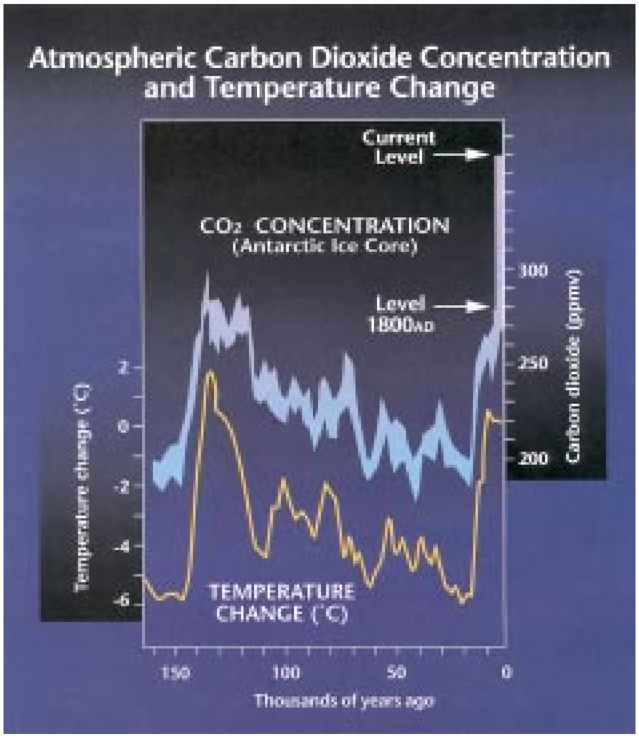


Figure 1.2.C: Data from tiny air bubbles trapped in an Antarctic ice core show that atmospheric $C0_2$ concentrations and temperatures from 160,000 years ago to pre-industrial times are closely correlated. Direct measurement of $C0_2$ concentration and temperature in recent decades extend this record to the present day, and confirm that $C0_2$ concentrations have risen to 360 ppm and temperatures have increased 0.5 ° C (1° F) over the last 100 years.

and industrial practices have also substantially increased the levels of other potent greenhouse gases -- methane concentrations have doubled and nitrous oxide levels have risen by about 15 percent. These gases have atmospheric lifetimes ranging from decades to centuries; today's emissions will be affecting the climate well into the 21st century.

The overall emissions of greenhouse gases are growing at about 1 percent per year. For millennia, there has been a clear correlation between CO_2 levels and the global temperature record. Fluctuations of CO_2 and temperature have roughly mirrored each other over the last 160,000 years (Figure 1.2.C). The current level of CO_2 is already far higher than it has been at any point during this period. If current emissions trends continue over the next century, concentrations will rise to levels not seen on the planet for 50 million years.

Which countries account for the largest proportions of CO_2 emissions? In 1995, 73 percent of the total CO_2 emissions from human activities came from the developed countries (Figure 1.2.D). The United States is the largest single source, accounting for 22 percent of the total, with carbon emissions per person now exceeding 5 tons per year. Over the next few decades, 90 percent of the world's population growth will take place in the developing countries, some of which are also undergoing rapid economic development. Per capita energy use in the developing countries, which is currently only 1/10 to 1/20 of the U.S. level, will also increase. If current trends continue, the developing countries will account for more than half of total global CO_2 emissions by 2035. China, which is currently the second largest source, is expected to have displaced the United

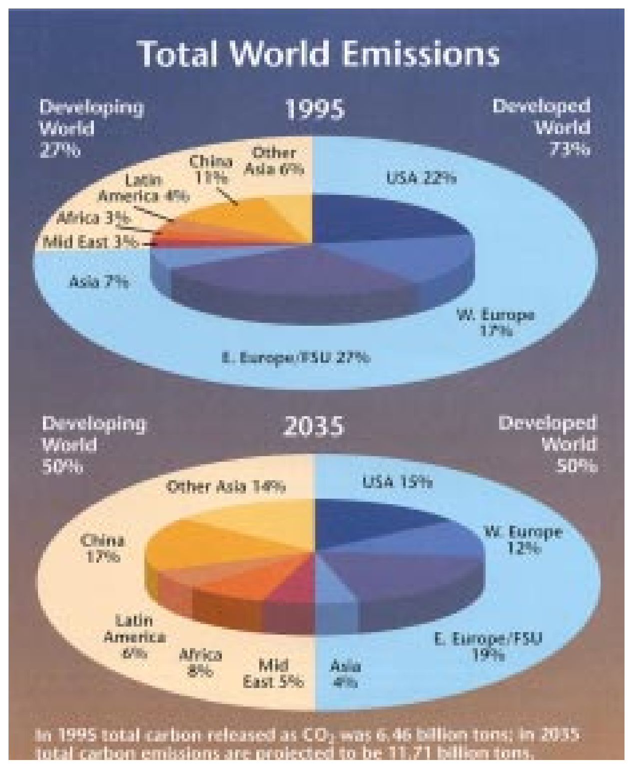


Figure 1.2.D: In 1995, the industrialized nations of the world contributed nearly three-quarters of the global emissions of carbon dioxide, with the U.S. being the largest single emitter. By 2035, developing nations will catch up and contribute half of the global emissions, with China becoming the largest single emitting country. Rapid population growth, industrialization, and increasing consumption per person in the developing world will contribute to this shift.

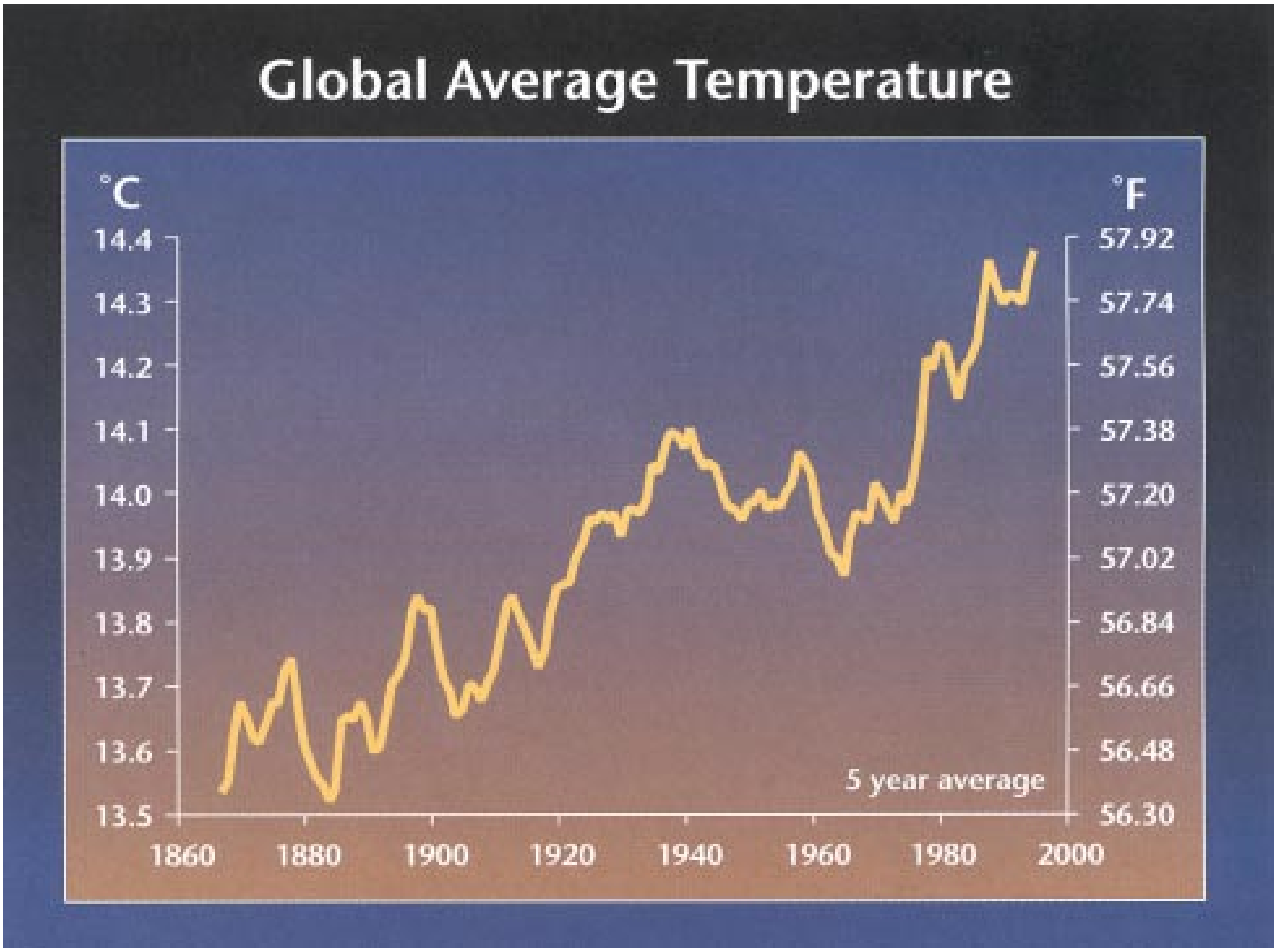


Figure 1.3.A: The global average temperature has risen by approximately 1° F over the last century.

States as the largest emitter by 2015.

1.3 CLIMATE CHANGE OVER THE LAST 100 YEARS

Global surface temperature has been measured since 1880 at a network of ground-based and ocean-based sites. Over the last century, the average surface temperature of the Earth has increased by about 1° F. The 11 warmest years of this century have all occurred since 1980, with 1995 the warmest on record (Figure 1.3.A). The higher latitudes have warmed more than the equatorial regions.

Beginning in 1979, satellites have been used to measure the temperature of the atmosphere up to a height of 30,000 feet. The long-term surface record and the recent satellite observations differ, but that fact is not surprising: the two techniques measure the temperature of different parts of the Earth system (the surface, and various layers of the atmosphere). In addition to this, a variety of factors, such as the presence of airborne materials from the 1991 eruption of the volcano Mt. Pinatubo, affect each record in a different way. Satellite observations were initially interpreted as showing a slight cooling, but more recent analyses accounting for natural, short-term fluctuations imply warming, just as the ground-based measurements have indicated over a longer time period. As more data from the satellite record become available, and as the quality of measurements is improved, comparison of these two records should yield additional insights.

What does warming do? A warmer Earth speeds up the global water cycle: the exchange of water among the oceans, atmosphere, and land. Higher temperatures cause more evaporation, and soils will tend to dry out faster. Increased amounts of water in the atmosphere will mean more rain or snow overall.

We may be seeing the first signs of changes in the water cycle. Since the beginning of the century, precipitation in the United States has increased by about 6 percent, while the frequency of intense precipitation events (heavy downpours of more than two inches per day) has increased by 20 percent. Such events can cause flooding, soil erosion, and even loss of life. In some midcontinental areas, increased evaporation has led to drought because the heavy rains fell elsewhere.

There is also evidence that ecosystems are reacting to warming. Between 1981 and 1991, the length of the growing season in the northern high latitudes (between 45° and 70° N) increased by a total of up to 12 days, as documented by satellite imagery. "Greening" in spring and summer occurred up to eight days earlier, and vegetation continued to photosynthesize an estimated four days longer.

Global mean sea level has risen 4 to 10 inches over the last 100 years, mainly because water expands when heated. The melting of glaciers, which has occurred worldwide over the last century, also contributes to the rise. Formerly frozen soils (permafrost) in the Alaskan and Siberian arctic have also begun to melt, damaging both ecosystems and infrastructure. Melting and tundra warming will also lead to decay of organic matter and the release of trapped carbon and methane, creating an additional source of greenhouse gases.

1.4 CLIMATE CHANGE OVER THE NEXT 100 YEARS

Where is the climate headed? If the world proceeds on a "business as usual" path, atmospheric CO_2 concentrations will likely be more than 700 ppm by 2100, and they will still be rising. This is nearly double the current level and much more than double the preindustrial level of 280 ppm (Figure 1.4.A). State-of-the-art climate models suggest that this will result in an increase of about 3.5° F in global temperatures over the next century. This would be a rate of climate change not seen on the planet for at least the last 10,000 years. It is the combined threat of elevated concentrations of greenhouse gases and this unprecedented rate of increase that causes great concern.

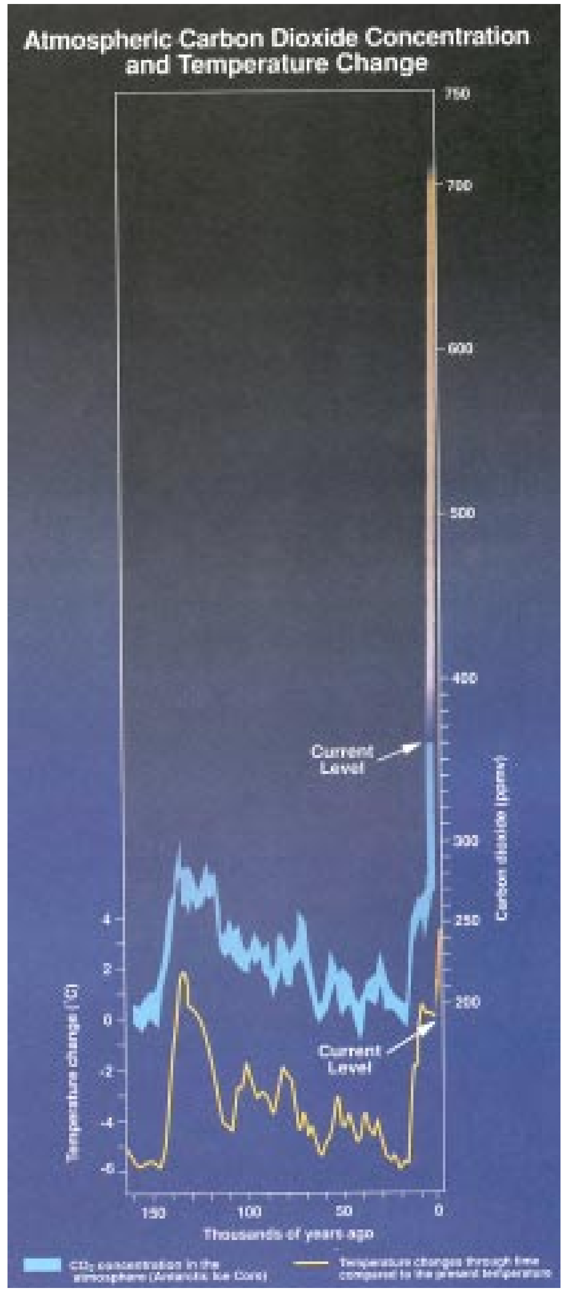


Figure 1.4.A. The CO_2 level has increased sharply since the beginning of the Industrial Era and is already outside the bounds of natural variability seen in the climate record of the last 160,000 years. Continuation of current levels of emissions will raise concentrations to over 700 ppm by 2100, a level not experienced since about 50 million years ago.

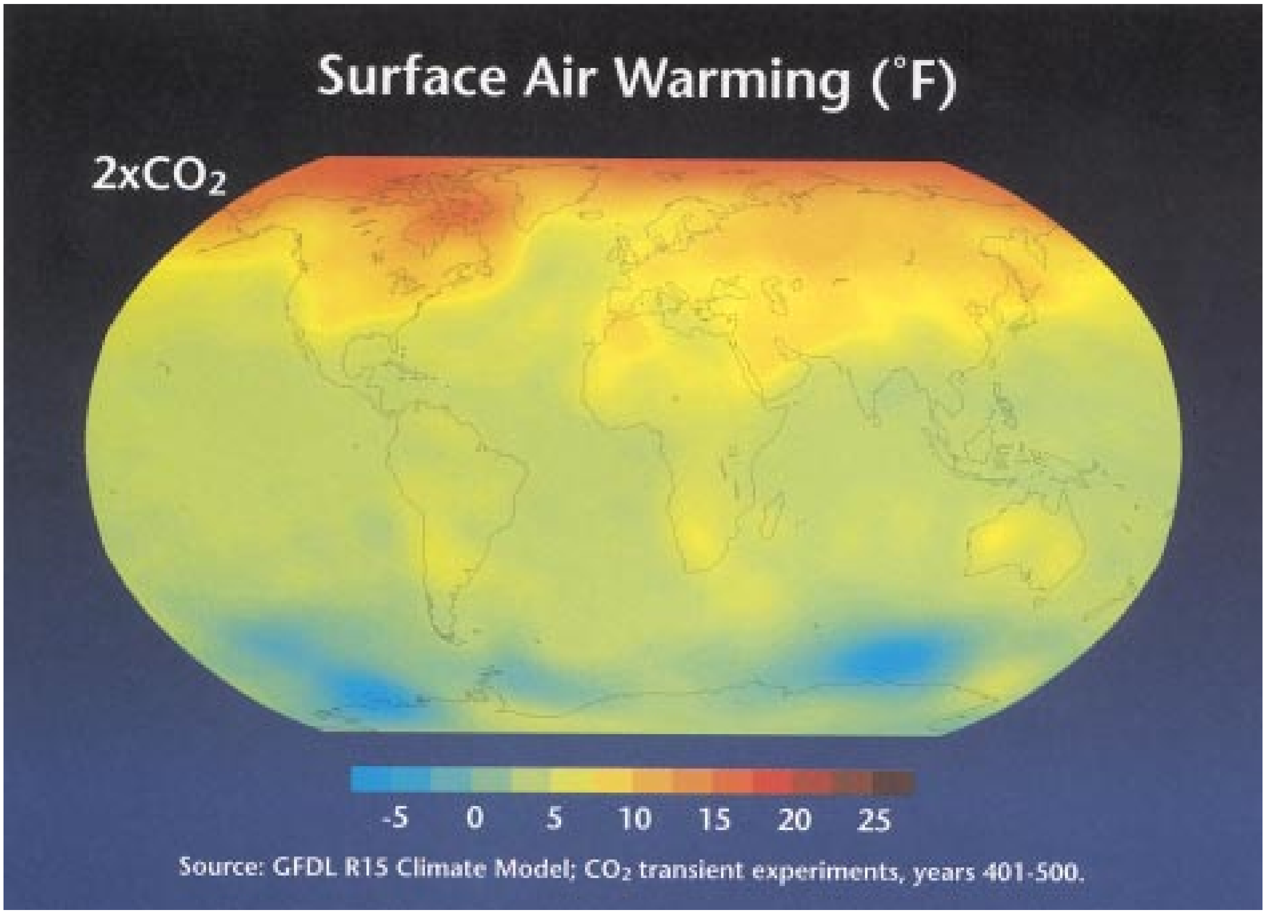


Figure 1.4.B. Even if CO_2 levels only rise to 560 ppm by the year 2100, U.S. temperatures will eventually be about 5-10° F warmer than today. Higher latitudes will warm more than equatorial regions.

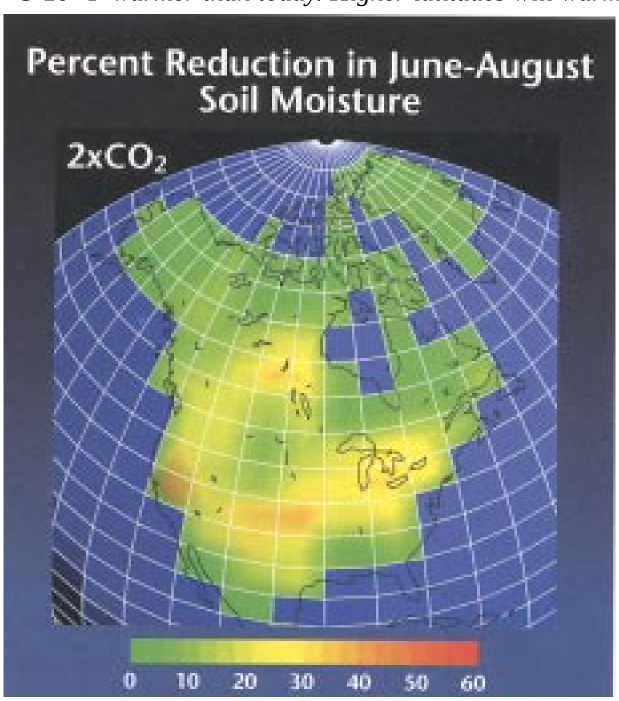


Figure 1.4.C. The extent of warming indicated in Figure 1.4.B will lead to substantial soil drying throughout the world, causing soil moisture decreases of 10 percent to 30 percent over North America.

What are the projected extent and pattern of warming over the globe? The higher latitude regions will warm relatively more than areas nearer to the equator. The land surface will warm more than the oceans, and there will be less variation in temperature from night to day.

Even if the rate of emissions is slowed enough to limit atmospheric concentrations to about 550 ppm, or roughly double the preindustrial level, the U.S. could experience temperature increases of 5° F to 10° F (Figure 1.4.B). These warmer temperatures would lead to soil drying in some regions, with drying estimated at 10 percent to 30 percent for the United States during the summer growing season (Figure 1.4.C).

Some modeling experiments have examined the consequences of CO_2 levels well beyond 700 ppm, which are likely to occur after 2100 if current emissions trajectories are not altered. If the CO_2

concentration were to continue to rise to four times the preindustrial level, or more than 1100 ppm, the estimated temperature increase for the United States would be 15° F to 20° F, and soil drying could approach 30 percent to 50 percent during the growing season (Figures 1.4.D and 1.4.E).

1.5 VULNERABILITIES AND POTENTIAL CONSEQUENCES

The climate changes expected from increased atmospheric concentrations of greenhouse gases are likely to have widespread effects, many of them negative, on ecological systems, human health, and socioeconomic sectors. In general, people in developing countries are more vulnerable to climate change because of limited infrastructure and capital and greater dependence on natural resources. Unless otherwise specified, the impacts and vulnerabilities discussed below are based on scenarios of doubling of current levels of CO_2 by 2100 (700 ppm). Beyond such concentrations, impacts appear to worsen, but uncer-

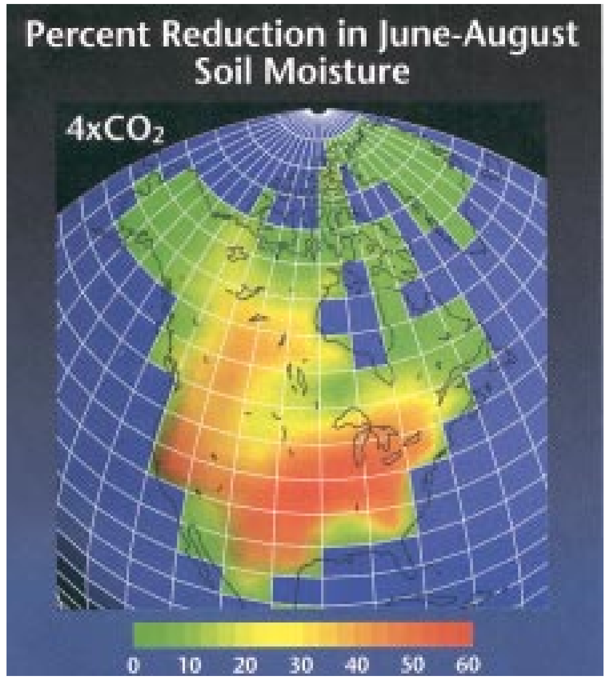


Figure 1.4.D. The extent of warming indicated in Figure 1.4.E would lead to severe soil drying in the U.S., with deficits reaching 30 percent to 50 percent during the growing season.

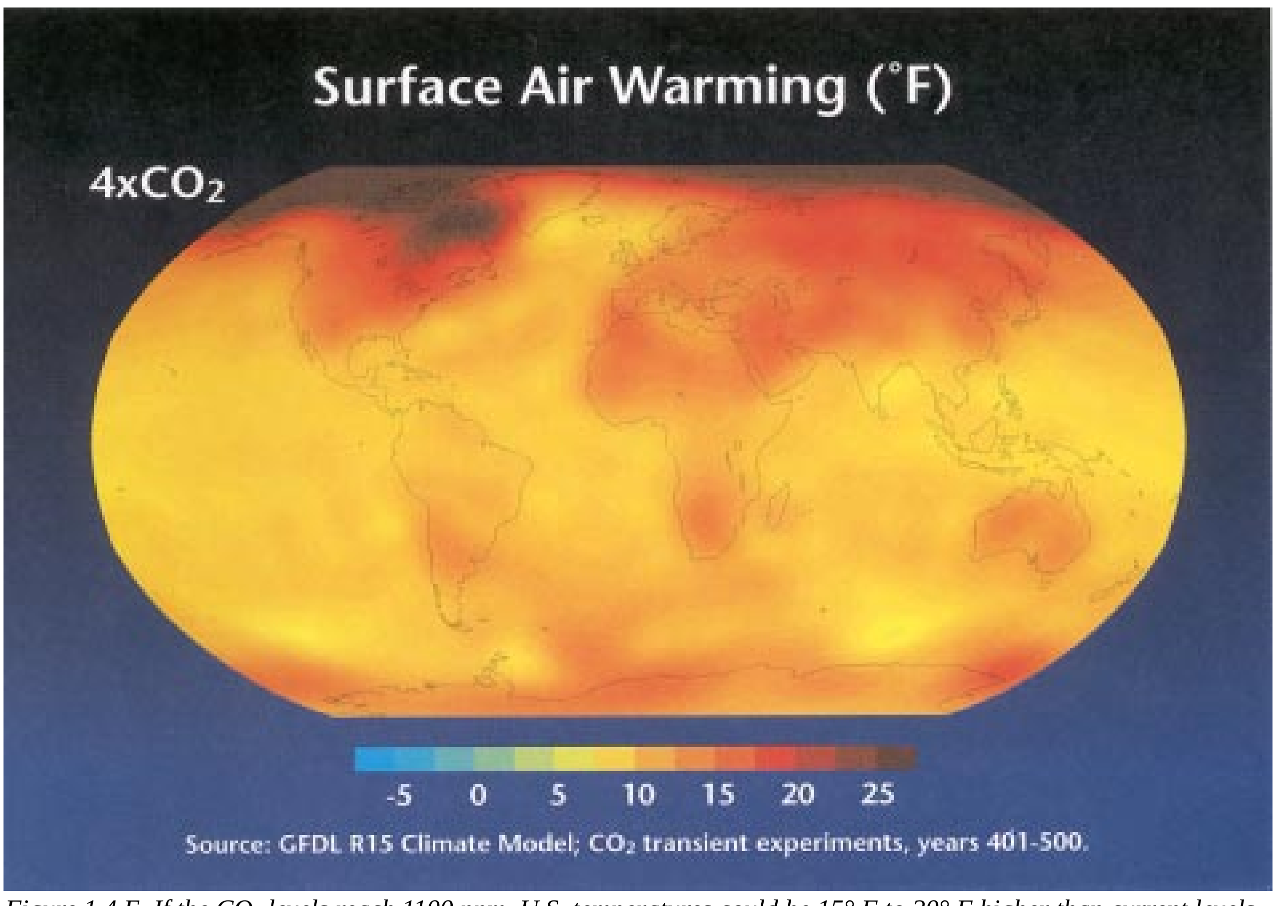


Figure 1.4.E. If the CO_2 levels reach 1100 ppm, U.S. temperatures could be 15° F to 20° F higher than current levels.

tainty about what will happen increases. In general, uncertainty cuts both ways: outcomes could be less dramatic than expected based on our current understanding, but could just as well be much more severe.

Worsening Health Effects - Climate change will impact human health in a variety of ways. Warmer temperatures increase the risk of mortality from heat stress. For example, in July 1995, 465 deaths in Chicago were attributed to a heat wave with temperatures exceeding 90° F day and night. Today, such events occur about once every 150 years. CO_2 concentrations of 550 ppm (double the pre-industrial level) could make such events 6 times more frequent. The potential increases in the heat index, a calculation combining temperature and humidity, illustrate the magnitude of this threat. Washington, D.C. currently has an average July heat index of 85° F, but if CO_2 levels reach 550 ppm, this could increase to 95° F, and if concentrations quadrupled to 1100 ppm, it could increase to 110° F. Climate change will also exacerbate air quality problems, such as smog, and increase levels of airborne pollen and spores that aggravate respiratory disease, asthma, and allergic disorders. Because children and the elderly are the most vulnerable populations, they are likely to suffer disproportionately with both warmer temperatures and poorer air quality.

Diseases that thrive in warmer climates, such as malaria, dengue and yellow fevers, encephalitis, and cholera, are likely to spread due to the expansion of the ranges of mosquitos and other disease-carrying organisms and increased rates of transmission. This could result in 50 million to 80 million additional malaria cases per year worldwide by 2100.

Rising Sea Level - Rising sea level erodes beaches and coastal wetlands, inundates low-lying areas, and increases the vulnerability of coastal areas to flooding from storm surges and intense rainfall. By 2100, sea level is expected to rise by 6 to 37 inches. A 20-inch sea level rise will result in substantial loss of coastal land in the United States, especially along the southern Atlantic and Gulf coasts, which are subsiding and are particularly vulnerable. The oceans will continue to expand for several centuries after temperatures stabilize. Because of this, the sea level rise associated with CO_2 levels of 550 ppm (double pre-industrial levels) could eventually exceed 40 inches. A CO_2 level of 1100 ppm could produce a sea level rise of 80 inches or even more, depending on the extent to which the Greenland and Antarctic ice sheets melt.

- A 20-inch sea level rise would double the global population at risk from storm surges, from roughly 45 million at present to over 90 million, and this figure does not account for any increases in coastal populations. A 40 inch rise would triple the number.

- South Florida is highly vulnerable to sea level rise (Figure 1.5.A). A third of the Everglades has an elevation of less than 12 inches. Salt water intrusion would adversely affect delicate ecological communities and degrade the habitat for many species.

Disruption of the Water Cycle - Among the most fundamental effects of climate change are intensification and disruption of the water cycle.

Droughts and floods - Intensification of the water cycle will produce more severe droughts in some places and floods in others. Such events are costly. Damages from the Southern Plains drought of 1996 were estimated at $4 billion, the 1993 Mississippi River flood damages at $10 billion to $20 billion, the Pacific Northwest floods in the winter of 1996-1997 at about $3 billion, the 1997 Ohio River flood at about $1 billion, and the 1997 Red River flood in the Northern Plains at about $2 billion.

Water quality and quantity - Areas of greatest vulnerability are those where quality and quantity of water are already problems, such as the arid and semiarid regions of the United States and the world.

- Climate change would likely increase water supply problems in several U.S. river basins, such as the Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado.

- Water scarcity in the Middle East and Africa is likely to be aggravated by climate change, which could increase international tension among countries that depend on water supplies originating outside their borders.

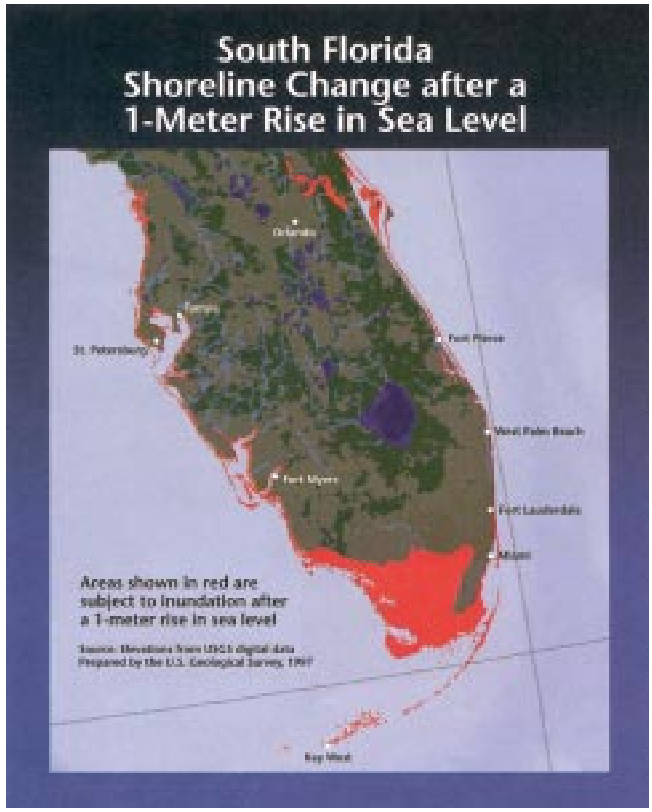


Figure 1.5.A. Sea level rise could inundate many low-lying coastal areas in Florida, and will increase the vulnerability of all such areas to storm surges.

Changing Forests and Natural Areas - Climate change could dramatically alter the geographic distributions of vegetation types. The composition of one-third of the Earth's forests would undergo major changes as a result of climate changes associated with a CO_2 level of 700 ppm. Over the next 100 years, the ideal range for some North American forest species will shift by as much as 300 miles to the north, far faster than the forests can migrate naturally. Economically important species, such as the sugar maple, could be lost from New England by the end of the next century (Figure 1.5.B).

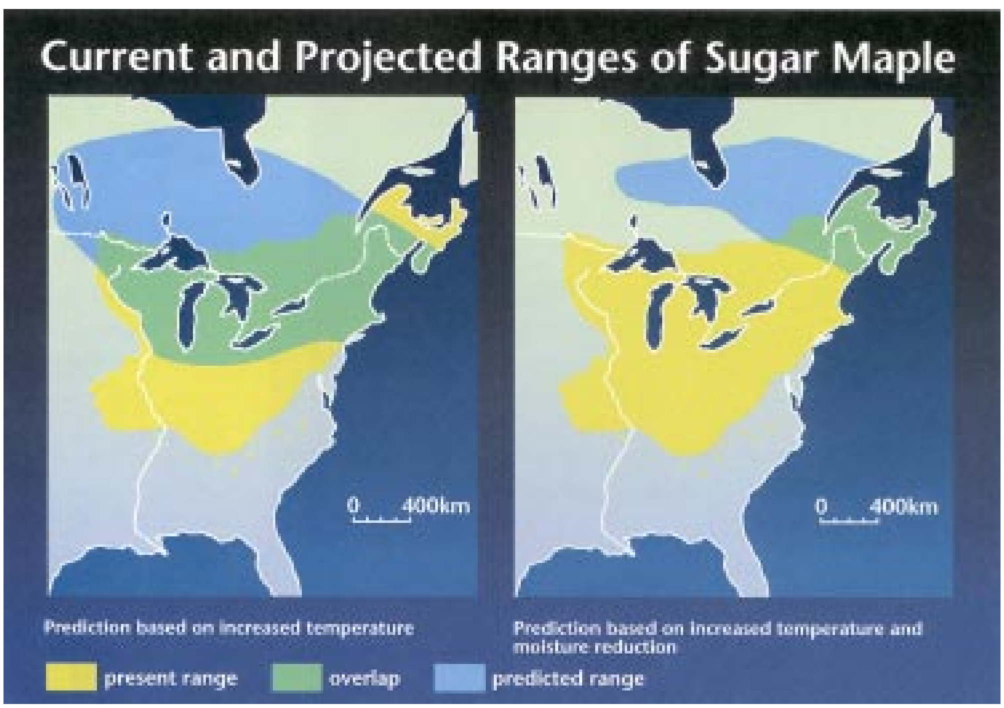


Figure 1.5.B. Climatic shifts will force some species to migrate northwards or to higher elevations in order to stay in the appropriate climatic zone. The climatic zone for sugar maple, for example, could shift northwards into Canada. This would compromise the maple syrup industry and the fall foliage colors, both of which make New England famous.

Such changes could have profound effects on the U.S. system of national parks and refuges, leading to reductions in biological diversity and in the benefits provided by ecosystems, such as clean water and recreation. Wetlands are particularly at risk. The wetlands of the prairie pothole region, which support half the waterfowl population of North America, could diminish in area and change dramatically in character in response to climate change. The glaciers of Glacier National Park have receded steadily for decades (Figure 1.5.C). Model projections indicate that all the Park's glaciers will disappear by 2030 unless temperatures begin to cool instead of warm.

Challenges to Agriculture and the Food Supply - Climate strongly affects crop yields. A CO_2 concentration of 550 ppm is likely to increase crop yields in some areas by as much as 30 percent to 40 percent, but it will decrease yields in other places by similar amounts, even for the same crop. A warmer climate would reduce flexibility in crop distribution and increase irrigation demands. Expansions of the ranges of pests could also increase vulnerability and result in greater use of pesticides. Despite these effects, total global food production is not expected to be altered substantially by climate change, but there are likely negative regional impacts. Agricultural systems in the developed countries are highly adaptable and can probably cope with the expected range of climate changes without dramatic reductions in yields. It is the poorest countries, already subject to hunger, that are the most likely to suffer significant decreases in agricultural productivity (Figure 1.5.D).

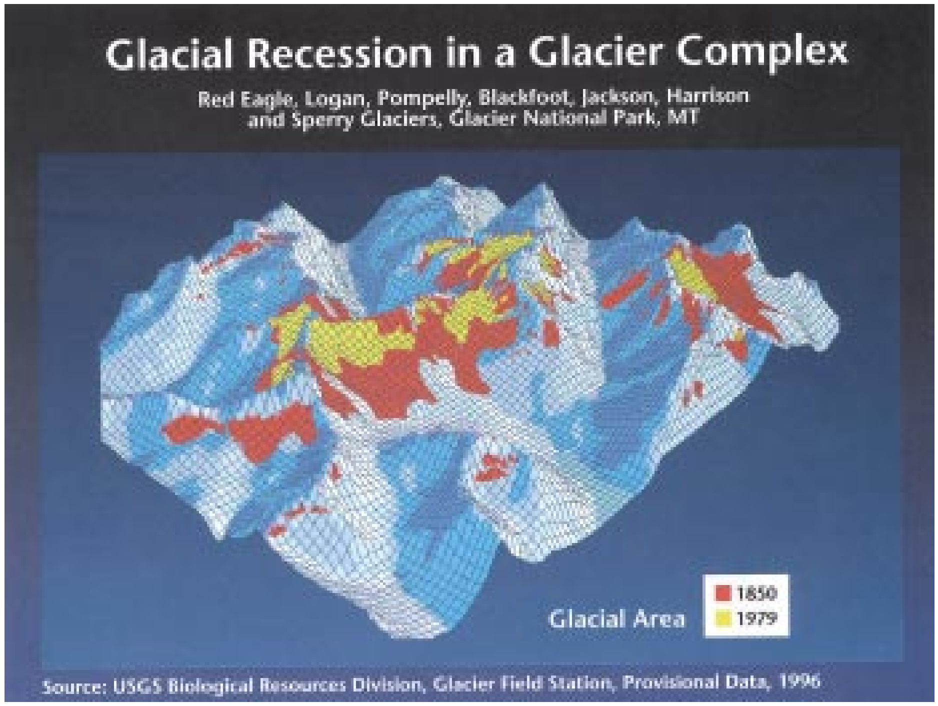


Figure 1.5.C. Warmer temperatures have already led to substantial glacier melting and shrinkage in Glacier National Park, Montana. Data indicate that more than 70 percent of some of the glaciers in the National Park have already melted.

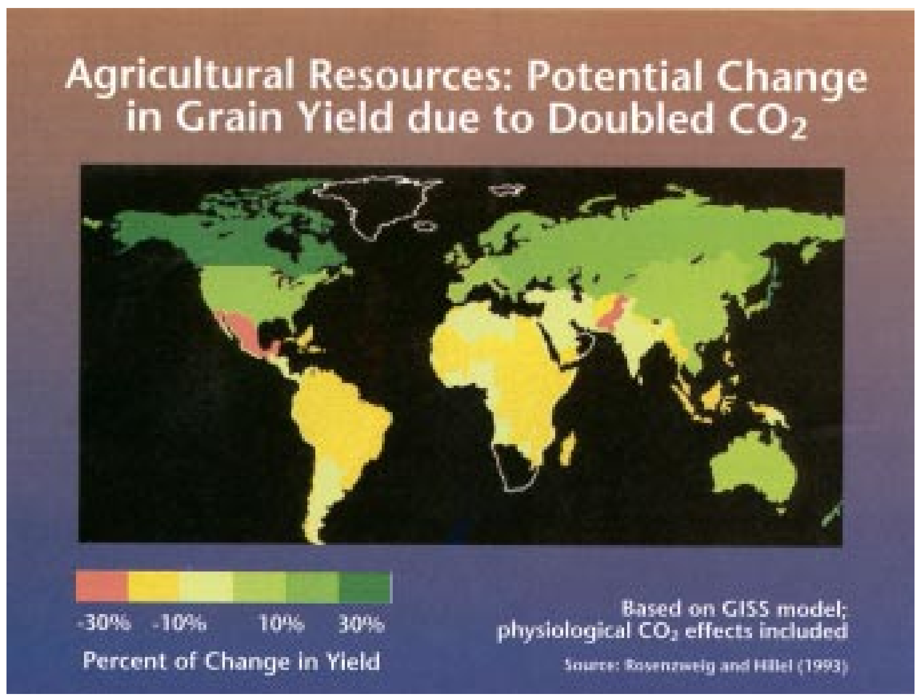


Figure 1.5.D. Agricultural production would increase in some areas, and decline in others as the climate warms and the CO_2 levels in the atmosphere increase. Farmers may need to shift crops, or re-locate agricultural lands. The need for irrigation may also increase.

1.6 CONCLUSION

As the world's expanding population burns large quantities of fossil fuels and simultaneously cuts down large expanses of forests worldwide, the concentrations of CO_2 and other greenhouse gases are building up in the atmosphere. There is mounting evidence that this shift in Earth's atmosphere will lead to global changes and potentially major climatic disruptions.

Human and ecological systems are already vulnerable to a range of environmental pressures, including climate extremes and variability. Global climate change is likely to amplify the effects of other pressures and to disrupt our lives in numerous ways. Significant impacts on our health, the vitality of forests and other natural areas, the distribution of freshwater supplies, and the productivity of agriculture are among the probable consequences of climate change.

On a business as usual path, the world is headed to concentrations far higher than have been observed during the time of human civilization and to levels not seen on the planet for millions of years--and all in one century, a geologic "blink of an eye." The faster the rate of change in climate, the less time there will be for both ecological and socioeconomic systems to adapt and the greater the potential for "surprises" or unanticipated events. Given the long time lags between cause and effect and between effect and remedy, a prudent course of action is to slow the rate of change. Investing now to protect Earth's climate will enable our children and grandchildren to live in a world that is not dramatically altered by an enhanced greenhouse effect.

Reference: Climate Change: State of Knowledge
Office of Science and Technology Policy
October 1997

CHAPTER 2

TENNESSEE GREENHOUSE GAS EMISSIONS PROJECTIONS THROUGH 2017

The Phase I Tennessee Greenhouse Gas Emissions Study established the levels of greenhouse gases emitted to the atmosphere from all major sources within Tennessee for the year 1990. The majority of the emissions from sources within Tennessee produce either CO_2 or methane (CH_4). A summary of the results of the 1990 greenhouse gas (GHG) inventory for Tennessee is shown in **Table 2.A**. The Phase II Tennessee Greenhouse Gas Emissions Study has as an overall goal the development of voluntary policy options for Tennessee to reduce greenhouse gas emissions from sources within the state. As a first step toward the completion of the Phase II study, annual emissions for Tennessee have been projected through the year 2017 assuming that no new initiatives are undertaken to reduce their growth rate. This chapter provides the details of those inventory projections. Later in the study the effects of various potential policy options will be investigated as to their economic impact on the state as well as their efficiency in reducing emissions.

In general, the approach taken to the inventory extension was to use the same calculation algorithms provided by the State Workbook for the Phase I Study. Projections have been made as to increases/decreases in all input parameters through the year 2017. Thus, in effect, an annual Phase I Study has been completed for every year from 1995 through 2017. This chapter reports a summary of the emissions projections.

The overall projections for Tennessee's greenhouse gas emissions are summarized in **Table 2.B**, where total equivalent CO_2 emissions are shown for the years 1995 through 2017. By using the term equivalent CO_2 emissions, the global climate change effects of other greenhouse gases such as methane and nitrous oxide can be included in the total by converting the amounts of those gases into an equivalent amount of CO_2. The 1990 inventory found that Tennessee's emissions were 134.4 million tons of eq$_u$ivalent CO_2. The inventory extension has projected Tennessee's 1995 emissions to be 161.5 million tons of equivalent CO_2, or an increase of 20.1 percent. The closing year of the projections shows a total emission level of 194.7 million tons of equivalent CO_2. This amount represents an increase of 44.8 percent from the 1990 emission levels. The projections are based on the last 10 years of data that are available. Trends developed with that data, along with the projected population increases, are used to project emissions through the year 2017. Improvements in efficiency and energy conservation efforts that have affected the last 10 years of consumption data are included in the emissions projections (Energy Information Administration, State Energy Data Report, 1994, 1996). New initiatives that will increase participation in energy efficiency improvements will be included in the suggested policy options. Tennessee's greenhouse gas emissions are broken down by sectors in **Table 2.C**. It is clear that the transportation and utility sectors represent the lion's share, totaling roughly 60-65 percent, of the state's emissions.

The Kyoto Protocol calls for the United States to reduce greenhouse gas emissions to seven percent below the 1990 levels. If this agreement is ratified by the U.S. Senate, it is possible that Tennessee could be asked to reduce its annual emission of greenhouse gases to 125.0 million tons of equivalent CO_2.

An analysis of the pie charts shown in **Figures 2.A** and **2.B** reveals that the combustion of fossil fuels dominates Tennessee's total equivalent greenhouse gas emissions now and in the year 2017. A further breakdown of the emissions from the combustion of fossil fuels is illustrated in **Figures 2.C** and **2.D**. Coal combustion represents 42.9 percent of the emissions from fossil fuels in 1995 and 44.0 percent in 2017. The vast majority of the coal combustion is by TVA for the generation of electric power. The transportation sector accounts for about 31 percent of fossil fuel emissions in 1995 and 29 percent in 2017. Thus, the combination of electric power generation and transportation represent approximately 65 percent of total equivalent emissions in 1995 and 61 percent of total equivalent emissions in 2017. The percentage of total greenhouse gas emissions by end use sector is shown in **Figure 2.E** for 1995 emissions and **Figure 2.F** for projected emissions in 2017. There is relatively little change in the sector breakdown between the years 1995 and 2017.

There have been several different approaches used in the projection of Tennessee's greenhouse gas emissions through the year 2017. The future consumption of fossil and biomass fuels was accomplished by obtaining ten years of consumption data for the years 1985 - 1994 and fitting a linear equation through this data. This equation was then used to project the consumption of that fuel type through 2017. This process is illustrated in **Figures 2.G** and **2.H** for the coal consumption data. The ten years of data are presented in **Figure 2.G**, and the linear best fit curve is shown projecting the coal consumption through 2017 in **Figure 2.H**.

Several of the emission calculation algorithms use the population of the state as a key input variable. Examples of these sources are landfill methane emissions and the emissions from waste water treatment facilities. Projections for the population of Tennessee were obtained and used to project the emissions from these sources through the year 2017.

There are a number of small emissions sources that are difficult to project because of the lack of sufficient data and definite trends in the data that are available. For these emission sources the 1990 levels have been used without change for the entire projection period. Sources falling into this category are production processes, methane emissions from domesticated animals, methane emissions from manure management, carbon sequestration, and nitrous oxide emissions from the burning of crop wastes. Data for emissions from these sources are shown in **Tables 2.D, 2.E** and **2.F**.

Graphs showing the projected emissions from all significant sources are included as **Figures 2.I-2.O**. The total equivalent CO_2 emission data shown in **Table 2.B** are plotted in **Figure 2.I** for the years 1995 through 2017. Carbon dioxide emissions from the combustion of fossil and biomass fuels is illustrated in **Figure 2.J**. Equivalent CO_2 emissions from landfills is shown in **Figure 2.K**. Equivalent CO_2 emissions from soil management is plotted in **Figure 2.L**. Equivalent CO_2 emissions from natural gas and oil systems is illustrated in **Figure 2.M**. Equivalent CO_2 emissions from coal mining is shown in **Figure 2.N**. Equivalent CO_2 emissions from municipal wastewater management is plotted in **Figure 2.O**.

The detailed spreadsheets used to calculate the greenhouse gas emissions from Tennessee by implementing the calculation algorithms detailed in the EPA State Workbook are included in the appendix of this report.

Table 2.A: Summary of Greenhouse Gas Emissions for Tennessee

Source/Sink	Emissions (tons)	Equivalence Factor	Equivalent Emissions (tons CO_2)
Carbon Dioxide			
Fuel Combustion	122,127,302	1	122,127,302
Production Processes	1,939,663	1	1,939,663
Forest Management	(4,887,589)	1	(4,887,589)
Total	119,179,376	1	119,179,376
Methane			
Gas and Oil Systems	24,537	22	539,819
Coal Mining	39,058	22	859,273
Landfills	283,011	22	6,226,234
Animals	211,342	22	4,649,531
Manure Management	57,870	22	1,273,129
Crop Wastes	719	22	15,819
Municipal Wastewater	5,875	22	129,241
Total	622,411	22	13,693,046
Nitrous Oxide			
Production Processes	0	270	0
Fertilizer	2,834	270	765,094
Crop Wastes	44	270	11,915
Total	2,878	270	777,009
Other			
PFCs (Production of Aluminum)	145	5,400	780,516
Total			**134,429,948**

Table 2.B: Total Equivalent CO_2 Emissions 1995-2017

Year	Carbon Dioxide Emissions	Equivalent CO_2 from Methane	Equivalent CO_2 from Nitrous Oxide	Total CO_2 Emissions
	million tons	*million tons*	*million tons*	*million tons*
1995	148.148	12.507	0.821	161.476
1996	149.568	12.586	0.846	163.000
1997	150.978	12.663	0.882	164.524
1998	152.388	12.739	0.918	166.045
1999	153.798	12.814	0.958	167.570
2000	155.188	12.885	1.003	169.076
2001	156.578	12.953	1.052	170.583
2002	157.958	13.017	1.106	172.082
2003	159.338	13.078	1.166	173.583
2004	160.698	13.136	1.233	175.067
2005	162.048	13.191	1.305	176.545
2006	163.398	13.243	1.386	178.026
2007	164.738	13.291	1.474	179.504
2008	166.078	13.338	1.571	180.987
2009	167.398	13.381	1.677	182.456
2010	168.728	13.424	1.794	183.947
2011	170.058	13.468	1.922	185.448
2012	171.378	13.511	2.063	186.952
2013	172.698	13.554	2.218	188.470
2014	174.018	13.596	2.387	190.002
2015	175.338	13.638	2.574	191.550
2016	176.658	13.680	2.778	193.116
2017	177.978	13.721	3.002	194.702

Table 2.C: Total Equivalent CO_2 Emissions by Sector

Year	Residential CO_2 Emissions Projections	Commercial CO_2 Emissions Projections	Industrial CO_2 Emissions Projections	Transportation CO_2 Emissions Projections	Utilities CO_2 Emissions Projections
	million tons	*million tons*	*million tons*	*million tons*	*million tons*
1995	20.68	11.13	29.69	50.92	54.32
1996	21.05	11.26	30.04	51.24	54.65
1997	21.40	11.41	30.40	51.57	54.99
1998	21.75	11.55	30.75	51.89	55.33
1999	22.10	11.69	31.10	52.21	55.66
2000	22.43	11.85	31.46	52.53	56.00
2001	22.76	12.00	31.81	52.85	56.33
2002	23.06	12.16	32.17	53.18	56.67
2003	23.36	12.33	32.53	53.50	57.01
2004	23.65	12.50	32.89	53.82	57.34
2005	23.92	12.68	33.25	54.14	57.68
2006	24.19	12.86	33.61	54.47	58.02
2007	24.44	13.06	33.97	54.79	58.35
2008	24.68	13.26	34.33	55.11	58.69
2009	24.92	13.47	34.69	55.43	59.02
2010	25.15	13.70	35.05	55.75	59.36
2011	25.38	13.93	35.42	56.08	59.70
2012	25.61	14.18	35.78	56.40	60.03
2013	25.84	14.44	36.15	56.72	60.37
2014	26.07	14.71	36.51	57.04	60.71
2015	26.29	15.00	36.88	57.36	61.04
2016	26.52	15.31	37.24	57.69	61.38
2017	26.74	15.64	37.61	58.01	61.72

Table 2.D: Total CO_2 Emissions 1995-2017

Year	Combustion of Fossil Fuels	Production Processes	Forest Management	Total CO_2 Emissions
	million tons	*million tons*	*million tons*	*million tons*
1995	150.119	2.917	-4.888	148.148
1996	151.539	2.917	-4.888	149.568
1997	152.949	2.917	-4.888	150.978
1998	154.359	2.917	-4.888	152.388
1999	155.769	2.917	-4.888	153.798
2000	157.159	2.917	-4.888	155.188
2001	158.549	2.917	-4.888	156.578
2002	159.929	2.917	-4.888	157.958
2003	161.309	2.917	-4.888	159.338
2004	162.669	2.917	-4.888	160.698
2005	164.019	2.917	-4.888	162.048
2006	165.369	2.917	-4.888	163.398
2007	166.709	2.917	-4.888	164.738
2008	168.049	2.917	-4.888	166.078
2009	169.369	2.917	-4.888	167.398
2010	170.699	2.917	-4.888	168.728
2011	172.029	2.917	-4.888	170.058
2012	173.349	2.917	-4.888	171.378
2013	174.669	2.917	-4.888	172.698
2014	175.989	2.917	-4.888	174.018
2015	177.309	2.917	-4.888	175.338
2016	178.629	2.917	-4.888	176.658
2017	179.949	2.917	-4.888	177.978

Table 2.E: Total Methane Emissions 1995-2017

Year	Natural Gas and Oil Systems	Landfills	Domesticated Animals	Manure Management	Municipal Wastewater	Agricultural Crop Waste	Coal Mining	Total Methane Emissions
year	*million tons*	*million tons*	*million tons*	*million tons*	*million tons*	*million tons*	*million tons*	*million tons*
1995	0.028	0.264	0.211	0.058	0.00633	0.00072	0.01823	0.586
1996	0.028	0.267	0.211	0.058	0.00643	0.00072	0.01731	0.589
1997	0.028	0.270	0.211	0.058	0.00653	0.00072	0.01644	0.591
1998	0.029	0.273	0.211	0.058	0.00663	0.00072	0.01561	0.594
1999	0.029	0.276	0.211	0.058	0.00672	0.00072	0.01482	0.597
2000	0.030	0.278	0.211	0.058	0.00681	0.00072	0.01407	0.599
2001	0.030	0.281	0.211	0.058	0.00690	0.00072	0.01336	0.601
2002	0.031	0.283	0.211	0.058	0.00698	0.00072	0.01269	0.604
2003	0.031	0.286	0.211	0.058	0.00705	0.00072	0.01205	0.606
2004	0.032	0.288	0.211	0.058	0.00712	0.00072	0.01144	0.608
2005	0.032	0.290	0.211	0.058	0.00719	0.00072	0.01086	0.610
2006	0.033	0.292	0.211	0.058	0.00725	0.00072	0.01032	0.612
2007	0.033	0.293	0.211	0.058	0.00730	0.00072	0.00980	0.613
2008	0.034	0.295	0.211	0.058	0.00735	0.00072	0.00930	0.615
2009	0.034	0.296	0.211	0.058	0.00740	0.00072	0.00883	0.617
2010	0.035	0.298	0.211	0.058	0.00744	0.00072	0.00839	0.618
2011	0.035	0.299	0.211	0.058	0.00749	0.00072	0.00796	0.620
2012	0.036	0.300	0.211	0.058	0.00754	0.00072	0.00756	0.621
2013	0.036	0.302	0.211	0.058	0.00758	0.00072	0.00718	0.623
2014	0.037	0.303	0.211	0.058	0.00762	0.00072	0.00682	0.624
2015	0.038	0.304	0.211	0.058	0.00767	0.00072	0.00648	0.626
2016	0.038	0.306	0.211	0.058	0.00771	0.00072	0.00615	0.628
2017	0.039	0.307	0.211	0.058	0.00775	0.00072	0.00584	0.629

Table 2.F: Total N_2O Emissions 1995-2017

Year	Agricultural Crop Waste	Production Processes	Soil Management	Total N2O Emissions
	tons	*tons*	*tons*	*tons*
1995	44.000	0.000	2996.488	3040.488
1996	44.000	0.000	3088.744	3132.744
1997	44.000	0.000	3223.543	3267.543
1998	44.000	0.000	3356.823	3400.823
1999	44.000	0.000	3505.170	3549.170
2000	44.000	0.000	3669.821	3713.821
2001	44.000	0.000	3852.148	3896.148
2002	44.000	0.000	4053.671	4097.671
2003	44.000	0.000	4276.070	4320.070
2004	44.000	0.000	4521.205	4565.205
2005	44.000	0.000	4791.126	4835.126
2006	44.000	0.000	5088.098	5132.098
2007	44.000	0.000	5414.617	5458.617
2008	44.000	0.000	5773.437	5817.437
2009	44.000	0.000	6167.592	6211.592
2010	44.000	0.000	6600.427	6644.427
2011	44.000	0.000	7075.625	7119.625
2012	44.000	0.000	7597.245	7641.245
2013	44.000	0.000	8169.757	8213.757
2014	44.000	0.000	8798.085	8842.085
2015	44.000	0.000	9487.649	9531.649
2016	44.000	0.000	10244.420	10288.420
2017	44.000	0.000	11074.975	11118.975

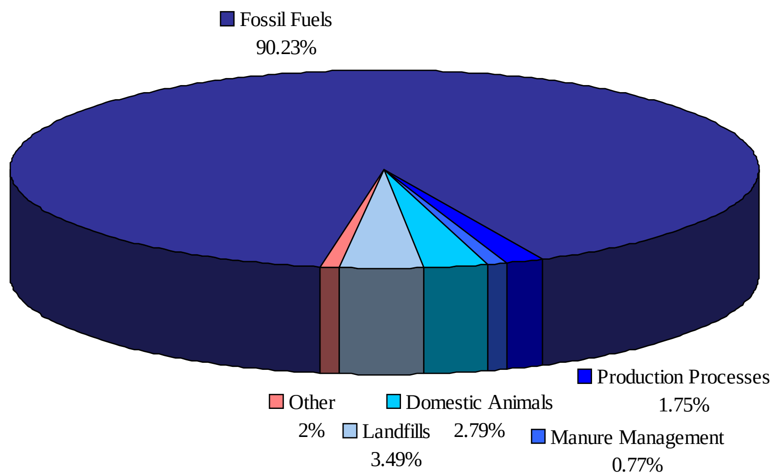


Figure 2.A: 1995 Equivalent CO_2 Emissions

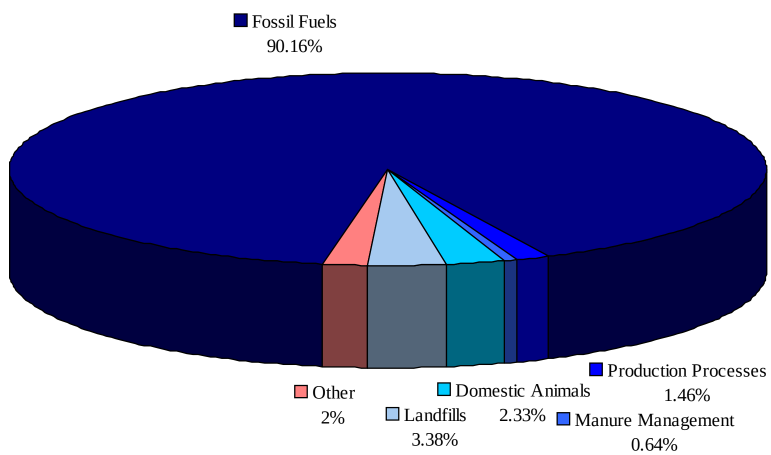


Figure 2.B: 2017 Equivalent CO_2 Emissions

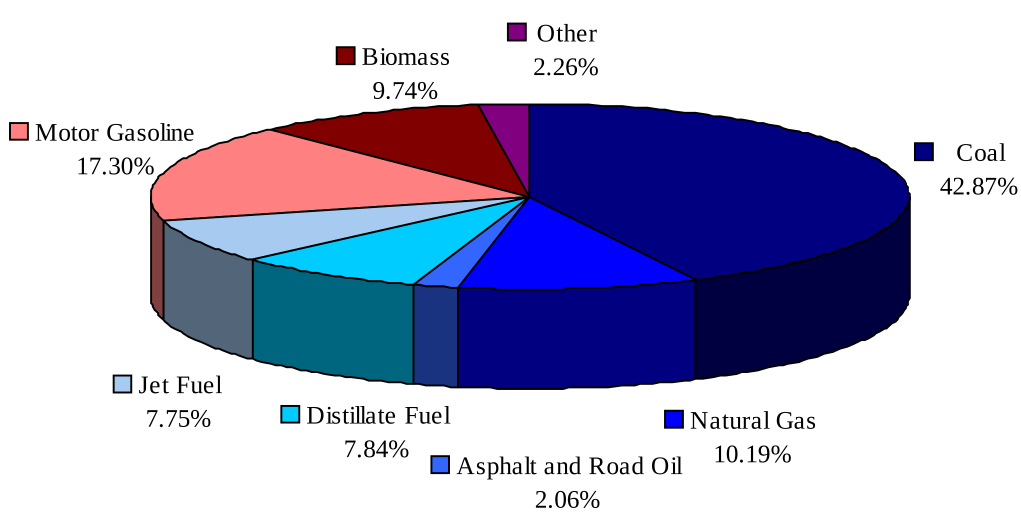


Figure 2.C: 1995 CO_2 Emissions from Fossil Fuel Combustion

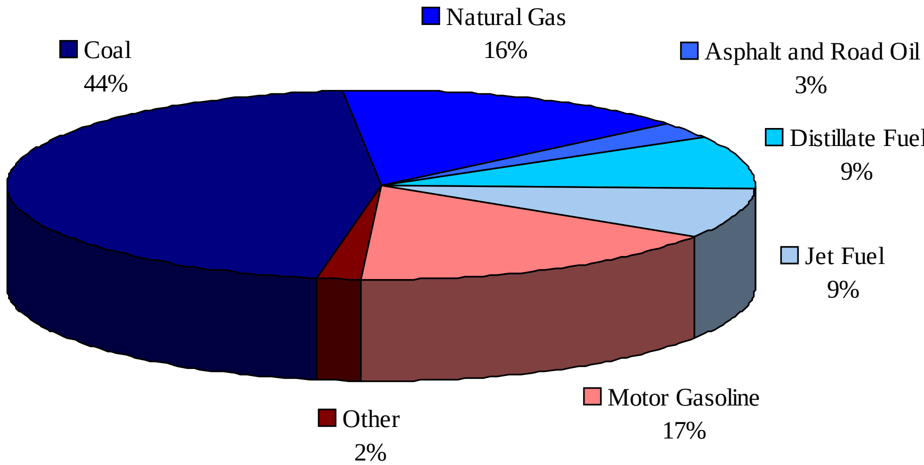


Figure 2.D: 2017 CO_2 Emissions from Fossil Fuel Combustion

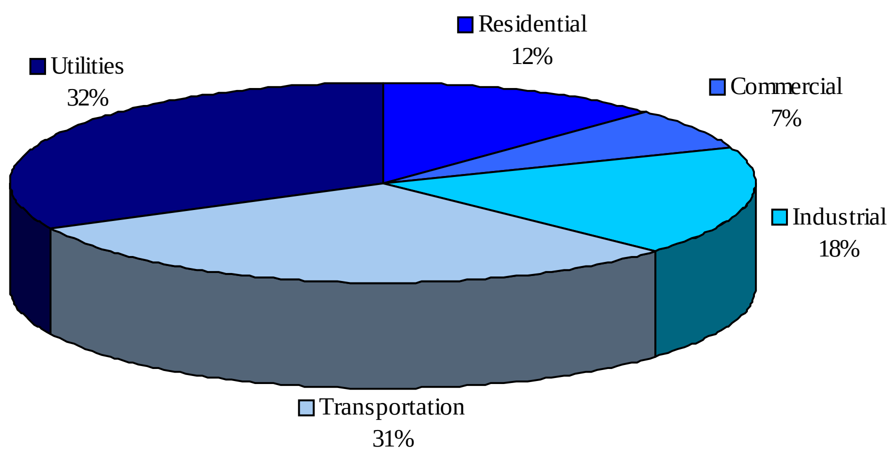


Figure 2.E: 1995 Equivalent CO_2 Emissions

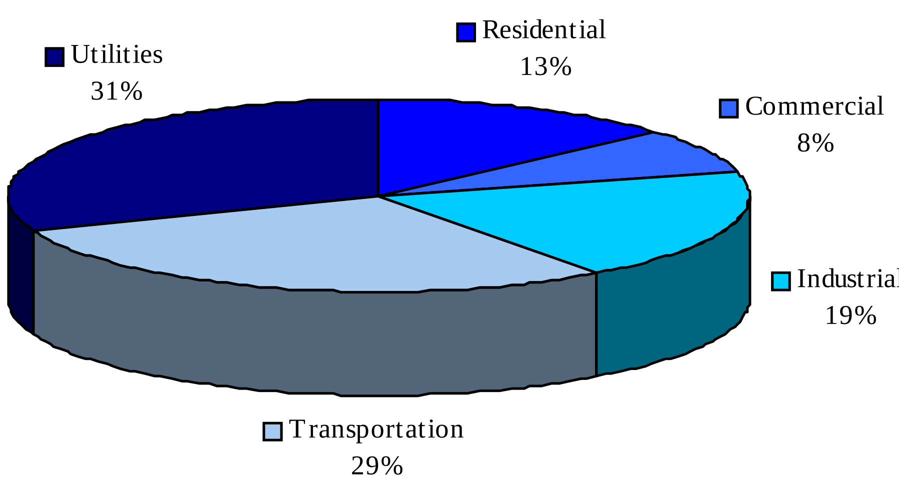


Figure 2.F: 2017 Equivalent CO_2 Emissions

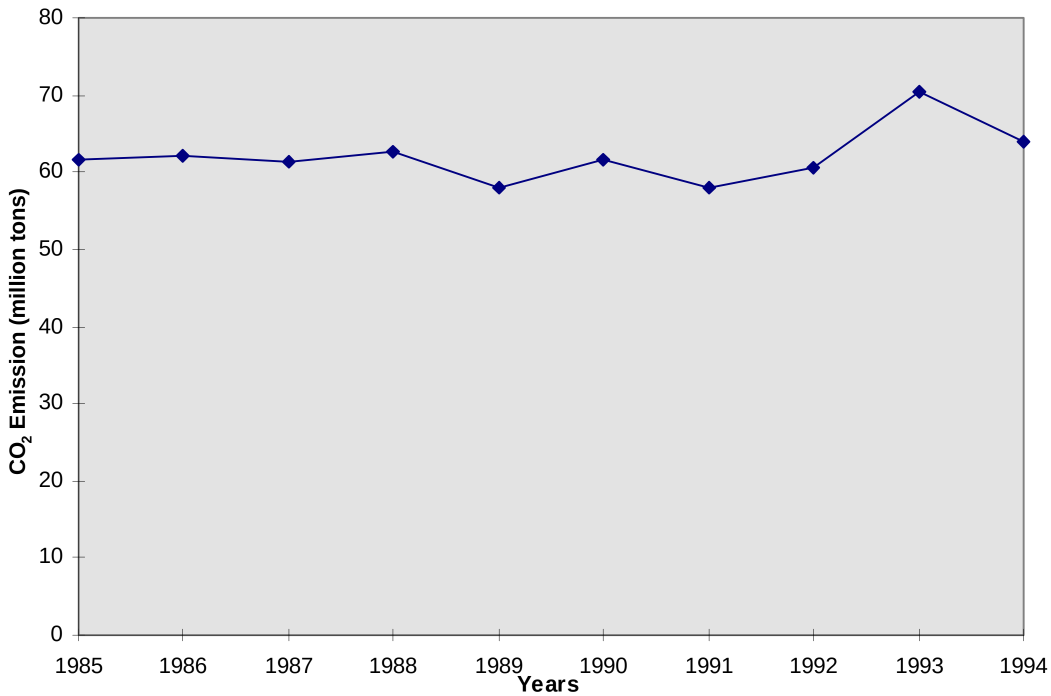


Figure 2.G: Calculated CO_2 Emissions from Coal Combustion Raw Data

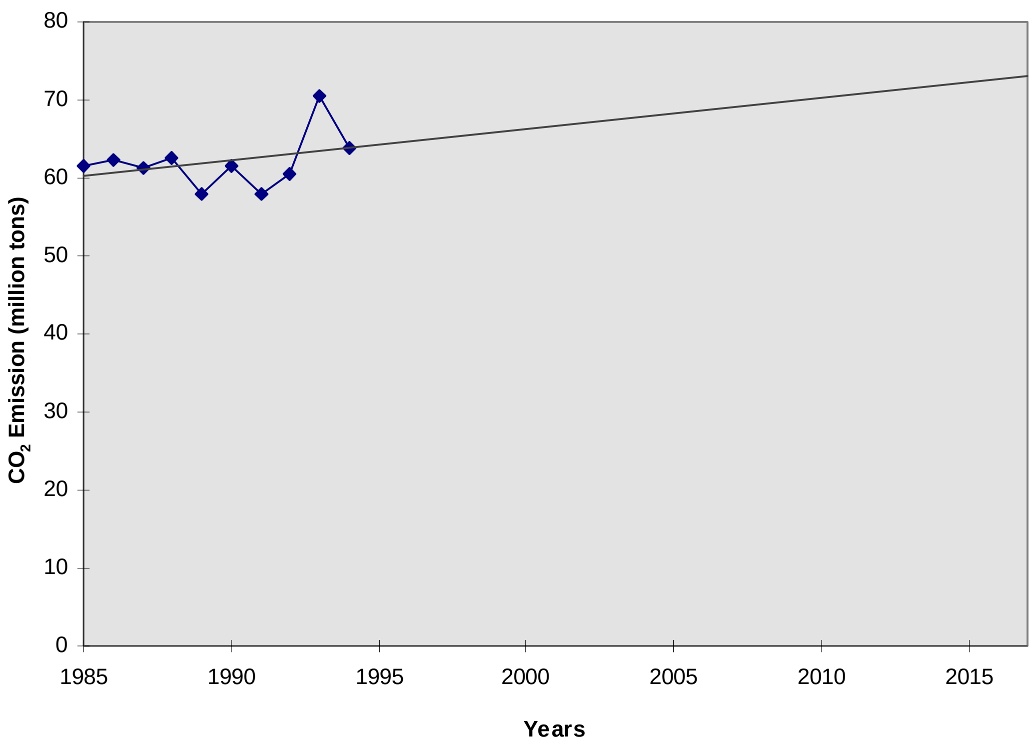


Figure 2.H: CO_2 Emissions from Coal Combustion

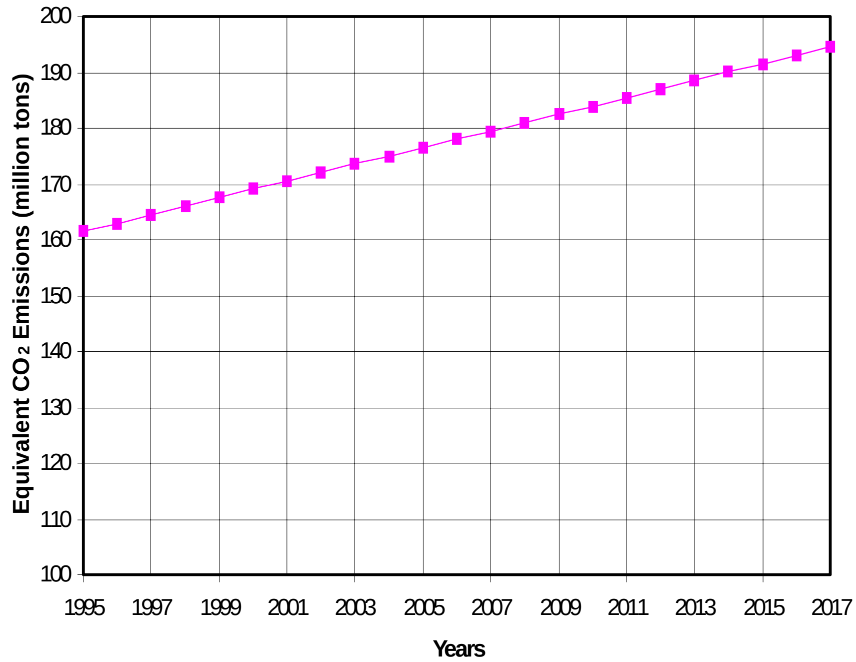


Figure 2.I: Total Equivalent CO_2 Emissions

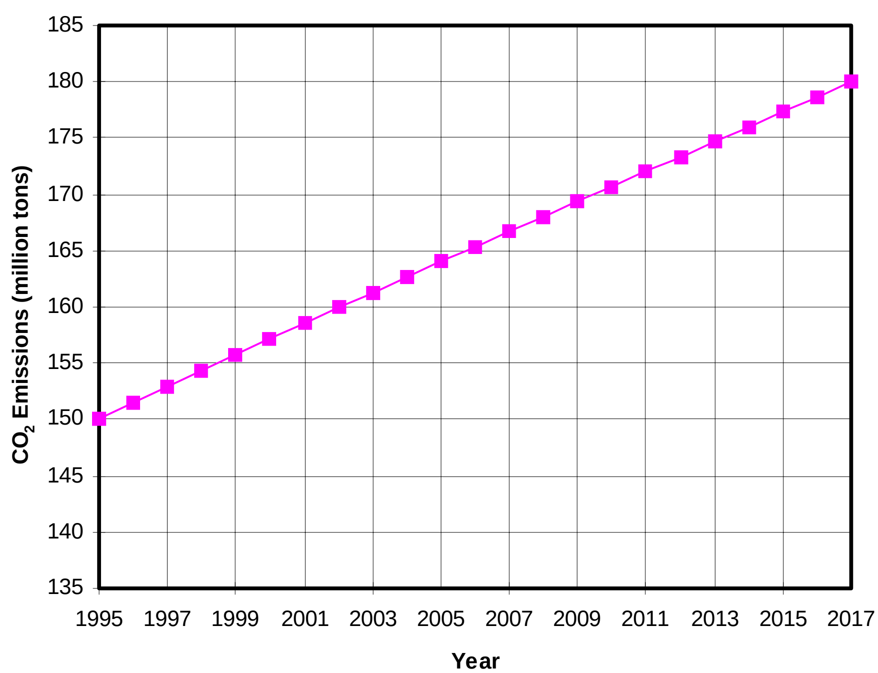


Figure 2.J: CO_2 Emissions from Fossil Fuel Combustion

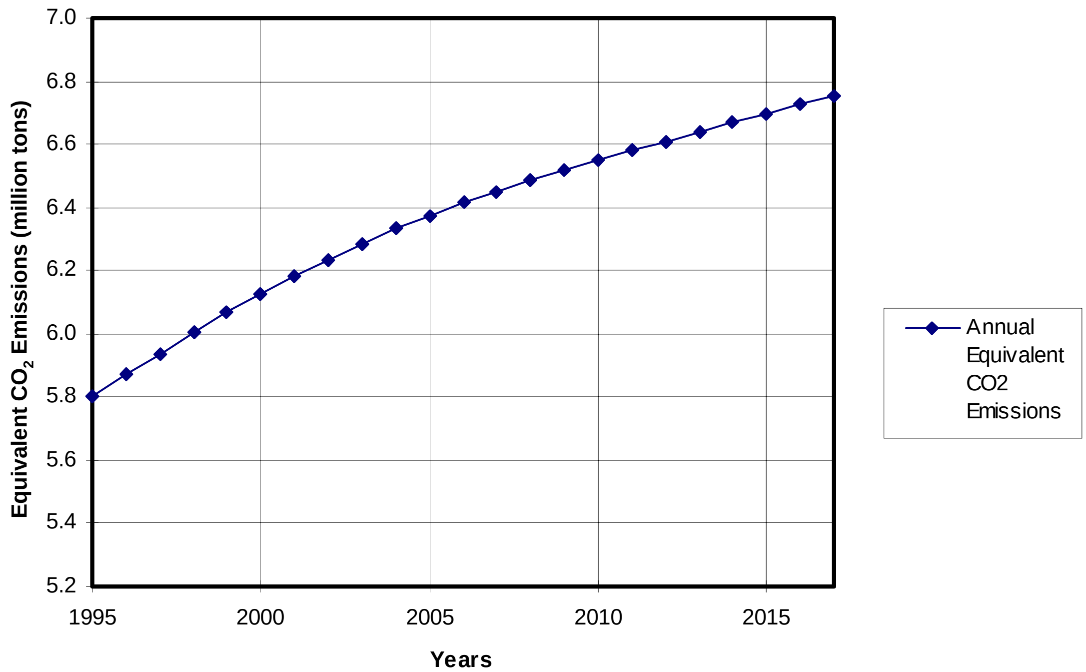


Figure 2.K: Equivalent CO_2 Emissions from Landfills

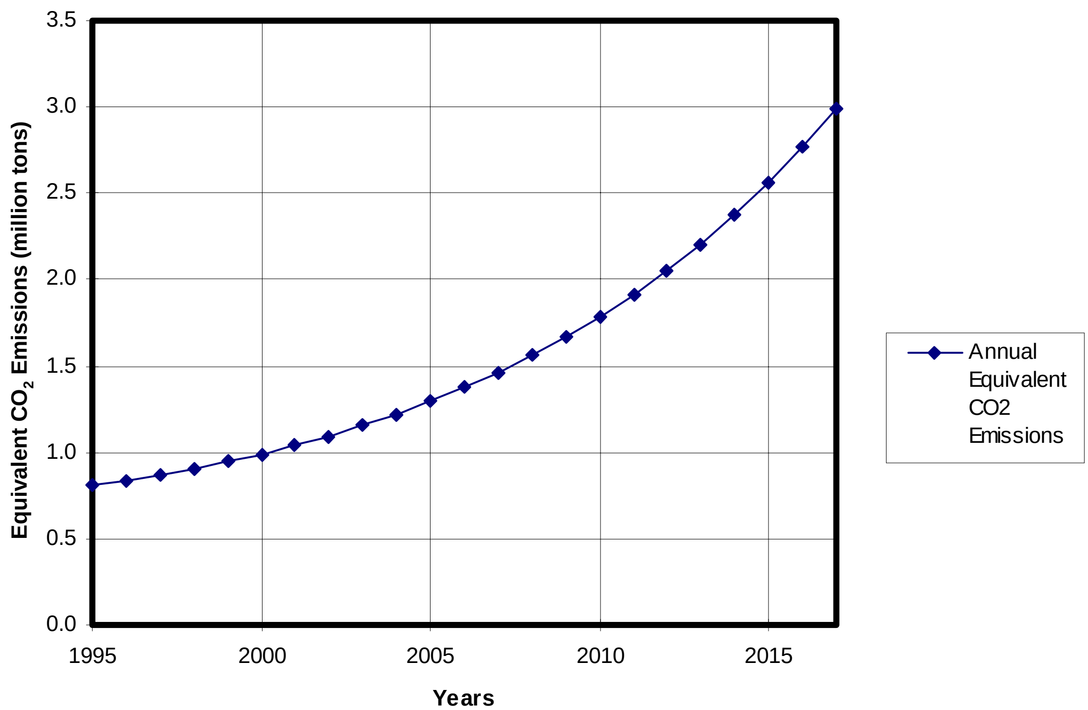


Figure 2.L: Equivalent CO_2 Emissions from Soil Management

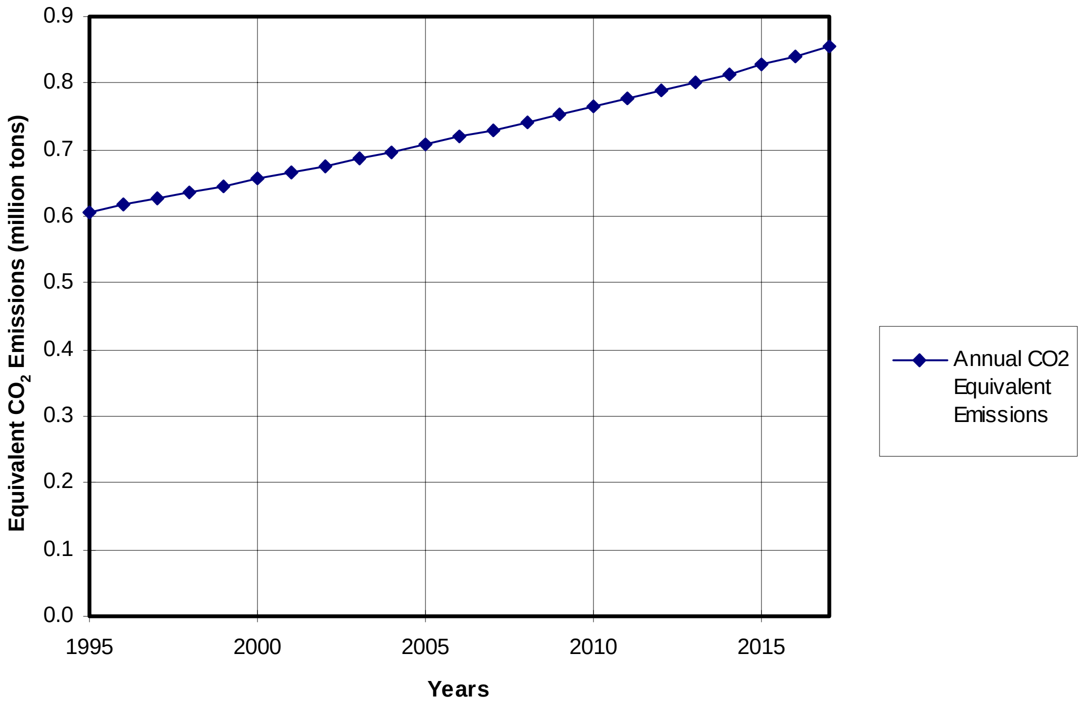


Figure 2.M: Equivalent CO_2 Emissions from Natural Gas and Oil Systems

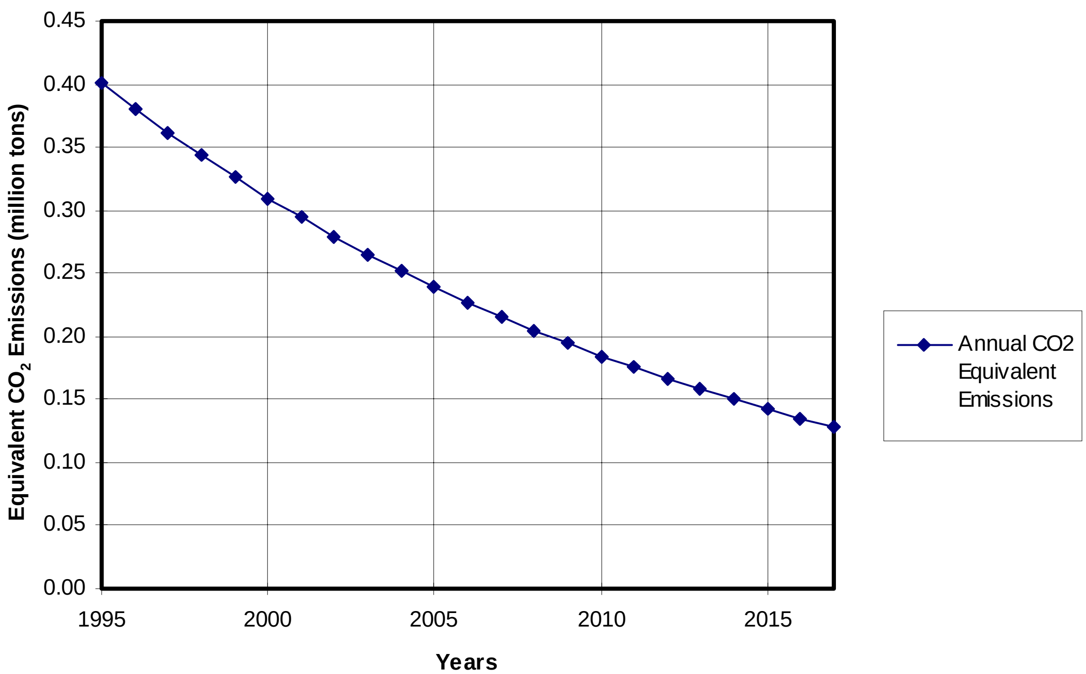


Figure 2.N: Equivalent CO_2 Emissions from Coal Mining

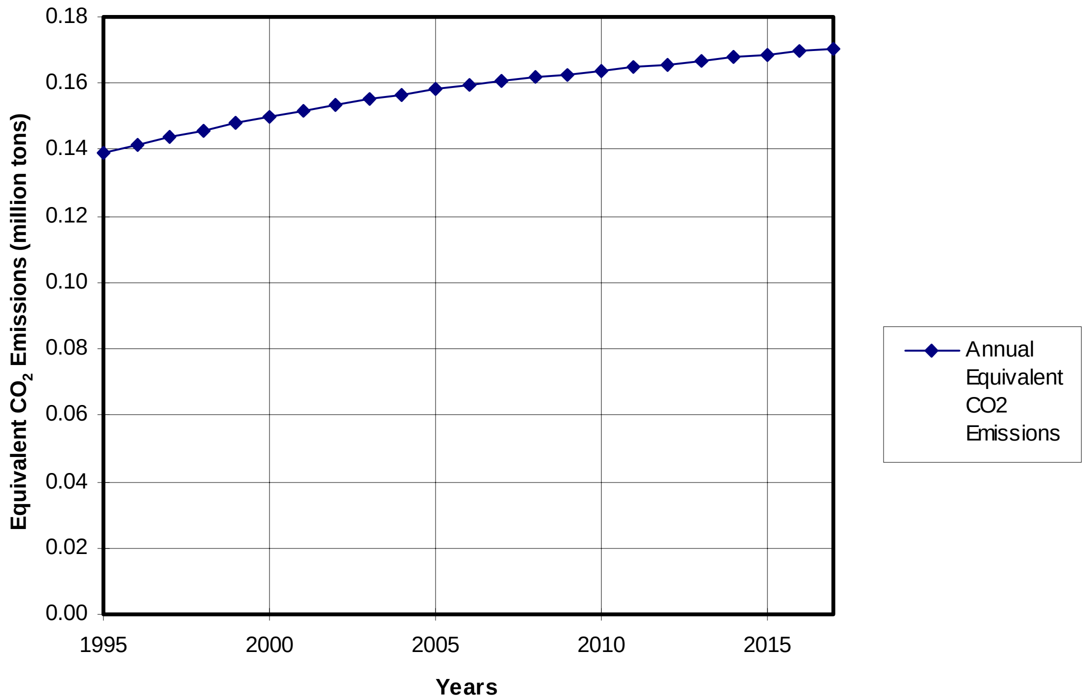


Figure 2.O: Equivalent CO_2 Emissions from Municipal Wastewater Management

CHAPTER 3

REMEDIATION POLICIES

Chapter 3 provides detailed information on many of the policy options proposed in the Executive Summary of this report. In many cases the economic impact on the state has been estimated and the results of that analysis included in the discussion.

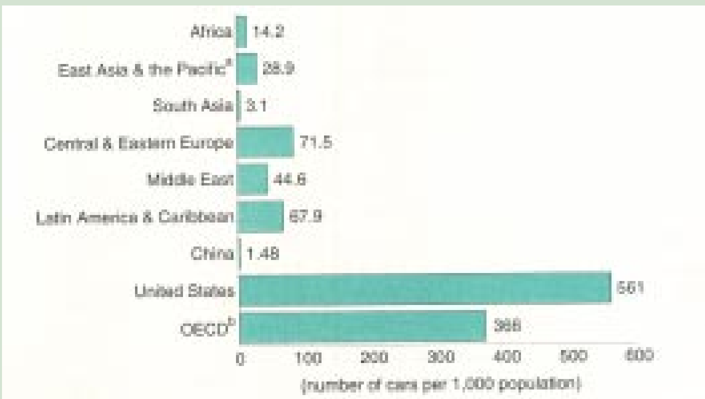
3.1 TRANSPORTATION SECTOR POLICIES

In Tennessee, the transportation sector is the second largest contributor to greenhouse gas emissions, accounting for almost 28 percent of equivalent CO_2 in 1990. Over the twenty year period from 1997 to 2017, the unmitigated levels of transportation-related equivalent CO_2 emissions will continue to rise. This reality is easily explained when one appreciates the rapid growth of passenger cars in the state and, indeed, in the world. **[See Box]** Between 1970 and 1992, the number of registered motor vehicles on Tennessee highways rose from 2,049,992 to 4,645,083 (CBER, 1994: 349). This represented a 127 percent increase over twenty-two years, or an average annual increase of about 5.8 percent, far ahead of rates of population growth.

The emission figures reported in Chapter 2 reflect the heavy environmental cost imposed by our singular reliance on passenger cars as our primary form of transportation. The fact that our dependence on cars is combined with a tendency to travel as single occupants makes the related issue of emission reduction especially intractable. Moreover, the social costs that result from reliance on

Growth in Motor Vehicle Ownership

The number of motor vehicles worldwide could grow from 580 million in 1990 to 816 million (excluding two- and three-wheel vehicles) by 2010, according to recent estimates. The forces driving this level of growth range from demographic factors (urbanization, increasing population, and smaller households), to economic factors (higher incomes and declining car prices, to social factors (increased leisure time and the status associated with vehicle ownership), to political factors (powerful lobbies and governments that view the automobile industry as an important generator of economic growth). Most of the world's vehicles are now concentrated in the wealthier regions of the world. In 1993, member countries of the OECD had 70% of the world's automobiles. Car ownership rates are by far the highest in the United States at 561 per 1,000 people. Among OECD countries, and excluding the U.S., the rate is 366 per 1,000 in the population (WRI, 1996:p82).



Source: American Automobile Manufacturers' Association (AAMA), *World Motor Vehicle Data, 1995 Edition* (AAMA, Detroit, 1995), pp. 16–18.

Notes:

a. Excluding China and Japan.

b. Excluding the United States. OECD is the Organisation for Economic Co-Operation and Development.

cars extend well beyond environmental problems that are conceived in terms of auto emissions alone. Rising levels of traffic congestion, noise pollution, and the worsening of already existing social inequities all exact a toll in terms of higher social costs. **[See Box]**

The transportation-related CO_2 mitigation policies considered for the state of Tennessee—commuter rail, telecommuting, high occupancy vehicle lanes, van and carpools, and emissions control and testing—draw on concrete proposals currently being either considered or implemented in some states to some degree. These are already standard policies in many areas of the United States and they are now finding proponents in Tennessee as the metropolitan areas of the state begin to experience severe problems associated with transportation by passenger car.

Costs Associated With Urban Traffic Growth:

Congestion

Congestion is perhaps the most visible manifestation of the failures in urban transportation planning. It undermines the central purpose of the automobile: ready access to people, goods, and services. Clogged city streets exact a major toll on economic productivity and exacerbate air and noise pollution.

In developed countries, congestion afflicts large and small cities alike. A study of cities in OECD countries found that in virtually every city, speeds in the central business district have declined dramatically since 1970. In the central business district of cities as diverse as Manchester, United Kingdom; Milan, Italy; Utsunomiya, Japan; and Trondheim, Norway morning peak period speeds were 20 kilometers per hour or less in 1990.

Congestion is frequently the result of an insufficient road network...yet, expanding the road network is rarely an adequate solution. Any increase in road capacity tends to be quickly swamped by new travel.

Noise Pollution

Traffic noise—from the constant drone of passing cars and trucks to the sound of screeching tires, blaring horns, radios, and car alarms—is extensive in urban areas. Noise pollution can damage human hearing and affect psychological well-being, as well as decrease property values. An estimated 100 million people in OECD countries are exposed to traffic noise in excess of 65dB—higher than the 55dB considered acceptable.

Social Inequities

The dispersed patterns of many of today's cities, made possible by the availability of motor vehicles, contribute to social inequities. In the United States, suburban flight has left the urban poor concentrated in city centers far from jobs, stores, and entertainment sources that have relocated to the periphery. Unable to afford cars, many poorer dwellers in the city center must rely on public transportation that rarely adequately serves the suburbs. This has played an important role in limiting job and income opportunities. In Detroit, for example, 40 percent of the central-city population does not have a car, yet most of the new jobs in the region are in outlying suburbs (WRI et al, 1996: pp.85-87).

3.1.1 Promote Commuter Rail Alternative

The substitution of commuter rail travel for cars is a travel alternative that has received attention in the Nashville metropolitan area in recent years. As a form of mass public transport, commuter rail could be expected to relieve the congested conditions of vehicular traffic on existing roadways as well as to provide reductions in greenhouse gas emissions.

A 1996 study titled "Nashville Regional Commuter Rail Evaluation" details the economic feasibility and environmental impact of a proposed light rail, public transportation network in the five county Nashville area (RTA et al, 1996). Five travel corridors, making use of existing or potential heavy rail facilities, were studied with respect to the projected ridership, estimated revenues, capital and operating costs, and the air quality impact that would result from decreased reliance on individual vehicular travel. The five corridors parallel the existing roadway commuter routes into Nashville. All ridership, cost, and environmental impact estimates were based on projections for the year 2015.

Table 3.1.1.A Annual Operating Costs and Revenues for Nashville Commuter Rail in 2015

	Northeast	East	Southeast	South	West
Rail Trips (One-way)	810,645	532,695	1,037,850	618,630	497,505
Revenues [$]	1,789,080	1,287,495	2,456,925	1,369,605	1,077,120
Total Operating Costs [$]	4,170,130	3,518,605	4,551,981	3,338,033	3,358,970
Operating Cost per Passenger Mile [$]	0.428	0.440	0.297	0.474	0.571
Operating Deficit [$]	2,381,050	2,231,110	2,095,056	1,968,428	2,281,850
Deficit per Passenger Mile [$]	0.245	0.279	0.137	0.280	0.388

Source: RTA et al, 1996:81.

Table 3.1.1.A reports ridership along with estimated revenues and operating costs for the five rail corridors for the year 2015 (RTA et al, 1996: 81). Revenues reflect projected ticket prices times the number of one-way rail trips. Depending on distance traveled and the corridor selected, ticket prices per trip range between $2.17 and $2.41. Operating costs per passenger mile vary across corridors. The fact that unit operating costs are lower for corridors with higher levels of ridership would indicate some economies of scale are present.

Given the proposed revenue structure, the system is projected to operate at a deficit. In the United States, public transportation operating ratios—defined as revenues as a proportion of operating costs—typically are well below one; thus implying the generation of a deficit. In most instances, this deficit is covered by local taxes on property, sales, gasoline, or downtown parking.

Significantly, a fifty percent rise in the price of daily parking was estimated to increase commuter rail ridership by approximately eighty-two percent, or from 7,418 trips per day up to 13,475. The high degree of price sensitivity to parking fees would indicate that increases in the cost of gasoline and other expenses in operating individual vehicles would be likely to induce an increased use of commuter rail. Pricing policies which promoted the substitution of commuter rail for individual vehicular travel could be anticipated, as well, to increase the operating ratio.

Apart from reducing traffic congestion on traditional commuter routes and roadways, commuter

Auto Production Sets Records

"Worldwide annual production of passenger cars grew 5.4 percent in 1997 or by 39 million cars, pushing the cumulative global automotive fleet to 501 million. Since 1950, numbers of cars in the U.S. have grown six times faster than the U.S. population; a general trend evidenced at the global level as well" (Brown et al, 1998:86). Policies that promote public forms of transportation or reduced reliance on single occupancy vehicles such as commuter rail and HOVs could help slow the trend toward rising numbers of personal vehicles.

Table 3.1.1.B

	Vehicular Miles Reduced	Tons CO_2 Reduced
Nashville Area	60,243,240	19,510
Total Tennessee*	118,377,967	38,337
*Includes Memphis area extrapolation estimate		

Source: RTA, et al., 1996: Appendix 2

rail travel would result in the abatement of greenhouse gas emissions. The estimated reduction in CO_2 emissions from the use of commuter rail services in Nashville are reported in **Table 3.1.1.B**. Utilizing figures reported in the commuter rail study (RTA et al, 1996: Appendix 2), it is possible to approximate net mileage reductions in vehicular traffic across the five corridors served by commuter rail. In 2015, the substitution into commuter rail travel could diminish vehicle miles traveled by 60,243,240. As reported in **Table 3.1.1.B**, the conversion of this number into emissions savings indicated that 2015 commuter rail travel would result in 19,510 fewer tons of CO_2. If one assumes that Memphis could support a commuter rail service of roughly similar scale, then extrapolation estimates indicate that an additional 18,827 tons of CO_2 reductions could be attained. As seen in **Table 3.1.1.B**, this would result in a total projected state-wide abatement of 38,337 tons of CO_2.

Section 3.1.2 Promote Telecommuting

Through the use of communications technology, telecommuting permits employees to work at home instead of traveling to their employer's business location, thereby reducing the total number of vehicular miles traveled. The federal government defines a telecommuter as "anyone who regularly works at an alternate location, at least once a pay period (every two weeks) with at least one of the following outcomes: quality of life improvements, environmental benefit, customer service benefit or other form of productivity improvement such as real estate saving or worker productivity" (cited in a Transportation Management Association Group Final Report, "Telecommuting as a Travel Management and Workplace Tool in Middle Tennessee," 1998:4). In the U.S., it has been estimated that approximately 11.1 million Americans telecommuted in 1997 and that each year about one million more workers are added to the ranks of telecommuters (TMA, 1998:3,6). By the year 2002, the Federal government plans to deploy about 15 percent of its workforce in some form of telecommuting.

Numerous studies indicate that telecommuting results in considerable net savings for individuals, corporations and society. Individuals have experienced reductions in expenditures on gas, auto

The Benefits of Telecommuting

A 1994 government study estimated that telecommuting in the 339 largest US cities could eliminate the need for between 7,300 and 11,200 lane-miles of freeways and major arterials by the year 2010, for an undiscounted cost savings of $13 to $20 billion dollars. A 1993 study found that nationwide, telecommuting could result in saving from 408 up to 815 lives and in preventing between 58,850 and 117,700 accidents by the year 2002. The latter study also reported that telecommuters would save from 826 million to 1.7 billion travel hours (Mokhtarian, 1996:2).

repairs, clothing and food (Pratt, 1984). Business benefits include increased workplace efficiency, lower costs associated with worker recruitment and retention, reduced absenteeism, increased daily work time, and real estate savings, among others (Nolan, 1989; Nilles, 1990; Klayton, 1994).

Environmental benefits are measured primarily in the lower levels of auto emissions and cleaner air. One study by the U.S. Department of Transportation estimated that between 5.2 percent and 10.4 percent of the country's total workforce will be telecommuting in the year 2002 with the result that total vehicle miles traveled will be between 0.7 percent and 1.4 percent lower than if there were no telecommuting. At the national level, this would mean a reduction of between 17.6 and 35.1 billion miles of vehicular travel and fuel savings that ranged from 840 to 1,679 million gallons of gasoline (TMA, 1998:16).

Carbon Emissions Still Rising

Annual global emissions of carbon generated from the burning of fossil fuels increased 107 million tons in 1997 to a new high of 6.3 billion tons. Western industrial countries account for 55 percent of the carbon emitted since 1950, and for 45 percent of current emissions. The world's leading emitter is the U.S. which is responsible for 23 percent of the total, followed by China with a 14 percent share. Between 1990 and 1996, U.S. carbon emissions rose by 8.8 percent, while in China and India the rate of increase was 29 percent and 38 percent, respectively, during this period. On a per capita basis, the average American accounts for 21 times as much carbon as the typical Indian.

Among European Union countries such as Germany, the United Kingdom, and France emissions in 1996 had fallen from 1990 levels by 7.6, 2.0 and 1.1 percent, respectively. These drops were attributed to policy reforms that resulted in the shutdown of energy intensive industries, the removal of coal subsidies and a reduction in reliance on electricity produced with fossil fuel (Brown et al, 1998: 66).

Environmental and Economic Benefits of Telecommuting in Tennessee

A survey carried out among telecommuters in the Nashville region found that workers who telecommuted did so on average three days per week and realized a net reduction in travel of 355 miles per week (TMA,1998:38). By scaling national estimates of increases in numbers of telecommuters to fit Tennessee's workforce and combining these with the results of the TMA survey cited above, it is possible to extrapolate estimates and to assess the likely impact of telecommuting on travel mileage and CO_2 emission reductions over time for the State.

Tables 3.1.2.A and **3.1.2.B** report the results of this exercise under the assumptions of low-range [5.2 percent] and high-range [10.4 percent] rates of expected telecommuting in the year 2002. As seen in the tables, by the year 2017 between more than 494,000 and 649,000 Tennessee workers could be expected to telecommute at least three days at week. Depending on the actual rate of telecommuting, this could mean reductions in CO_2 emissions of 2.75 up to 3.61 million tons annually.

Based on the findings of the Nashville-area telecommuting survey, the economic benefits of telecommuting for households, in particular, appeared to be significant. Ninety-two percent of respondents believed that their productivity had increased as a result of their telecommuting experience (TMA, 1998:28). Out-of-pocket savings to individual telecommuters averaged $49.86 per person per week in 1997. Factoring out the increased at home costs of electricity and food for telecommuters, the average, weekly net per capita savings amounted to $41.76. On an annual basis, the savings realized would be approximately $2,088 per worker (TMA, 1998: 36) (Note 5). As the figures cited above were based on an average of three telecommuting days per week, one could infer

Table 3.1.2.A Estimated State-Wide Reductions in Vehicular Travel and Emissions Resulting From Telecommuting at Low- and High-Range Levels

LOW-RANGE

	1997	1998	1999
United States Labor Force (000)	135881000	137372000	138897000
Number of Telecommuters in U.S.	2236688	3336688	4436688
Tennessee Labor Force	2794000	2835502	2876231
TN Labor Force / US Labor Force (%)	2.1	2.1	2.1
Number of Tennessee Workers Telecommuting	39704	62804	85904
Tennessee Labor Force Telecommuting (%)	1.4	2.2	3.0
Vehicle Miles Traveled Reduced	704751254	1114776254	1524801254
Average U.S. Passenger Car MPG	21.6	22.0	22.3
Reductions in Gallons of Gasoline Used	32627372.87	50747308	68252346
Tons of Carbon Reduced	85287.7	132653.1	178411.1
CO2 Reduced in Tons	309594.4	481530.8	647632.5
Economic Benefits per Person per Year	$ 2,088	$ 1,898	$ 1,726
Total Economic Benefit to Tennessee per Year	$ 82,902,570	$ 119,213,973	$ 148,238,157
	2000	2001	2002
United States Labor Force (000)	140354000	141866000	143272000
Number of Telecommuters in U.S.	5536688	6636688	7736688
Tennessee Labor Force	2914580	2950804	2984698
TN Labor Force / US Labor Force (%)	2.1	2.1	2.1
Number of Tennessee Workers Telecommuting	109004	132104	155204
Tennessee Labor Force Telecommuting (%)	3.7	4.5	5.2
Vehicle Miles Traveled Reduced	1934826254	2344851254	2754876254
Average U.S. Passenger Car MPG	22.7	23.1	23.5
Reductions in Gallons of Gasoline Used	85157982	101479364	117231300
Tons of Carbon Reduced	222602.4	265266.3	306441.8
CO2 Reduced in Tons	808046.6	962916.8	1112383.7
Economic Benefits per Person per Year	$ 1,569	$ 1,426	$ 1,296
Total Economic Benefit to Tennessee per Year	$ 170,999,977	$ 188,398,176	$ 201,219,843
	2003	2004	2005
United States Labor Force (000)	144641000	146042000	147386000
Number of Telecommuters in U.S.	8836688	9936688	11036688
Tennessee Labor Force	3016469	3046116	3073494
TN Labor Force / US Labor Force (%)	2.1	2.1	2.1
Number of Tennessee Workers Telecommuting	178304	201404	224504
Tennessee Labor Force Telecommuting (%)	5.9	6.6	7.3
Vehicle Miles Traveled Reduced	3164901254	3574926254	3984951254
Average U.S. Passenger Car MPG	23.9	24.3	24.7
Reductions in Gallons of Gasoline Used	132428267	147084418	161213586
Tons of Carbon Reduced	346166.5	384477.6	421411.2
CO2 Reduced in Tons	1256584.6	1395653.8	1529722.5
Economic Benefits per Person per Year	$ 1,179	$ 1,071	$ 974
Total Economic Benefit to Tennessee per Year	$ 210,153,289	$ 215,799,497	$ 218,682,318
	2006	2007	2008
United States Labor Force (000)	148842000	150420000	152014000
Number of Telecommuters in U.S.	12136688	13236688	14336688
Tennessee Labor Force	3098956	3122644	3144377
TN Labor Force / US Labor Force (%)	2.1	2.1	2.1
Number of Tennessee Workers Telecommuting	247604	270704	293804
Tennessee Labor Force Telecommuting (%)	8.0	8.7	9.3
Vehicle Miles Traveled Reduced	4394976254	4805001254	5215026254
Average U.S. Passenger Car MPG	25.1	25.6	26.0
Reductions in Gallons of Gasoline Used	174829295	187944761	200572906
Tons of Carbon Reduced	457002.5	491286.3	524296.1
CO2 Reduced in Tons	1658919.2	1783369.1	1903195.0
Economic Benefits per Person per Year	$ 886	$ 805	$ 732
Total Economic Benefit to Tennessee per Year	$ 219,257,523	$ 217,920,853	$ 215,015,169

Table 3.1.2.A Estimated State-Wide Reductions in Vehicular Travel and Emissions Resulting From Telecommuting at Low- and High-Range Levels

LOW-RANGE (Continued)

	2009	2010	2011
United States Labor Force (000)	153626000	155254000	156900000
Number of Telecommuters in U.S.	15436688	16536688	17636688
Tennessee Labor Force	3164302	3184089	3203780
TN Labor Force / US Labor Force (%)	2.1	2.1	2.0
Number of Tennessee Workers Telecommuting	316904	340004	362004
Tennessee Labor Force Telecommuting (%)	10.0	10.7	11.3
Vehicle Miles Traveled Reduced	5625051254	6035076254	6425576254
Average U.S. Passenger Car MPG	26.4	26.9	27.3
Reductions in Gallons of Gasoline Used	212726355	224417450	234944342
Tons of Carbon Reduced	556065.2	586625.6	614142.8
CO2 Reduced in Tons	2018516.6	2129451.0	2229338.5
Economic Benefits per Person per Year	$ 665	$ 605	$ 550
Total Economic Benefit to Tennessee per Year	$ 210,836,792	$ 205,641,135	$ 199,042,871
	2012	2013	2014
United States Labor Force (000)	158563000	160244000	161942000
Number of Telecommuters in U.S.	18736688	19836688	20936688
Tennessee Labor Force	3223122	3242236	3260915
TN Labor Force / US Labor Force (%)	2.0	2.0	2.0
Number of Tennessee Workers Telecommuting	384004	406004	428004
Tennessee Labor Force Telecommuting (%)	11.9	12.5	13.1
Vehicle Miles Traveled Reduced	6816076254	7206576254	7597076254
Average U.S. Passenger Car MPG	27.8	28.3	28.8
Reductions in Gallons of Gasoline Used	245056595	254765132	264080622
Tons of Carbon Reduced	640576.2	665954.2	690304.9
CO2 Reduced in Tons	2325291.6	2417413.9	2505806.6
Economic Benefits per Person per Year	$ 500	$ 454	$ 413
Total Economic Benefit to Tennessee per Year	$ 191,944,777	$ 184,492,264	$ 176,808,433
	2015	2016	2017
United States Labor Force (000)	163659000	165396000	167147000
Number of Telecommuters in U.S.	22036688	23136688	24236688
Tennessee Labor Force	3279183	3297027	3314482
TN Labor Force / US Labor Force (%)	2.0	2.0	2.0
Number of Tennessee Workers Telecommuting	450004	472004	494004
Tennessee Labor Force Telecommuting (%)	13.7	14.3	14.9
Vehicle Miles Traveled Reduced	7987576254	8378076254	8768576254
Average U.S. Passenger Car MPG	29.3	29.8	30.3
Reductions in Gallons of Gasoline Used	273013494	281573936	289771903
Tons of Carbon Reduced	713655.3	736032.3	757461.7
CO2 Reduced in Tons	2590568.8	2671797.1	2749585.9
Economic Benefits per Person per Year	$ 376	$ 341	$ 310
Total Economic Benefit to Tennessee per Year	$ 168,996,932	$ 161,144,478	$ 153,323,074

HIGH-RANGE

	1997	1998	1999
United States Labor Force (000)	135881000	137372000	138897000
Number of Telecommuters in U.S.	2236688	3336688	4436688
Tennessee Labor Force	2794000	2835502	2876231
TN Labor Force / US Labor Force (%)	2.1	2.1	2.1
Number of Tennessee Workers Telecommuting	194909	218009	241109
Tennessee Labor Force Telecommuting (%)	7.0	7.7	8.4
Vehicle Miles Traveled Reduced	3459627508	3869652508	4279677508
Average U.S. Passenger Car MPG	21.6	22.0	22.3
Reductions in Gallons of Gasoline Used	160167940.2	176155928	191564657
Tons of Carbon Reduced	418677.9	460470.3	500748.6
CO2 Reduced in Tons	1519800.6	1671507.3	1817717.6
Economic Benefits per Person per Year	$ 2,088	$ 1,898	$ 1,726
Total Economic Benefit to Tennessee per Year	$ 406,969,140	$ 413,819,946	$ 416,061,769

Table 3.1.2.A Estimated State-Wide Reductions in Vehicular Travel and Emissions Resulting From Telecommuting at Low- and High-Range Levels

HIGH-RANGE (Continued)

	2000	2001	2002
United States Labor Force (000)	140354000	141866000	143272000
Number of Telecommuters in U.S.	5536688	6636688	7736688
Tennessee Labor Force	2914580	2950804	2984698
TN Labor Force / US Labor Force (%)	2.1	2.1	2.1
Number of Tennessee Workers Telecommuting	264209	287309	310409
Tennessee Labor Force Telecommuting (%)	9.1	9.7	10.4
Vehicle Miles Traveled Reduced	4689702508	5099727508	5509752508
Average U.S. Passenger Car MPG	22.7	23.1	23.5
Reductions in Gallons of Gasoline Used	206409026	220703596	234462599
Tons of Carbon Reduced	539551.7	576917.6	612883.6
CO2 Reduced in Tons	1958572.7	2094211.0	2224767.3
Economic Benefits per Person per Year	$ 1,569	$ 1,426	$ 1,296
Total Economic Benefit to Tennessee per Year	$ 414,475,988	$ 409,740,004	$ 402,439,687

	2003	2004	2005
United States Labor Force (000)	144641000	146042000	147386000
Number of Telecommuters in U.S.	8836688	9936688	11036688
Tennessee Labor Force	3016469	3046116	3073494
TN Labor Force / US Labor Force (%)	2.1	2.1	2.1
Number of Tennessee Workers Telecommuting	333509	356609	379709
Tennessee Labor Force Telecommuting (%)	11.1	11.7	12.4
Vehicle Miles Traveled Reduced	5919777508	6329802508	6739827508
Average U.S. Passenger Car MPG	23.9	24.3	24.7
Reductions in Gallons of Gasoline Used	247699948	260429237	272663752
Tons of Carbon Reduced	647485.9	680760.2	712741.1
CO2 Reduced in Tons	2350373.8	2471159.4	2587250.2
Economic Benefits per Person per Year	$ 1,179	$ 1,071	$ 974
Total Economic Benefit to Tennessee per Year	$ 393,080,419	$ 382,096,888	$ 369,861,765

	2006	2007	2008
United States Labor Force (000)	148842000	150420000	152014000
Number of Telecommuters in U.S.	12136688	13236688	14336688
Tennessee Labor Force	3098956	3122644	3144377
TN Labor Force / US Labor Force (%)	2.1	2.1	2.1
Number of Tennessee Workers Telecommuting	402809	425909	449009
Tennessee Labor Force Telecommuting (%)	13.0	13.6	14.3
Vehicle Miles Traveled Reduced	7149852508	7559877508	7969902508
Average U.S. Passenger Car MPG	25.1	25.6	26.0
Reductions in Gallons of Gasoline Used	284416479	295700105	306527029
Tons of Carbon Reduced	743462.6	772958.0	801259.5
CO2 Reduced in Tons	2698769.4	2805837.4	2908571.9
Economic Benefits per Person per Year	$ 886	$ 805	$ 732
Total Economic Benefit to Tennessee per Year	$ 356,693,384	$ 342,862,545	$ 328,598,525

	2009	2010	2011
United States Labor Force (000)	153626000	155254000	156900000
Number of Telecommuters in U.S.	15436688	16536688	17636688
Tennessee Labor Force	3164302	3184089	3203780
TN Labor Force / US Labor Force (%)	2.1	2.1	2.0
Number of Tennessee Workers Telecommuting	472109	495209	517209
Tennessee Labor Force Telecommuting (%)	14.9	15.6	16.1
Vehicle Miles Traveled Reduced	8379927508	8789952508	9180452508
Average U.S. Passenger Car MPG	26.4	26.9	27.3
Reductions in Gallons of Gasoline Used	316909367	326858956	335673453
Tons of Carbon Reduced	828398.8	854407.0	877448.0
CO2 Reduced in Tons	3007087.7	3101497.3	3185136.3
Economic Benefits per Person per Year	$ 665	$ 605	$ 550
Total Economic Benefit to Tennessee per Year	$ 314,094,388	$ 299,511,677	$ 284,379,727

Table 3.1.2.A Estimated State-Wide Reductions in Vehicular Travel and Emissions Resulting From Telecommuting at Low- and High-Range Levels

HIGH-RANGE (Continued)

	2012	2013	2014
United States Labor Force (000)	158563000	160244000	161942000
Number of Telecommuters in U.S.	18736688	19836688	20936688
Tennessee Labor Force	3223122	3242236	3260915
TN Labor Force / US Labor Force (%)	2.0	2.0	2.0
Number of Tennessee Workers Telecommuting	539209	561209	583209
Tennessee Labor Force Telecommuting (%)	16.7	17.3	17.9
Vehicle Miles Traveled Reduced	9570952508	9961452508	10351952508
Average U.S. Passenger Car MPG	27.8	28.3	28.8
Reductions in Gallons of Gasoline Used	344101936	352154847	359842388
Tons of Carbon Reduced	899480.0	920530.3	940625.4
CO2 Reduced in Tons	3265112.4	3341524.8	3414470.3
Economic Benefits per Person per Year	$ 500	$ 454	$ 413
Total Economic Benefit to Tennessee per Year	$ 269,523,738	$ 255,018,592	$ 240,923,276
	2015	**2016**	**2017**
United States Labor Force (000)	163659000	165396000	167147000
Number of Telecommuters in U.S.	22036688	23136688	24236688
Tennessee Labor Force	3279183	3297027	3314482
TN Labor Force / US Labor Force (%)	2.0	2.0	2.0
Number of Tennessee Workers Telecommuting	605209	627209	649209
Tennessee Labor Force Telecommuting (%)	18.5	19.0	19.6
Vehicle Miles Traveled Reduced	10742452508	11132952508	11523452508
Average U.S. Passenger Car MPG	29.3	29.8	30.3
Reductions in Gallons of Gasoline Used	367174522	374160985	380811282
Tons of Carbon Reduced	959791.6	978054.1	995438.0
CO2 Reduced in Tons	3484043.4	3550336.5	3613439.8
Economic Benefits per Person per Year	$ 376	$ 341	$ 310
Total Economic Benefit to Tennessee per Year	$ 227,283,153	$ 214,131,952	$ 201,493,504

Table 3.1.2.B Estimated State-wide Benefits or Cost-savings from Telecommuting at Low- and High-Range Levels

TOTAL ECONOMIC BENEFIT OF TELECOMMUTING TO TENNESSEE PER YEAR			
LOW-RANGE		HIGH-RANGE	
1997	$82,902,570	1997	$406,969,140
1998	119,213,973	1998	413,819,946
1999	148,238,157	1999	416,061,769
2000	170,999,977	2000	414,475,988
2001	188,398,176	2001	409,740,004
2002	201,219,843	2002	402,439,687
2003	210,153,289	2003	393,080,419
2004	215,799,497	2004	382,096,888
2005	218,682,318	2005	369,861,765
2006	219,257,523	2006	356,693,384
2007	217,920,853	2007	342,862,545
2008	215,015,169	2008	328,598,525
2009	210,836,792	2009	314,094,388
2010	205,641,135	2010	299,511,677
2011	199,042,871	2011	284,379,727
2012	191,944,777	2012	269,523,738
2013	184,492,264	2013	255,018,592
2014	176,808,433	2014	240,923,276
2015	168,996,932	2015	227,283,153
2016	161,144,478	2016	214,131,952
2017	153,323,074	2017	201,493,504

TeleBank 24 Program

"SunTrust Bank, Inc. is a premier financial services company based in the Southeastern United States with offices in Nashville. Through its 689 full-service banking offices in Florida, Georgia, Tennessee and Alabama, SunTrust provides a wide range of financial services. TeleBank 24 is part of SunTrust's critical support infrastructure and its agents assist customers through sales, marketing and service segments. These workers typically telecommute.

The TeleBank 24 concept has been met with overwhelmingly positive response and just as favorable results. TeleBank 24 management believes the program has increased productivity, boosted employee morale and proved to top management that supervising a remote worker is no different than guiding staff who work in the next office.

According to automatic call distribution software statistics, the program resulted in a 15% increase in productivity in participating agents. They were on-line 95% of the time compared to 80% of time on the phone for agents in on-site work posts. In addition, the organization has realized cost-savings as a result of telecommuting since TeleBank 24 avoids the payment of rent for office space for those working at home. Supervision problems of telecommuters relative to in-house agents appear to be minimal.

The success of the pilot group in Nashville generated outcomes that suggested to SunTrust the concept should be replicated at other sites" (TMA, 1998:23-25).

that even greater household savings would result were the number of weekly telecommuting days to increase.

By extrapolating from the Nashville telecommuter survey, it was possible to evaluate the compound value of the net benefits that would accrue to telecommuting households over time. These values are also given in **Table 3.1.2.B**. Under the assumption that the cost savings were invested at current bond rates, Tennessee telecommuters could expect the future value of these savings in 2017 to exceed between $153 million at the low-range rate of telecommuting and up to $201 million dollars at the high range. Since the Nashville-area survey did not attempt to quantify the net benefits to businesses from telecommuting, the household savings reported above are apt to underestimate significantly the overall economic gains.

Policy Recommendations

Since telecommuting apparently holds out considerable societal gains, public policies promoting greater levels of telecommuting have an important role to play. Education is seen as a central element of the policy response. The Tennessee-based Transportation Management Association (TMA) has advised that Federal, State, and Local governments take the lead by expanding telecommuting opportunities among their employees (TMA, 1998:44,46). In addition, the TMA suggests that public educational efforts include the development and distribution of technical manuals on telecommuting for employers and workers as well as video presentations and speakers.

While support for telecommuting among workers is generally high—reaching 88 percent in one study—support among executive decision-makers is apparently more tepid—measuring only 16 percent (Yen el al, 1994). Significantly, the Yen et al study found that once an employer had personal contact with a telecommuting worker, employer support rose to 59 percent. This experience indicates that imperfect information—very likely associated with the costs to businesses of attaining relevant information—is responsible for notable efficiency losses. In this regard, it would be advisable that the state subsidize educational materials and services promoting telecommuting; these services could be disseminated through State Energy and Transportation Departments and directed at private sector employers and employees. It has been suggested that Tennessee state policy-makers could draw lessons from the experience of California, Arizona, Oregon and Washington where educational programs to promote telecommuting have been developed (TMA, 1998:45).

Section 3.1.3 High Occupancy Vehicle Lanes

The predominant response to the problem of traffic congestion in the United States has been to expand roadway capacity. This expansion is most evident in the interstate network that was constructed throughout the country over the last thirty years. As population and vehicular traffic have increased, the expansion of the interstate system, especially in urban areas, has proceeded apace.

In spite of roadway expansion, the rapid rate of growth of vehicular traffic has run ahead of roadway capacity with the result that traffic congestion and costly time delays are an ever-present fact of urban life. The escalating economic and political cost of purchasing additional right-of-ways has forced municipalities to reexamine the forms of utilization of the existing transportation infrastructure with an eye toward enhancing that infrastructure's efficiency. One alternative that has been considered in Tennessee and elsewhere is the use of high occupancy vehicles.

A high occupancy vehicle [HOV] is typically defined as a vehicle with more than one occupant. In some areas and on particular roadways, however, HOV travel is understood to designate vehicles that carry three or more riders. Carpools, vanpools and buses are all considered HOVs. Higher vehicle occupancy levels along a given corridor mean that a larger number of travelers can be accommodated for a given number of vehicles. In the U.S., policies which increase the incentives for HOV travel are becoming one method of managing travel demand.

The most common way of providing for HOV travel has been to designate special HOV lanes wherein only vehicles with multiple riders are permitted to travel. In metropolitan areas, the fact that interstate systems generally intersect with themselves and form radial patterns that allow travelers to bypass city streets, means that HOV lanes can be readily incorporated into existing infrastructure. Once established, HOV lanes can be operated over variable time periods, running, for instance, on a 24 hour basis or functioning only during peak travel times during the morning and evening "rush hours". Enforcement of HOV lane utilization becomes a central element in assuring the success of the policy.

Nashville Tennessee's transportation infrastructure has not escaped growing problems with traffic congestion. In 1993, the Tennessee Department of Transportation, the Federal Highway Administration, and the Nashville Area Metropolitan Planning Organization began an investigation of the feasibility of HOV travel in Nashville called the "High Occupancy Vehicle Lane and Improved Accessibility Study"; henceforth the HOV Study.

The focus of the research centered on the evaluation of the benefits and costs of establishing HOV lanes on nine main corridors leading into and around Nashville. As a first step, the nine corridors were studied in order to determine which were most likely to be successful in attracting substantial levels of HOV traffic. Six corridors were eventually identified. As a second

Zero Parking Cost and Public Transit: A Zero Sum Game

"Work commuters often receive free parking and thus do not face the true, market-determined cost of parking. Under such circumstances, the cost of commuting in a single-occupancy vehicle is confined to the vehicle operation costs. One study found that free parking "overwhelms any inducement for employees to commute by public transit that is currently offered by a partial tax exemption of the value of employer-supplied transit passes. At most, a free transit pass can be worth about $270 in annual taxable salary...In contrast employer's offers of free parking are typically equivalent to salary increases four times as large and can range in value up to ten or more times that amount" (Pickerll, 1990).

step, the preferred six corridors were examined in more detail for: 1] likely levels of HOV traffic in the year 2016; 2] levels of vehicular air pollutant emissions; 3] estimated construction costs; and 4] the form that the HOV lanes would take, among other considerations (HOV Summary, 1993: pp.4,5) (Note 6). The HOV system finally chosen for the Nashville area incorporated HOV lanes only on radial corridors. Furthermore, the preferred corridor design consisted of HOV lanes with no barriers between them and the non-HOV lanes. In this manner the HOV lanes could be easily converted to general purpose use in off-peak times (HOV Summary, 1993: pp.8,9).

For the purposes of the present analysis, the HOV Study serves as the basis for evaluating the estimated impact of HOV lanes on CO_2 emission reductions for the year 2016 in Nashville. In addition, by extrapolating from the data in the Nashville study, estimates are made on likely levels of CO_2 reductions in other Tennessee metropolitan areas where HOV travel was considered to be a feasible option. A central factor prompting Nashville to consider HOV traffic was the fact that the locality had been determined to be a moderate nonattainment area for ozone levels. By reducing vehicle miles traveled, HOV lanes would reduce the levels, not only of CO_2, but of NO_x—a major contributor to ozone levels—as well. NO_x reductions would, thereby, help to bring the area into air quality compliance status (HOV Study, 1993: pp.7.1-7.9).

Based on the reported survey results from the six corridors, it was possible to generate the estimated total daily miles traveled by HOVs. For the purpose of appraising future HOV lane usage, the study operated under the assumption that in the year 2016 there would be no modal shift or vehicle mile reductions over the 1996 base year as a result of HOV travel. This assumption was considered the "worst case" scenario and was made in order to determine if HOV demand in a corridor would be sufficient given the 2016 average daily traffic estimates and the current (1996) percentage of HOV traffic in a particular corridor during peak hours (HOV Summary, 1993: p.5).

Under a "better case" scenario, it was believed that there would likely be an increase in the number of HOV vehicles in 2016 of between 20 percent and 60 percent (Note 7). If one makes the additional—and conservative—assumption that there are on average only two riders in HOV vehicles, then it would be possible to estimate the likely reduction in vehicle miles traveled due to higher HOV use. Once mileage reductions were determined, it was possible to convert the effects of such mileage declines into estimates of CO_2 reductions.

An extrapolation of the Nashville-area study results to the state of Tennessee was made on the assumption that at least four other metropolitan areas—Memphis, Knoxville, Chattanooga, and Johnson City—would be large enough to consider employing HOV lanes in 2016. Moreover, if these areas were assumed to utilize HOV lanes over relatively equal distances with proportionate levels of HOV travel, then by adjusting the mentioned areas with their respective population coefficients one could derive a general estimate of the state-wide mileage and CO_2 reductions. The population coefficients were derived by dividing the 1996 metropolitan statistical area [MSA] populations of the four cities by the 1996 Nashville MSA population.

The results of this extrapolation are reported in **Table 3.1.3.A**. In 2016, increased HOV ridership is calculated to reduce vehicle miles traveled by over 80 million miles at the low range estimate and by over 214 million miles at the high range. The reported drops in vehicle miles traveled translate into approximately 25,646 and 76,943 fewer tons of CO_2 emissions at the low and high range estimates, respectively. The decline in vehicle miles and CO_2 reductions should be seen as conservative estimates given the assumption that the average HOV vehicle in 2016 would carry only two riders.

Table 3.1.3.A Estimated State-Wide Reductions in Vehicular Travel and Emissions Resulting From HOV Travel at Low- and High-Range Levels

	Low Range (20% HOV Increase)	High Range (60% HOV Increase)
Miles of Reduced Travel	80,547,679	214,643,037
Tons CO_2 Reduced	25,646	76,943

Extrapolated from: HOV Study, 1993: pp.8.1-8.72.

3.2 RESIDENTIAL SECTOR POLICIES

The primary residential energy needs are focused around lighting, heating/cooling, water heating, and appliance operation. Six policies have been identified to promote residential energy conservation in these areas.

3.2.1 Promote the Replacement of Incandescent Lighting with Compact Fluorescent

One proven lighting measure to reduce the electrical consumption of residences is to replace existing incandescent light bulbs with more efficient compact fluorescent lamps. For example, a compact fluorescent lamp consuming 18-25 watts can typically replace a 100-watt incandescent bulb. Using readily available projections on the future population of the state and the current housing breakdown for Tennessee, it is possible to project the savings potential for residential lighting energy conservation projects. The calculations presented here assume that the residential lighting energy conservation program will be initiated in the year 2002 and will cause about 11.26 million 100-watt incandescent bulbs to be replaced with 18-watt compact fluorescent lamps. The installed cost per compact fluorescent lamp is $12. However, the compact fluorescent lamp is rated for a 10,000-hour life, while the 100-watt incandescent bulb has a 750-hour rated life. The total first year cost to fund the conversion program is $135.14 million. After the large initial investment during the first year of the program, only the annual new construction would have to be converted on a year-by-year basis.

The 2002 estimated savings from the initial year of the program are $65.77 million dollars, and the subsequent annual savings grow to $73.03 million by the year 2017. The savings increase as the lights in the new construction are installed as compact fluorescent lamps instead of incandescent bulbs. The initial investment of $135.14 million to start the program in 2002 will be recovered by Tennessee residents in just over two years with the avoided utility costs. The reduction in CO_2 emissions starts at 1.09 million tons for 2002 and grows to 1.21 million tons by the year 2017.

It is believed that by publicizing potential dollar savings for replacing incandescent bulbs with compact fluorescent lamps, homeowners will voluntarily change at least one-third of their incandescent bulbs. Each 100-watt bulb replaced results in an estimated average net savings of $5.32 per year. For a single-family house with around 15 incandescent bulbs, that amounts to nearly $80 saved every year. These savings have been calculated assuming $0.065 per kilowatt-hour as the average cost of electricity. A typical 100-watt incandescent bulb has a rated life of 750 hours and costs $0.54. The resulting annual replacement cost is $0.81 assuming a 3-hour burn time each day. An 18-watt compact fluorescent lamp rated for 10,000 hours costs about $12 each. The annual replacement cost for the compact fluorescent is approximately $1.33 per year. The simple payback for the $12 investment is 2.3 years.

An econometric analysis of the macroeconomic effects on the state of Tennessee of this proposal to change out existing incandescent light bulbs with compact fluorescent lamps was carried out using the REMI model for Tennessee. Given the initial investment by residents on the purchase of compact fluorescent bulbs and the resulting cost saving in terms of lower residential energy bills, there appears to be a substantial positive impact on the state's economy as can be seen in **Table 3.2.1.A**.

The overall positive impact can be illustrated in a variety of ways. First, over the period 2002 through 2017 an average of 799 new jobs per year, a total of 12,784 new jobs over the period, will be created in Tennessee as a result of this proposal. In addition, Tennessee Gross State Product (GSP) will rise on average by $37.4 million per year. While at the same time the state's Personal Consumption Expenditure Index (PCE) will fall on average by 0.04 percent. These positive employment and income effects reflect both the direct and indirect impact of producing, distributing, and installing these new more energy efficient compact fluorescent lamps in residences across the state. While the direct impacts, derived from the production and distribution of these new lamps are rather small, the indirect impact is large due to the fact that lower energy bills allow residents more real income, thus generating additional demand for other consumer goods that may also be produced in the state. Also, lower energy bills reduce the cost of living in Tennessee and thus draw more migrants to the state, again generating additional demand for all types of consumer goods, some of which are produced locally and lead to the creation of new jobs and income. Thus, it appears clear that the overall impact on the state of this particular proposal is positive. For a more detailed break

Table 3.2.1.A

Year	Employment (thous)	GRP (Bil 92$)	Real Disp Pers Inc (Bil 92$)	Output (Bil 92$)	PCE-Price Index 92$ (%)
2002	0.813	0.036	0.064	0.061	-0.041%
2003	0.784	0.035	0.065	0.056	-0.044%
2004	0.768	0.035	0.065	0.054	-0.044%
2005	0.761	0.035	0.065	0.053	-0.042%
2006	0.760	0.035	0.065	0.052	-0.041%
2007	0.763	0.036	0.065	0.052	-0.040%
2008	0.770	0.036	0.065	0.052	-0.039%
2009	0.780	0.037	0.066	0.053	-0.039%
2010	0.791	0.037	0.066	0.054	-0.038%
2011	0.804	0.038	0.066	0.055	-0.037%
2012	0.813	0.038	0.066	0.056	-0.036%
2013	0.823	0.039	0.066	0.057	-0.035%
2014	0.832	0.039	0.066	0.058	-0.034%
2015	0.838	0.040	0.065	0.058	-0.033%
2016	0.844	0.040	0.065	0.059	-0.032%
2017	0.848	0.041	0.065	0.060	-0.031%
Average	0.799	0.037	0.065	0.056	-0.038%

down of the impact of this proposal, by sector, please refer to the appendix at the end of this document.

3.2.2 Promote New Efficiency Levels for Residential and Apartment Construction

The cost associated with adding additional insulation during new construction is very low relative to the long term benefits. Thus, it is proposed to establish high minimum standards for the levels of insulation in roofs and walls for new residential and apartment construction. High quality double pane windows would also be required to reduce window energy losses. Computer simulations have been conducted to project potential savings accomplished with the higher insulation levels. Overall, savings numbers have been projected from the expected population growth of the state.

It is projected that if the program is initiated in 2003, there would be approximately 168,400 homes affected by 2017. The additional insulation levels would save about 0.93 million tons of CO_2 annually from being emitted to the atmosphere. The electrical savings in 2017 are projected to be 210 million kWh with a value of $13.6 million.

The minimum insulation levels simulated in the study are R-38 for roofs, R-22 for walls, and tight fitting double pane windows with frame insulation and thermal breaks. The final levels of minimum energy efficiency should be determined after additional study.

3.2.3 Promote the Use of Low Flow Shower Heads

The widespread use of low flow shower heads has the potential to save significant amounts of energy, water and provide reductions in GHG emissions. A low flow shower head can save approximately 1 gallon of hot water per shower. Assuming that one third of the state population bathes daily and one half of those baths are showers and that 25 percent of the state can be convinced to install low flow shower heads, then by year 2017 the emissions reductions would be 455,000 tons of CO_2 per year. A reduction in 268,000 gallons of hot water used per day would lead to utility cost savings of roughly $27.5 million per year. The overall cost of the program through year 2017 is estimated to be about $2.7 million.

3.3 COMMERCIAL SECTOR POLICIES

The bulk of the energy use for the commercial sector is for space heating/cooling and lighting. Thus, policies have been devised to specifically address these areas. Based on the development of new high efficiency refrigeration equipment for supermarkets, a policy to promote its use is included. Finally, more general policies are proposed that will encourage participation in federal government programs promoting energy efficiency, promote a new construction energy efficiency code, and establish an energy efficiency clearinghouse.

3.3.1 Promote and Encourage the Replacement of Inefficient Water Chillers

In large, air-conditioned buildings and industrial facilities requiring significant refrigeration, the chiller plant is one of the major energy consumers. Consequently, the energy performance of the chiller is critical to minimizing overall operating costs. Most large water chillers in operation today are at least 15 years old. Chiller efficiency improvements of recent years have made the return on investment for chiller retrofit projects very attractive, and in many cases in the 15 to 35 percent range. Along with the energy cost savings potential, the phasing out of refrigerants commonly used by older chillers gives extra incentive to the replacement of these units. The Montreal Protocol calls for the phasing out of common refrigerants such as R11, R12 and other chlorofluorocarbons (CFCs).

Production of these refrigerants has been limited or stopped altogether, making their cost extremely high relative the refrigerants used in new chillers. These older chillers will have to be replaced in the next 5 to 10 years.

New developments in commercial and industrial size water chillers have led to units that require roughly one-half of the electrical input of older units. Instead of consuming electricity at the rate of about 1.0 to1.2 kW/ton, these newer, more efficient chillers require only 0.5 to 0.6 kW/ton. By estimating approximately 400 ft^2 of conditioned space per ton of installed chiller capacity and assuming 50 percent of chillers could be replaced, the total reduction in electrical energy use would be 2.16 billion kWh per year. This would correspond to a reduction in CO_2 output of almost 2.3 million tons. The expected cost of this project would be $784 million and, with a savings of $140 million per year in electricity bills, would result in a 5.6-year simple payback. **Table 3.3.1.A** shows the details of the chiller replacement initiative.

Water Chiller Replacement Mitigation Option

Table 3.3.1.A Chiller Replacement Initiative Details

Chillers	Schools K-12	Medical Care Facilities	Commercial Office Space	Retail Office Space	State Government	Total
Sq ft	69,542,180	6,233,184	653,043,109	768,080,948	70,412,320	1,567,311,741
Tons Chiller	173,855	15,583	1,632,608	1,920,202	176,031	3,918,279
Current kW	208,627	18,700	1,959,129	2,304,243	211,237	4,701,935
New kW (100%)	104,313	9,350	979,565	1,152,121	105,618	2,350,968
New kW (50%)	156,470	14,025	1,469,347	1,728,182	158,428	3,526,451
Current kWh/year	383,038,327	34,332,377	3,596,961,443	4,230,589,862	387,831,059	8,632,753,068
kWh per year (100%)	191,519,164	17,166,189	1,798,480,721	2,115,294,931	193,915,529	4,316,376,534
kWh per year (50%)	287,278,746	25,749,283	2,697,721,082	3,172,942,396	290,873,294	6,474,564,801
kWh Savings (100%)	191,519,164	17,166,189	1,798,480,721	2,115,294,931	193,915,529	4,316,376,534
kWh Savings (50%)	95,759,582	8,583,094	899,240,361	1,057,647,465	96,957,765	2,158,188,267
Savings $million (100%)	$ 12.45	$ 1.12	$ 116.90	$ 137.49	$ 12.60	$ 280.56
Savings $million (50%)	$ 6.22	$ 0.56	$ 58.45	$ 68.75	$ 6.30	$ 140.28
CO_2 Savings (100%)	205,868	18,452	1,933,227	2,273,777	208,444	4,639,768
CO_2 Savings (50%)	102,934	9,226	966,613	1,136,889	104,222	2,319,884
Project Cost $million (100%)	$ 69.54	$ 6.23	$ 653.04	$ 768.08	$ 70.41	$ 1,567.31
Project Cost $million (50%)	$ 34.77	$ 3.12	$ 326.52	$ 384.04	$ 35.21	$ 783.66

As a policy option to reduce GHG emissions from Tennessee, the state should actively promote the replacement of old inefficient water chillers, most of which utilize refrigerants that are being phased out. The economic returns from such projects should be sufficient to encourage owners to make these replacements on their own. The state's role would be to provide enough information, promotion and encouragement to get these retrofit projects implemented.

Economic Impact Analysis

Based upon the estimated implementation costs and the energy saving associated with the investment in new technologically efficient water chilling equipment, an econometric analysis of the macroeconomic effects on the state of Tennessee of the proposed investments was carried out using the REMI model for Tennessee. It was assumed that the initial investments would be carried out over a two-year period in the following five sectors: (1) Schools K-12, (2) Medical Care Facilities,

(3) Commercial Office Space, (4) Retail Office Space, (5) State Government. The estimated savings were assumed to begin in the second year of the project. This particular strategy appears to be a very promising one due to the large positive impact that these investments and energy savings are predicted to have on the state of Tennessee. As can be seen in **Table 3.3.1.B**, the overall positive impact can be illustrated in several ways.

First, over the period 1997 through 2017 an average of 3,758 new jobs per year, or a total of 78,918 new jobs, will be created in Tennessee as a result of this particular energy strategy. In addition, Tennessee Gross State Product is predicted to rise on average by $171 million per year. While at the same time the state's Personal Consumption Expenditure Index will fall slightly by an average of 0.054 percent per year. These positive employment and income effects reflect both the direct and indirect impact of producing and installing these more efficient chillers across the state. The direct impacts are derived from the production and installation of this new equipment. The indirect impacts are largely due to the lower energy bills that result from the installation of this new equipment and the induced spending brought about by the increased investment in the state. This increased investment generates new jobs and increased incomes, which in turn leads to higher levels of spending. As with any type of technological improvement not only do we see increases in output but also lower prices. These lower price levels make Tennessee more competitive relative to other regions and draws more businesses into Tennessee and with it more jobs and higher incomes. Thus, it appears clear that the overall economic impact on the state of these proposed investments are positive and would be highly beneficial for Tennessee. For a more detailed breakdown of the impact of this proposal, by sector, please refer to the appendix at the end of this document.

Table 3.3.1.B

Year	Employment (thous)	GRP (Bil 92$)	Real Disp Pers Inc (Bil 92$)	Output (Bil 92$)	PCE-Price Index 92$ (%)
1997	6.590	0.266	0.128	0.511	0.028%
1998	8.456	0.340	0.259	0.641	-0.042%
1999	2.221	0.089	0.143	0.144	-0.067%
2000	2.464	0.102	0.146	0.165	-0.071%
2001	2.727	0.116	0.151	0.187	-0.071%
2002	2.958	0.128	0.156	0.207	-0.070%
2003	3.152	0.139	0.160	0.224	-0.069%
2004	3.311	0.148	0.165	0.238	-0.067%
2005	3.438	0.156	0.169	0.250	-0.066%
2006	3.527	0.162	0.171	0.260	-0.064%
2007	3.602	0.167	0.173	0.269	-0.061%
2008	3.652	0.172	0.174	0.275	-0.059%
2009	3.685	0.175	0.175	0.280	-0.057%
2010	3.701	0.177	0.176	0.283	-0.055%
2011	3.705	0.179	0.177	0.286	-0.054%
2012	3.693	0.180	0.176	0.287	-0.052%
2013	3.672	0.180	0.176	0.288	-0.051%
2014	3.646	0.180	0.175	0.288	-0.050%
2015	3.613	0.180	0.174	0.288	-0.048%
2016	3.575	0.179	0.173	0.287	-0.047%
2017	3.536	0.179	0.172	0.286	-0.046%
Average	3.758	0.171	0.170	0.283	-0.054%

3.3.2 Promote and Encourage Lighting Retrofit Projects to Increase the Efficiency of Lighting Systems

There is a vast potential for energy savings and GHG emissions reduction by implementing current state of the art lighting technologies into the existing building stock throughout Tennessee. In this section estimates have been made of the square footage of facilities in 6 major classifications within Tennessee. From the square footage numbers, projections are made of the possible energy savings due to lighting retrofit projects. The building categories include public schools (K-12), medical care facilities, commercial office space, retail office space, state government owned buildings, and manufacturing facilities.

The energy savings potential for lighting retrofit projects in the public schools, grades K-12, has been projected by the following algorithm. Using the Rules of the Tennessee Department of Education, Chapter 0520-1-4, an approximate average school size was determined and applied to the number of public schools in Tennessee to arrive at an approximate total square footage of 69,542,180. Assuming the schools have exclusively fluorescent lighting that operates 10 hours per day, 260 days per year, a retrofit program that produces a 20 percent reduction in lighting energy consumption for half of the schools would save over 45 million kilowatt-hours of electricity per year. This reduction in energy consumption translates into over $2.9 million per year saved on electricity costs, and results in the avoidance of releasing over 48,500 tons annually of CO_2.

Medical Care Facilities were assumed to have 240 square feet of floor space per bed. With over 21,000 hospital beds in Tennessee, this accounts for over 6 million square feet of space when a hall-to-room floor space ratio of 20 percent is assumed. Breaking down the space allocation into rooms and hallways was beneficial. It allowed an estimated 4 hours operation per day for lights in rooms, and around-the-clock operation of lights in hallways. If a retrofit was initiated in 50 percent of all hospitals, the electricity consumed per year for hospital lighting would drop from 41.7 million kWh to 37.5 million, a savings of 4.2 million kWh, translating into $271,118 in electricity costs, abating the release of 4,484 tons of CO_2 annually.

Commercial Office Space in Tennessee was calculated using the Statement of the 1997 Taxable Property and Tax Levied Report obtained from the Tennessee Association of Business. Taxes on commercial property were assessed at 40 percent of the property's actual value. After adjusting for this, it was decided that the average value of commercial property was around $50 per square foot, and that 70 percent of the property value was actually taken up by buildings. This yielded a total estimated commercial square footage of 653 million. If half of Commercial Office Space lighting was retrofitted with more efficient lamps, a reduction of almost 635 million kWh could be achieved annually, representing over 682,000 tons of CO_2 and a savings of over $41.2 million in electricity costs per year.

The retail sector represents the largest by square footage of these categories. By utilizing the Summary Statistics for the State: 1992, and taking measurements of representative retail businesses for each of 10 sub-categories, a total of over 768 million square feet of retail space was estimated. By retrofitting the lighting systems of one half of these structures, at an efficiency improvement of 10 percent, a reduction of over 641,000 tons of CO_2 annually could be achieved. The energy savings for the retail sector lighting projects would amount to almost 600 million kWh per year. The energy costs reduced by the retrofit projects would amount to almost $39 million annually.

State government buildings, including all public colleges and universities, account for over

70 million square feet of space. If a 20 percent reduction in lighting energy use could be achieved by retrofit, with 50 percent of state government-controlled facilities participating, the State of Tennessee would save over $4.4 million dollars per year and prevent the release of over 73,500 tons of CO_2 annually by conserving more than 68 million kWh.

The last category, manufacturing facilities, represents over 380 million square feet of space. This number was determined by consulting the Tennessee Statistical Abstract and combining its numbers for manufacturing with average facility sizes calculated from the 1998 Directory of Tennessee Manufacturers. If an improvement in efficiency of 5 percent could be achieved by retrofitting 50 percent of manufacturing complexes, it would result in a reduction in CO_2 emissions of more than 66,200 tons annually, representing an electrical cost reduction of $4.0 million, from the 61.6 million kWh drop in energy consumption.

The total reduction of CO_2 emissions from these lighting retrofit projects would be more than 1,516,000 tons annually. A cost of 6.5 cents/kWh was assumed for all electrical cost calculations. The square footages, usage times, watts per square foot, and other information are listed in **Table 3.3.2.A.**

Table 3.3.2.A Lighting Statistics

	Schools K-12	Medical Care Facilities	Commercial Office Space	Retail Office Space	State Government	Manufacturing	Total
Sq ft	69,542,180	6,233,184	653,043,109	768,080,948	70,412,320	380,698,429	1,948,010,170
Watts/sq ft	2.5	2.5	3.0	3.0	3.0	2.0	
Hours per day	10	7.33	9	14.39	9	9	
Days per year	260	365	360	360	360	360	
kWh per year	452,024,170	41,710,390	6,347,579,016	11,935,217,560	684,407,750	2,466,925,821	21,927,864,707
New kWh	406,821,753	37,539,351	5,712,821,115	11,338,456,682	615,966,975	2,405,252,676	20,516,858,551
kWh savings	45,202,417	4,171,039	634,757,902	596,760,878	68,440,775	61,673,146	1,411,006,156
Cost savings	$2,938,157	$271,118	$41,259,264	$38,789,457	$4,448,650	$4,008,754	$91,715,400
CO_2 savings (tons)	48,589	4,484	682,315	641,471	73,568	66,294	1,516,722
Retrofit Cost	$15,091,619	$1,352,688	$170,063,310	$200,021,080	$18,336,542	$66,093,477	$470,958,715

The new lighting technologies that make these projected savings possible include the new T-8 fluorescent tubes used with an electronic ballast and in many cases a high quality reflector to line the fixture. The new T-8 lamps replace the older T-12 lamps that have been the standard for fluorescent lighting for many years. The T-8 tubes produce more light output per unit of electrical input energy (75 – 90 lumens per Watt) than the conventional fluorescent tubes (61 – 73 lumens per Watt). The new electronic ballasts used with the T-8 lamps have only a 1 to 2 percent energy loss as compared with a 15 to 20 percent loss for the old magnetic ballasts. Often an existing fixture burning 4-40 Watt T-12 tubes with magnetic ballasts can be retrofitted to 2 T-8 tubes, electronic ballast and a reflector in the top of the fixture. The reflector makes sure that all the light produced by the tubes leaves the fixture in the proper direction.

Economic Impact Analysis

Based upon the estimated implementation costs and the energy saving associated with the investment in new technologically efficient fluorescent lighting equipment, an econometric analysis of the macroeconomic effects on the state of Tennessee of the proposed investments was carried out using the REMI model for Tennessee. It was assumed, as in the case of chiller retrofits, that the initial investments would be carried out over a two year period, in this case, beginning in 1998. The sectors affected by this proposal include: (1) Schools K-12, (2) Medical Care Facilities, (3) Commercial Office Space, (4) Retail Office Space, (5) State Government, and (6) Manufacturing. This particular strategy appears to also have very promising results. As can be seen in **Table 3.3.2.B**, the overall positive impact can be illustrated in several ways.

Table 3.3.2.B Economic Impact of Retrofitting Existing Fluorescent Lamps

Variable	Employment (thous)	GRP (Bil 92$)	Real Disp Pers Inc (Bil 92$)	Output (Bil 92$)	PCE-Price Index 92$ (%)
1998	1.324	0.0523	0.0773	0.0976	-0.047%
1999	1.539	0.0631	0.0820	0.1136	-0.049%
2000	1.742	0.0740	0.0871	0.1306	-0.046%
2001	1.895	0.0827	0.0911	0.1435	-0.044%
2002	2.004	0.0893	0.0944	0.1530	-0.042%
2003	2.080	0.0943	0.0970	0.1596	-0.040%
2004	2.132	0.0984	0.0991	0.1645	-0.039%
2005	2.168	0.1014	0.1009	0.1681	-0.037%
2006	2.187	0.1039	0.1021	0.1712	-0.036%
2007	2.203	0.1060	0.1029	0.1737	-0.035%
2008	2.209	0.1075	0.1033	0.1753	-0.034%
2009	2.209	0.1086	0.1037	0.1766	-0.033%
2010	2.206	0.1094	0.1040	0.1774	-0.032%
2011	2.199	0.1101	0.1041	0.1781	-0.031%
2012	2.185	0.1104	0.1039	0.1782	-0.030%
2013	2.167	0.1103	0.1034	0.1779	-0.029%
2014	2.148	0.1102	0.1030	0.1776	-0.029%
2015	2.125	0.1098	0.1024	0.1769	-0.028%
2016	2.102	0.1094	0.1018	0.1763	-0.028%
2017	2.078	0.1089	0.1012	0.1756	-0.027%
Average	2.045	0.0980	0.0982	0.1623	-0.036%

First, over the period 1998 through 2017 an average of 2,045 new jobs per year, or a total of 40,900 new jobs, will be created in Tennessee as a result of this particular energy strategy. In addition, Tennessee Gross State Product is predicted to rise on average by $98 million per year. At the same time, the state's Personal Consumption Expenditure Index is predicted to fall slightly by an average of 0.036 percent per year. These positive employment and income effects reflect both the direct and indirect impact of producing and installing these more efficient lighting fixtures across the state. The direct impacts are derived from the production and installation of these new fixtures. The indirect impacts are derived largely from the lower energy bill that results from the installation of these new fixtures and the induced spending brought about by the increased investment in the state. This increased investment generates new jobs and increased incomes that in turn leads to higher levels of spending. As with any type of technological improvement not only do we see increases in output but also lower prices. These lower price levels make Tennessee more competitive relative to other regions drawing more businesses into Tennessee and with it more jobs and higher incomes. Thus, it appears that the overall economic impact on the state of this proposed policy is positive and would be highly beneficial for Tennessee. For a more detailed breakdown of the impact of this proposal, by sector, please refer to the appendix at the end of this document.

3.3.3 Exit Sign Retrofit

Exit signs are a common facet of everyday life, required by law for the safety of those who live and work in almost any type of building. Most exit signs currently in service are inefficiently lit with incandescent lamps. New technologies are now available in the marketplace that can significantly reduce the operating and maintenance costs of exit signs.

In an effort to quantify the savings potential associated with exit sign retrofit projects, a large number of exit signs currently in use in a variety of retail and commercial buildings were studied. From the results of this investigation it has been assumed that a typical exit sign uses 2-20 watt incandescent bulbs. The most energy efficient exit signs available today employ several LED (light-emitting diode) strips and consume 2 watts of electrical energy per exit sign. Thus, the new signs will reduce the electrical energy consumption from 40 watts to 2 watts per sign. This represents a 95 percent reduction. The existing exit signs can be retrofitted with the LED strips, making fixture replacement unnecessary. The cost of the retrofit per sign is typically about $50, including labor. The LED lighting strips have a 10-year rated life versus 3,000 hours for the incandescent lamps. Thus, there is a decrease in the costs associated with bulb replacement.

Since there is not an accurate count of the number of exit signs currently in service in Tennessee, it has been necessary to estimate the exit sign population for the state. This has been accomplished by surveying a number of different types of buildings to determine an average number of square feet of building space per exit sign. The building survey has determined that there is approximately one exit sign for every 3,500 square feet of floor space. The building types included in the calculations are colleges and universities, public schools (K-12), retail stores, commercial offices, state owned and operated space, medical facilities, and manufacturing plants. It has been assumed that electricity costs an average of $0.065 per kWh and that exit signs burn continuously throughout the year. If it is assumed that all of the exit signs in Tennessee are retrofitted with LED strips, the annual savings is almost 200,000 tons CO_2 annually, translating to a $12,042,000 reduction in electric bills. This measure is documented in **Table 3.3.3.A**.

Table 3.3.3.A: Exit Signs

Sq ft	1,948,010,170
Sq ft/sign	3,500
Number of signs	556,574
Original sign wattage	40
New sign wattage	2
Hours of use per year	8,760
Watts saved per sign	38
Annual kWh savings (total)	185,272,464
Annual CO_2 savings (tons)	199,153
Cost of new signs @	$27,828,717
Annual cost savings *	$12,042,710
Simple payback (years) +	2.3
Bulbs:	
Bulbs per incandescent sign	2
Bulb life (hours)	3,000
Bulbs used per year	3,250,394
Cost of each bulb	$4.86
Savings on replacements *	$15,796,915
Simple payback (years) #	1.0
Total annual cost savings	$27,839,626

* indicates enduring savings/costs
@ indicates one time savings/costs
+ indicates excluding maintenance costs
# indicates including maintenance costs

Additionally, the Environmental Protection Agency (EPA) states that an LED exit sign can last as long as 10 years with no need for maintenance. An incandescent exit sign, whose bulbs are rated for 3000 hours of operation, need approximately six replacement bulbs each year. When the cost of materials and labor for relamping are taken into consideration, an additional $15,800,000 is saved annually. The overall total cost savings for retrofitting all the exit signs in Tennessee is almost $27,840,000 annually.

3.3.4 Promote Efficient Refrigeration Systems for Supermarkets

Commercial food refrigeration systems move heat from one place to another. Energy conservation opportunities exist and include measures to improve the efficiency of these systems. Plastic strips on supermarket refrigerated display cases reduce energy use 15 to 45 percent. Glass doors reduce energy consumption 30 to 60 percent. Improvements to the refrigeration system offer large energy savings potential. The use of multiple compressors in parallel reduce energy use 13 to 27 percent. Tuning the compressor pressure to ambient conditions (instead of the hottest day) lowers energy demand by over 20 percent. Variable speed drives for the compressors also save considerable amounts of energy. Heat recovery devices which recover waste heat from the refrigeration system for use as space heat or for heating water also improve efficiency. One side-by-side test of conventional and advanced commercial refrigeration systems revealed a 23 percent energy savings for the advanced system. Assuming that the supermarket refrigeration retrofit program begins in 2002, the 2017 annual CO_2 emissions reduction would be 138,000 tons. The value of the annual electrical savings in 2017 is projected to be $6.4 million and the total cumulative project cost is about $19.4 million between 2002 and 2017.

3.4 UTILITY SECTOR POLICIES

In Tennessee and the wider Tennessee Valley region, if one speaks of policies that will affect levels of CO_2 emissions generated by electric power utilities, then one must understand the policies of the Tennessee Valley Authority [TVA]. While the TVA's service population and area are primarily located in the state of Tennessee, the entire population and area encompass 7.7 million people [1994] who live in 201 county jurisdictions of seven states (TVA, 1995:s.7).

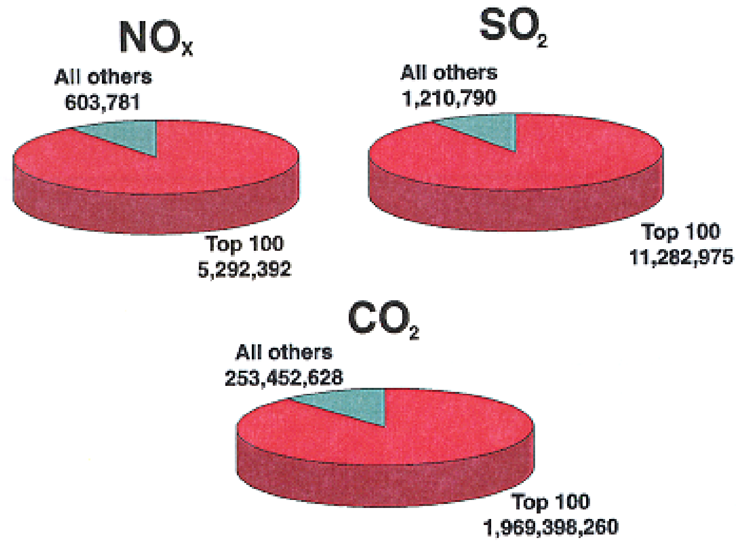
TVA has 33 operating coal-fired units that are located at 7 plant sites in Tennessee. The oldest such unit began operations in 1951, while the latest unit to come on line commenced electric generation in 1973. The combined capacity of the coal-fired units is 14,743 megawatts, or 57 percent of TVA's total capacity. By comparison, TVA's hydroelectric power and nuclear power units generate 4,044 megawatts and 3,282 megawatts, respectively. TVA foresees no technical problems that would preclude the continued operation of these units through the year 2020 (TVA, 1995:4.2-4.4).

TVA's existing coal-fired plants are responsible for the largest portion of the smog-producing and greenhouse gas emissions of sulfur dioxide, nitrogen dioxides, nitrogen oxides, particulate matter, and CO_2 , among others. In the TVA source region, power generation activities by TVA in 1990 accounted for 73 percent of sulfur dioxide, 33 percent of nitrogen oxide emissions, and considerably smaller percentages of volatile organic compounds and suspended particulate matter (TVA, 1995: 3.12). TVA's contribution to these emissions was undoubtedly higher in past years, since TVA's sulfur dioxide emissions are now 60 percent lower than they were 20 years ago. If one considers the greater source area of sulfur dioxide emissions that reach the Tennessee Valley region from outside the region proper, then TVA's portion falls to 25 percent of the total. In the case of CO_2 , TVA accounted for almost 40 percent of total CO_2 emissions in the state of Tennessee—exclusive of the wider Tennessee Valley region—in 1990 (Cunningham and Anderson, 1995:11).

TVA and Other Electric Utilities: The Relative Scale of Electric Generation and Emission Levels

In the U.S. as a whole, air emissions from producers of electric power are major contributors to a variety of environmental problems. Developing public policies to address these emissions and their related problems is aided by information on emission levels and relative performance, in terms of emission rates, of various producers of electricity. Ranked by electric generation levels, the 100 largest electric utilities in the U.S. account for fully 90 percent of the nationwide utility emissions of NO_x, SO_2, and CO_2 (NRDC et al, 1998). The biggest twenty companies are responsible for upwards of 50 percent of the above mentioned emissions. Of the more than 2.22 billon tons of CO_2 emissions generated by electric utilities, 1.97 billion originate among the top 100 companies. [See **Figure 3.4.A]**

Figure 3.4.A Emission Levels for Top 100 Electric Utilities, 1996



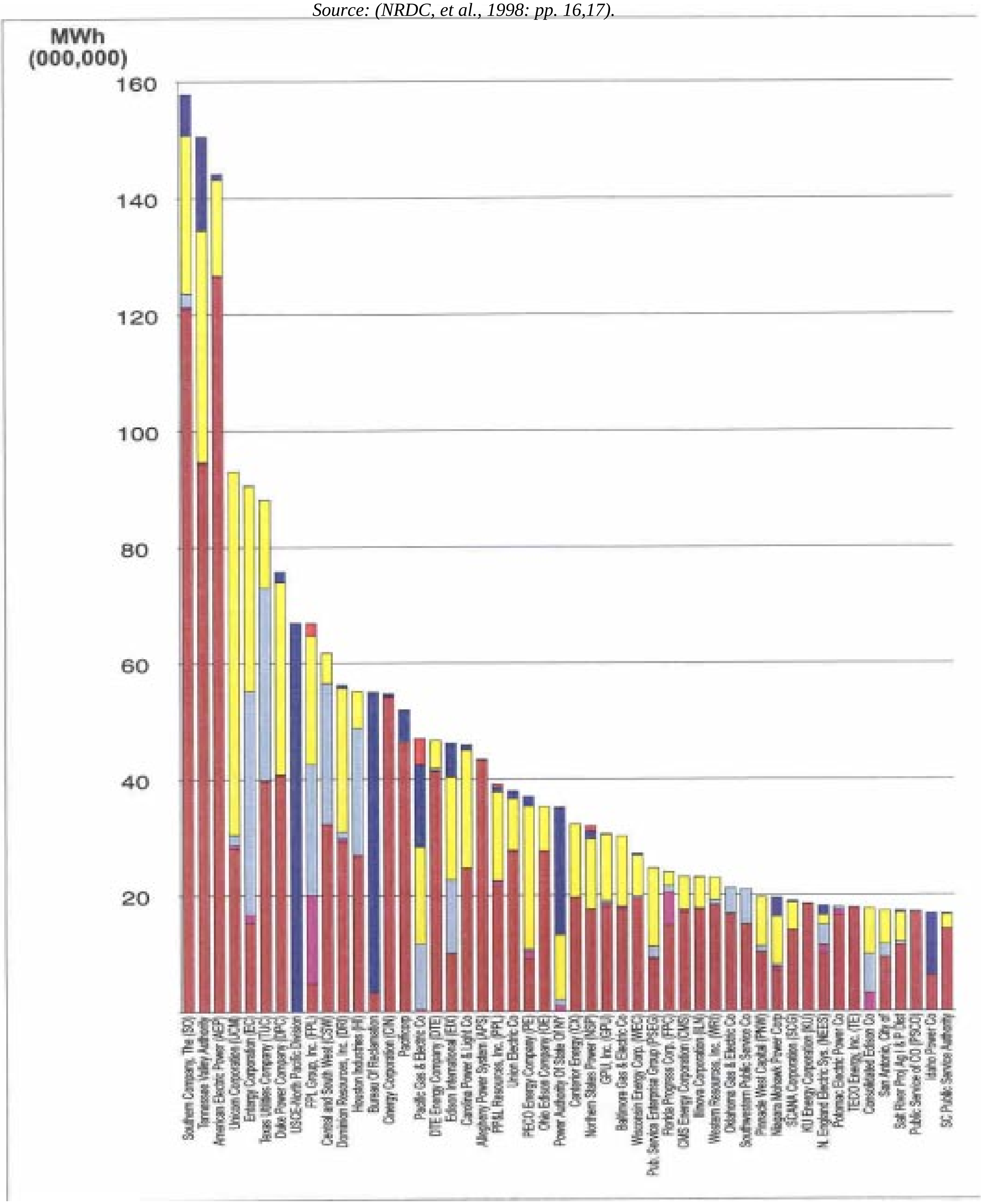
Source: (NRDC, et al., 1998: p. 13).

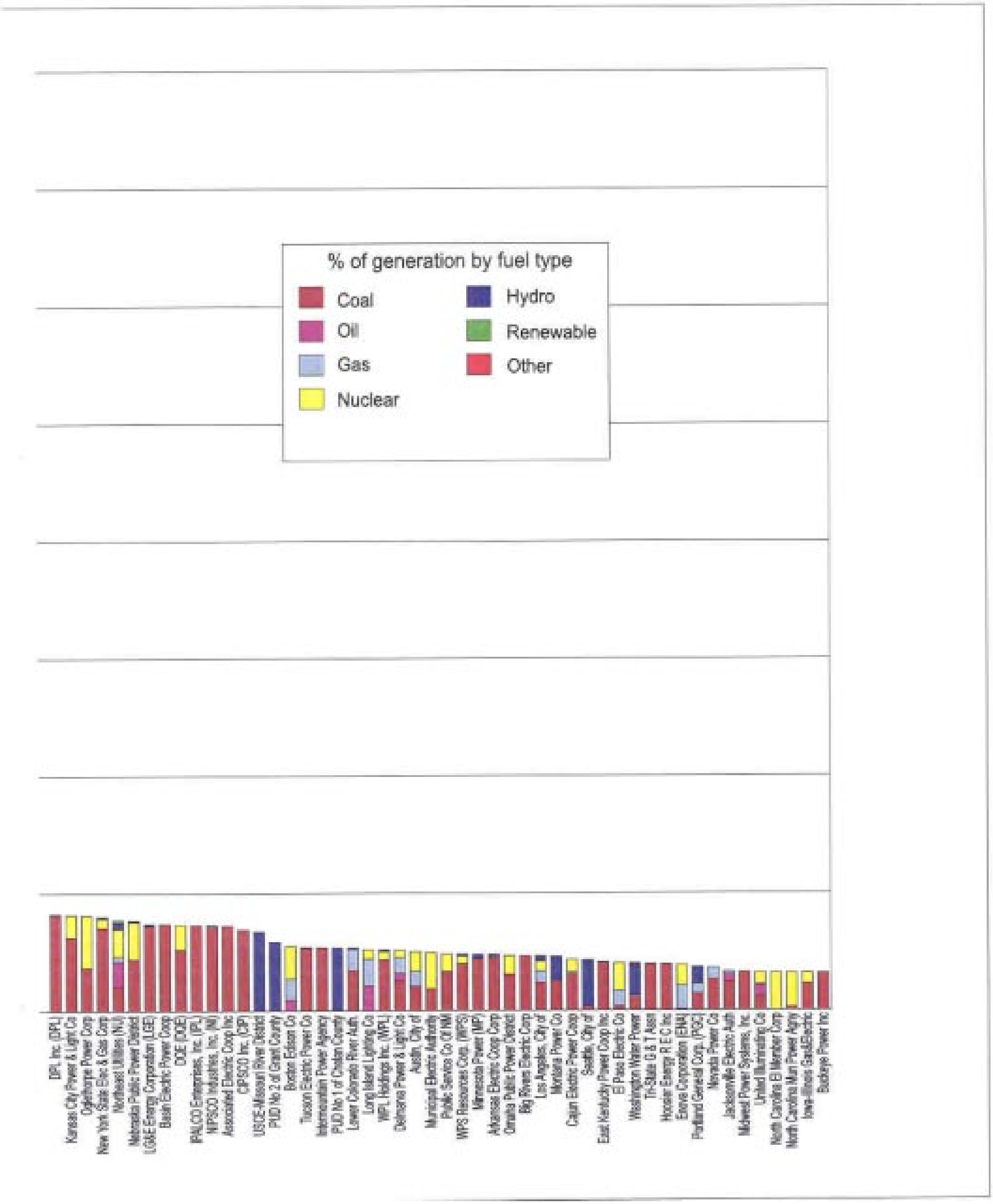
For the year 1996, **Figure 3.4.B** reports the level of megawatt-hours (MWh) of electricity production among the 100 largest producers according to the mix of fuel used (i.e., coal, oil, gas, nuclear, hydro, etc.). TVA was the second largest generator with approximately 150 million MWh of electricity. Coal and nuclear energy provided the lions share of fuel sources for its production. With the exception of a handful of utilities in the Pacific Northwest which relied almost exclusively on hydro power, the remaining U.S. utilities also employed coal as their principal fuel source. In terms of absolute levels of emissions of NO_x, SO_2, and CO_2 relative to the other 100 big utilities, TVA's position was essentially proportionate to its ranking in the electric production scale of the previous figure. TVA ranked second as the largest emitter of NO_x and third largest for SO_2 and CO_2.

When one considers rates of emissions—as measured in terms of pounds of emissions per MWh—TVA's ranking improved moderately in the cases of NO_x and SO_2 and more notably in the instance of CO_2. **Figures 3.4.C, 3.4.D and 3.4.E** report, respectively, the emission rates of NO_x, SO_2 and CO_2. While TVA was second or third in terms of overall emission levels, the utility now fell to 10th place for NO_x and 23rd place for SO_2 in the ranking of emission rates. In terms of CO_2 emission rates, TVA's performance was markedly better, as it ranked 59th among the 100 utilities. In the cases of SO_2 and NO_x, the utilities that demonstrated the worst performance regarding emission rates—those that were ranked highest—were those that appeared to rely almost exclusively on coal as a fuel source.

Figure 3.4.B Megawatt-Hours Produced by 100 Largest Utilities According to Fuel Source, 1996

Source: (NRDC, et al., 1998: pp. 16,17).

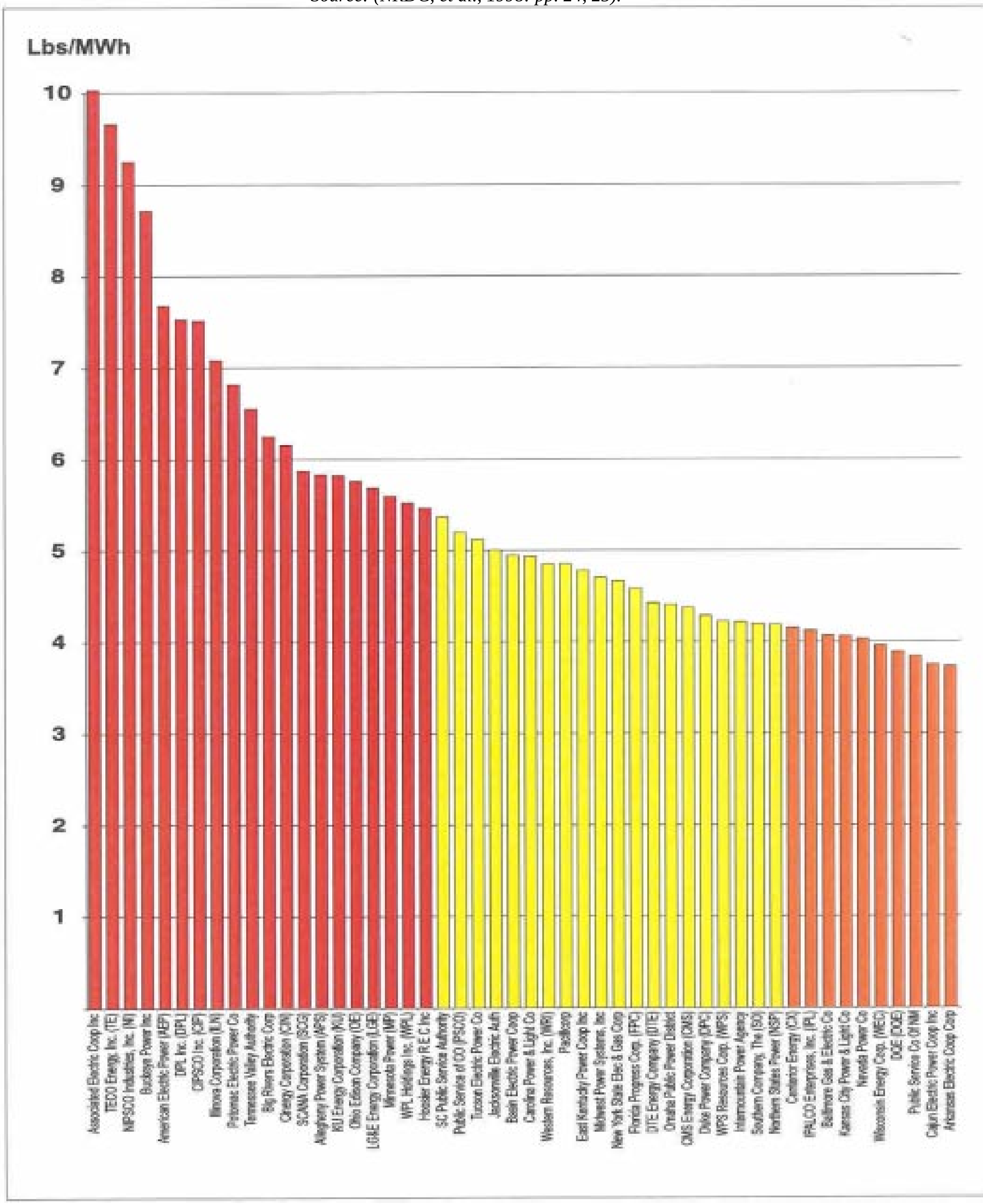




% of generation by fuel type
Coal
Oil
Gas
Nuclear
Hydro
Renewable
Other
DPL Inc (DPL)
Kansas City Power & Light Co
Oglethorpe Power Corp
New York State Elec & Gas Corp
Northeast Utilities (NU)
Nebraska Public Power District
LG&E Energy Corporation (LEE)
Basin Electric Power Coop
DOE (DOE)
IPALCO Enterprises, Inc. (IPL)
NIPSCO Industries, Inc. (NI)
Associated Electric Coop Inc
CIPSCO Inc. (CIP)
USCE-Missouri River District
PUD No 2 of Grant County
Boston Edison Co
Tucson Electric Power Co
Intermountain Power Agency
PUD No 1 of Chelan County
Lower Colorado River Auth
Long Island Lighting Co
WPL Holdings Inc. (WPL)
Delmarva Power & Light Co
Austin, City of
Municipal Electric Authority
Public Service Co Of NM
WPS Resources Corp. (WPS)
Minnesota Power (MP)
Arkansas Electric Coop Corp
Omaha Public Power District
Big Rivers Electric Corp
Los Angeles, City of
Montana Power Co
Cajun Electric Power Coop
Seattle, City of
East Kentucky Power Coop Inc
El Paso Electric Co
Washington Water Power
Tri-State G & T Assn
Hoosier Energy R E C Inc
Enova Corporation (ENA)
Portland General Corp. (PGC)
Nevada Power Co
Jacksonville Electric Auth
Midwest Power Systems, Inc.
United Illuminating Co
North Carolina El Member Corp
North Carolina Mun Power Agny
Iowa-Illinois Gas&Electric
Buckeye Power Inc

Figure 3.4.C Utility Emission Rates: Pounds of NO_x per MWH, 1996

Source: (NRDC, et al., 1998: pp. 24, 25).



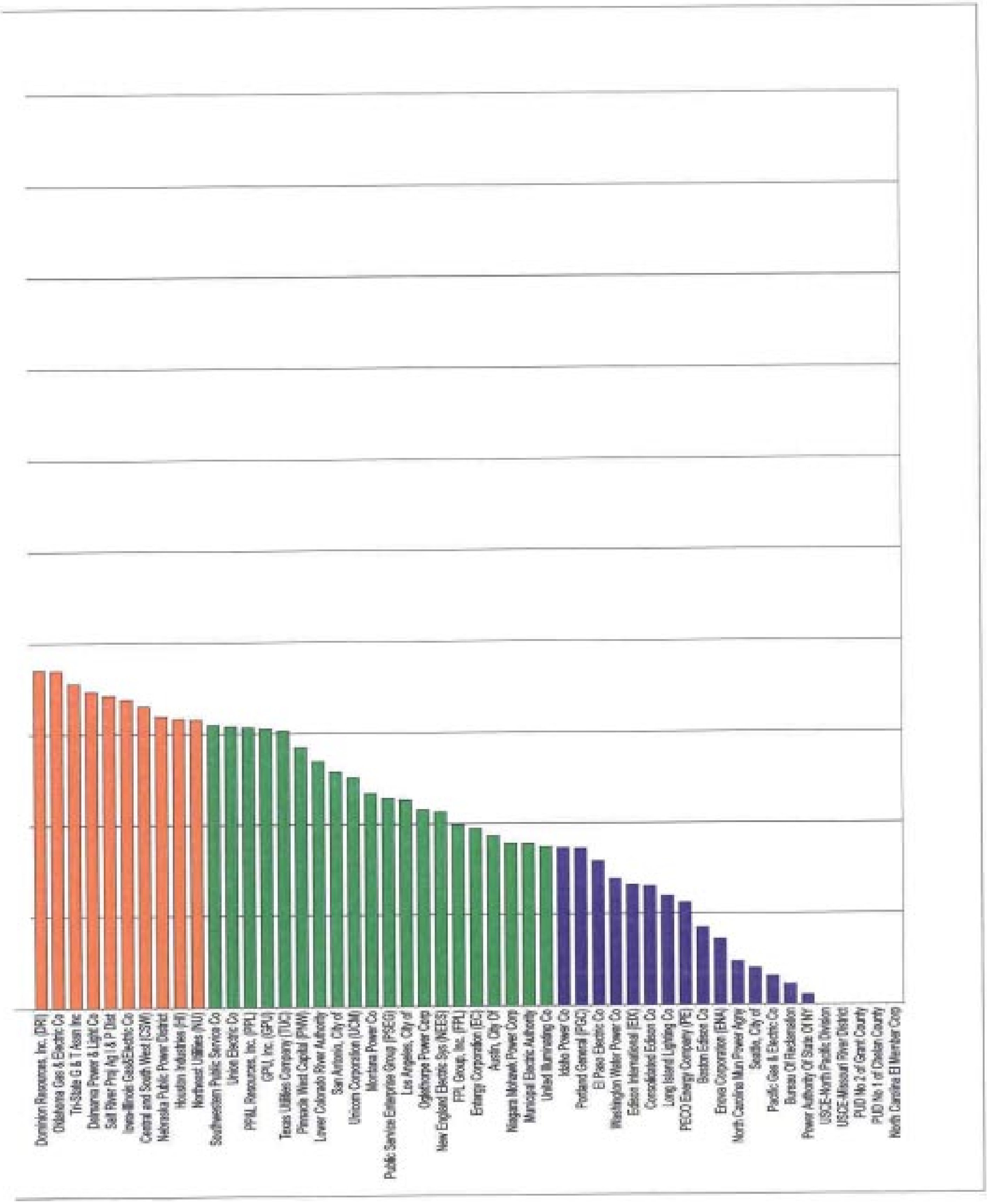
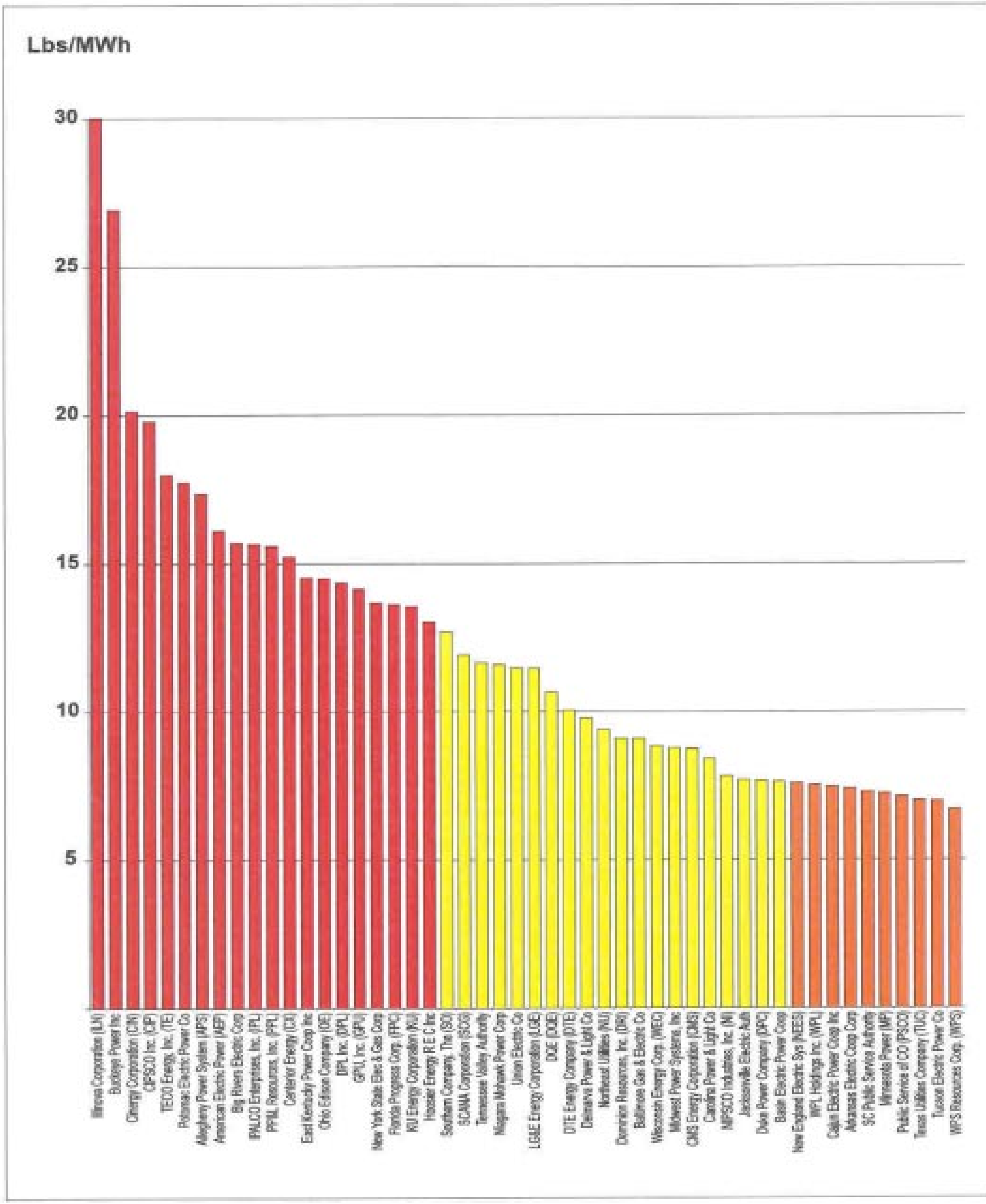
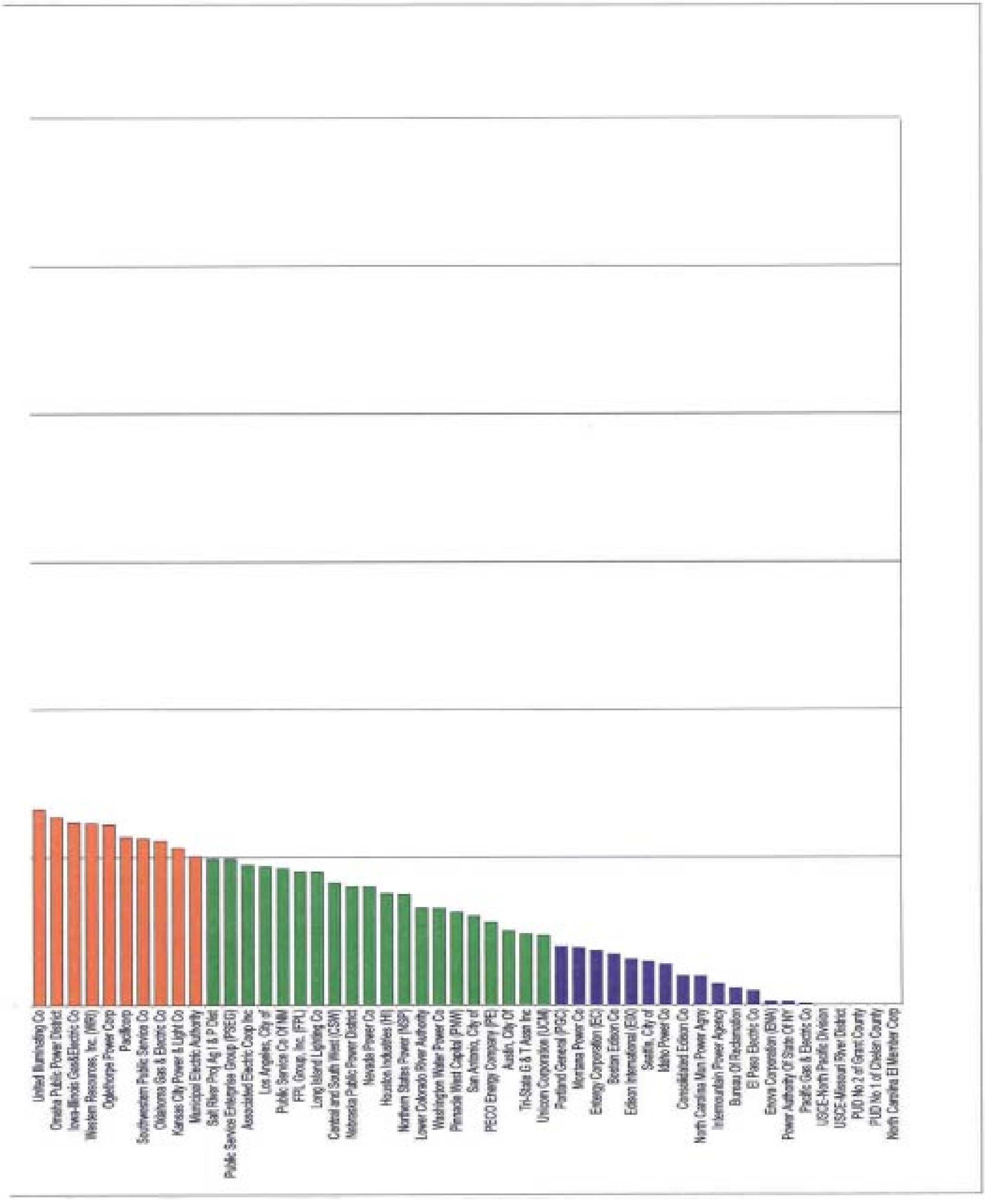

Dominion Resources, Inc. (DR)
Oklahoma Gas & Electric Co
Tri-State G & T Assn Inc
Delmarva Power & Light Co
Salt River Proj Ag I & P Dist
Central and South West (CSW)
Nebraska Public Power District
Houston Industries (HI)
Northeast Utilities (NU)
Southwestern Public Service Co
Union Electric Co
PP&L Resources, Inc. (PPL)
GPU, Inc. (GPU)
Texas Utilities Company (TUC)
Pinnacle West Capital (PNW)
Lower Colorado River Authority
San Antonio, City of
Unicom Corporation (UCM)
Montana Power Co
Public Service Enterprise Group (PSEG)
Los Angeles, City of
Oglethorpe Power Corp
New England Electric Sys (NEES)
FPL Group, Inc. (FPL)
Entergy Corporation (EC)
Austin, City Of
Niagara Mohawk Power Corp
Municipal Electric Authority
United Illuminating Co
Idaho Power Co
Portland General (PGC)
El Paso Electric Co
Washington Water Power Co
Edison International (EIX)
Consolidated Edison Co
Long Island Lighting Co
PECO Energy Company (PE)
Boston Edison Co
Enova Corporation (ENA)
North Carolina Mun Power Agny
Seattle, City of
Pacific Gas & Electric Co
Bureau Of Reclamation
Power Authority Of State Of NY
USCE-North Pacific Division
USCE-Missouri River District
PUD No 2 of Grant County
PUD No 1 of Chelan County
North Carolina El Member Corp

Figure 3.4.D Utility Emission Rates: Pounds of SO_2 per MWH, 1996

Source: (NRDC, et al., 1998: pp. 26,27).

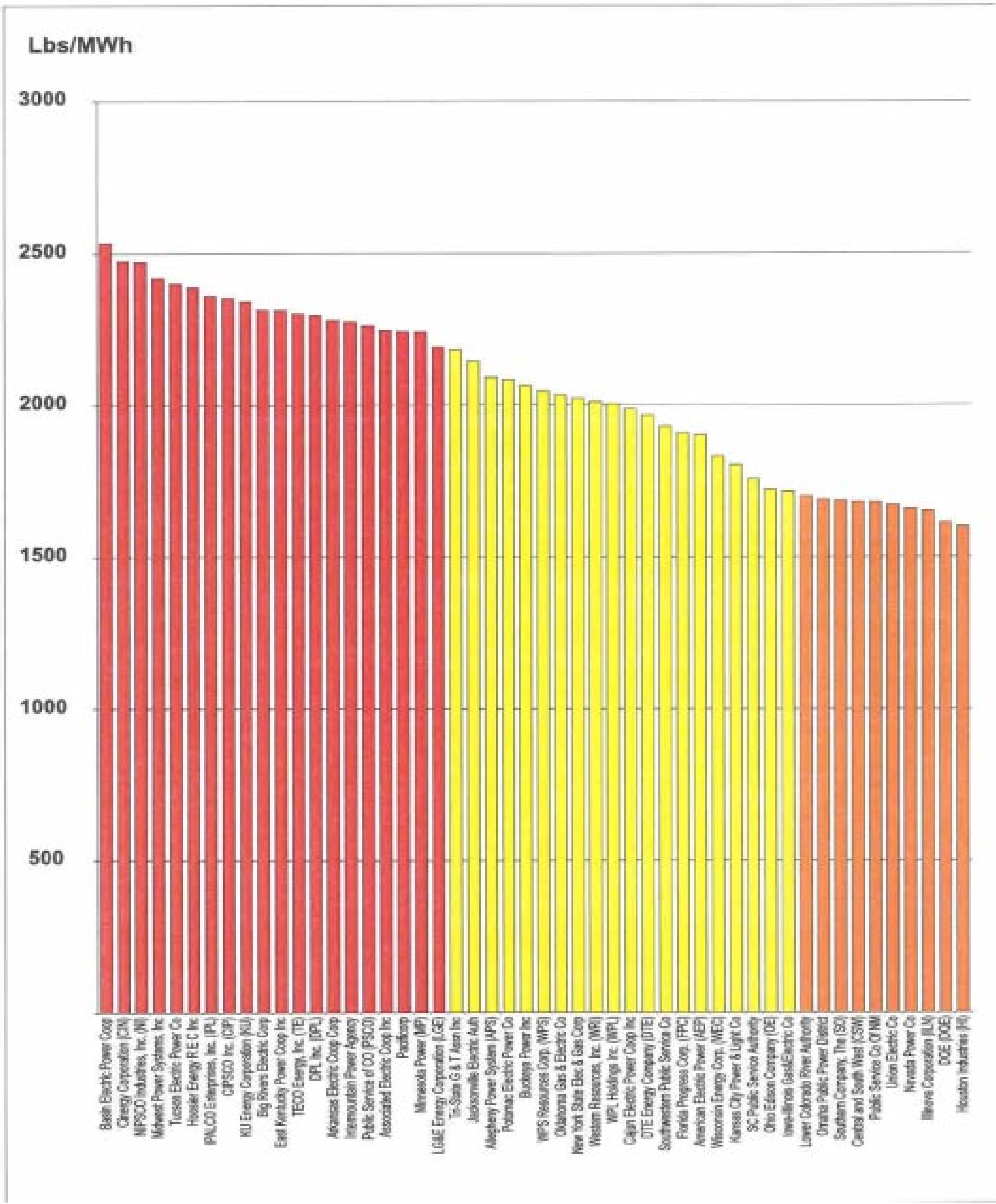




United Illuminating Co
Omaha Public Power District
Iowa-Illinois Gas&Electric Co
Western Resources, Inc. (WR)
Oglethorpe Power Corp
PacifiCorp
Southwestern Public Service Co
Oklahoma Gas & Electric Co
Kansas City Power & Light Co
Municipal Electric Authority
Salt River Proj Ag I & P Dist
Public Service Enterprise Group (PSEG)
Associated Electric Coop Inc
Los Angeles, City of
Public Service Co Of NM
FPL Group, Inc. (FPL)
Long Island Lighting Co
Central and South West (CSW)
Nebraska Public Power District
Nevada Power Co
Houston Industries (HI)
Northern States Power (NSP)
Lower Colorado River Authority
Washington Water Power Co
Pinnacle West Capital (PNW)
San Antonio, City of
PECO Energy Company (PE)
Austin, City Of
Tri-State G & T Assn Inc
Unicom Corporation (UCM)
Portland General (PGC)
Montana Power Co
Entergy Corporation (EC)
Boston Edison Co
Edison International (EIX)
Seattle, City of
Idaho Power Co
Consolidated Edison Co
North Carolina Mun Power Agny
Intermountain Power Agency
Bureau Of Reclamation
El Paso Electric Co
Enova Corporation (ENA)
Power Authority Of State Of NY
Pacific Gas & Electric Co
USCE-North Pacific Division
USCE-Missouri River District
PUD No 2 of Grant County
PUD No 1 of Chelan County
North Carolina El Member Corp

Figure 3.4.E Utility Emission Rates: Pounds of CO_2 per MWH, 1996

Source: (NRDC, et al., 1998: pp. 28, 29).



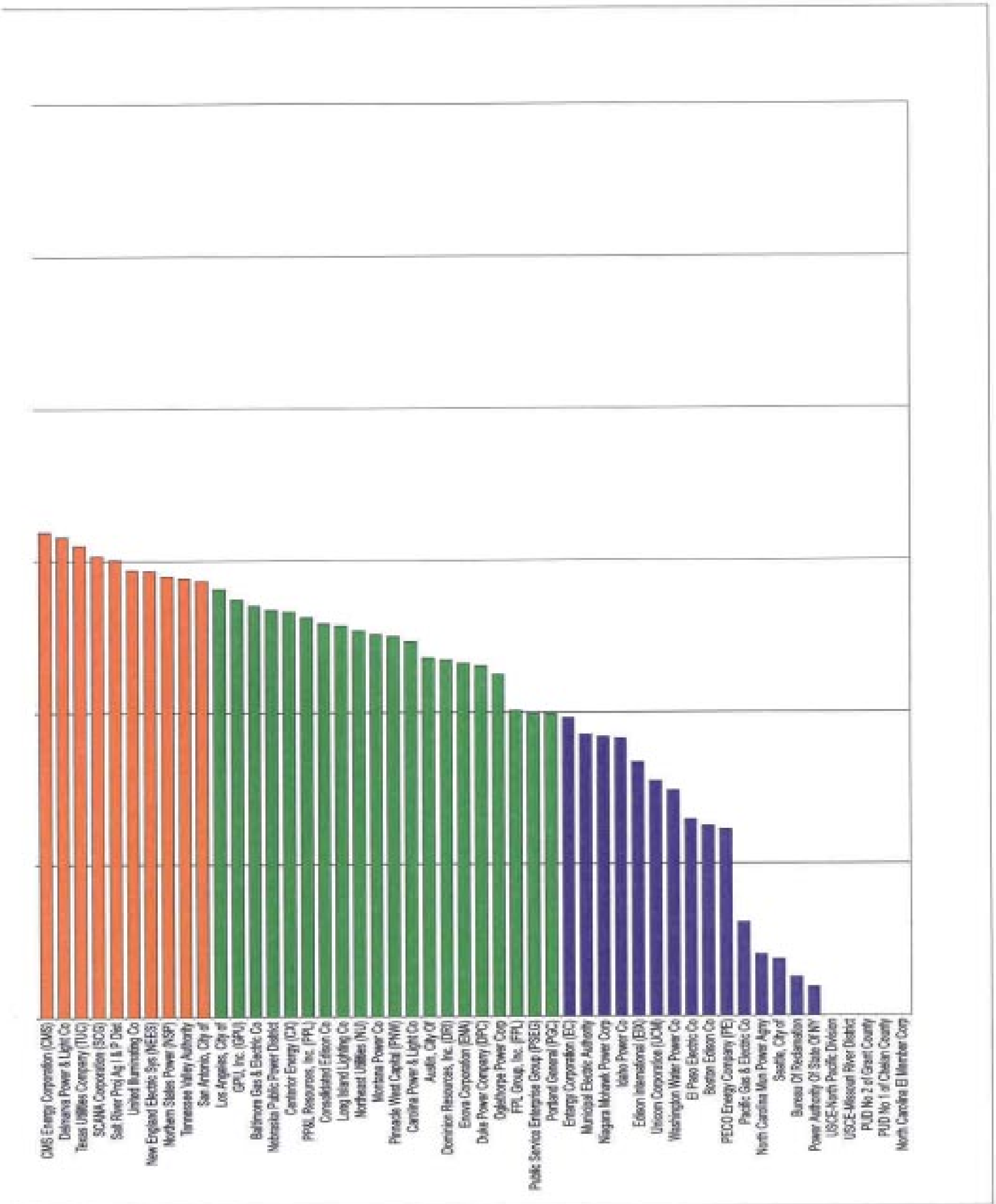
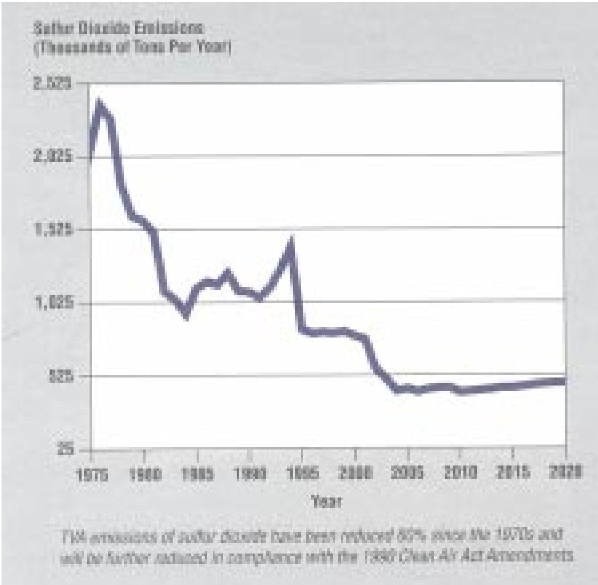
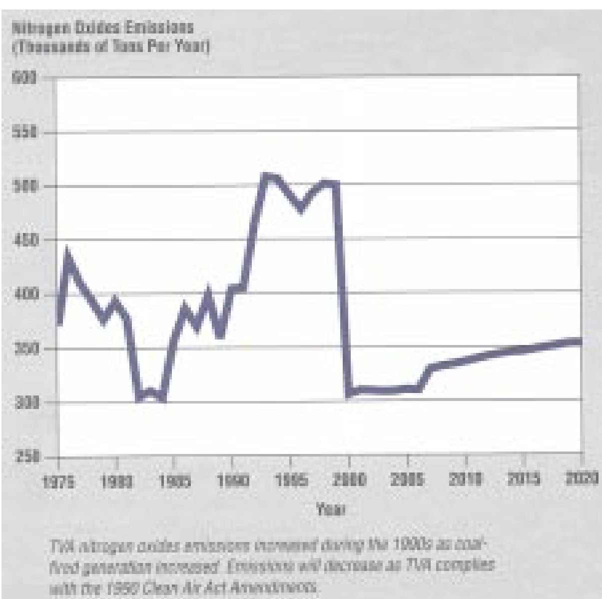

CMS Energy Corporation (CMS)
Delmarva Power & Light Co
Texas Utilities Company (TUC)
SCANA Corporation (SCG)
Salt River Proj Ag I & P Dist
United Illuminating Co
New England Electric Sys (NEES)
Northern States Power (NSP)
Tennessee Valley Authority
San Antonio, City of
Los Angeles, City of
GPU, Inc. (GPU)
Baltimore Gas & Electric Co
Nebraska Public Power District
Centerior Energy (CX)
PP&L Resources, Inc. (PPL)
Consolidated Edison Co
Long Island Lighting Co
Northeast Utilities (NU)
Montana Power Co
Pinnacle West Capital (PNW)
Carolina Power & Light Co
Austin, City Of
Dominion Resources, Inc. (DRI)
Enova Corporation (ENA)
Duke Power Company (DPC)
Oglethorpe Power Corp
FPL Group, Inc. (FPL)
Public Service Enterprise Group (PSEG)
Portland General (PGC)
Entergy Corporation (EC)
Municipal Electric Authority
Niagara Mohawk Power Corp
Idaho Power Co
Edison International (EIX)
Unicom Corporation (UCM)
Washington Water Power Co
El Paso Electric Co
Boston Edison Co
PECO Energy Company (PE)
Pacific Gas & Electric Co
North Carolina Mun Power Agny
Seattle, City of
Bureau Of Reclamation
Power Authority Of State Of NY
USCE-North Pacific Division
USCE-Missouri River District
PUD No 2 of Grant County
PUD No 1 of Chelan County
North Carolina El Member Corp

Figure 3.4.F Historic and Projected TVA Emissions of Sulfur Dioxide



Source: (TVA, 1995: 3.13).

Figure 3.4.G Historic and Projected TVA Emissions of Nitorgen Oxides



Source: (TVA, 1995: 3.13).

Environmental Impacts

At the level of the state and region, the adverse environmental impacts of sulfur dioxide, nitrogen oxides and VOCs—and indirectly ozone—are indicated largely through decreased visibility, the aggravation of respiratory problems and rising levels of acid deposition (acid rain) in soils and the related degradation of forests, in particular. In an especially ironic twist, one of the most protected habitats in the Tennessee Valley—the Great Smoky Mountains National Park—has apparently suffered egregious damage from what is recognized by some in the scientific community to be increasing acidification of the cloud water and the soils due to the burning of fossil fuels, particularly coal. The near total destruction of spruce and, especially, fir forests in the Park and surrounding high elevation areas is thought to be largely due to acid rain (Nolt, 1997:9-11; Eaher and Adams, 1992) (Note 8). In the case of CO_2 and other greenhouse gases, the environmental impact of increasing concentrations may be evidenced in regional and global climate change—notably the warming of the earth's surface temperatures and which is apt to be accompanied by uncertain consequences.

Following the passage of the Clean Air Act Amendments of 1990, new controls were imposed on the utility industry in the U.S. which required significant reductions of sulfur dioxide and nitrogen oxide emissions. In order to comply with this legislation, TVA's projected emission reductions of these gases would resemble the trends reported in **Figures 3.4.F** and **3.4.G** (TVA, 1995: 3.13).

Climate Challenge Participation

TVA, along with other utilities representing about 70 percent of the nation's electricity generation, is a participant in the Climate Challenge Program. The Climate Challenge is a voluntary partnership between the electric utility industry and the Department of Energy to reduce, avoid or sequester greenhouse gas emissions. TVA has committed to reduce GHG emissions by 24.9 million tons in the year 2000 relative to the emissions that would otherwise occur in 2000 had TVA not implemented a series of actions. These actions aare identified in the TVA Climate Challenge Participation Accord.

Energy Vision 2020

Environmental concerns have also been addressed as part of a long-run project described in a study entitled **Energy Vision 2020**, henceforth EV2020 (TVA, 1995). In EV2020, TVA has developed a detailed plan for meeting future power demand that establishes four broad policy goals that require the utility to be: [1] customer-driven, [2] environmentally responsible, [3] growth-oriented, and [4] employee sensitive (TVA, 1995:1.5). Under this scenario, reconciling the "environmentally responsible" objective with the "growth-oriented" goal will not be easy. Indeed, TVA has determined that to meet its medium load forecast in the year 2020, the utility will need 16,500 megawatts of additional generating capacity; a level that would represent a 64 percent increase over its total capacity of 25,600 megawatts in 1995 (TVA, 1995: s.3, s.4).

In order to assess attainment of the policy goals, evaluation criteria -- involving rate structures, supply reliability, economic development, financing, risk management, equity, and the environment -- were established (TVA, 1995: 5,1-5.7). Of the 42 criteria proposed, 30 were related to environmental objectives (TVA, 1995: 9.4). TVA subsequently identified over 2,000 specific strategies relating to supply-side [electrical production technologies] and demand-side [consumer service] policies that were considered relevant to criteria and goal attainment. Following extensive study from this broad range of options and option mixes, TVA identified seven strategies incorporating a mix of the supply- and demand-side policies that promised lower cost, lower debt, improved environmental conditions and greater economic development (TVA, 1995: s.4). A summary presentation of the supply- and demand-side options and the seven preferred strategies is provided below. In terms of environmental outcomes and particularly that of CO_2 mitigation, the seven strategies identified all promised CO_2 emission levels that were below the base case, or reference, scenario.

EV2020: Supply-Side Options

The main, supply-side options considered in the EV2020 study were: existing conventional technologies (coal, natural gas, nuclear and hydro), the conversion of existing technologies, new technologies, renewable source technologies, variable forms of power purchase agreements from other (non-TVA) power producers and flexible supply-side options (TVA, 1995:7.3-7.9). Cost and environmental improvements could be expected by design alterations, or conversions, of existing technologies that would affect output productivity and gas emissions. The conversion of the Bellefonte Nuclear Plant to an integrated gasification combined cycle plant that would produce both power and chemicals in partnership with the private sector exemplified the alternative designs of traditional power technology that were considered (TVA, 1995:7.8).

New or currently commercially unavailable technologies were considered if their cost, performance, and availability were sufficiently developed to be credibly estimated. These technologies were not specifically identified. Renewable sources, such as wind turbines and solar photovoltaic cells, were characterized by small modular sizes, the possibility of widely dispersed use, and low gas emission rates. Due to climatic characteristics of the Tennessee Valley, however, the two mentioned renewable technologies were not apt to be extensively used in the region.

Variable forms of power purchase agreements such as call and put options or forward contracts were thought to hold considerable promise. In the case of options, these agreements would permit TVA to purchase power from other suppliers on the basis of premium payments that would secure the option to buy [call option] or to sell [put option] power at some future date. Forward contracts represent firm obligations on the part of TVA to buy power from a seller at a designated price and time. In all cases forward agreements would help to stabilize power delivery at peak and base-load levels. While cost savings might be expected from such agreements, the environmental improvements would likely be minimal.

Flexible supply-side options incorporated strategies that permitted alteration or modification of projects that would more nearly accommodate current needs. Each option had its own implementation sequence and time-line requirements. Overall project schedules could be shortened and made flexible, for instance, by identifying those options whose sequential requirements -- of siting and environmental impact studies -- could be carried out prior to the decision to make firm commitments to the project.

While TVA's primary environmental impact concern regarding the supply-side options was aimed at reducing levels of SO_2 in order to comply with the stricter regulations in the 1990 Clean Air Act amendments, potential reductions in levels of CO_2 were also sought. Significant CO_2 mitigation could be expected to follow from greater reliance on selected supply-side technological options that simultaneously reduced levels of SO_2 (TVA, 1995: 7.10). **Table 3.4.A** reports differences in cost and gas emissions from twelve technologies considered in the EV2020 study. The variation in CO_2 emissions ranges from a -798 pounds per million Btu's in the case of power generated by landfill methane up to 210 pounds per million Btu's for pulverized coal plants. Interestingly, for the two mentioned technologies, the base capital and operating and maintenance costs are estimated to be considerably lower in the case of landfill methane, which was projected to result in declines in absolute levels of CO_2 levels.

Table 3.4.A

Option Name	Base Capital ($/kW)	Fuel Cost ($/MMBtu)	Base Fixed Operating & Maintenance ($/kW-Yr)	Sulfur Dioxide (lb/MMBtu)	Nitrogen Oxides (lb/MMBtu)	Carbon Dioxide (lb/MMBtu)
Supercritical Pulverized Coal Plant (4x300 MW)	$1,345	$1.00	$20.0	0.3	0.1	210
Simple Cycle Combustion Turbine (1x150 MW)	$360	$2.48	$2.0	0	0.08	115
Natural Gas-Fired Combined Cycle (1x470 MW)	$655	$2.48	$4.7	0	0.08	115
Compressed Air Energy Storage with Humidification (3x337 MW)	$315	$2.48	$2.2	0	0.03	115
Integrated Gasification Combined Cycle (IGCC) (3x245 MW)	$1,524	$1.00	$20.8	0.05	0.035	205
Integrated Gasification Cascaded Humidified Advanced Turbine (G Series CT) (2x420 MW)	$1,126	$2.48	$18.6	0.05	0.01	205
Landfill Methane (1x2 MW)	$1,034	$1.29	$9.8	0	0.16	-798
Hydro Generation: Modernization at Existing Projects	$52	NA	$6.9	0	0	0
Bellefonte (BLN) Repowering - IGCC with Coproduction with Partners (2x242 MW)	$465	$3.59	$4.7	0.03	0.08	131
Generic Natural Gas Combined Cycle Independent Power Producer (1x150 MW)	$0	$2.48	$86.7	0	0.08	115
Wind - 39 Meter Variable Speed Advanced Wind Turbine (444x0.45 MW)	$958	NA	$15.0	0	0	0
Power Purchase - Peaking	$0	NA	$33.6	0	0.1	115

Fuel cost data are in 1995 dollars. Other cost data are in 1994 dollars. *Source: (EV2020 Study TVA, 1995: 7.10).*

EV2020: Demand-Side Options

The primary, demand-side or "customer-service" options considered in the EV2020 study included: demand-side management, self-generation, beneficial electrification, and rate options (TVA, 1995: 8.2, 8.3). Demand-side management policies consisted primarily of measures that promoted home insulation and the use of more efficient appliances and that affected building construction design. Self-generation options were largely targeted toward large industrial and commercial users of electricity who would find it feasible to produce some portion of their electricity needs by employing their own power generating system. Beneficial electrification, like demand-side management, sought to induce shifts toward more efficient electrically-driven technologies used by household and industrial consumers. Instances of such shifts would be increased use of microwave heating, and electric buses and lawnmowers. Rate options included charges based on administrative costs (customer charges), the quantity of electricity used (demand charges), and the variable production costs of each unit of electricity (energy charges). Energy charges might be modified, in particular, to reflect the time-of-day of electricity use.

The range of options identified above were designed with the idea of encouraging customer acceptance, meeting economic objectives, and providing alternatives for all classes of customers. More specifically, the goals were to raise energy efficiency and customer value by overcoming perceived obstacles to customer adoption of the new technologies. The main obstacles to adoption were understood to relate to inadequate information and financial barriers. Programs that could be employed to overcome information problems included technical assistance to assist with adoption; auditing services to help customers determine the most cost-effective technologies; the distribution of mail-order catalogs that highlight energy efficient appliances; and site specific assistance to identify areas where energy savings could be attained by technology adoption. Overcoming financial barriers could be addressed by offering a range of rebates on energy efficient equipment; by not charging for the direct installation services for high efficiency equipment; and by special financing and leasing arrangements that promoted new technology adoption (TVA, 1995: 8.6,8.7).

Apart from seeking environmental benefits via reduced electricity use and emissions, a major goal of the customer-service options was to attain cost reductions by minimizing the variability over time in the demand or "load schedule" for electricity. By flattening out the distribution curve for electricity demand through load management, TVA would be able to utilize generating facilities that have lower operating and fuel costs.

A summary of the estimated impacts of the customer-service options are reported in **Table 3.4.B** (TVA, 1995: 8.3). The combination of energy efficiency and load management, self-generation, and time-of-day rate options is projected to reduce electrical usage by 6,705 megawatts, while beneficial electrification and declining block rates would likely increase electric use by 374 megawatts. The net result from the various options would be a decline in electrical demand by about 6,331 megawatts.

EV2020: The Preferred Strategies

In determining the preferred strategies, TVA employed a process of "multi-attribute tradeoff analysis" (TVA, 1995: 2.1-2.8; 9.1-9.6) that ranked the various strategies on the basis of their ability to attain simultaneously the preferred outcomes: lower cost, lower debt, improved environmental conditions, and greater economic development. **Table 3.4.C** lists 8 of the 21 strategy evaluations -- D, J, M, O, Q, R, S, T -- that TVA reported in detail. Varying combinations of the supply- and demand-side policies discussed earlier were captured by each of the listed options. With the exception of strategy D, the other seven strategies were those options that proved most promising in their capacity to limit the tradeoffs and, thereby, best realize the outcomes noted above (TVA, 1995: 9.21) (Note 10). Strategy D, which plotted a course involving none of the supply- or demand-side changes, served as the benchmark, or reference strategy, to which the others were contrasted.

Table 3.4.B

Resource Acquisition (Saving)	Options	Megawatts
Energy Efficiency & Load Management	39	5532
Self-Generation	8	281
Rates (Time-of-Day)	3	892
Load Growth (Sales)	**Options**	**Megawatts**
Beneficial Electrification	14	205
Rates(Declining Block)	3	169

Values are the impacts occurring only in the year 2010 for the cumulative participation in the program to that date. The customer service options identify a potential to save 6,705 megawatts of alternative capacity. Beneficial electrification and declining block rates would increase the required electricity production capacity by 374 megawatts.

Strategy D, the benchmark alternative, had supply-side plans that emphasized coal for meeting all base-load, or minimum, energy requirements. In addition, the supply-side options included combustion turbines along with combined cycle and cogeneration processes. Combined cycle units merge a simple cycle combustion turbine and a heat recovery steam generator which uses the exhaust heat from the combustion turbine to "cogenerate" steam which subsequently drives a steam turbine. Electricity is generated from a single fuel source by both the combustion turbine and

Table 3.4.C

		Customer Value Test Contribution Split ($mil.)	TRC ($mil.)	Short-Term Rates (mills/kWh)	Total Debt 2001 ($mil.)	CO_2 (kTons/yr.)	SO_2 (kTons/yr.)	Solids (kTons/yr.)	Annual Average Income ($mil.)
D	Reference (Combined Cycle, Purchased Power, Coal)	(1,076)	86,634	44	27,514	130,352	563,048	6,166,437	1,711
		Relative to Reference Case	Percent of Reference Case						
D	Reference (Combined Cycle, Purchased Power, Coal)	(1,076)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
J	Bellefonte Coproduct, Renewables, IPPs	**820**	**0.97**	**0.99**	**0.99**	**0.92**	**0.96**	**0.94**	**1.43**
M	Combined DSM and Off-System Sales	(397)	**0.99**	**0.99**	**0.98**	**0.91**	**0.91**	1.08	**1.31**
O	Bellefonte Coproduct, More DSM, More Off-System Sales	**872**	**0.97**	**0.99**	**0.99**	**0.90**	**0.92**	**0.94**	**1.52**
Q	Flexible Strategy with External Options	**3,450**	**0.98**	**0.98**	**0.97**	**0.93**	**0.90**	**0.97**	**1.61**
R	Flexible Strategy with Internal Options	**3,511**	**0.98**	**0.98**	**0.99**	**0.93**	**0.93**	**0.96**	**1.62**
S	Low Cost, Low Rates, Improved Environment	**2,829**	**0.98**	**0.98**	**0.99**	**0.93**	**0.93**	**0.96**	**1.54**
T	Low-Cost Renewables, Low-Price DSM, Repowering, BLN Coproduct Partnership	**542**	**0.99**	**0.99**	**0.99**	**0.88**	**0.92**	**0.85**	**1.40**

All seven strategies are evaluated for selected criteria and compared to the reference or no action alternative strategy (Strategy D). The customer value is measured in millions of dollars and the other criteria are compared to the reference strategy. The reference strategy is indexed as 1.0. Strategies whose criteria are in bold type are better than the reference strategy.

the steam turbine. Combustion turbines typically burn natural gas or fuel oil, not coal. Strategy D also included purchases of electricity from Independent Power Producers [IPPs] and clean coal technologies which centered on the use of low-sulfur coals at some plants. Demand-side plans for Strategy D employed load management and easy financing options, along with minimum rate increases. Load management of residential water heaters and air conditioning meant that attempts would be made to reduce consumer demand during peak demand periods or supply shortfall times by pricing policies which made power more expensive, or through the direct curtailment of power. Other demand-side policies included rebates and special financing terms for residential heat pumps, high-efficiency and industrial motors. Finally, efforts to conserve energy would be promoted by producing a residential energy efficiency catalog which served to educate the public on cost-effective conservation options.

Strategy J's supply-side plans featured an integrated coal gasification plant; a facility that would convert coal into a synthetic fuel gas before burning. The plant would also produce a high-value chemical co-product. In addition, Strategy J included utilizing methane gas from landfill and coalbed sources; clean [low sulfur] coal technologies; the modernization of hydro plants; IPP combined cycle plants; and combustion turbines. Demand-side alternatives for Strategy J incorporated the same elements as noted in Strategy D above. The environmental payoff from Strategy J would come from the addition of scrubbers at several coal-fired plants which would reduce levels of SO_2 emissions, low sulfur coals, and energy efficiency improvements which would lower levels of CO_2 emissions relative to the base case.

Strategy M's supply-side option mix emphasized the expansion of coal use and low-cost renewable fuel sources. Pulverized coal in conjunction with scrubbers and other clean coal technologies were highlighted. Landfill and coalbed generated methane gas would be used, along with hydro plant modernization. Combustion turbines also figured into the supply-side strategy. Demand-side plans centered on low-price and low-cost options that reduced the need for generation. Demand would be reduced through programs which promoted: residential self-auditing to promote energy-use awareness; low-income residential efficiency upgrades such as home weatherization; residential load-management for water heaters and air conditioning; residential solar water heaters; rebates and financing for residential heat pumps and appliances; small commercial retrofitting and appliance rebates for more energy efficient technologies; renewable energy sources for new commercial construction; and rebates for industrial processes switching to compressed air technology. Finally, "off-system sales" of electricity would be made to utilities outside the TVA-area network and would generate revenue.

Strategy O's supply-side option mix closely resembled that of Strategy J where the focus was on coal gasification and chemical co-products; landfill and coalbed methane; clean coal technology; hydro plant modernization; and combustion turbines. Demand-side features of Strategy O were identical to the low-price and low-cost options discussed above for Strategy M.

Strategy Q's supply-side options centered around "flexible" [non-obligatory] power purchase rights with other utilities. The purchase agreements were established to meet either peak or base capacity demand schedules. Also part of the supply-side plans were the use of combustion turbines, conversion to an integrated gasification combined cycle with a chemical coproduct, landfill and coalbed methane sources, clean coal technologies and hydro-electric plant modernization. "Off-system sales" of TVA produced electricity to other utilities was also planned. Demand-side features were similar to those of Strategy D which employed load management, easy financing options for energy efficient technologies for consumers and producers, and minimum rate increases.

Strategy R's supply-side options were identical to those of Strategy Q but included preplanning, design, and siting work that supported flexible starting dates for TVA-constructed operations. The flexible starting dates provided for lower implementation costs. The demand-side options were the same as those discussed above for Strategy Q.

Strategy S's supply-side options featured an integrated coal gasification plant that produced a chemical coproduct, combustion turbines, an IPP combined cycle and cleaner fuels associated with landfill and coalbed methane, clean coal technologies, and hydro-electric modernization. Off-system electricity sales—similar to those of Strategy Q—were also planned. Demand-side strategies were identical to the load management and easy financing of energy efficient technologies discussed in Strategy D.

Strategy T's supply-side options relied on low emission fuel sources, renewable fuel sources, and the integrated gasification plant that produced the high-value chemical coproduct. Low emission fuel sources included natural gas repowering capabilities at several existing coal units, clean coal technologies, landfill and coalbed methane, and pulverized coal. Renewable sources incorporated wind produced electricity and hydro-plant modernization. In addition, compressed air energy storage—used to drive turbines during moments of peak demand—is planned. Off-system sales would be used as well. Demand-side policies are, again, identical to those of Strategy D discussed above.

Strategy L was not among the seven preferred strategies due to higher costs associated with its more beneficial environmental impact. Strategy L, in fact, would result in the greatest reductions of emissions of CO_2 and SO_2, as reported in **Table 3.4.C**. For this reason, the supply- and demand-side components are indicated. Strategy L's higher costs reflected its relatively greater reliance on low emission options and renewable energy sources. Apart from natural gas combined cycle repowering of coal units, combustion turbines, and coalbed and landfill methane, Strategy L centered around wind energy sources, hydro-plant modernization, fuel cells, and biomass and refuse-derived fuels. Demand-side options were identical to those of Strategy M noted above.

There was no single year or time period associated with the implementation of any given strategy since the supply- and demand-side components of a particular strategy could be phased in over time. For purposes of evaluation, each strategy was divided into a short-run [1996-2005] and a long-run [2006-2020] period. Thus, the results of the multiple-attribute tradeoff analysis reported in **Table 3.4.C** captured the effects of the variable phase-in of the different demand- and supply-side options that characterized each strategy (TVA, 1995: 9.5). Once any given strategy was fully implemented -- that is, in the long-run after 2006 -- one could expect the strategy to attain the estimated index values reported in the table.

Among the strategies documented in **Table 3.4.C**, the indices or values reported indicated some level of improvements in customer value, total resource cost savings, price rate impact, debt, environmental outcomes, average regional income when contrasted to reference Strategy D. The total resource cost [TRC] variable measured the net effect of customer benefits along with customer and utility costs for a given option. The price rate factor [short-term rates] gauged the impact on customer electric rates due to changes in long-term utility costs that varied according to strategy.

The debt index reflected a strategy's effect on existing debt which was largely acquired via capital expenditures on nuclear plants. Environmental indices computed a strategy's impact on changes in levels of CO_2 and SO_2 emissions and the generation of solid waste materials. Finally, the annual average income variable tracked the effect on gross regional product.

In regard to environmental improvements, all the strategies listed carried indices which fell below one (1) indicating the percentage reduction in CO_2 levels relative to the reference strategy D. CO_2 reductions could be expected to range between 7 percent [Strategies Q, R, and S] and 12 percent [Strategy T]. Strategy T centered around low-cost renewable energy sources, demand-side management emphasis, and the repowering of the Bellefonte Nuclear Plant organized under a coproduct partnership with private business and promised the greatest CO_2 mitigation levels among the preferred options. In absolute terms, Strategy T would produce a regional decline in CO_2 levels of 15.642 million tons per year once the strategy was fully implemented (Note 12). At the same time, SO_2 reductions would be substantial as well. Relative to the six other preferred strategies, however, strategy T would generate less desirable customer value and annual average income levels.

Figure 3.4.H excerpts from the regional CO_2 emission levels and plots only TVA's Tennessee emissions in tons of CO_2 over the twenty year period from 1997 to 2017 (Note 13). The top trend line reflects emission levels for the reference strategy. The impact of strategies R and T on reduced emission levels are seen in the two trend lines below the reference case. Among the preferred strategies, R and T represented those that would have the lowest [R] and highest [T] levels of expected CO_2 reductions.

The actual levels of CO_2 emissions for reference case D, along with the expected reductions in emissions from selected strategies after 2006, are reported in **Table 3.4.D**. As in **Figure 3.4.H**, the reductions given in **Table 3.4.D** are for Tennessee. Emission reductions were only reported for the long-run scenarios which were considered to be operative around 2006. At this time, the full complement of supply- and demand-side policies that characterized any given strategy would be assumed to be functioning.

Among the preferred options, strategies R and T, again, reflected the lower and upper boundaries of the expected drops in CO_2 levels. By 2017, the annual CO_2 emission reductions were

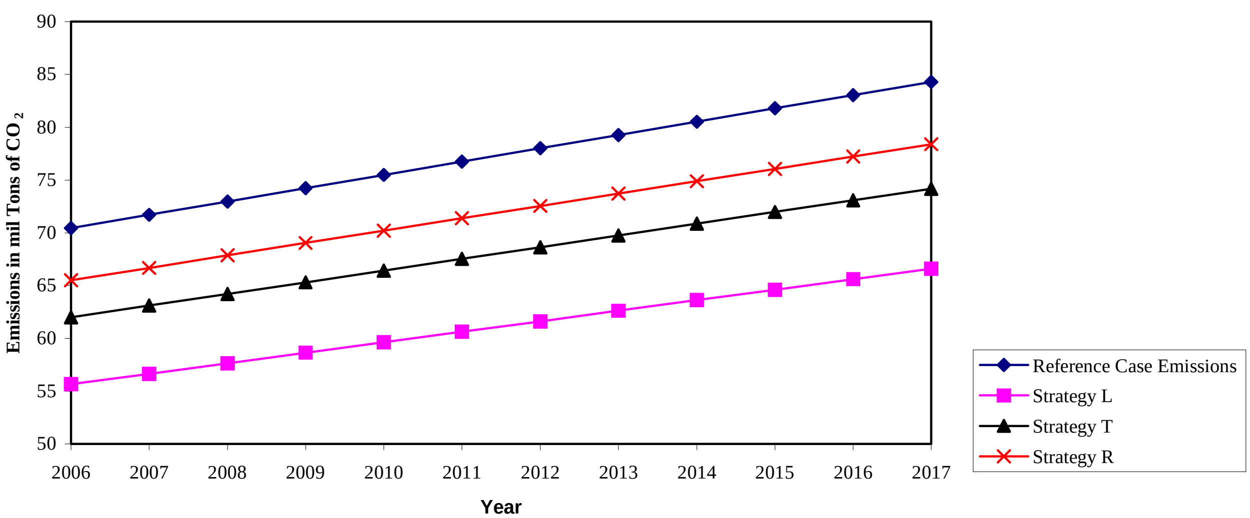


Figure 3.4.H Alternative CO_2 Emission Reduction Strategies for Tennessee

estimated to be between 5.9 and 10.1 million tons. Also reported in **Table 3.4.D**, are the emission reductions from Strategy L which had one of the highest projected drops in CO_2 levels. Strategy L was not included among the preferred options due to the fact that it generated moderately less desirable outcomes for the customer value and short-term rate factors (TVA, 1995: 9.21). Were Strategy L implemented, however, one could expect a 21 percent decline, or 17.7 fewer tons of CO_2 relative to the base case. In this regard, it should be recalled that if CO_2 reductions were valued in economic terms, then the larger avoided costs -- or net benefits -- that would ensue from the larger reductions projected by Strategy L, might well have resulted in that strategy being ranked as a highly preferred option.

Table 3.4.D

Year	Reference Case Emissions	Strategy L Reductions	Strategy T Reductions	Strategy R Reductions
2006	70.4	14.8	8.5	4.9
2007	71.7	15.1	8.6	5.0
2008	73.0	15.3	8.8	5.1
2009	74.2	15.6	8.9	5.2
2010	75.5	15.9	9.1	5.3
2011	76.7	16.1	9.2	5.4
2012	78.0	16.4	9.4	5.5
2013	79.3	16.6	9.5	5.5
2014	80.5	16.9	9.7	5.6
2015	81.8	17.2	9.8	5.7
2016	83.0	17.4	10.0	5.8
2017	84.3	17.7	10.1	5.9

Proposed Strategy Option

The State of Tennessee should support and promote participation in TVA's GHG emissions reduction efforts. The TVA demand side reduction program includes initiatives dealing with areas such as home insulation levels, home weatherization, high efficiency heat pumps, and energy efficiency programs for industry and commercial businesses. Tennessee should not attempt to duplicate programs and services already in existence through TVA. Instead, the state should work in conjunction with TVA to educate the citizens of Tennessee about the issues behind GHG emissions and encourage participation in TVA's existing demand side reduction program.

3.5 INDUSTRY SECTOR POLICIES

3.5.1 Industry-Wide Policy Initiatives

The United States Environmental Protection Agency (EPA), in cooperation with the U.S. Department of Energy (DOE), has sponsored a voluntary program, called Climate Wise, in which manufacturing companies participate in audits to determine where energy savings can be realized. These audits focus on a broad range of areas including updating boiler systems, steam system improvement, process heating, waste heat recovery and cogeneration, compressed air system improvement, and process cooling enhancements. Audits have been performed on Climate Wise partner companies throughout the United States. The *Wise Rules for Industrial Efficiency Handbook* (EPA

231-R-98-014) is a compilation of the results of these audits. The Handbook provides a summary of common energy conservation measures, how often they are implemented, their cost of implementation, the resulting savings, and other pertinent information. Handbook data are broken into categories corresponding to 18 Standard Industrial Classification (SIC) codes. By applying data obtained from the Tennessee Statistical Abstract 1994/95, the approximate number of industries within Tennessee falling into the 18 SIC codes has been determined (see **Table 3.5.1.A**). The energy conservation potential for all the industries in these 18 SIC codes has been estimated by the application of average data from the Handbook.

If all of the recommended measures were carried out for all industries in each SIC code, statewide energy use would decrease by over 30,909,100 million Btu per year. The two sectors representing the largest share of the potential savings, Lumber and Wood Products (SIC 24) and Stone, Clay, and Glass Products (SIC 32), account for over 39 percent of the savings, at 6,885,600 and 5,426,400 million Btu per year, respectively. If 50 percent of this energy is provided by electricity generated off-site, and the remainder by natural gas fired units on-site, these reductions would prevent the release of more than 5.9 million tons of CO_2 annually.

Table 3.5.1.A: Industrial SIC Codes Included in Conservation Analysis

SIC Code	Classification
20	Food and Kindred Products
21	Tobacco
22	Textile Mill Products
23	Apparel and Other Textile Products
24	Lumber and Wood Products
25	Furniture and Fixtures
26	Paper and Allied Products
27	Printing and Publishing
28	Chemicals and Allied Products
29	Petroleum and Coal Products
30	Rubber and Misc. Plastics Products
31	Leather and Leather Products
32	Stone, Clay and Glass Products
33	Primary Metal Industries
34	Fabricated Metal Industries
35	Industrial Machinery and Equipment
36	Electronic and Other Electric Equipment
37	Transportation Equipment
38	Instruments and Related Products
39	Misc. Manufacturing Industries

3.5.2 Energy Conservation with Industrial Boilers

Boilers are a critically important user of energy for manufacturing industries. Typically boilers consume more than one third of the total energy used for manufacturing. Boilers are used to generate hot water or steam from the combustion of fuels such as coal, oil, natural gas or wood. A network of pipes delivers the hot water or steam for a wide variety of process and heating applications. Once the heat has been extracted from the hot water or steam, another network of pipes returns the condensed water back to the boiler where it is reheated and circulated again. There are several different types of boilers including induced draft, forced draft, hot water or steam, and water tube or fire tube. The typical boiler in small-to-medium sized industrial operations is a forced draft steam boiler generating steam at 120-150 psi and approximately 150 hp (equivalent to 5 MMBtu/hr) (Rutgers University, 1995). Large industrial boilers can exceed 7,500 hp (250 MMBtu/hr). Typical boiler efficiencies range from about 70 to 85 percent depending on the fuel type, configuration and heat recovery capability (O'Callaghan, 1993). The energy conservation measures considered here include: boiler load management, burner replacement, upgraded instrumentation, tune-up and air/fuel ratio optimization, stack heat loss prevention, waste heat recovery, and blowdown control.

Boiler Load Management - One of the most basic energy savings measures is effective boiler load management. This means to properly size the boiler to meet the steam or hot water heating load. A good example of this is replacing a large boiler with several smaller ones, allowing for high efficiency operation during light and full load periods (Talpin, 1991).

Tune-Up and Air/Fuel Ratio Optimization – Periodic measurement of flue gas oxygen, carbon monoxide, opacity and temperature provides the fundamental data required for a boiler tune-up. It is useful to have the following instruments on hand to best manage boiler operation: stack thermometers, fuel meters, make-up feedwater meters, oxygen analyzers, run-time recorders, energy output meters, and return condensate thermometers (Talpin, 1991). A typical tune-up might consist of a reduction in excess air, boiler tube cleaning, and re-calibration of boiler controls. Maintaining a proper air-to-fuel ratio is very important for optimizing fuel combustion efficiency. When boilers are operating at low loads, excess-air requirements may be greater than the optimal levels and the efficiency may be lower (Turner, 1997). Manual or automatic oxygen control can ensure that the proper air/fuel mixture ratio is maintained (Garay, 1995). Secondary impacts of boiler efficiency measures include changes in the emission levels of: nitrogen oxides, particulates and carbon monoxide.

Burner Replacement – The method by which fuel is delivered to the burner affects boiler efficiency. Fuel atomization can add flexibility in fuel choice and can improve low load operation. Atomizers suspend fine droplets of fuel on a cone of air or steam allowing better control of fuel delivery (Talpin, 1991).

Stack Heat Losses and Waste Heat Recovery – Stack heat losses are usually the largest single energy loss in boiler operations. Key measures to minimize stack heat losses are air/fuel ratio optimization and stack gas heat recovery for pre-heating combustion air or boiler feedwater (Talpin, 1991). To maximize boiler efficiency and prevent flue gas condensation, stack temperature should be 50^{o}F to 100^{o}F above the water temperature (Talpin, 1991).

Blowdown Control and Heat Recovery – Dissolved and suspended solids in boiler feedwater can deposit on heat transfer surfaces and reduce boiler efficiency. Boiler manufacturers usually establish a maximum acceptable concentration of dissolved solids. To maintain low concentration levels, boiler water is periodically diluted in a process called "blowdown" during which boiler water is drained off and new water is added (Garay, 1995). Heat losses during blowdown are often overlooked because they are hard to measure and facility personnel may not fully understand water chemistry. Hot water drained to the sewer and excess heat vented to the atmosphere contains unused energy (Talpin, 1991). Warming make-up feedwater with blowdown waste heat can minimize heat losses.

3.5.3 Energy Conservation with Industrial Steam Systems

Steam system efficiency improvements are a logical complement to boiler efficiency measures. Useful energy escapes from steam distribution systems, from malfunctioning steam traps, steam leaks, and via radiative losses from steam lines, condensate lines and storage tanks. Each of these areas presents opportunities for energy savings.

Maintenance of Steam Traps – Steam traps are the link between the steam supply piping system and the condensate return piping system. The steam trap can sense the presence of liquid and opens to allow the condensate to flow into the condensate return system. When all the liquid has been passed to the return system the steam trap senses the presence of live steam and closes so that steam will not be vented into the condensate return piping. Steam trap operation can be checked by comparing the temperature on each side of the trap. In properly functioning traps, there will be a large temperature difference between the two sides of the trap and no steam downstream of the trap. Malfunctioning traps waste steam and result in higher boiler fuel consumption (Rutgers University, 1995). Typically, 15 to 60 percent of the steam traps in a plant may be malfunctioning and wasting large amounts of energy (Turner, 1997).

Reducing Steam Leaks – Repairing leaks in steam pipes, condensate return lines, and fittings can yield significant energy and cost savings. Steam leaks increase boiler fuel use because additional steam must be generated to make up the wasted steam. Leaky consensate return lines increase make-up water requirements and increase boiler fuel use because more energy is required to heat the cooler make-up boiler feedwater than would be required to heat the return condensate (Rutgers University, 1995).

Reducing Steam System Heat Losses – Often boiler and steam system insulation is removed to make repairs and is not replaced. Uninsulated surfaces in boiler and steam systems can reach 450^{o}F. Such high temperatures can threaten employee safety and can pose a fire hazard, as well as waste significant amounts of energy.

3.5.4 Process Heating

Industrial companies use furnaces, ovens, and kilns to raise the temperature of raw material or intermediate product as part of a manufacturing process. Important process heating efficiency measures include: insulation, combustion air control, burner adjustment, automatic stack dampers, waste heat recovery, temperature optimization, use of minimum safe ventilation, immersion heating, and enhanced sensitivity of temperature control and cutoff. Minimizing equipment heat-up time can can also save energy.

Insulation and Heat Containment – Heat loss can cause major reductions in process heating efficiency. Heat containment measures include insulation of bare equipment and open tanks, isolating hot or cold equipment from air conditioned areas, and reducing infiltration into hot or cold process equipment. New refractory fiber material, with low thermal conductivity and heat storage, can produce significant improvements in efficiency with minimal detriment to the work environment. Typical applications include furnace covers, installing fiber liner between the standard refractory linings and the shell wall, or installing ceramic fiber linings over the present refractory liner (Rutgers University, 1995).

Combustion Air Control – Maintaining a proper air-fuel-ratio is very important for optimizing fuel combustion efficiency in process heating. In a "lean" mix (high air-fuel-ratio), heat will be lost to the excess air, while in a "rich" mix (low air-fuel-ratio), unburned fuel will be emitted with the exhaust gases. Automatic burner control is an effective strategy for optimizing the air-fuel-ratio. Automatic control system technologies include programmable logic controllers, direct stack temperature monitors, and intelligent high-level computer controllers (CADDET, 1990).

Process Waste Heat Recovery – Exhaust gas heat losses are another source of process efficiency loss. Heat recovery systems can recapture this heat and reintroduce it into processing heat and other end-uses. A recuperator extracts heat from furnace waste gases to preheat incoming combustion air. A regenerator uses porous ceramic beds for waste gas heat recovery and short-term heat storage (CADDET, 1990). Additional heat recovery and cogeneration options are presented in the next section of this report.

3.5.5 Waste Heat Recovery and Cogeneration

Heat exchangers recover heat that would ordinarily be lost. Generally, a heated gas or liquid leaving a process passes through a heat exchanger to preheat another gas or liquid entering a process or an HVAC system. Cogeneration takes heat recovery a step further by recovering heat that would normally be wasted in the process and using it for power generation and steam production. Cogeneration systems can reach efficiencies that are three to four times higher than conventional systems for power and steam generation.

Waste Heat Recovery – Heat recovery is often a viable retrofit option for existing equipment. Ventilation and exhaust from process heating or combustion equipment are some common sources of potentially recoverable energy. Heat recovered is beneficial only if it can be used elsewhere and if it is available when it is needed. Typical applications of waste heat include process heating, combustion air preheating, boiler feedwater preheating, and space heating (Rutgers University, 1995).

Cogeneration – Cogeneration is the simultaneous production of electric power and thermal energy from a single fuel. In a typical configuration, an industrial boiler is replaced by a gas turbine. The turbine is used to generate electricity, and the waste heat is used to generate steam in a heat recovery steam generator (HRSG). Other cogeneration configurations combine boilers and steam turbines, or gas turbines and steam turbines (combined cycle units). Two emerging technologies that are applicable to cogeneration are the use of fuel cells and the Kalina cycle – a vapor heat engine cycle using an ammonia-water working fluid (Orlando, 1996). Cogeneration is often a more efficient way of providing electricity and process heat than producing them independently given the overall efficiency gain, as well as a potential fuel shift. Average efficiencies for traditional cogeneration systems can range from 70 percent to more than 80 percent (Stromberg, 1993). Cogeneration makes most sense in facilities where steam and electrical demand are balanced with the output of the cogeneration unit.

3.5.6 Compressed Air Systems

Compressed air is used to power tools and machines, to control HVAC systems, and for drying or cleaning various items. The two main types of air compressors are reciprocating compressors and screw compressors. Screw compressors generally use more energy than reciprocating compressors, especially when they are oversized. Compressor energy use is a function of many variables including compressor type, part-load efficiency, and control mechanisms (Talbott, 1992). Several compressed air efficiency measures are included here. Those energy conservation measures include: using cooler intake air, optimizing load, reducing pressure, eliminating or reducing air use, repairing leaks, recovering waste heat, replacing filters, and cleaning coolers.

Use Cooler Intake Air – The amount of energy required to compress air is a function of the intake air temperature, with warm air requiring more energy to compress than cool air. There is a potential for energy savings when cooler air, typically from outside, is used instead of warmer compressor room air. Often ductwork can be supplied to deliver cooler outside air to the compressor intake (Rutgers University, 1995).

Match Compressor with Load Requirements – Matching the compressor size with load can result in significant energy savings. Because air compressors can consume 16 to 100 percent of full load power at low loads, it is a good idea to optimize compressor loading to minimize compressor operating at low output levels (Oregon State University, 1996/97). This optimization can be achieved with unloading controls, automatic shutdown timers, and manual or automatic compressor sequencing. Small compressors can be added to the existing compressor size matrix to operate at very low loads.

Reduce Compressor Air Pressure – Air is often compressed to a higher pressure than required by the process equipment. Lowering air pressure reduces compressor demand and energy use. Typically, the compressor air pressure should be reduced if it is more than 10 pounds per square inch above that required by the process equipment (Rutgers University, 1995).

Reduce or Eliminate Compressed Air Use – In some facilities, compressed air use can be reduced or eliminated entirely. Less expensive alternatives may exist for processes such as cooling, agitating liquids, or moving products. In addition, some air-powered tools can be replaced with electric tools. Reducing compressed air use may result in an existing compressor operating at reduced load and lower efficiency. If the reductions are significant, the load control and compressor sequencing will need to be examined.

Eliminate Air Leaks – Compressed air distribution system leaks along piping, around valves, fittings, flanges, hoses, traps, and filters can result in significant energy losses in manufacturing facilities. Typical leakage rates range from 2 to 20 percent of system capacity. In poorly maintained systems, leakage rates can be as high as 40 percent (Talbott, 1992). The cost of compressed air leaks increases exponentially as the size of the hole increases.

Recover Waste Heat – Sixty to 90 percent of the energy of compression is available as heat that can be recovered (Talbott, 1992). Recovered waste heat may be used for space heating or to supply heat to a manufacturing process. The amount of heat energy that can be recovered depends on compressor characteristics and use factor. Waste heat recovery will be most cost-effective when the compressor is located near the process in which the heat is to be used (Rutgers University, 1995). Air compressors 100 hp and larger are often cooled with water from a cooling tower. The temperature of the water leaving the compressor cooling coils may be high enough that heat can be extracted and used elsewhere. For example, boiler feedwater could be preheated by the compressor cooling water.

Filters and Coolers – Compressed air system efficiency suffers as compressed air system filters and coolers become soiled. When filters are obstructed with pipeline contaminants, significant pressure drops can develop, requiring an increase in compressor discharge pressure. As a result of the pressure increase, air leaks will become more costly (Oregon State University, 1996/97).

3.5.7 Process Cooling

Many manufacturing processes require that materials or components be cooled to lower temperatures. Chillers, heat pumps and other refrigeration equipment are used as heat sinks for a variety of industrial processes. Efficiency measures for process cooling include using cooling tower water in place of refrigeration or chilling, modifying the refrigeration system to operate at a lower pressure, increasing chilled water temperatures, and using variable speed drives.

Energy Efficient Chillers and Refrigeration Units – There are several energy efficiency options available when installing new chilling equipment. For example, oversizing condenser water supply pipes can reduce compressor head pressure and pumping requirements. Evaporative cooled chillers consume considerably less energy per ton of cooling capacity than water and air cooled chillers. The use of high efficiency compressors can also reduce chiller energy consumption.

Cooling Tower Water – Using cooling tower water in place of chilled water from a chiller can dramatically reduce energy use when the outside temperature is low enough to achieve the required process temperature. This method of cooling is termed “free cooling” because the chiller is not used.

Refrigeration and Chillers – Reducing the cooling load is a direct approach to cutting chiller energy use. A cooling system audit may identify opportunities for improving insulation and eliminating unnecessary heat sources. Raising the chilled water set temperature can also reduce chiller energy use. By monitoring the minimum requirements on the chilled water temperature, the chiller can be reset appropriately to meet the demands of the system without wasting energy. Refrigerant subcooling decreases the load on the compressor and reduces chiller energy use. Oversizing or continuous operation of cooling towers can lower condenser water temperature and reduce cooling system energy use. Careful system maintenance and removal of non-condensable fluids can lower operating pressure and save energy.

Freezing – The freezing process in a manufacturing facility can be made more efficient by reducing heat loss through the use of improved insulation (such as air locks) and by freezing products in batches rather than continuously.

Variable Speed Drives – The application of variable speed drives (VSD) can reduce energy use when cooling loads vary over time. VSDs can be applied to the compressor within the chiller or, in some situations, utilized in chilled water distribution.

Proposed Strategy Option – The State of Tennessee, as a CO_2 reduction policy, should promote these types of energy conservation projects by actively publicizing the economic attractiveness and environmental benefits of these and similar measures. The overall simple payback for all the measures mentioned in this section is about 20 months, as reported in the Climate Wise information. A summary of the proposed projects, listed by industrial sectors, is provided in **Table 3.5.7.A**.

Table 3.5.7.A

Sector	Number of Sites	Avg Energy Savings per sector (MMBTU)	Implementation Cost (dollars)	Annual Cost Savings (dollars)	Simple Payback (months)	Total MMBTU	CO_2 Saved (tons)
Food and Kindred Products	322	4,400	18,949,378	9,554,706	24	1,416,800	116,874
Tobacco	11	8,800	935,000	572,000	20	96,800	7,985
Textile Mill Products	166	8,300	12,745,148	8,226,628	19	1,377,800	113,657
Apparel and Other Textile Products	527	1,700	9,534,748	7,655,729	15	895,900	73,904
Lumber and Wood Products	906	7,600	57,660,558	31,795,164	22	6,885,600	568,005
Furniture and Fixtures	283	3,700	10,541,750	5,793,576	22	1,047,100	86,377
Paper and Allied Products	178	7,900	8,608,970	6,160,758	17	1,406,200	116,000
Printing and Publishing	1,214	1,800	30,004,010	17,601,786	20	2,185,200	180,261
Chemicals and Allied Products	248	6,200	13,721,468	6,386,000	26	1,537,600	126,839
Petroleum and Coal Products	53	16,400	8,914,070	3,591,492	30	869,200	71,702
Rubber and Misc. Plasics Products	316	2,500	7,228,816	6,012,532	14	790,000	65,168
Leather and Leather Products	66	1,300	1,245,189	916,080	16	85,800	7,078
Stone, Clay, and Glass Products	323	16,800	46,384,092	23,208,519	24	5,426,400	447,633
Primary Metal Industries	138	5,700	5,100,342	3,476,220	18	786,600	64,888
Fabricated Metal Industries	647	2,900	14,689,812	10,511,162	17	1,876,300	154,779
Industrial Machinery and Equipment	839	2,200	15,916,669	11,615,955	16	1,845,800	152,263
Electronic and Other Electric Equipment	246	3,200	7,722,924	5,690,718	16	787,200	64,938
Transportation Equipment	234	2,600	5,129,046	4,349,124	14	608,400	50,188
Instruments and Related Products	131	2,300	4,059,559	2,679,081	18	301,300	24,855
Misc. Manufacturing Industries	297	2,300	5,605,578	4,033,260	17	683,100	56,350
Total			284,697,126	169,830,490	20	30,909,100	5,920,202

Economic Impact Analysis

Based upon the estimated implementation costs and energy saving associated with each of the proposed investment strategies discussed above, an econometric analysis of the macroeconomic effects of the proposed changes combined on the state of Tennessee was carried out using the REMI model for Tennessee. It was assumed that the initial investments by businesses in each of the 18 SIC codes on new capital were carried out over a two year period, with the proposed saving being in the second year of the period of study. The combined impact of the various investments to be made by firms in the 18 SIC code sectors appears to have an extremely large positive impact on the state of Tennessee. As can be seen in **Table 3.5.7.B**, the overall positive impact can be illustrated in several ways.

First, over the period 1997 through 2017 an average of 3,097 new jobs per year, or a total of 65,037 new jobs, will be created in Tennessee as a result of these proposed investments. In addition, Tennessee Gross State Product (GSP) will rise on average by $160.5 million per year. While at the same time the state's Personal Consumption Expenditure Index (PCE) will remain virtually constant as a result of these projects, showing a very slight increase of 0.08 percent per year on average. These positive employment and income effects reflect both the direct and indirect impact of producing, distributing, and installing these new more energy efficient types of capital in businesses across the state. The direct impacts are derived from the production, distribution, and installation of these new types of capital equipment. The indirect impacts are largely due the lower energy bills that result from the installation of more efficient capital and the increased spending by households that is made possible by the higher incomes generated by the increased investment spending of businesses. By generating more jobs residents have more real income, thus generating additional demand for other consumer goods that may also be produced in the state. Also, lower energy bills reduce firm's cost and thereby make Tennessee firms better able to compete with firms in other states and thus lead to increased production locally. Thus, it appears clear that the overall impact on the state of these proposed investments is positive and would be highly beneficial for Tennessee. For a more

Table 3.5.7.B

Year	Employment (thous)	GRP (Bil 92$)	Real Disp Pers Inc (Bil 92$)	Output (Bil 92$)	PCE-Price Index 92$ (%)
1997	0.758	0.041	0.017	0.078	0.020%
1998	2.396	0.111	0.084	0.218	0.059%
1999	2.364	0.104	0.084	0.210	0.058%
2000	2.842	0.129	0.096	0.261	0.071%
2001	3.173	0.147	0.105	0.299	0.081%
2002	3.383	0.160	0.112	0.325	0.088%
2003	3.493	0.168	0.117	0.340	0.092%
2004	3.551	0.174	0.121	0.351	0.094%
2005	3.564	0.177	0.123	0.357	0.095%
2006	3.558	0.180	0.125	0.363	0.095%
2007	3.540	0.182	0.126	0.367	0.094%
2008	3.503	0.183	0.127	0.368	0.093%
2009	3.456	0.184	0.127	0.368	0.091%
2010	3.401	0.183	0.127	0.367	0.090%
2011	3.344	0.183	0.127	0.365	0.088%
2012	3.280	0.182	0.126	0.362	0.086%
2013	3.216	0.180	0.125	0.359	0.084%
2014	3.149	0.179	0.124	0.355	0.082%
2015	3.082	0.177	0.123	0.351	0.079%
2016	3.018	0.175	0.121	0.347	0.077%
2017	2.956	0.173	0.120	0.343	0.075%
Average	3.097	0.161	0.112	0.322	0.081%

detailed breakdown of the impact of these proposals, by sector, please refer to the appendix at the end of this document.

3.6 CARBON SEQUESTRATION POLICIES

3.6.1 Forest Management

The United States Department of Agriculture Soil Conservation Service performed a National Resource Inventory in 1992, and reported that the state of Tennessee has approximately 1,858,600 acres of marginal and sub-marginal pasture and cropland. This land “returns little or no income to landowners, provides little wildlife habitat, and contributes a significant amount of sediment and pollutants that not only reduce the productive capacity of the land but impairs the water quality.” (Proposal for Reforestation Project on Private Lands in Tennessee)

By supporting a program aimed at planting the entire 1.86 million acres with pine trees, Tennessee could sequester 3.4 million tons of CO_2 annually for the first 10 years, with that amount blossoming to 8.5 million tons annually at the end of the next 10-year period. Presumably, these trees could be harvested and replanted, continuing the cycle. It is estimated that the cost to plant an acre is approximately $100. Thus, the cost to plant the entire 1.86 million acres is about $186 million. Assuming that the trees are harvested after 20 years of growth, their value (estimated at $750 per acre) would be $1.395 billion dollars.

The harvested wood, in order to maintain the storage of the captured carbon, should be used for construction, furniture or other long-lasting applications. If the harvested wood were to be burned, most of the captured carbon would be re-released to the atmosphere, nullifying the effects of the planting. Turning the wood into paper would also release some CO_2, but in lesser quantities than by burning.

The Proposal for a Reforestation Project on Private Lands in Tennessee contains a list of many positive effects of such a project to plant marginal and submarginal crop and pasture lands with pine trees. Improvement of water quality, prevention of land erosion, and creating wildlife habitat are among the benefits. Farmers could be encouraged to participate in the program through education as to the potential value of the tree crop. The state may choose to subsidize the cost of the saplings, at least initially to get the program established. Other related activities could include the initiation of a profit-sharing program between the landowners and the state. Further, schools could be encouraged to have celebrations of Arbor Day and Earth Day in which students plant trees on school grounds or at other participating locations.

Table 3.6.1.A Cumulative Carbon Sequestration from Tree Planting

Year	Carbon Sequestered tons CO_2	Cumulative Totals
2002	3,407,433	3,407,433
2003	3,407,433	6,814,866
2004	3,407,433	10,222,299
2005	3,407,433	13,629,732
2006	3,407,433	17,037,165
2007	3,407,433	20,444,598
2008	3,407,433	23,852,031
2009	3,407,433	27,259,464
2010	3,407,433	30,666,897
2011	3,407,433	34,074,330
2012	3,407,433	37,481,763
2013	8,518,583	46,000,346
2014	8,518,583	54,518,929
2015	8,518,583	63,037,512
2016	8,518,583	71,556,095
2017	8,518,583	80,074,678

Even if only half of marginal and submarginal crop and pasture lands were forested, the project would still sequester 1.7 and 4.3 million tons of CO_2 per year in the first and last years, respectively. This program is a no-regrets solution to reducing Tennessee's production of CO_2. Planting trees beautifies the state, provides for more shade, and, perhaps most importantly, turns land that is marginally profitable into a good, long-term investment.

3.7 POLICY IMPACTS: AGGREGATE AND COMPARATIVE

The policies presented in Chapter 3 have had as their central—and dual—goal the attainment of cutbacks in GHG emissions while protecting the state's economy from negative shocks associated with the policy-induced changes in the choices of producers and consumers. The emission reduction objective was realized by proposing and assessing policies that promised to reduce levels of fossil fuel use or that, as in the case of tree planting, served to sequester carbon. More specifically, the objective was to bring Tennessee's emissions into compliance with the Kyoto Protocol agreements which established that countries should strive to reduce their GHG emissions—in equivalent CO_2 — to levels 7 percent below the 1990 amounts.

Equivalent 1990 CO_2 emission levels for the state of Tennessee were calculated to be 134.4 million tons; while for the year 2017, the estimated equivalent emissions reached 194.7 million tons of CO_2. By the Kyoto benchmark, it would be necessary for Tennessee's CO_2 emissions in 2017 not to exceed 125.0 million tons. This would mean that the state would be expected to reduce CO_2 levels by 69.7 million tons.

A simple aggregation of the total expected equivalent CO_2 reductions realized by the ensemble of policies analyzed in this report permits a comparison of these levels with the targeted, Kyoto reduction objective. Two aggregations—incorporating low- and high-ranges estimates—are reported.[1] The total equivalent CO_2 reductions at the respective low and high-ranges were 34.4 million tons and 39.5 million tons. As a percentage of the Kyoto benchmark of an approximate 69.7 million tons sought by Tennessee, the low and high-range reductions accounted for around 49 percent and 57 percent, respectively. Were TVA's environmentally-friendly Strategy L to be employed, the high-range estimate of CO_2 reductions would be increased by an additional 2.8 million tons and the overall abatement would reach 61 percent of the Kyoto target. While all these scenarios fall short of the objective, the policies proposed in Chapter 3, if implemented, would go a long way toward securing large portions of the targeted emission reduction level.

A wide variety of emerging technologies possessing great potential for helping to reduce GHG emissions from Tennessee are included in Chapter 4 of this report. It is with great optimism that the authors include this information, as it and additional innovations too numerous for inclusion, represent the means by which Tennessee will be able to reach its GHG emissions target. It is not clear at this time the exact timetable for the specific emissions reductions, but within a 10 to 20 year time frame it should be possible for Tennessee to reduce it's annual GHG emissions to or below the target level of 125.0 million tons of equivalent CO_2.

CHAPTER 4

EMERGING TECHNOLOGIES

4.1 INTRODUCTION

This chapter contains diverse materials describing a wide variety of technologies, each of which hold the potential to economically reduce greenhouse gas emissions from Tennessee sources. Currently, these technologies are not commonly applied within Tennessee for various reasons. Tennessee's ability to meet its GHG emissions target is dependent on these and other technological advances under development. As these new approaches and processes become better developed, more refined and economically viable, their implementation will allow Tennessee to reduce its GHG emissions to levels considered impossible today. In general, it is thought that most of these new technologies will begin to penetrate the marketplace in the next 10 to 20 years.

4.1.1 BREAKTHROUGHS ON THE HORIZON

In its first environmental technology forecast, a team of researchers at the Department of Energy's Pacific Northwest National Laboratory has identified the 10 most important technological breakthroughs that will lead to a cleaner environment while providing major benefits to consumers over the next decade. Technologies that help prevent problems before they arise surfaced as a major theme.

"Our team members represent decades of experience on national and international environmental issues including global climate change, environmental technology development and remediation of major waste sites worldwide," says Gerry Stokes, associate laboratory director at Pacific Northwest. "Dreams and demos now, these technologies will have real impacts by 2008."

Pacific Northwest researchers ranked the top 10 environmental technological breakthroughs for 2008 as:

Agrogenetics: Genetic engineering and plant manipulation will reduce agricultural impacts on the environment. Growing crops will require less pesticide due to greater resistance to pests. Other crops will be engineered to use their nutrients efficiently, requiring less fertilizer or water while providing higher yields. And, crops with several new features—such as soybeans that taste better, use less fertilizer and resist pests —will be available.

Smart Water Treatment: Smart membranes, or filters, will improve water treatment at sewage plants and municipal water supplies by adjusting automatically to unclog themselves. Membranes and other techniques will remove organic compounds, which currently can result in undesired reactions with chlorine. Sponge-like grains of sand will attract and hold nitrates and heavy metals to further protect drinking water in large and small systems.

Renewable Energy Storage: In 10 years, improved power storage will increase the use of electricity from solar and wind power. For example, solar power collected during the day could be stored in rapidly spinning flywheels and used at night. The result will be power on demand instead of when the sun shines or wind blows. These renewable energy sources also will help slow increases in greenhouse gases by replacing carbon-based fuels.

Micro is Beautiful: The silicon chip ushered in micromanufacturing. Now micro technology for producing and using everything from chemicals to energy will provide economic and environmental advantages. For example, room air will be heated and cooled more efficiently in tiny channels of micro heat pumps, saving energy. And, micro chemical plants will produce industrial chemicals as needed, thereby eliminating storage and transportation safety issues.

Paperless Society: Innovative displays, wireless communications and customized web magazines will help reduce the mounds of paper in our lives as well as the environmental impacts from paper and ink manufacturing and use. Advanced display systems may imitate paper in their flexibility and portability. One approach will project images directly on the retina of the eye. This capability, coupled with a cellular phone, could provide everyone from couch potatoes to business travelers with faxes and customized news anywhere. For paper products that continue to be used, biodegradable inks will be more common.

Molecular Design: An understanding of how materials behave at the molecular level will help in the development of advanced materials and more efficient solar cells. Molecular design of catalysts could make chemical reactions and processing so precise that little or no wastes are produced. And sensors designed at the molecular level will monitor manufacturing of materials and chemicals more precisely, halting or correcting processes sensitive to temperature changes and other parameters. The result will be higher quality products with fewer environmental impacts.

Bioprocessing Grows More Products: Microorganisms and plants will "grow" environmentally friendly chemical and biological products such as drugs, proteins and enzymes for many uses. Producing chemical feedstocks, fuels and pharmaceuticals in this manner will be cost effective and better for the environment. Microorganisms retrieved from extremely hot, cold or forbidding environments are renewing excitement in the bioprocessing industry for the production of "extremozymes." These enzymes expand the range of temperatures and conditions used in manufacturing biotech products, creating opportunity for new, environmentally friendly bioprocesses while saving time and energy.

Real-time Environmental Sensors: These innovative sensors will be a major boon to public health. Supermarkets will use sensors to detect E. coli and other dangerous pathogens in food. Workplace air quality will be monitored to prevent "sick building syndrome." Other benefits include monitoring the environment on airplanes, at hospitals to prevent infections and in municipal water supplies. The same technology will help guard against pathogens used in biological terrorism.

Enviromanufacturing and Recycling: In 10 years, "green" companies will create products that are environmentally friendly from cradle to grave. Plastics, paper, beverage containers and inks, as well as cars and computers, will be more biodegradable or recyclable. Also, newer processes, such as dry cleaning with liquid CO_2 , will minimize or eliminate waste. Hazardous chemicals no longer will be used to clean clothes and the CO_2 will be captured and recycled so as not to add to atmospheric carbon.

Lightweight Cars: Squeezing every ounce possible out of cars will mean a family sedan that gets at least 80 miles per gallon of gas, generates less pollution and uses less gas. Lighter cars will be built with less steel and more lightweight aluminum, magnesium, titanium and composites. Advanced metal-forming techniques will provide precisely the strength needed at every point, eliminating all excess weight from today's designs. Creating a composite sandwich of glass and plastic will cut the 68 kilograms (150 pounds) of glass in today's cars a third or more. Composite glass also will begin playing a structural role so that metal can be reduced. Today's 45.4-kilogram (100-pound) air conditioners will weigh half as much once glass is specially coated to reflect or absorb heat radiation.

Given the time and resources, modern science will find innovative new technologies to solve the GHG emissions problem. We must buy the scientists and researchers the time they need to solve these problems by implementing today's best economic approaches to reducing GHG emissions.

4.1.2 RENEWABLE VERSUS FOSSIL FUEL ENERGY

Fossil fuel combustion represents roughly 90 percent of Tennessee's GHG emissions. Any long term significant reductions in GHG emissions have to address the use of fossil fuels in one form or another. The two largest sectors in Tennessee and throughout the nation are transportation and electric power generation.

The production and use of conventional, fossil fuel based energy accounts for 95 percent of all air pollution, $50 billion in U.S. annual health care costs, and are also the primary sources of greenhouse gases. Decreasing these environmental impacts and costs through the use of renewable energy technologies will save money and help preserve and sustain our natural resources. Using renewable technologies can also decrease the volume of greenhouse gases added to the atmosphere. With widespread use, these technologies could avoid as much as 10 percent of the emissions produced by the electricity sector alone on an annual basis.

Economic benefits of renewable energy use occur in several ways:

- The more efficient use of energy saves money.
- Decreasing our nation's dependence on oil imports saves money and enhances national security.
- Avoiding the environmental costs of using conventional energy sources saves money.
- Business growth surrounding the development and sales—domestic and international—of renewable energy technologies generates income and jobs.

Renewable technologies create domestic jobs. Jobs created directly by these technologies are in design, production, installation and operation of systems. Typically, these are opportunities for engineers, programmers, skilled assembly workers, plumbers, electricians, mechanics, plant operations and marketing and sales experts. In addition, "indirect" jobs become available in the firms that supply renewable energy businesses with raw materials, transportation equipment and professional services. Expanded development of renewable energy technologies will create as many as 300,000 new jobs for American workers.

One survey regarding the public's interest in renewables was conducted by Research Strategy Management, Inc. in November, 1996. One of the survey questions dealt with the level of federal support for research and development for five different energy options; renewable energy, nuclear power, energy efficiency and conservation, fossil fuels and natural gas. From all of these options, the majority chose either renewable energy (34 percent) or energy efficiency (22 percent) as their preference. Other questions revealed that 75 percent of those surveyed were willing to pay anywhere from 2 percent to 10 percent more for electricity supplied by solar, wind, biomass, geothermal or hydro. Several municipal utilities are taking advantage of this public support, and have initiated "green pricing" projects, where customers sign up to pay an additional amount on their utility bill in order to support the purchase or installation of renewable projects. Information on specific renewable energy sources is included in some of the following sections of this chapter.

4.2 RENEWABLE ENERGY

4.2.1 PHOTOVOLTAICS

The electric utility sector in Tennessee is responsible for approximately 30 percent of the state's GHG emissions. The widespread use of photovoltaic cells could produce massive reductions in GHG emissions when the cost of PV generated electricity can rival that of power produced from fossil fuels. It is a question of economics. The point in the future when PV power will become economically viable for mass electric generation is not clear at this time.

Photovoltaic (or PV) cells are devices that use semiconductor material to convert sunlight directly into electricity. Individual solar cells, most commonly squares of silicon, are wired together and laminated within a thin, protective glass case to make a module. In other cases, a very thin layer of noncrystalline silicon is coated on an inexpensive base. Though the thin-film material is less efficient at converting sunlight to electricity compared with other systems, its low cost and simplicity are perfect characteristics for certain applications. These modules can then be joined to form PV arrays. The amount of electricity generated by an array increases as more modules are added.

PV systems range from very simple to complex. They can also be either remote or connected to the electric utility grid. In remote (or off-grid) applications, PV power is independent of existing utility lines and power grids. There are numerous examples of cost-effective PV applications within the United States, most of which are off-grid.

To determine how a given photovoltaic system will operate at a given geographic location, one must obtain a detailed characterization of the solar resource.

Earth's source of solar radiation-the nuclear fusion reactor 151 million kilometers from us-provides a bountiful, inexhaustible source of energy. On a typical land area of earth, approximately 1,000 W/m^2 of energy from photons is available for conversion into electrical power at solar noon. The solar radiation is reduced from the level outside earth's atmosphere as a result of absorption by such gases as CO_2, water vapor and ozone. Before these various absorptions occur, the radiation above earth's surface is 1,367 W/m^2, defined as AM0, or air mass zero. On earth's surface, when the sun is directly overhead, the radiation that makes it through a cloudless atmosphere is labeled AM1.

To put all of this into perspective, L41 a photovoltaic generation station 140 x 140 km in area at an average U.S. location could generate all the electricity needed in the U.S. (2.5 x 1012 kW-h/yr), assuming a system efficiency of 10 percent, a balance-of-systems efficiency of 81 percent and a system packing factor of 50 percent. Thus, although the solar resource is dispersed in area, it is ample in reasonably small areas to provide whatever amount of photovoltaic power is required. Obviously, because the sun does not shine at all times in any one location on earth, some practical means of energy storage also is needed.

The simplest PV system generates direct-current electricity when the sun is shining and runs equipment such as water pumps or fans. A power inverter can be used to convert direct current to alternating current. And for powering equipment in remote locations, PV systems include batteries that store electricity for use at night or when the sun isn't shining. The primary uses for PV today are for telecommunications, security and lighting systems, water pumps, and load management.

In some cases, power must be available on demand, or perhaps the electricity required occasionally exceeds the PV system's supply. Here, an electric generator can work effectively with PV to supply the load. Remote locations where loads are currently supplied by diesel generators alone are good candidates for PV systems with generators. Sites in national parks and national forests present good opportunities for PV/hybrid systems. PV systems have many benefits:

- Portability—can move PV units easily to other locations
- High reliability—PV modules operate reliably for long periods of time with virtually no maintenance
- Low operating costs—fuel is free, and there are no moving parts
- Low environmental impact—non-polluting and quiet
- Stand-alone capability—for remote areas not served by a utility power grid
- Modularity—energy output can easily be increased or decreased by changing the number of panels
- Safety—not flammable
- Versatility—appropriate for virtually any climate.

Photovoltaics should be considered for any remote application with a daily electrical load of a few watt-hours up to about 100 kilowatt-hours.

On a first-cost basis, PV systems' installed costs can be less than the cost of utility service. For larger loads where utility power exists, PV may still be applicable. For example, the reliability of the utility's power may be too low for a particular application. Or a facility may have higher electricity charges for midday use of electricity.

The National Park Service has 455 existing PV systems primarily associated with equipment for monitoring resources. And other cost-effective, widely demonstrated residential and commercial off-grid applications include:

- Street lights for highways
- Offshore drilling platforms
- Campgrounds and marinas
- Water-supply disinfection
- Remote-area fans and lights
- Remote monitoring equipment
- Communications equipment/facilities (e.g., emergency roadside phones, microwave repeater stations)
- Weather stations
- Cathodic protection
- Highway/warning signs
- Fire watch towers
- Landscape lighting
- Security systems
- Livestock watering pumps and irrigation systems
- Transmission tower beacons
- Emergency power during crises.

What is required?

- Modules need to face south and be unshaded
- Modules can be mounted on the application itself, on the roof, or on the ground
- Batteries require maintenance and are usually needed to meet peak loads or nighttime usage
- The system needs a power inverter if the load requires alternating current
- PV system must be evaluated on cost, system performance, system reliability, and maintenance requirements.

What does it cost?

On a 20-year life-cycle cost basis, the cost of a remote PV system ranges from 25¢-50¢ per kilowatt-hour. For off-grid sites, there are numerous examples where PV is more cost effective than the alternative fuel sources.

Photovoltaics will not make a significant impact on Tennessee's GHG emissions for the foreseeable future. If the efficiency of large-scale production could make PV electricity competitive with conventional generation on a cost basis, then PV could substantially reduce Tennessee's GHG emissions.

4.2.2 WOOD WASTE

Tennessee has over 1,100 companies involved in the lumber, wood products and furniture industries. Many of these are manufacturing concerns that produce sizable amounts of waste wood and sawdust. While a few of these companies utilize their waste wood as an asset, most simply dispose of it in the most economical means possible. The efficient utilization of wood waste in Tennessee as an alternative energy source could have a positive affect on the state's GHG emissions.

One biomass energy source abundant in Tennessee is wood waste. Biomass energy is defined as energy derived from any renewable fuel source that was once living, i.e., plant materials and their byproducts.

Several programs exist to promote biomass recovery such as Southeastern Regional Biomass Energy Program (SERBEP). SERBEP is under the Regional Biomass Energy Program (RBEP) and attempts to facilitate the development of cost-effective and environmentally acceptable biomass energy facilities in the Southeast. Tennessee and twelve other states participate in SERBEP.

Throughout the Southeast a growing number of solid waste authorities, private entrepreneurs and industries that generate wood waste are separating wood from other solid waste and processing it into fuel, as well as a variety of other products. Yet, despite the favorable opportunities for increasing recycling and encouraging renewable energy development, thousands of tons of wood waste are still disposed of in landfills or sometimes burned in outdoor piles in the Southeast.

Wood waste separation and recycling initiatives have been completed during the past few years in order to reduce the amount of material disposed of in landfills and other solid waste management facilities. The increasing emphasis on recovering and utilizing wood waste is important because the material represents a significant portion of the solid waste stream, and is often not addressed by recycling programs instituted at the local level. In addition, a variety of wood residue is generated that never enters the municipal solid waste stream, but must be handled, reused, recycled or disposed of in some way.

A variety of solid waste management, energy production, and environmental objectives can be achieved through the separation, recovery and processing of wood waste for fuel and other purposes. Now more than ever, increasing waste disposal costs, decreasing landfill capacity and growing markets for recycled products indicate new opportunities for reusing and recycling wood waste materials.

Wood is such a huge part of the solid waste stream that a trend is developing in more populated states in the region as landfills stop accepting wood waste. Disposal options are becoming more limited, and tipping fees paid to solid waste management facilities are increasing. Similar trends are expected in the future in less populated states, as existing disposal facilities reach capacity and as the relatively high costs to site, permit, and construct new facilities becomes apparent.

Companies that do not use their wood waste on-site often pay haulers to transport the waste to landfills or other disposal sites. Some private haulers own their own materials recovery facilities or landfills, and some do not. Waste haulers have been greatly affected by increasing tipping fees and shortages of landfill space in some locations in the Southeast. Some haulers have raised their hauling prices dramatically during the past five years, and have increased the distances they travel to dispose of waste picked up by the company.

As landfills become full and markets for processed wood develop, haulers can benefit from the opportunity to “dispose” of wood waste at new processing facilities. This can help stabilize the increase in trucking distances and can help slow, but probably not stop, the rise in tipping fees.

Transfer stations can also gain substantially by separating wood from other waste. Unless a transfer station is owned by a disposal facility, the station owner must also pay tipping fees at landfills or other facilities for permanent disposal of the waste. By separating and processing wood waste, the transfer station can decrease its tipping fees at landfills or other facilities. In some cases, a transfer station can develop a new source of revenue by selling recovered wood waste to end-use markets.

Landfill owners themselves can also benefit from separating wood. During the past several years, a number of landfill operators have invested in wood processing equipment. The landfills process wood delivered by haulers and then process the waste. Their purposes are either to reduce its volume or to sell for reuse. Some landfills charge a lower tipping fee for wood separated from other waste before it is delivered to the landfill. The advantage of processing wood received at a landfill is that it can reduce the amount of waste needing disposal, thereby extending the life of the landfill.

A variety of factors affect wood waste processing facilities. This is particularly true because processing facilities require successful operation of two distinct components. One component involves obtaining sufficient supplies of wood waste. The second component involves securing a reliable demand, and suitable price, for products recovered from the wood. In some locations, there is an adequate supply of wood needing “disposal,” but there are insufficient end use markets. In other locations, the reverse is true. Major factors affecting wood waste processors include: existing solid waste and recycling programs, policies, and regulations; the availability of wood waste for processing; the extent of end use markets; and specifications for end products. These factors affect a processor’s selection of equipment, determination of the appropriate capacity of a facility, and facility location.

Wood accounts for a significant portion of the total waste stream and is a material with high potential for recycling. There are virtually unlimited end uses for wood and some end use markets are, or potentially could be, extremely large. Some of the major end uses for wood waste include fuel and wood pellets.

Wood waste may be processed and used as fuel in residential, institutional, municipal, commercial, industrial, or utility boilers or furnaces for the production of thermal and/or electrical energy. Wood may be used as the only fuel or it may be co-fired with other fuels, such as coal and oil. Combustion equipment may be specifically designed to burn wood, or may be retrofitted equipment originally designed to burn other fuels. Combustion equipment ranges in size from very small energy systems (in residential or commercial facilities) to large utility-scale power plants that generate 50 to 100 MW of electricity.

The market potential for wood waste used as fuel is large in the Southeast. This is due to a variety of factors. Wood waste is an indigenous, abundant, renewable energy source. The use of wood as fuel has several air emission benefits compared to fossil fuels. Due to the low sulfur content of wood, significantly less sulfur dioxide, reduced sulfur compounds, and sulfuric acid are emitted than during fossil fuel combustion. Carbon emissions may also be reduced compared to fossil fuel combustion. Wood waste may be co-fired with coal in utility and industrial boilers, resulting in significant acid gas emission reductions. Air pollution control regulators and permit engineers are familiar with the combustion characteristics and emissions of clean, untreated wood. Research, demonstration, and operating experience indicates that several types of treated wood waste may be burned with minor or no negative impact on air and ash emissions.

Wood pellets can be made from small particles of wood waste (typically 3/16th of an inch in size) that are dried (if necessary), compressed, and extruded into pellets. Binder(s) may be added to help the extrusion process, increase the energy value, and protect the pellets from breaking and absorbing moisture. The moisture content of wood pellets is typically 10 percent or less. Pellets may be used as fuel in residential, institutional, municipal, commercial, industrial, or utility boilers or furnaces for the production of thermal and/or electrical energy. In addition, markets are increasing for pellets used as absorbents, such as "kitty litter".

Tennessee has generous supplies of wood and agricultural residues that could be used for energy. Research indicates that wood fuel for industrial use can be financially attractive. However, market and institutional barriers prevent industry and small business from choosing wood energy over fossil fuels. The lack of a fully active technology transfer program also hinders the appeal of biomass as an energy source.

The Energy Division of the Tennessee Department of Economic and Community Development directs SERBEP activities in the state. SERBEP related projects include:

- A Small Business Energy Loan Program is operated by the Energy Division to increase the energy efficiency of small businesses. Loans from the program have been used to upgrade boilers and to convert boilers to use wood waste as fuel.
- A study at the Tennessee Technological University that examined the use of wood gasification to produce fuel gas and activated carbon char which could be used locally for wastewater treatment. The fuel gas could potentially be used by the University to generate steam. The cost of the facility is estimated to be $8.1 million, and the rate of return is estimated to be almost 30 percent.
- The installation of an induction generator on a wood-fired boiler at a medium-sized sawmill. The generator supplies approximately 35 percent of the mill's electrical requirements while eliminating the mill's wood waste disposal problem.

In the future, substantial opportunities will exist to utilize the state's abundant wood residues for energy production. State solid waste regulations will continue to intensify pressure to find alternatives to landfilling wood waste, including waste-to-energy and resource recovery options.

4.2.3 ALTERNATIVE LIQUID FUELS

There is considerable interest in producing large quantities of alternative liquid fuel products from biomass. Not only is this interest driven by the desires for greater energy security, but also by changes in federal policy promulgated under the Clean Air Act Amendments of 1990 and the National Energy Policy Act of 1992 (EPACT) which focus attention on the environmental impacts of transportation fuels. These legislative acts are stimulating the search for cleaner-burning alternatives to gasoline and diesel fuels. One alternative to gasoline is biomass-derived ethanol, which can be used in pure form or blended with gasoline to increase oxygenation and thereby reduce the amounts of certain pollutants. One alternative to conventional diesel fuel is biodiesel, which can be used in unmodified diesel engines. Biodiesel is produced from some animal fats or vegetable oils after undergoing a relatively simple process called transesterfication. All Regional Biomass Energy Program (RBEP) regions have been involved in the area of alternative liquid fuels from biomass and continue to fund significant projects in this field.

The Southeast RBEP, in which Tennessee participates, has recently completed a study evaluating the potential to produce industrial rapeseed on land idled by federal farm programs for use as a feedstock for biodiesel. The study used plot yields at eight locations in the region as a basis for estimating seed yields and oil volumes that could be produced in the southeastern US. It estimated that the biodiesel potential for the region could result in the production of about 640 million gallons of fuel, assuming all 5.8 million acres of idled land were used with a yield of 110 gallons of oil per acre. Nationally, about 50 billion gallons of diesel fuel are used annually. Although the total amount of biodiesel which can be produced on idle lands in the Southeast appears to be a small amount, according to the researchers it appears that biodiesel could provide some very important advantages. The use of biodiesel would provide an unlimited industrial market for agricultural products beyond the limited traditional feed and food markets, and thereby stimulate rural investment and employment opportunities. The environmental benefits of reduced air emissions and the biodegradability of biodiesel would provide additional benefits for communities and metropolitan areas with air quality problems. Further, the nation would enjoy increased energy security from the reduction in imported oil.

With a significant level of activity around the country directed toward the development of alternative liquid fuel products from biomass, it seems inevitable that transportation sector emissions will at some point be reduced from the use of bio-fuels. The timing of those GHG emissions reductions as well as the specific fuels and technologies that will penetrate the market place are not clear at this time.

4.2.4 BIOMASS-FIRED POWER GENERATION

Introduction

Worldwide, biomass ranks fourth as an energy resource, providing approximately 14 percent of the world's energy needs; biomass is the most important source of energy in developing nations, providing approximately 35 percent of their energy, particularly in rural areas where it is often the only accessible and affordable source of energy (McGowan 1991, and Hall 1992). Considering the vastness of the photosynthetic productivity of biomass (conservatively an order of magnitude greater than the world's total energy consumption), that bioenergy can be produced and used in a clean and sustainable manner, and that technological advances in biomass conversion are occurring along several fronts worldwide, there is much optimism that biomass will continue to play a significant and probably increasing role in the world's future energy mix. The extent and rate of increase of its use, especially in industrialized countries, will depend on greater exploitation of existing biomass stocks (particularly residues) and the development of dedicated energy feedstock supply systems.

Biomass Energy Potential

Biomass residues are the most readily accessible and often least costly (sometimes having a negative cost associated with their disposal) form of biomass available today. The approximate quantities of such feedstocks and their energy values are summarized, continent by continent in **Table 4.2.4.A** (Kinoshita 1996). In many instances, crop processing provides much synergism with power production, the former serving to upgrade the quality of the biomass feedstock to facilitate the latter. An example is seen in sugar cane processed to produce sugar as a primary product and electricity as a by-product. Harvested sugar cane contains more than 1 percent alkali compounds per unit of fibre harvested. Alkalis, when reacted with sulphates and chlorine, are problematic for thermochemical conversion systems, fouling heat exchange surfaces, gas turbine blades, and other power system components. The milling process that extracts sugar from the sugar cane crop produces the fibrous residue, bagasse, which is used as fuel to generate steam and electricity. The bagasse contains only 0.3 percent alkali per unit of fibre (less than 30 percent of the amount contained in the original sugar cane crop) as well as lower moisture content, and the resulting fuel particle size is better suited for power generation than the original sugar cane received by the mill.

The data in **Table 4.2.4.A** show that in some instances, particularly in developing countries, the energy contained in existing biomass residues rivals or exceeds the amount of electric energy generated from traditional sources. It must be recognized, however, that biomass residues have many applications, including use as animal feed, soil amendments, industrial feedstock, and commercial products; and that each application carries an economic value for the feedstock. Therefore, not all residues can or should be diverted to power generation. Animal wastes are another significant potential biomass resource for electricity generation, and like crop residues, have many applications, especially in developing countries.

Although residues are most widely used as sources of energy in developing nations, where such resources are often the only form of energy readily available, under favorable circumstances they can contribute significantly to the energy mix even in industrialized countries. For example, in the early 1980’s, some 10 percent of the electricity generated in the state of Hawaii originated from sugar cane bagasse and in some counties of the state over 50 percent came from bagasse. However, if biomass is to play a major role in the world’s energy mix in the longer term, crops will need to be grown specifically for energy. Studies performed by a number investigators (Graham IEA Bioenergy Implementing Agreement, Richard L. Bain National Renewable Energy Laboratory Golden, Colorado, USA 80401-3393 1995) have suggested that within ten years, the United States could produce large quantities (more than 5 EJ) of high yielding energy crops for $30-50/ton (dry basis) or lower. These projections will need to be validated in thousand hectare commercial plantings. Initial installations of energy crops will need to be profitable in order for the concept of dedicated energy feedstock supplies to gain broader acceptance.

This biomass usage potential should be considered in the light of the total anticipated growth of electricity capacity additions. Between 1994-2003 capacity additions are estimated to be 629 gigawatts (GW) worldwide (McGraw Hill 1995) and represents a growth of 21 percent over the installed base now in service. Much of this growth will take place in China and Asia.

Status

In the United States, the period from 1973 to the present has shown a dramatic upswing in bioenergy use, especially in thermal and electrical applications of wood residues. The wood processing and pulp and paper sectors became about 70 percent self sufficient in energy in this period; and the amount of grid connected electrical capacity has increased from less than 200 MW, in 1978 to over 7,500 MW, today. This dramatic growth, stimulated in part by federal tax policy and state utility regulatory actions, occurred after the Public Utilities Regulatory Policies Act (PURPA) of 1978 guaranteed small electricity producers that utilities would purchase electricity at a price equal to the utilities' avoided cost.

More than 70 percent of biomass power is cogenerated with process heat. Wood-fired systems account for 88 percent, landfill gas 8 percent, agricultural waste 3 percent, and anaerobic digester 1 percent. There are nearly 1000 woodfired plants in the U.S., typically ranging from 10 to 25 MW. Only a third of these plants offer electricity for sale. The rest are owned and operated by the paper and wood products industries for their own use. Most of today's biomass grid connected power installations are the smaller scale independent power and cogeneration systems. To date, utilities have been involved in only a handful of dedicated wood-fired plants in the 40 to 50 MW size range, and in some co-firing of wood and municipal solid waste in conventional coal fired plants. Net plant heat rates for 25 MW plants in the California PG&E service territory average approximately 20 percent efficiency (17,000 Btu/kWh). By comparison the 43 MW, utility-operated plant at Kettle Falls, Washington has a reported heat rate of 23.7 percent efficiency (14,382 Btu/kWh).

The advantageous power purchase agreements that were negotiated under PURPA in the 1980s are no longer available at high avoided cost rates. As a result a number of plants are closing as their power contracts come up for renewal. These plants could be competitive in today's environment using low cost waste and residue fuels if their efficiency was much higher. This has been demonstrated in the Hawaii sugar industry where the sugar mill power plants operate for a major part of the year as combined heat and power (CHP) installations. Investments in efficient steam cycles have resulted in a competitive rate of power generation under PURPA. Low pressure boilers were systematically replaced by higher pressure boiler systems of larger capacity in the period 1960 through 1980, with the average steam pressure and temperature increasing from 1.3 MPa and 210° C to 4.4 MPa. and 380° C. Meanwhile the net steam consumption in the mills decreased significantly from 600 kg /tc (ton of cane) to about 300-400 kg/tc; resulting in a power output of about 60 kWh/tc on average, with the best mills reaching over 100 kWh/tc.

Technology

The technologies for the primary conversion of biomass for electricity production are direct combustion, gasification, and pyrolysis. Direct combustion involves the oxidation of biomass with excess air, giving hot flue gases which are used to produce steam in the heat recovery sections of boilers. The steam is used to produce electricity in a Rankine cycle; usually only electricity is produced in a condensing steam cycle, while electricity and steam are cogenerated in an extracting steam cycle. In combined heat and power systems waste heat is used to generate either steam for industrial process use or hot water for district heating. Historical combustion systems were based on pile burner technology. The majority of combustion systems in the United States are stoker-grate systems. The major manufacturers are Zurn Nepco, Foster Wheeler and Babcock and Wilcox (Hollenbacher 1993). Increasingly, new systems are using bubbling fluid beds and circulating bed designs. A major advantage of circulating fluid bed boilers is the ability to handle varying feedstocks with different compositions and moisture contents. The major manufacturers of circulating fluid bed boilers for biomass are Combustion Engineering (CE-Lurgi), B&W-Studsvik, Foster Wheeler (formerly Ahlstrorn Pyropower), and Gotaverken. A number of plants have been built in the 25 MW size range, primarily in California.

In air-based gasification cycles, biomass is partially oxidized by sub-stoichiometric amounts of oxygen, normally with steam present, to provide energy for thermal conversion of the remaining biomass to gases and organic vapors. For power production the cleaned gasification product gases will be fed directly

TABLE 4.2.4.A BIOMASS RESIDUES AND DEDICATED FEEDSTOCKS FOR ELECTRIC POWER GENERATION

	Africa	N. Amer	S. Amer	Asia	Europe	Oceania	World
Biomass Residues (EJ[MMt])							
Selected Crop Residues	5 [253]	15 [809]	4 [230]	27 [1053]	10 [565]	1 [72]	62 [3433]
Animal Wastes	5 [347]	3 [198]	7 [465]	20 [1263]	4 [272]	1 [89]	41 [2634]
Round woods	4 [203]	9 [429]	4 [180]	14 [724]	5 [227]	0 [23]	36 [1785]
Dedicated Feedstocks (EJ [MMt])	14 [789]	10 [535]	12 [659]	12 [668]	2 [119]	5 [293]	55 [3063]
Total Biomass Energy [b] (EJ [MMt])	21 [1190]	23 [1253]	19 [1096]	43 [2413]	12 [651]	7 [385]	12 [6988]
Biomass Electric Potential [c] (EJe)	7	8	7	15	4	2	44
Present Generation, Major Sources (EJe)	1	14	2	12	15	1	44

a Assumes production on 5% of existing forest lands with a yield of 10 tonnes hectare per year
b Consists of dedicated feedstock plus 50% of biomass residues
c Assumes generation efficiency = 35%

to a boiler or to the combustion section of an industrial or aeroderivative turbine. In indirect gasification cycles an external heat source, instead of oxygen, is used to provide the energy for high-temperature steam gasification of the organic fraction of biomass to vapors and gases. Some developers are now referring to indirect steam gasification as steam reforming of biomass. In pyrolysis processes, indirect heating is also used to convert biomass to a mixture of gases and organic vapors. Pyrolysis is defined as the thermal destruction of organic materials in the absence of oxygen. Technically, therefore, indirect gasification is a pyrolysis process. For the purposes of this discussion, if the primary pyrolysis product is gas, the process is considered gasification. If the primary products are condensable vapors, the process is considered pyrolysis. In addition, pyrolysis processes usually do not involve steam addition.

Economics

Over the years, a large number of organizations have projected the ultimate performance of biomass-based power systems. These projections, however, often covered a broad range which led inevitably to reluctance on the part of developers to invest in these technologies. In fact, using today's technology, the maximum scale that would be risked is probably about 18 MW, efficiency in the range 30-33 percent, with a capital investment of over $2500/kW.

Recently, the U.S. Environmental Protection Agency embarked on a study to evaluate the penetration of various technologies into the power generation marketplace in the coming decades and their effect on carbon emissions to the atmosphere. This study (Turnure 1995) required as input cost and efficiency estimates for biomass, coal, and natural gas power generation systems. Given the disparity of opinion on these figures in the published literature, a panel consisting of representatives from NREL, EPRI, the Princeton Center for Energy and Environmental Studies, EPA, USDA, and the Colorado School of Mines was convened to arrive at a consensus position. The panel was able to agree upon likely ranges of cost and performance for systems utilizing these fuels. **Table 4.2.4.B** summarizes these ranges.

A recent paper (Asplund 1995) has presented investment costs for small cogeneration plants in Finland. These costs, **Table 4.2.4.C**, are for bubbling fluid bed and circulating fluid bed combustor systems less than 10 MWe producing electricity and district heat and/or industrial process heat. These systems are

TABLE 4.2.4.B TECHNOLOGY CHARACTERIZATIONS USED FOR EPA MODELING

	Industrial Biomass	Turbine Coal	Advanced Biomass	Turbine Coal	System Component Natural Gas
"Low" Technology Specifications					
Heat Rate (Btus/kWh)	8,660	8,700	7,579	7,614	6,202
Efficiency (%, HHV)	39.4	39.2	45.0	44.8	55.0
Fixed O+M, U.S.$/kW	51.25	51.25	39.66	39.66	28.80
Var. O+M, mils/kWh	3.15	3.15	2.46	2.46	0.712
Total Capital, U.S.$/kW	1,230	1,254	1,023	1,047	522.50
"High" Technology Specifications					
Heat Rate (Btus/kWh)	9,400	8,700	8,227	7,614	6,202
Efficiency (%, HHV)	36.3	39.2	41.5	44.8	55.0
Fixed O+M	44.71	36.44	34.60	28.20	28.80
Var. O+M	3.65	2.60	2.85	2.03	0.712
Total Capital	1,488	1,254	1,243	1,047	522.50

TABLE 4.2.4.C NEW SMALL COGENERATION PLANTS IN FINLAND

	Plant Investment Cost	Takeover Power/Heat Conditions	Capacity Million ECU	Steam MWe/MWt	Type of Boiler °C/bar
Pieksämäki	1992	9/25	510/60	BFBC	9.5
Kankaanpää	1992	6/16	510/60	BFBC	8.0
Kuhmo	1992	5/13	490/81	CFBC	12.3
Ylivieska	1993	5/15	510/60	BFBC	8.7
Kuusamo	1993	6/17	510/60	BFBC	8.0
Lieksa	1994	8/22	510/61	CFBC	11.3

primarily fueled by peat and wood wastes and have power to heat ratios of about 0.35.

Environmental Benefits

Significant environmental benefits can be obtained by using biomass fuels in direct combustion, gasification, or pyrolysis systems, although some uncertainties exist at present. SO_2, CO_2, and ash production will be typically far lower for biomass power systems than for coal combustion and conversion systems. Biomass power is one of the most attractive options for addressing CO_2 concerns, because both growth and conversion involve recycling atmospheric carbon, resulting in no net addition of CO_2 into the atmosphere. Emissions of air toxins from biomass direct/indirect combustion requires further characterization, but will probably be less of a problem than the air toxic emissions from coal combustion. Water quality impacts should be smaller for biomass-fueled systems than for coal-fueled systems, even though water usage in biomass combustion is comparable to that used in coal combustion. However, feedstock growth could require significant use of water and petrochemical-based fertilization, and raises concerns about nutrient run-off. Solid waste, in the form of ash, is generally viewed as non-hazardous and is produced in smaller quantities than in coal-fueled systems. Solid waste production is lower because of the relatively low ash content of biomass fuel. Long-term ecological effects such as destruction of wildlife habitat, loss of biodiversity, and sustainability of soil productivity are other issues unique to the biomass fuel resource and deserve further attention.

Fields of Application

Biomass-based power systems are unique among non-hydro renewable power sources because of their wide range of applicability to a diverse set of needs. Biomass systems can be used for village power applications in the 10-250 kW scale, for larger scale municipal electricity and heating applications, for industrial application such as bog-fuel boilers and black-liquor recovery boilers, in agricultural applications such as electricity and steam generation in the sugar cane industry, and for utility-scale electricity generation in the 100MW, scale. Biomass-based systems are the only nonhydro renewable source of electricity that can be used for base load electricity generation.

4.2.5 BIOGAS TECHNOLOGY

4.2.5.1 Introduction

Methane gas emitted from manure management systems in Tennessee represents a little less than 1 percent of the state's total annual GHG emissions. While not a large component of the state's emissions, applying biogas technologies to reduce the methane emitted from animal manure to produce a renewable energy source and valuable by-products represent what can be a lucrative opportunity for farmers. The education of the state's farmers as to the economic potential of producing biogas from animal manure is a policy that should be considered.

The U.S. biogas experience has demonstrated that biogas technology is not applicable for all farms. In many situations however, it can be a cost-effective and environmentally-friendly method for treating manure and liquid waste. Biogas production is best suited for farms that handle large amounts of manure as a liquid, slurry, or semi-solid with little or no bedding added. Biogas systems require a financial investment and a management responsibility. The system must be designed by an experienced designer, who is well versed with the common problems associated with biogas production. Additionally, the farm owner or operator must be committed to the digester's success.

4.2.5.2 Biogas System Components

Biogas technology is a manure management tool that promotes the recovery and use of biogas as energy by adapting manure management practices to collect biogas. The biogas can be used as a fuel source to generate electricity for on-farm use or for sale to the electrical grid, or for heating or cooling needs. The biologically stabilized by-products of anaerobic digestion can be used in a number of ways, depending on local needs and resources. Successful byproduct applications include use as a crop fertilizer, animal feed, bedding, and as aquaculture supplements.

A typical biogas system consists of the following components:

- Manure Collection
- Anaerobic Digester
- Effluent Storage
- Gas Handling
- Gas Use

Each of these components is discussed briefly.

4.2.5.3 Manure Collection

Livestock facilities use manure management systems to collect and store manure because of sanitary, environmental, and farm operational considerations. Manure is collected and stored as either liquids, slurries, semi-solids, or solids.

Raw Manure. Manure is deposited with a solids content of 8 to 25 percent, depending upon animal type. It can be diluted by various process waters or thickened by air drying or by adding bedding materials.

Liquid Manure. Manure handled as a liquid has been diluted to a solids content of less than 3 percent. This manure is typically "flushed" from where it is deposited, often using fresh or recycled water. The manure and flush water can be pumped to treatment and storage tanks, ponds, lagoons or other suitable structures before land application. Liquid manure systems may be adapted for biogas production and energy recovery in "warm" climates. In colder climates, biogas recovery can be used, but is usually limited to gas flaring for odor control.

Slurry Manure. Manure handled as a slurry has been diluted to a solids content of about 3 to 10 percent. Slurry manure is usually collected by a mechanical "scraper" system. This manure can be pumped, and is often treated or stored in tanks, ponds or lagoons prior to land application. Some amount of water is generally mixed with the manure to create a slurry. For example, spilled drinking water mixes with pig manure to create a slurry. Manure managed in this manner may be used for biogas recovery and energy production, depending on climate and dilution factors.

Semi-Solid Manure. Manure handled as a semi-solid has a solids content of 10 to 20 percent. This manure is typically scraped. Water is not added to the manure, and the manure is typically stored until it is spread on local fields. Fresh scraped manure (<1 week old) can be used for biogas and energy production in all climates, because it can be heated to promote bacterial growth.

Solid Manure. Manure with a solids content of greater than 20 percent is handled as a solid by a scoop loader. Aged solid manure or manure that is left "unmanaged" (i.e., is left in the pasture where it is deposited by the animals) or allowed to dry is not suitable for biogas recovery.

4.2.5.4 Digester Types

The digester is the component of the manure management system that optimizes naturally occurring anaerobic bacteria to decompose and treat the manure while producing biogas. Digesters are covered with an air-tight impermeable cover to trap the biogas for on-farm energy use. The choice of which digester to use is driven by the existing (or planned) manure handling system at the facility. The digester must be designed to operate as part of the facility's operations. One of three basic options will generally be suitable for most conditions. **Table 4.2.5.4.A** summarizes the main characteristics of these digester technologies.

Covered Lagoon. Covered lagoons are used to treat and produce biogas from liquid manure with less than 2 percent solids. Generally, large lagoon volumes are required, preferably with depths greater than 12 feet. The typical volume of the required lagoon can be roughly estimated by multiplying the daily manure flush volume by 40 to 60 days. Covered lagoons for energy recovery are compatible with flush manure systems in warm climates. Covered lagoons may be used in cold climates for seasonal biogas recovery and odor control (gas flaring). **Figure 4.2.5.4.A** illustrates a floating cover module for lagoon applications. Typically, multiple modules cover the lagoon surface and can be fabricated from various materials.

Complete Mix Digester. Complete mix digesters are engineered tanks, above or below ground, that treat slurry manure with a solids concentration in the range of 3 to 10 percent. These structures require less land than lagoons and are heated. Complete mix digesters are compatible with combinations of scraped and flushed manure.

Plug Flow Digester. Plug flow digesters are engineered, heated, rectangular tanks that treat scraped dairy manure with a range of 11 to 13 percent total solids. Swine manure cannot be treated with a plug flow digester due to its lack of fiber.

4.2.5.5 Effluent Storage

The products of the anaerobic digestion of manure in digesters are biogas and effluent. The effluent is a stabilized organic solution that has value as a fertilizer, and other potential uses. Waste storage facilities are required to store treated effluent because the nutrients in the effluent cannot be applied to land and crops year round.

The size of the storage facility and storage period must be adequate to meet farm requirements during the non-growing season. Facilities with longer storage periods allow flexibility in managing the waste to accommodate weather changes, equipment availability and breakdown, and overall operation management.

4.2.5.6 Gas Handling

A gas handling system removes biogas from the digester and transports it to the end-use, such as an engine or boiler. Gas handling includes: piping; gas pump or blower; gas meter; pressure regulator; and condensate drain(s).

Biogas produced in the digester is trapped under an air-tight cover placed over the digester. The biogas is removed by pulling a slight vacuum on the collection pipe (e.g., by connecting a gas pump/blower to the end of the pipe) which draws the collected gas from under the cover. A gas meter is used to monitor the gas flow rate. Sometimes a gas scrubber is needed to clean or "scrub" the biogas of corrosive compounds contained in the biogas (e.g., hydrogen sulfide). Since the gas storage space is limited (i.e., the volume under the cover), a pressure regulator is used to release excess gas pressure from the cover. Warm biogas cools as it travels through the piping and water vapor in the gas condenses. A condensate drain(s) removes the condensate produced.

4.2.5.7 Gas Use

Recovered biogas can be utilized in a variety of ways. The recovered gas is 60-80 percent methane, with a heating value of approximately 600-800 Btu/ft^3. Gas of this quality can be used to generate electricity; it may be used as fuel for a boiler, space heater, or refrigeration equipment; or it may be directly combusted as a cooking and lighting fuel. Most equipment that uses natural gas, propane, or butane as fuel can be fueled by biogas.

Electricity can be generated for on-farm use or for sale to the local electric power grid. The most common technology for generating electricity is an internal combustion engine with a generator. The predicted gas flow rate and the operating plan are used to size the electricity generation equipment.

Engine-generator sets are available in many sizes. Some brands have a long history of reliable operation when fueled by biogas. Electricity generated in this manner can replace energy purchased from the local utility, or can be sold directly to the local electricity supply system. In addition, waste heat from these engines can provide heating or hot water for farm use.

Boilers and Space Heaters. Boilers and space heaters fired with biogas produce heat for use in the facility operations. Although this may not be the most efficient use of the gas, in some situations it may be a farm's best option.

Chilling/Refrigeration. Dairy farms use considerable amounts of energy for refrigeration. Approximately 15 to 30 percent of a dairy's electricity load is used to cool milk. Gas-fired chillers are commercially available and can be used for this purpose. For some dairies, this may be the most cost effective option for biogas utilization.

Other energy use options may exist. For example, a nearby greenhouse could be heated with the biogas, and CO_2 from the heater exhaust could be used to enhance plant growth. These options need to be evaluated on a case-by-case basis.

Benefits of Biogas Technology

Most confined livestock operations handle manure as liquids, slurries, semi-solids, or solids that are stored in lagoons, concrete basins, tanks, and other containment structures. These structures are typically designed to comply with local and state environmental regulations and are a necessary cost of production.

Biogas technology can be a cost-effective, environment and neighborhood friendly addition to existing manure management strategies. Biogas technologies anaerobically digest manure, resulting in biogas and a liquefied, low-odor effluent. By managing the anaerobic digestion of manure, biogas technologies significantly reduce Biochemical Oxygen Demand (BOD), and pathogen levels; remove most noxious odors; and convert most of the organic nitrogen to inorganic N (e.g., ammonium).

The principal reasons a farmer or producer would consider installing a biogas system are:

On-Site Farm Energy. By recovering biogas and producing on-farm energy, livestock producers can reduce monthly energy purchases from electric and gas suppliers.

Reduced Odors. Biogas systems reduce offensive odors from overloaded or improperly managed manure storage facilities. These odors impair air quality and may be a nuisance to nearby communities. Biogas systems reduce these offensive odors because the volatile organic acids, the odor causing compounds, are consumed by biogas producing bacteria.

High Quality Fertilizer. In the process of anaerobic digestion, the organic nitrogen in the manure is largely converted to ammonium, the primary constituent of commercial fertilizer, which is readily available and utilized by plants.

TABLE 4.2.5.4.A SUMMARY CHARACTERISTICS OF DIGESTER TECHNOLOGIES

Characteristics	Covered Lagoon	Complete Mix Digester	Plug Flow Digester
Digestion Vessel	Deep Lagoon	Round/Square In/Above-Ground Tank	Rectangular In-Ground Tank
Level of Technology	Low	Medium	Low
Supplemental Heat	No	Yes	Yes
Total Solids	0.5 - 3%	3 - 10%	11 - 13%
Solids Characteristics	Fine	Coarse	Coarse
HRT (days)	40 - 60	15+	15+
Farm Type	Dairy, Hog	Dairy, Hog	Dairy Only
Optimum Location	Temperate and Warm Climates	All Climates	All Climates

Hydraulic Retention Time (HRT) is the average number of days a volume of manure remains in the digester.

Reduced Surface and Groundwater Contamination. Digester effluent is a more uniform and predictable product than untreated manure. The higher ammonium content allows better crop utilization and the physical properties allow easier land application. Properly applied, digester effluent reduces the likelihood of surface or ground-water pollution.

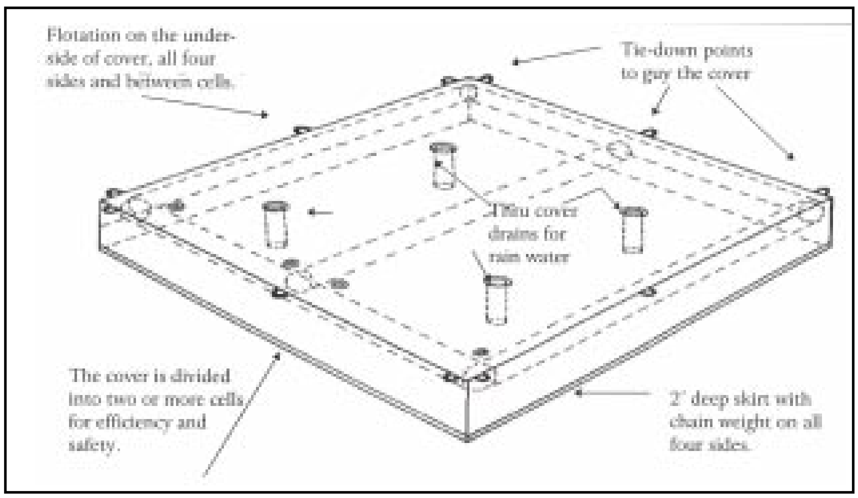


Figure 4.2.5.4.A Floating Cover Module for Lagoon Application

Pathogen Reduction. Heated digesters reduce pathogen populations dramatically in a few days. Lagoon digesters isolate pathogens and allow pathogen kill and die-off prior to entering storage for land application.

Biogas recovery can improve profitability while improving environmental quality. Maximizing farm resources in such a manner may prove essential to remain competitive and environmentally sustainable in today's livestock industry. In addition, more widespread use of biogas technology will create jobs related to the design, operation, and manufacture of energy recovery systems and lead to the advancement of U.S. agri-business.

The U.S. Biogas Experience

Rising oil prices in the 1970s triggered an interest in developing "commercial farm-scale" biogas systems in the United States.

During this developmental period approximately 140 biogas systems were installed in the U.S., of which about 71 were installed at commercial swine, dairy, and caged layer farms. **Table 4.2.5.7.A** summarizes the status and technical classification for those farm-based systems. This table does not include the 70 digesters that were installed as university research and demonstration projects. This is a key distinction because to understand the commercial status of U.S. biogas development it is important to look at the commercial farms that operate biogas systems.

As indicated in **Table 4.2.5.7.A**, many biogas systems failed. These failures have contributed to the current poor technical perception held by the livestock industry, and have resulted in very limited biogas development since the 1970s.

TABLE 4.2.5.7.A STATUS AND DISTRIBUTION OF COMMERCIAL FARM-BASED BIOGAS SYSTEMS IN THE U.S.

	Complete Mix Digester	Plug Flow Digester	Covered Lagoon	TOTAL
Operating	9	9	7	25
Not Operating	13	30	3	46
TOTAL	22	39	10	71

Source: DOE, 1995 "Methane Recovery from Animal Manures: A Current Opportunities Casebook," August 1995.

However, learning from failures is part of the technology development process. Examining past failures led to improvements and refinements in existing technologies and newer, more practical systems. For example, the success rate of biogas systems built after 1982 was far greater than that of digesters built before 1982.

The main reasons for the success and failure of biogas recovery projects follow.

Reasons for Success

Biogas recovery projects succeeded because:

1) The owner/operator realized the benefits biogas technology had to offer and wanted to make it work.

2) The owner/operator had some mechanical knowledge and ability and had access to technical support.

3) The designer/builder built systems that were compatible with farm operation.

4) The owner/operator increased the profitability of biogas systems through the utilization and sale of manure byproducts. One facility operator generates more revenues from the sale of electricity and other manure byproducts than from the sale of milk.

Reasons for Failure

Biogas recovery projects failed because:

1) Operators did not have the skills or the time required to keep a marginal system operating.

2) Producers selected digester systems that were not compatible with their manure handling methods or layout of their farms.

3) Some designer/builders sold "cookie cutter" designs to farms. For example, of the 30 plug flow digesters built, 19 were built by one designer and 90 percent failed.

4) The designer/builders installed the wrong type of equipment, such as incorrectly sized engine-generators, gas transmission equipment, and electrical relays.

5) The systems became too expensive to maintain and repair because of poor system design.

6) Farmers did not receive adequate training and technical support for their systems.

7) There were no financial returns of the system or returns diminished over time.

8) Farms went out of business due to non-digester factors.

4.3 ENERGY CONSERVATION

4.3.1 LED TRAFFIC LIGHTS

An estimated 3 to 4.5 million traffic signals are presently operating in the U.S. (Hodapp, 1997; Suozzo, 1998). Each contains three 200- or 300-mm diameter signal heads, one each of red, yellow and green. Typically, each signal head contains an incandescent bulb of a wattage between 67 W and 150 W. The wattage required varies with the color: red signals require the highest wattage lamp; yellow and green signals require lower wattages. The energy demand of the average traffic signal is approximately 990 kWh/year. (Hoffman, 1990).

An increasing number of red traffic signal heads in the U.S. utilize light-emitting diode (LED) light sources. Red LED signal heads use only 10 W to 15 W, approximately 90 percent less than the 150 W incandescent heads they replace. Thus energy savings, as well as other perceived benefits such as the longer rated lives of solid-state LEDs (IESNA, 1993), have prompted many state and municipal transportation agencies to consider installing LED traffic signals.

Several barriers prevent more widespread use of LED traffic signals. There is a dearth of objective and accurate technical information about the performance of LED traffic signals in the field. Standard-setting bodies such as the Institute for Transportation Engineers (ITE) are presently revising decades-old incandescent-specific performance standards. Researchers are voicing concerns about the visibility of LED signals, especially by color-deficient individuals. The initial cost of LED signal heads is expensive relative to the cost of a replacement incandescent bulb. Furthermore, the initial investment of money and personnel needed to replace existing traffic signals and heads is not a trivial matter for cash-strapped municipalities. However, there appears to be widespread agreement among the specification community that LED traffic signals will replace conventional incandescent signals.

Regardless of the metric used to measure them, however, LEDs remain relatively low-power solid state devices (IESNA, 1993). For example, one red LED traffic signal head that contains 196 individual

LEDs operates on a 120 V circuit, and has a wattage of less than 10 W, in comparison with a 150 W incandescent lamp it is intended to replace. Published estimates of the energy savings that can be achieved due to the replacement of a red signal head with an LED unit range from 82 percent to 93 percent (Vargas, 1994; Delean, 1996; Snel, 1996; Haussler, 1997; Stahl, 1997).

Because the red signal head is on an estimated 50 percent of the time throughout the day for a typical traffic cycle (Suozzo, 1998), estimates of the total traffic signal energy that could be saved by installing red LED signal heads alone range from 35 percent to 40 percent (Pollack, 1996; Deemer, 1997). In order to determine the added capital cost of purchasing LED traffic signal heads for installation, several cities and U.S. states have estimated the "payback" period for LED traffic signal heads - the time required to recoup capital costs through savings (ignoring the time effect on monetary values due to inflation). These times can vary widely. Payback periods of 1 to 1.5 years (Delean, 1996), 1.5 to 3 years (Lundberg, 1997), 4.5 years (Haussler, 1997), and 6 to 7 years (Vargas, 1994) have all been reported. The actual payback period will be a function of the utility energy cost, the actual cost of the unit, and possible financial incentives offered by utility or government organizations.

A number of electric utilities and public agencies offer or have offered financial incentives to municipalities that install LED traffic signals, including Pacific Gas and Electric, the Colorado Public Service Company, San Diego Gas and Electric, the Sacramento Municipal Utility District and Pacific Power and Portland General Electric (Vargas, 1994; Snel, 1996; Wyland, 1996; Deemer, 1997; Suozzo, 1998). This incentive often takes the form of rebates which partially cover the initial costs of purchasing the signals. Still, the high initial cost of LED traffic signal heads appears to be a significant barrier to wider use of this technology.

As discussed above, the operating costs of LED traffic signals are much less than that of corresponding conventional signals, largely because of reduced energy costs. Maintenance costs are also lower, largely because LEDs have much longer rated lives than the incandescent lamps used in traffic signals. LEDs are often reported to have lives of over 100,000 hours (Bierman, 1998), in comparison to the 8000-hour life of an incandescent traffic signal lamp (Snel, 1996). When incorporated into traffic signal heads, the claimed life of the products may range from 5 to 30 years, with 10 years being the most common estimate (Delean, 1996; Miller, 1996; Pollack, 1996; Deemer, 1997; Haussler, 1997; Stahl, 1997; Kiely, 1998). This compares to the usual life of the incandescent signal lamp between 1 and 2 years (Vargas, 1994; Delean, 1996; Pollack, 1996; Deemer, 1997; Haussler, 1997; Stahl, 1997).

It is very likely that LED traffic signals will continue to grow in use in lighting applications throughout North America and the world, due in large part to the potential for significant energy savings that they furnish. Technological and market forces appear to be in alignment. LEDs are popular, and interest in their progress is widespread.

4.3.2 HEAT PUMP WATER HEATERS FOR RESIDENTIAL AND COMMERCIAL BUILDINGS

Introduction

The impact of domestic water heating on GHG emissions is not commonly discussed. A typical household electric water heater that provides 80 gallons of heated water per day is responsible for more than 9 tons of CO_2 per year, twice as much as the typical car. There are over 35 million electric water heaters in use nationwide. Natural gas water heaters contribute over 2 tons of CO_2 annually, and they outnumber electric heaters. Overall, the annual total CO_2 produced by residential water heaters is essentially equal to the CO_2 produced by all the cars in the United States.

It is estimated that there are about 2 million residences in Tennessee. Assuming a 60 percent to 40 percent mixture of natural gas to electric water heaters, one could roughly estimate that residential water heating in Tennessee is responsible for about 9.6 million tons of CO_2 emissions annually.

Heat pumps and desuperheaters offer an energy-efficient method of heating domestic water for residential and commercial buildings. As a result, there have been numerous efforts over the years to develop dedicated (i.e., water heating only) heat pump-based water heating equipment and to integrate water heating into existing space conditioning heat pump equipment. The former have established small market niches while the latter are more widely available, particularly on heat pump systems with relatively constant heating capacity. Numerous applications in North America, Europe and Japan have a dedicated heat pump recovering heat from a waste heat stream, such as building exhaust air, to produce domestic hot water.

Heat pump water heating equipment in different countries comes in a variety of configurations, capacities and efficiencies. The products are available worldwide from a number of manufacturers (Caneta Research Inc., 1993).

The **ambient air-source** heat pump water heater (**Figure 4.3.2.A**) was developed in the 1970s and resembles the conventional electric resistance storage water heater. The heat pump condenser is often the immersion-type, while the evaporator is located in an enclosure on top of the tank with the compressor. The heat pump water heater can also be remotely located from the storage tank. Sizes for both residential and commercial applications are available from about 15 manufacturers worldwide. There are about nine manufacturers in North America alone.

The **residential exhaust-air** heat pump water heater (**Figure 4.3.2.B**) is similar in many respects to the ambient air-source unit except that the air cooled by the evaporator is exhausted outdoors. Make-up air for ventilation purposes is brought in separately. The output from the unit is for water heating and/or space heating. There are about five manufacturers worldwide, with three located in North America.

A **desuperheater** (**Figure 4.3.2.C**) is a refrigerant hot-gas-to-water heat exchanger which is installed between the compressor and reversing valve of a conventional water-to-air or air-to-air heat pump. The desuperheater removes the superheat from the compressor discharge gas prior to entry into the refriger-

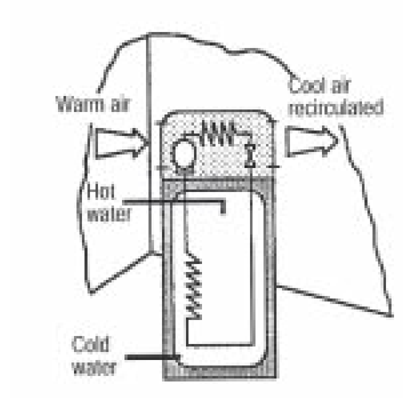


Figure 4.3.2.A Ambient Air-Source.

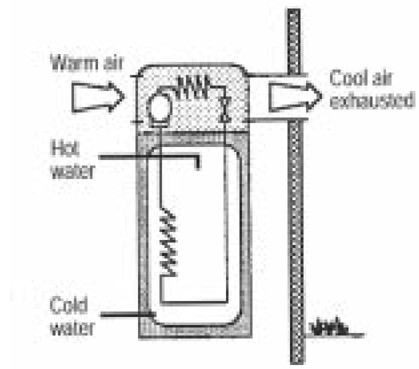


Figure 4.3.2.B Residential Exhaust-Air.

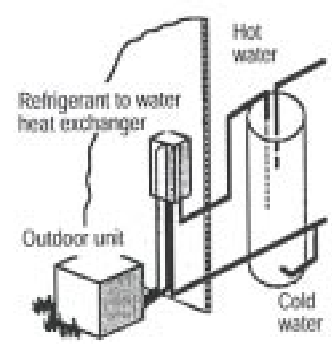


Figure 4.3.2.C Desuperheater.

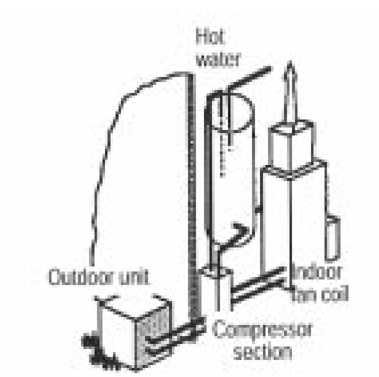


Figure 4.3.2.D Integrated Unit.

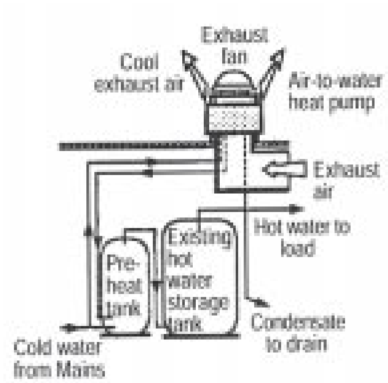


Figure 4.3.2.E Commercial Exhaust-Air Heat Pump.

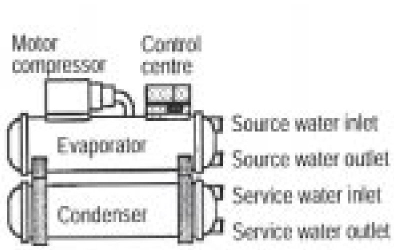


Figure 4.3.2.F Heat Recovery Heat Pump.

ant condenser. There are about 10 desuperheater manufacturers in North America.

Integrated units (**Figure 4.3.2.D**) are heat pumps which provide space heating, cooling and water heating, often on demand, and are sometimes combined with a ventilation function in the same unit. Water heating is by desuperheating or by full-condensing of refrigerant hot gas emerging from the compressor. Water heating can often be done, on demand, when no space heating or cooling is required. There are about seven manufacturers offering such products worldwide, with three in North America.

The **commercial exhaust-air** heat pump is depicted in **Figure 4.3.2.E**. This unit, which provides service water heating, is roof-mounted over central exhaust-air outlets in commercial and multiple-residential buildings. The water is heated in a water-to-refrigerant condenser and stored in a pre-heat tank located in close proximity to the central storage water heater. The cooled exhaust-air is discharged to the outdoors in most applications. The cooled air can be re-circulated in some applications to augment the space cooling load, thus providing "free cooling."

Finally, the largest type of hot water heat pump is the **heat recovery heat pump** (**Figure 4.3.2.F**). These water-to- water units are essentially modified chillers available in heating capacities of up to 6MW. They can produce hot water up to 120° F and have been used in large commercial and institutional buildings where heat can be recovered from cooling tower water or other waste heat sources.

4.3.2.1 Heat Pump Water Heating

Equipment Characteristics

Table 4.3.2.1.A summarizes the important characteristics of the different types of heat pump water heating equipment. The water heating capacity of the different types of heat pump water heaters varies considerably. The residential exhaust-air heat pump units have the lowest water heating capacity but in application often run continuously. The ambient air source heat pump water heaters range in size from 1.5 kW, for a residential unit, to 120 kW in the case of large commercial units. Desuperheater water heating capacity and that of integrated heat pumps currently range up to 6 kW. The large commercial exhaust-air units and the heat recovery heat pumps have much higher capacities and coefficients of performance than the smaller products.

The majority of these heat pump water heaters employ HCFC-22 refrigerant. The exception is the heat recovery heat pump which has traditionally used CFC-114. At this time no acceptable alternative has been identified for CFC-114 for the high temperature applications.

Table 4.3.2.1.A also provides typical energy savings from field performance results (Caneta Research Inc., 1993) expressed in kWh/year or as percent of hot water load displaced in the case of desuperheaters or integrated heat pumps.

TABLE 4.3.2.1.A IMPORTANT PERFORMANCE CHARACTERISTICS OF HEAT PUMP WATER HEATERS.

HWHP Type	Water Heating Capacity Range kW	Rated COP	Typical Energy Savings [1] kWh/yr
Ambient Air-Source	1.5 -120	2.8-4.0	800-1600 res. 10,000-30,000 comm.
Residential Exhaust-Air	1.5 - 2.0	up to 2.9	1600
Desuperheaters	3.0 - 6.0	N.A.	15-30% of load
Integrated	5.0 - 6.0	2.0 - 3.25	75-80% of load
Commercial Exhaust-Air	20-25	up to 5.3	40,000-120,000
Heat Recovery Heat Pump	200-6000	4.7-6.0	-

Equipment Suppliers

The analysis project obtained product specifications from 15 manufacturers of dedicated HWHPs, 8 desuperheater manufacturers, 3 exhaust-air heat pump manufacturers and 7 integrated system manufacturers. **Table 4.3.2.1.B** lists the suppliers and the capacities available.

Market Trends and Status

The heat pump water heater peaked in popularity in the early 1980s in both North America and Europe, as demonstrated in **Figure 4.3.2.1.A**. In 1983 there were 135 companies in Germany and Austria who offered ambient air source heat pump water heaters. Today, with the softening of world oil prices and natural gas deregulation, there are only about 20. Similarly, in the United States the Gas Appliance Manufacturers Association listed 17 manufacturers in 1984, yet only six today.

Current estimates of annual sales for some European and North American countries are shown in **Table 4.3.2.1.C**. Sweden stands out from the other countries of **Table 4.3.2.1.C** and **Figure 4.3.2.1.A** because of its high number of sales of exhaust air heat pumps. In Sweden, there is a regulation for minimum mechanical ventilation in residences, with a further requirement to recover 50 percent of the enthalpy in the exhaust-air. This regulation has resulted in approximately 75 percent of all new homes in Sweden being equipped

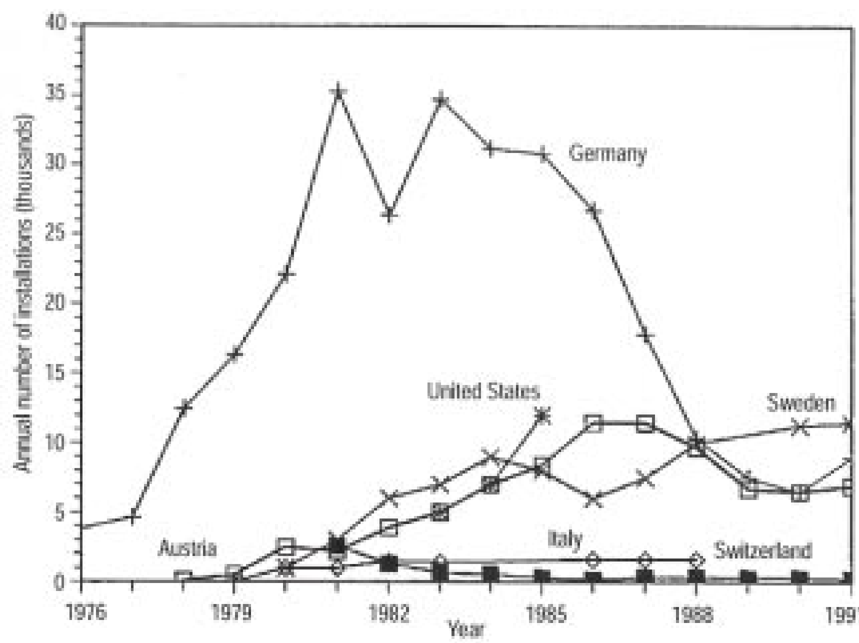


Figure 4.3.2.1.A Trends in HPWHs Installations.

TABLE 4.3.2.1.B EQUIPMENT SUMMARY

Manufacturer	Country	WATER HEATING CAPACITY kW	(kBtu/hr)
AMBIENT-AIR-SOURCE (WITH TANK)			
AL-KO Kober	Austria	1.5	(5.1)
Blomberg - Werke GmbH	Germany	1.85	(6.3)
Dec International - Therma-Stor Products Group	United States	up to 18.1	(up to 62)
Heizbösch	Austria	1.8	(6.1)
Hoval	Austria	1.9	(6.5)
Mueller Commercial Refrigeration Products	United States	10.1 to 48.0	(35 to 167)
Ochsner	Austria	1.8	(6.1)
Reliance Water Heater Company	United States	3.3	(11.3)
Siemens - KKW	Germany	1.9	(6.5)
State Industries Inc.	United States	3.3	(11.3)
Stiebel Eltron	Germany	1.2	(4.1)
Vestherm	Denmark	1.8	(6.1)
Vogel	Austria	1.8	(6.1)
AMBIENT-AIR-SOURCE (WITHOUT TANK)			
Colmac Coil Manufacturing Inc.	United States	17.3 to 120	(59 to 410)
Crispaire Company	United States	3.3 to 58.6	(12.7 to 200)
Daikin Industries	Japan	33 to 66	(113 to 226)
Energy Utilization Systems Inc.	United States	3.5	(12.0)
Mitsubishi Heavy Industries Ltd.	Japan	27.3 to 74.2	(93 to 253)
Mueller Commercial Refrigeration Products	United States	14.1 to 103	(48 to 352)
Ochsner	Austria	1.75 to 4.3	(6 to 14.7)
Rheem Manufacturing Co. Water Heater Division	United States	-	-
Stiebel Eltron	Germany	1.6	(5.5)
Thermo Energie	Austria	1.7	(5.8)
AMBIENT-AIR-SOURCE SPA & POOL HEATERS			
Crispaire Company	United States	4.7 to 22.9	(16.2 to 78)
Energy Utilization Systems Inc.	United States	4.1 to 30.9	(14.0 to 106)
Nilan A/S	Denmark	from 11.7	(from 40)
DESUPERHEATER WATER HEATERS			
Addison Products Company, Weatherking Division	United States	17.6	(60)
American Equipment Systems Corp.	United States	17.6 to 352	(60 to 1200)
American Energy Products	United States	17.6	(60)
Crispaire Company	United States	17.6	(60)
Energy Conservation Unlimited Inc.	United States	17.6 to 176	(60 to 600)
Enro Manufacturing Inc.	United States	5.6 to 12.3	(19.2 to 42)
Florida Heat Pump Mfg. Division, Harrow Products	United States	7.9 to 17.6	(27 to 60)
National Energy Systems Inc.	United States	17.6 to 703	(60 to 703)
EXHAUST-AIR SYSTEMS			
Dec International - Therma-Stor Products Group	United States	up to 1.95	(up to 6.6)
Elektro Standard AB	Sweden	1.5	(5.1)
Heatrade Inc.	Canada	22.0	(75)
INTEGRATED SYSTEMS			
Carrier Corp.	United States	6.0	(20.5)
Daikin Industries	Japan	3.4	(11.6)
Dec International - Therma-Stor Products Group	United States	-	-
Elektro Standard AB	Sweden	2.0	(6.8)
Nilan A/S	Denmark	1.2 to 1.8	(4.1 to 6.1)
Nobo Stardal A.S	Norway	1.5	(5.1)
Nordyne, A Nortek Company	United States	-	-
HPWHs WITH HYDRONIC SPACE HEATING			
Blomberg - Werke GmbH	Germany	up to 1.85	(up to 6.3)
Ochsner	Austria	1.75 to 4.3	(6 to 14.7)
Siemens - KKW	Germany	1.9	(6.5)
Stiebel Eltron	Germany	1.2	(4.1)
Thermo Energie	Austria	1.7	(5.8)
Vestherm	Denmark	1.8	(6.1)
Vogel	Austria	1.7	(5.8)
HEAT RECOVERY HEAT PUMPS			
McQuay - Snyder General Corporation	United States	197.5 to 5215	(674 to 17,800)

TABLE 4.3.2.1.C HPWHS - MARKET STATUS.

Reference	Country	Estimated Annual Sales (Units)	Estimated Total Number Installed
Halozan	Austria	6000-10,000	80,000
Berlin	Canada	<50	
Goricke	Germany	5000-10,000	300,000
Manduzio	Italy	1800	
Ruyg	Netherlands		1500
Aarlien	Norway	300-400	2000
Backstrom, Fehrm	Sweden	11,500*	70,000*
Prista	Switzerland	290	7,500
Air Conditioning, Heating & Refrig. News	USA	10,000-15,000	
	Total about	38,000-52,000	

Estimates are based on information supplied by references shown.
* number represents exhaust-air units providing water and space heating.

TABLE 4.3.2.1.D SUMMARY OF UTILITY AND GOVERNMENT PROGRAMS.

Utility	Country	Incentive/Promotion Status
Oberosterreichische Kraft. AG	Austria	offer incentives of $510 per installation
	Austria	incentives offered by government up to $450 per installation
British Columbia Hydro	Canada	do not have an incentive or promotion programme
Ontario Hydro	Canada	"Savings by Design" programme allows incentives of up to $500/kW or 50% of the incremental cost
Ente Nazionale per l'Energia	Italy	provide financial loans of up to 70% of HWHP cost
Ellettrica	Italy	
Kyushu Electric Power Co.	Japan	have not explored HWHPs in commercial building sector
Tokyo Electric Power Company	Japan	supported development of an integrated system by Daikin
KEMA N.V.	Netherlands	conducting demonstration projects for 30 installations
REMU N.V.	Netherlands	rent HWHPs to residential customers for NLG 207/year
	Norway	offer investment subsidies of up to 40% of cost of HWHP
Alabama Power Company	USA	incentive of $400/kW for commercial units
Florida Power Corporation	USA	initiated a dealer award programme in July 1992
Florida Power & Light	USA	performing demonstration projects before proceeding with an incentive programme
Georgia Power Company	USA	provide assistance to commercial customers; may have an incentive programme for 1993
Gulf Power Company	USA	"Good Sense Home Programme" includes HWHPs
Hawaiian Electric Company	USA	state tax credit of 20% exists in Hawaii
Potomac Electric Power Co.	USA	offer incentive of $500/HWHP under 50 gallons; $1000/HWHP over 50 gallons
Puget Sound Power & Light	USA	offer commercial incentives based on utility avoided cost
Tennessee Valley Authority	USA	offer loans, proposing a commercial incentive programme
Wisconsin Public Service Corp.	USA	offer an incentive of $300/kW for commercial customers

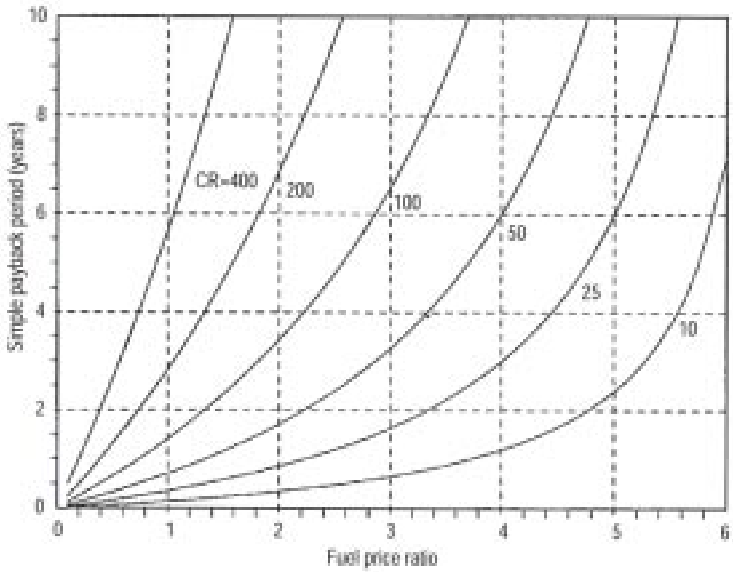


Figure 4.3.2.2.A Commercial HWHP - Economic Attractiveness.
COP(HP) = 4.0 COP(base) = 0.6 Load = 50,000 kWh

with an exhaust-air heat recovery heat pump water heater.

Utility and Government Programs

Table 4.3.2.1.D presents a summary of the survey findings of utility and government marketing and promotion programs. There are programs in Austria, Italy, the Netherlands, Norway and the United States which offer capital cost rebates or incentives to encourage the sales of hot water heat pumps. Some programs are a flat rate rebate while others are based on a kilowatt demand reduction.

4.3.2.2 Cost Benefit Analysis

To assist in estimating the economics of HWHPs, a series of graphs were developed, an example of which is shown in **Figure 4.3.2.2.A**. Given the fuel price ratio (the customer cost for electricity divided by the customer cost for fuel in similar units) for a given region, the cost ratio for a given application and a given payback period can be obtained. The cost ratio is the incremental cost over the base case system (in this example a fuel-fired system with an annual COP of 0.6), in thousands of dollars, divided by the customer cost for electricity in dollars per kWh. Alternatively, if the incremental cost is known, the cost ratio can be calculated and the simple payback period can be determined.

Table 4.3.2.2.A gives similar information to **Figure 4.3.2.2.A**. The numbers shown represent the maximum allowable incremental cost of a heat pump water heating system over a conventional system which would permit a simple payback period of three years or less. Three years was selected as an acceptable simple payback period typical for a commercial system. Results are shown for two heat pump efficiency levels and two gas efficiency levels. It was estimated that the heat pump system in this example would cost between $7,200 and $12,800 installed, while a fuel-fired system would cost $2,500. Since a system of this size would be installed in a commercial application, credit has been given to the “free cooling” provided by the heat pump water heater. The free cooling reduces the cooling load on the conventional cooling system, thus providing greater electrical savings. Similar figures and tables, as for the last example, are contained within the analysis report (Caneta Research Inc., 1993) for residential and large commercial installations.

In work undertaken by Oak Ridge National Laboratory (Olszweski and Fontana, 1983), energy savings with desuperheaters on residential air-source heat pumps were found to be related to operating time of heat pump and capacity. A correlation was developed from a number of computer simulations and the savings were presented as a function of annual space heating and cooling loads (**Figure 4.3.2.2.B**). It would be valuable if a similar correlation were developed for heat pumps with full condensing capabilities in addition to desuperheating.

TABLE 4.3.2.2.A ECONOMIC ATTRACTIVENESS OF HWHPS - COMMERCIAL APPLICATION (INCLUDING EFFECT OF FREE COOLING).

Maximum allowable incremental cost to achieve a payback period of 3 years or less (US$):

	Versus gas-fired system COP=2.5/COP=4	**Versus high-efficiency gas** COP=2.5/COP=4	**Versus oil-fired system** COP=2.5/COP=4
Austria	4390/9930	1970/7510	4930/10,470
Canada	1850/3790	920/2860	6150/8080
Denmark	11,020/15,380	7220/11,580	13,300/17,660
Finland	420/3440	N.E./2610	5300/8330
Germany	2600/8350	580/6320	5490/11,240
Italy	-	-	16,770/21,890
Netherlands	3780/7350	1980/5550	6040/9610
New Zealand	3760/5420	2420/4080	-
Norway	-	-	9680/11,860
Sweden	-	-	11,600/14,840
Switzerland	7290/10,830	4620/8160	2360/5900
United Kingdom	3610/7420	1790/5610	2680/6490
United States	2270/4690	1120/3540	4200/6620

N.E. represents a system that has negative energy savings. Assumed conditions were an annual hot water load of 50,000 kWh and a base technology COP of 0.6 for the gas-fired and oil-fired systems and 0.8 for the high-efficiency gas system. COPs shown are annual heating COPs for heat pump (condenser output capacity divided by input power).

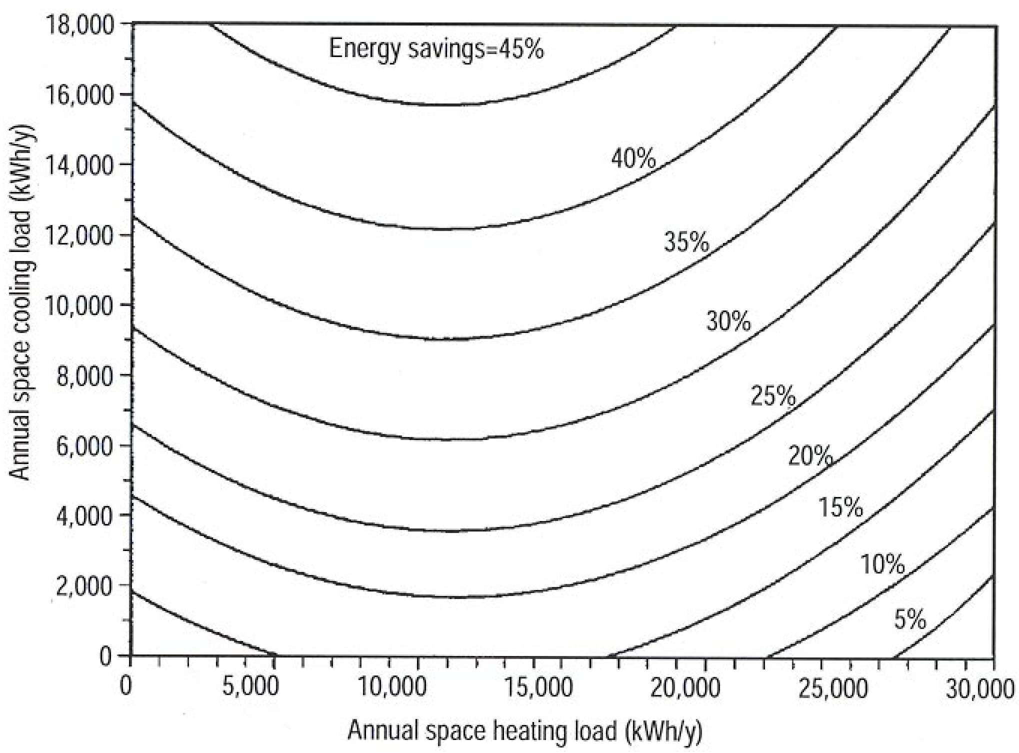


Figure 4.3.2.2.B Water Heating Energy Savings With a Desuperheater.

4.3.2.3 Conclusions

Market Status

The estimated number of present day sales of heat pump water heaters in North America, Europe and Japan range between 40,000 and 50,000 per year. In the United States, heat pump water heater sales are currently about 0.2 percent of annual water heater shipments. Niche markets do exist where heat pump water heaters have made a significant impact, such as in Sweden where about 75 percent of new homes have a HPWH installation, and in Hawaii where there are over 600 commercial installations.

Heat Pump Water Heater Competitiveness -Residential Market

The competitiveness of a heat pump water heater versus other forms of residential water heating depends on the electricity to fuel price ratio, hot water requirements, the incremental capital cost of the HPWH, and the efficiencies of the competing technologies. In general, typical applications of residential heat pump water heaters are not competitive with natural gas water heating. Compared to fuel oil, however, payback periods of less than 5 years do exist for installations in some IEA countries. Compared to electric resistance water heating, payback periods of under 5 years exist in every country examined. This suggests that the potential residential market for heat pump water heaters could be much larger than at present.

Heat Pump Water Heater Competitiveness-Commercial Market

Where space cooling at a site is required at all times of the year, the "free cooling" provided by a heat pump water heater improves its economic attractiveness. The simple payback period is under 3 years when compared to gas-fired water heating in all markets examined, with the exception of the United States and Canada. Where natural gas is unavailable, the simple payback period drops below the 3 year level in all IEA countries examined, including the United States and Canada.

Societal Benefits

Heat pump water heaters can have lower societal costs than electric resistance water heaters in residential and commercial applications. The societal costs depend on the cost of new generation capacity and competing fuels, and assumptions about efficiencies, electrical energy costs, incremental equipment capital and maintenance costs. The result of a comparison of societal costs also depends strongly on whether or not environmental benefits, such as lower overall resource energy use, are accounted for in the analysis.

Market Drivers

Higher fuel prices are unlikely in the 1990s and will not influence market growth as occurred in the early 1980s. High incentives and high promotion, based on the experiences of the electrical utilities surveyed, can yield sales. As well, minimum ventilation requirements can create a large market, as evidenced in Sweden. The creation of higher minimum efficiency standards than present levels for electric water heating could be considered as a means of encouraging more efficient products such as heat pump water heaters.

Promising Product Developments

The integration of space conditioning and water heating equipment presents the opportunity for improved economic performance because of the functions combined in one package. More operating data, however, is required to fully assess the cost benefit performance.

4.3.3 ELECTRIC POWER GENERATION FOR THE NEXT 50 YEARS

Introduction

Ask the average person where electricity comes from, and he or she is likely to reply, "Out of a wall socket." Pressed further, they may suggest a thermal or hydroelectric plant as the source, depending on where they live in the country. In response to further probing, some may guess either nuclear power or fossil fuel as the origin. But it would be only a guess. Most people do not have a clue where their electricity comes from. And why should they, as long as it is available when they need it? Plug something in, switch it on, and the power is there. No one thinks too much about how the kilowatts are made.

Some kilowatts come from hydroelectric sources, but most come from thermal plants using nuclear power or fossil fuels to produce gas and steam to run turbines which, in turn, drive generators. What most people do not know is that more than half the electricity used in America comes from coal.

The fuel of the 19th century is the fuel of the late 20th century, and it looks like it will be the best bet for the 21st century as well. How is this possible? Wasn't coal the cause of pollution that blackened buildings, created killer smog and caused emphysema (not to mention miners' health problems like black lung disease)?

All true once, but true no longer. Coal has changed. Not only do environmental regulations require that coal mining leaves the land in at least as good condition as before mining began, but also working conditions for miners have improved beyond all measure. Our forebears would not recognize the mechanized and automated mines of today—or the green fields and hillsides that were once surface mines. Nor would they believe that the power we take for granted comes from plants that give no visible evidence of the sooty fuel that fouled their cities, thickened their air and ruined their health.

Coal is Clean—The Rise and Fall of Nuclear Power

In the 1950s and 60s, coal-fired thermal generating plants were inefficient and dirty and environmental concerns made their future precarious. Biomass plants, oil-fired plants, natural gas-fired plants and nuclear plants were thought to be the way of the future. Relatively pollution-free and more efficient, they were expected to replace coal-fired plants, and huge investments were made in these new plants to meet America's growing energy demand. But, with the exception of natural gas, the promise of these fuels has not been kept. Nuclear power has proved to be both costly and unpopular. The last U.S. nuclear plant to enter service started up in 1996.

What happened to nuclear power? What became of the pollution-free technology that was to produce electricity at incredibly low prices. Like most lavish promises, it came with hidden costs. Those nuclear plants that were built and put into operation demand a larger work force than do fossil fuel plants of comparable size. They attract strong opposition because of perceived safety concerns. They are efficient, have low fuel costs and are pollution free, but disposal of nuclear waste is always a potential problem. The likelihood of anyone building a new nuclear plant is remote simply because it probably would prove impossible to gain the necessary approvals.

Coal currently supplies about 55 percent of America's electricity; nuclear power provides 23 percent. Natural gas generation amounts to 10 percent; hydroelectric and other renewable sources 11 percent; and oil 2 percent. Some of the nation's nuclear capacity is getting old. When it shuts down, it will not be replaced with new nuclear plants unless there are major changes both in regulation and in public attitudes. Natural gas or coal are the most viable sources of electricity now and, most likely, in the years to come.

Natural gas-fired generation is expected to grow seven times as fast as coal-fired generation in the next 15 years. Even so, nuclear sources will decline, renewable sources are not expected to grow much, and that leaves coal to fill the gap. According to James Markowsky, executive vice president power-generation for American Electric Power (AEP), this will mean a 20 percent increase in the amount of electricity currently generated from coal. "The use of coal to fuel our nation's electric infrastructure is an absolute necessity," he says. "Our economy and lifestyles depend on coal now and will continue to depend on coal well into the future."

Alternate fossil fuels are more expensive than coal. Currently, natural gas is the fuel of choice for new electric generation. Seventy-five percent of new plants chose it because initial costs per installed kilowatt are less than half as much as a coal plant. This is because of pollution control measures in coal plants that are not required in natural gas plants. But if expansion continues at the current rate, the demand for natural gas, and so its price, will probably rise faster than the price of coal. Clean coal will help moderate the price of natural gas if it is available as an option. Coal is the most economical source of energy we have. Moreover, it is available in abundance. America has proven coal reserves to last at least 250 years at current rates of consumption.

The World View

The situation is similar in the rest of the world. Coal is the world's most abundant fossil fuel. It is found the globe over, and distributed quite evenly. It is the most economical and most widely available fuel in developing and developed countries. Is it any wonder that the use of coal to generate electricity is expected to grow rapidly? The World Energy Council and the International Energy Agency predict that coal consumption for electrical generation will double in the next 15 years. Sixty percent of this growth will take place in Asia-Pacific countries. It is clean-coal technology that will make this growth not only possible but acceptable. Even if natural gas continues to be an economical choice, many other countries do not have this option and instead will pay to import American clean-coal technology. AEP's Markowsky says that while the choice of natural gas makes sense, it is equally sensible to have an alternative. "We need coal as a viable option," he said, going on to describe the Clean Coal Technology Program—a joint government and industry effort to develop clean coal technology. "The CCTP is driven by industry. DOE and industry have shared the cost, and currently there are 42 projects in 19 states, either underway or completed, that demonstrate the potential of clean coal."

While not a CCTP project, the Zimmer plant, owned in part by Cincinnati Gas & Electric, is a coal-fired plant in New Richmond, Ohio that was converted from nuclear power. The plant was 90 percent completed in 1984 when it became evident that it would never be licensed. At that time the owners decided to convert the plant to coal. This took another seven years, and the 1300-megawatt plant went into operation in 1991 burning high-sulfur local coal.

High Sulfur: No Problem

What about pollution abatement? Can you burn high-sulfur coal and meet pollution requirements? Yes, you can. Scrubber technology at the Zimmer plant traps the three main pollutants that result from burning coal: sulfur dioxide (SO_2), nitrogen oxide (NO_x) and fly ash. Zimmer plant emissions meet not only current Clean Air Act requirements but also the new standards that go into effect in 2004.

Modern scrubbers, a "post-combustion" approach to clean coal, are capable of removing up to 98 percent of SO_2 and up to 99 percent of particulate matter from burnt coal. Scrubbers are just one solution. There are four ways to clean coal. These are: Pre-combustion, Combustion, Post-combustion, and Conversion.

The pre-combustion method consists of cleaning sulfur from coal. This can be done by physically washing the crushed coal with water. In this way, up to 90 percent of pyritic sulfur can be removed. Organic sulfur cannot be washed away because it is chemically bonded to the coal molecule. Experimental chemical and biological techniques may improve on this rate in the future. The second process removes pollutants during combustion. This involves circulating fluidized bed combustion or CFB, in which coal is burned in the presence of limestone on a cushion of air. The limestone captures the SO_2 as the coal burns, and the temperature remains below the level required for NO_x to form. This process was known as far back as the 1920s, but in it latest form, combustion takes place under pressure. The combined-cycle turbine operation boosts overall efficiency to as high as 50 percent, compared to 36 percent for the conventional process.

With partial funding from the U.S. Department of Energy (DOE), AEP has built the 70-megawatt Tidd pressurized fluidized bed combustion plant in Brilliant, Ohio, as a demonstration project. This was the country's first large-scale demonstration of new environmentally clean coal combustion technology and the first to be funded by the CCTP. The result has been described as self-scrubbing coal. In Florida, the Jacksonville Electric Authority and DOE are sharing the cost of refurbishing an existing plant and installing what will be the largest CFB facility in the world—and one of the cleanest.

Post-combustion cleaning involves the use of scrubber systems like the one at Cincinnati Gas & Electric's Zimmer plant. Another example is Georgia Power Company's Newnan, Georgia plant where the scrubber removes up to 98 percent of the SO_2, captures 99 percent of other particulate, and produces gypsum as a byproduct. Sulfur collected by scrubbing often is used for other commercial applications.

The fourth method of cleaning coal is conversion. Since all fossil fuels share the same chemical heritage, it is not particularly difficult to convert them one to another. The process of changing coal into oil or gas has been known since 1913, but the availability of inexpensive natural gas or oil makes higher-cost conversion unattractive. Generally it has been done only on a large scale when gas or oil was either unavailable or in short supply. For thermal generation, conversion is attractive because oil made from coal can be cleaned more easily before burning. Gas made from coal burns almost as cleanly as natural gas.

The Wabash River Coal Gasification Project in Indiana, a DOE joint venture demonstration project, has been in operation since 1995. It processes high-sulfur local coal into gas that is burned at PSI Energy's Wabash River Generating Station in West Terre Haute, Indiana. At 262-megawatts, it is the largest single-train coal gasification combined-cycle power plant operating in the United States. The project reportedly exceeds the Phase II limits of the Clean Air Act. Tampa Electric has a 250-megawatt plant that is one of the cleanest coal-fired power stations in the world. It turns coal into gas and filters out impurities. The plant achieves emission levels closer to a natural gas plant than a coal-burning facility, with more than 95 percent of the sulfur pollutants removed. An integrated gasification combined-cycle system, the plant produces power at 42 to 50 percent efficiency. Other CCTP projects that are complete include the pyropower circulating fluidized bed combustion process at Nucla, Colorado; the coal reburning project of Wisconsin Power & Light at Casville, Wisconsin; the natural gas reburning and sorbent injection project of Illinois Power at Hennepin, Illinois; and the Passamaquoddy recovery scrubber at Thomaston, Maine.

Down the Line

Representatives from 170 countries met recently in Kyoto, Japan, to agree to terms of an international treaty to limit production of so-called greenhouse gases. Carbon dioxide, the leading greenhouse gas, is produced by burning any fossil fuel. However, conversion brings increased efficiency to burning coal. Eventually, new gasification combined-cycle power systems may cut CO_2 emissions by nearly 40 percent compared to a traditional coal plant. With the growth in coal consumption that forecasters predict, this efficiency, and reduction in CO_2, will be essential to the achievement of reduced greenhouse gas targets around the world.

Ninety percent of all the coal used in America is burned to generate electricity, according to the Energy Information Administration. Abundant coal reserves in the rest of the world enable this resource to be used all over the globe. The key to development everywhere is increased energy supplies, and coal can provide this. As America and other countries face the twin struggles of meeting demand for energy and reducing emissions, they likely will turn more and more to clean coal for the answer.

America already has invested more than $7.5 billion in the development of clean-coal technology. The results are the coal-fired plants that are cleanly generating electricity today. Research and development investment is ongoing to ensure that not only will the wall socket deliver when we want it to, but that the power will be there without unacceptable environmental cost.

4.3.4 FUEL CELLS

4.3.4.1 Background

Electrical energy is produced by a fuel cell as if by magic. It has no moving parts and makes no noise. The secret behind the "magic" is to force two fuels (hydrogen and oxygen) to produce electrical energy by means of a chemical reaction.

Fuel cells are functionally superior to batteries because a fuel cell's lifetime limitation is the supply of the two things—hydrogen and oxygen (which are called “reactants”). Batteries by contrast have a defined lifetime, are heavy, have disposal restrictions, and may require extended periods of recharging before reuse. The fuel cell "battery" has four attractive features over existing power sources (including internal combustion engines):

- provides power as long as each cell has hydrogen and oxygen—no recharging required
- a fuel cell 'stack' has no moving parts to wear out.
- will produce energy at equal costs to existing forms of power.
- is absolutely noise-free
- is "environmentally friendly."

4.3.4.2 History

A bit of "fuel cell" history—the first working fuel cell was produced by Sir William Grove in 1842. The technology advanced slowly over the years but took a giant leap in the 1960s.

During the early 1960s General Electric produced the first practical application for a fuel cell when it provided on-board electrical power for the Gemini and Apollo space capsules.

In the early 1970s, DuPont introduced the Nafion membrane from which all PEM (Proton Exchange Membrane) fuel cells have traditionally been constructed. Because Nafion based fuel cells are expensive and require specialized environments (additional heat, compression, hydrated oxygen and hydrogen) to operate efficiently, fuel cells have not been affordable to the marketplace.

Recent developments have produced fuel cells that are less expensive and do not require "specialized environments" in which to operate. These advances make it cost effective to produce commercial devices that can now compete with rechargeable batteries and internal combustion engines.

4.3.4.3 Fuel Cell and "Stack" Components

Fuel cells are surprisingly simple in their construction. The only essential components are:

- A fuel: Hydrogen
- Oxygen: Taken from the air we breathe
- Fuel cells: Each cell is a thin, flat, multi-layered "sandwich." The "sandwich" consists of two electrodes (an "anode" and a "cathode"). The two electrodes are separated by a plastic sheet (a "membrane"). These three pieces produce electricity. **Figure 4.3.4.3.A** shows a cross-sectional view of a fuel cell.
- A housing: The housing contains multiple fuel cells (referred to as a "stack"), the hydrogen fuel (a bottle of varied sizes), and the unit's controls.
- Controls: The purpose of the controls is to start and stop the electricity produced by the collection of fuel cells.

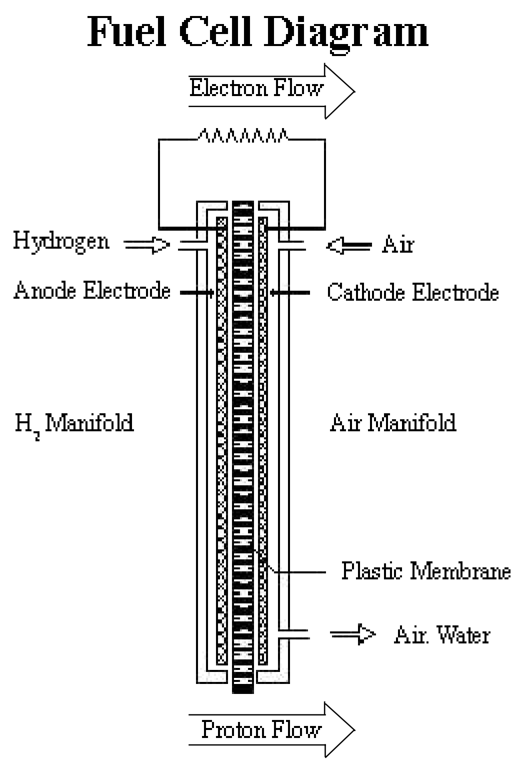


Figure 4.3.4.3.A Cross-sectional view of a fuel cell

4.3.4.4 Making Electricity

There are four steps by which fuel cells create electricity. These four steps are:

Step 1: The chemical reaction starts when one side, the anode of each fuel cell, is exposed to the hydrogen fuel. The anode allows the hydrogen to give up its elecrons leaving a positively charged particle called a proton.

Step 2: On the opposite side of the cell, the cathode adsorbs oxygen from the air generating a potential which pulls the electrons through an external circuit to give them to the adsorbed oxygen. When the adsorbed oxygen receives two electrons it forms a negatively charged particle called an oxygen anion. Oxygen anions then combine with protons.

Step 3: On each side of the membrane there is a positive and a negative charge that want to come together. The membrane, acting as a "one-way valve" blocks the electrons, hydrogen gas, oxygen gas and oxygen radicals, and allows only the positively charged protons to diffuse through to the other side.

Step 4: When two positively charged protons encounter a negatively charged oxygen radical they join together to form water. The cathode expels the water and adsorbs more oxygen to start the reaction all over again.

One advantage of the fuel cell is that it is so simple in operation. There are no moving parts. Only water and a little waste heat are the by-products of making electricity. Each fuel cell will generate an electrical potential of up to 1.0 volt depending on how much electrical current it is asked to produce (by the load or the device requesting power). Higher voltages can be created by arranging cells together--similar to connecting several batteries together inside a flashlight. A collection of individual cells is called a stack. The amount of electrical current a cell can produce is proportional to the total area of the cell. For example the greater the area of the cell the more current can be produced at a given voltage. Thus, a fuel cell stack can produce any required amount of electrical potential and current by stacking the proper numbers of cells, with each cell having a specific area or size.

4.3.4.5 Types of Fuel Cells

Phosphoric Acid. This is the most commercially developed type of fuel cell. It is already being used in such diverse applications as hospitals, nursing homes, hotels, office buildings, schools, utility power plants and airport terminals. Phosphoric acid fuel cells generate electricity at more than 40 percent efficiency—and nearly 85 percent if the steam this fuel cell produces is used for cogeneration—compared to 30 percent for the most efficient internal combustion engine. Operating temperatures are in the range of 400° F. These fuel cells also can be used in larger vehicles, such as buses and locomotives.

Proton Exchange Membrane. These cells operate at relatively low temperatures (about 200° F), have high power density, can vary their output quickly to meet shifts in power demand, and are suited for applications,—such as in automobiles—where quick startup is required. According to the U.S. Department of Energy, "they are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications such as replacements for rechargeable batteries in video cameras."

Molten Carbonate. Molten carbonate fuel cells promise high fuel-to-electricity efficiencies and the ability to consume coal-based fuels. This cell operates at about 1,200° F. The first full-scale molten carbonate stacks have been tested, and demonstration units are being readied for testing in California.

Solid Oxide. Another highly promising fuel cell, the solid oxide fuel cell could be used in big, high - power applications including industrial and large-scale central electricity generating stations. Some developers also see solid oxide use in motor vehicles. A 100-kilowatt test is being conducted in Europe. Two small, 25-kilowatt units are already on line in Japan. A solid oxide system usually uses a hard ceramic material instead of a liquid electrolyte, allowing operating temperatures to reach 1,800° F. Power generating efficiencies could reach 60 percent. One type of solid oxide fuel cell uses an array of meter-long tubes. Other variations include a compressed disc that resembles the top of a soup can.

Alkaline. Long used by NASA on space missions, these cells can achieve power generating efficiencies of up to 70 percent. They use alkaline potassium hydroxide as the electrolyte. Until recently they were too costly for commercial applications, but several companies are examining ways to reduce costs and improve operating flexibility.

Other Fuel Cells. Direct methanol fuel cells (DMFC) are a relatively new member of the fuel cell family. These cells are similar to the PEM cells in that they both use a polymer membrane as the electrolyte. However, in the DMFC, the anode catalyst itself draws the hydrogen from the liquid methanol, eliminating the need for a fuel reformer. Efficiencies of about 40 percent are expected with this type of fuel cell, which would typically operate at a temperature between 120-190° F. Higher efficiencies are achieved at higher temperatures.

Regenerative Fuel Cells. Still a very young member of the fuel cell family, regenerative fuel cells would be attractive as a closed-loop form of power generation. Water is separated into hydrogen and oxygen by a solar-powered electrolyser. The hydrogen and oxygen are fed into the fuel cell which generates electricity, heat and water. The water is then recirculated back to the solar-powered electrolyser and the process begins again. These types of fuel cells are currently being researched by NASA and others world-wide.

4.3.4.6 Benefits of Fuel Cells

New Markets. Fuel cell power system markets could exceed $3 billion worldwide by 2000, according to a recent Arthur D. Little, Inc., study.

- A mere one percent of the global vehicle market, 450,000 vehicles, would mean another $2 billion or more.
- Another recent study projected global demand for transportation fuel cells in 2007 at $9 billion.

Energy Security. U.S. energy dependence is higher today than it was during the "oil shock" of the 1970's, and oil imports are projected to increase.

- Passenger vehicles alone consume 6 million barrels of oil every single day, equivalent to 85 percent of oil imports.
- If just 20 percent of cars used fuel cells, we could cut oil imports by 1.5 million barrels every day.
- If every new vehicle sold in the U.S. next year was equipped with a 60 kW fuel cell, we would double the amount of the country's available electricity supply.
- 10,000 fuel cell vehicles running on non-petroleum fuel would reduce oil consumption by 6.98 million gallons per year.

Clean and Efficient. Fuel cells could dramatically reduce urban air pollution, decrease oil imports, reduce the trade deficit and produce American jobs.

The U.S. Department of Energy projects that if a mere 10 percent of automobiles nationwide were powered by fuel cells, regulated air pollutants would be cut by one million tons per year and 60 million tons of the greenhouse gas CO_2 would be eliminated. DOE projects that the same number of fuel cell cars would cut oil imports by 800,000 barrels a day—about 13 percent of total imports.

Economic Growth. Fuel cells could create new markets for steel, electronics, electrical and control industries and other equipment suppliers. They could provide tens of thousands of high-quality jobs and reduce trade deficits. The consulting firm Arthur D. Little projects that fuel cell sales could reach $3 billion by the year 2000, with a market of 1,500-2,000 MW per year. The consultants estimate that each 1,000 MW will create 5,000 jobs. If just 20 percent of cars used fuel cells, 800,000 jobs would be created.

(From The Role of Fuel Cell Technology in the International Power Equipment Market, Arthur D. Little, Inc, Cambridge, MA, September 1993, reference #44335.)

4.4 COMPLEMENTARY AND EMERGING TRANSPORTATION ALTERNATIVES

4.4.1 PARK-AND-RIDE LOTS

Park-and-ride lots are an important component in the development of alternatives to single occupant auto travel. Studies in the U.S. have shown that successful park-and-ride lots within a region are situated within travel corridors that experience high levels of traffic congestion (RTA, 1993: p.1). The vast majority of the trips that make use of currently existing park-and-ride lots are work-related. The upstream location of park-and-ride lots from areas suffering traffic congestion can often mitigate traffic problems while serving to lessen the environmental problems related to single occupancy vehicle travel. Moreover, strategically located park-and-ride lots serve as complementary infrastructure to carpooling, vanpooling, commuter bus, and commuter rail services. In locales with limited carpooling activities and no commuter transit service, park-and-ride lots can foster the development of such activities.

A study of the Middle Tennessee area developed a comprehensive inventory of existing park-and-ride lots in the five county area surrounding Nashville and identified areas where additional lots could be best located (RTA, 1993: p.1). The RTA study was carried out in order to aid traffic planning for interrelated activities such as commuter rail and to serve as an information tool for the promotion of ridesharing.

4.4.2 HYBRID VEHICLES

Hybrid vehicles combine standard type engines with electric powered motors. In sensitive city environments where low emission or low noise requirements are the standard, hybrid vehicles permit diesel or gasoline engines to be shut off and the electric propulsion system activated. When outside the areas where environmental regulations are less restrictive, the vehicles are powered with diesel or ethanol or biogas engines which can be used as well to drive the electric motors and to recharge the batteries (CADDET, 1998: pp.4-14). Typically, hybrid buses are powered by two electric motors and a combustion engine, which are integrated into a traction hybrid system. In Sweden, where the most extensive hybrid vehicle demonstrations are being carried out, passenger vehicles as well as buses and trucks are involved. Elsewhere, Toyota has developed the first mass-produced hybrid gasoline engine/electric motor passenger car, the Prius. The hybrid sedan has attained a range of 66 miles per gallon of gasoline while halving CO_2 emissions (CADDET, 1998: p.9).

4.4.3 NEW VEHICLE FUELS: A-21

A-21 is a hybrid fuel composed of 55 percent water and 45 percent naphtha, a cheap-to-produce by-product of petroleum distillation. According to studies, A-21 not only is cleaner burning and safer than diesel fuel, but cheaper as well (Miller, 1999: p.533). The fuel has been tested primarily in bus fleets and power generators. A-21 appears especially attractive to the trucking industry which faces increasingly strict regulations on the emissions generated from diesel fuel. Tests have shown that A-21 leads to a 60 percent drop in emission levels of carbon monoxide, nitrous oxide, and hydrocarbons. The only adaption required of standard vehicles is a set of special spark plugs. Since the fuel is immune to fire and explosions, it can be stored above ground, thereby avoiding problems of leakage and groundwater contamination that is common with tanks of traditional fuels. Moreover, the use of naphtha would eliminate up to 90 percent of the air pollutants emitted by oil refineries in their production processes.

4.5 CARBON SEQUESTRATION FROM SOIL MANAGEMENT

Recent research just beginning to be published indicates that by the judicious selection of farming techniques and crop rotation, the soil used to grow crops can act like a giant siphon to pull in and store CO_2 from the atmosphere. Some scientists now think that with the change of a few simple farming practices applied across the United States, the nation's farms could be transformed into CO_2 sponges, sopping up millions of tons of the gas per year. A battery of recent studies has prompted national policy makers to focus on the potential of farms and new farming techniques to help fight global climate change by offsetting emissions from the burning of fossil fuels. Farmers could find themselves with a new cash crop: pollution-reduction credits that can be sold to electric utilities and others emitting greenhouse gases. The Kyoto Protocol allows for countries to create new sinks to meet part of their required emissions reductions. Thus, it may turn out to be easier and cheaper to capture and sequester carbon from the atmosphere than to prevent its release in the first place.

In a 15-year experiment at the Rodale Institute, researchers discovered they could dramatically increase the carbon content of soils simply by changing crop rotations and cutting back on chemical fertilizers. Using techniques already familiar to thousands of organic farmers, the researchers alternated their corn crops with soybeans and other legumes that are natural sources of nitrogen. Over the 15 years, the experimental plots performed at least as well as adjacent, conventionally grown crops, while the soil's carbon level soared. Meanwhile, the nitrogen losses were cut in half compared with crops that used commercial fertilizer, reducing the risk of contamination of nearby streams.

Different researchers contend that the country's net CO_2 emissions can be reduced by between 2 to 8.5 percent by changing farming practices. These activities will reduce the carbon content of the atmosphere and at the same time improve the quality of the soil. One of the remaining problems is in deciding how to measure and verify reductions in carbon from agriculture.

There is not universal agreement about soil carbon sequestration, even among the scientific community. Thus, additional research is needed to provide the answers before policy options are proposed regarding changes in farming practices. There appears to be great potential for Tennessee to increase its atmospheric carbon sequestration into the agricultural soils of the state.

With the relatively large amount of farming that occurs within Tennessee, pollution-reduction credits could have a significant impact on the state's GHG emissions, as well as provide a revenue source for it's farmers. These ideas are too premature for quantification at this time. As the science improves over the next 10 years the justification for specific policy options may emerge.

4.6 SMART GROWTH

Introduction

Green pastures and lush forest lands, strong and friendly neighborhoods, prosperous businesses and family-supporting jobs, good schools and a healthy environment: these are the qualities we all want for Tennessee, for now and generations to come. That is why Tennessee should promote smart growth and neighborhood conservation initiatives. Through these efforts a wide variety of initiatives can be made to promote smart growth.

Financial incentives and neighborhood improvements can encourage companies and individuals to move back into downtown areas. Job opportunities spring from businesses that take advantage of tax cuts and brownfields cleanup assistance. Local governments and land trusts can team to preserve thousands of acres of Tennessee's farmlands and natural resource areas before they are lost forever to unplanned development.

Smart growth policies can set a wise and prudent course for the future. They will save taxpayer dollars while reversing debilitating economic, social and environmental costs caused by years of government supported sprawl development. For decades many of our cities have been in decline as our open space has been devoured by a growing migration away from established neighborhoods. Smart growth can help restore our downtown economies, our sense of community and our environment. It is time to reverse these trends.

A few specific initiatives will be outlined to give the flavor of the types of activities that should be undertaken to promote smart growth.

Priority Funding Areas - In much the same way that a family decides to save or spend its limited resources, the state prioritizes its spending. Each county and municipality should work to analyze its future growth needs. With the assistance of state government, counties can use tools such as existing zoning, comprehensive plan maps, and water and sewer plans to define their "Priority Funding Areas." These are locally certified areas where growth is planned, infrastructure is already in place, and that are consistent with criteria established under the state's Smart Growth program. By investing funds in only these areas, the state will save taxpayer dollars, protect open space from sprawl development and preserve its heritage. Focusing state investments and programs will strengthen neighborhoods, support the entrepreneurial spirit and create job opportunities.

Rural Legacy - Tennesseans can unite in their desire to protect the environment through this smart growth initiative. Creative proposals should be crafted to preserve forests, open spaces, wildlife habitats and agricultural lands. It is possible to create greenbelts around sensitive areas to protect from the hazards of development. A rural legacy program can provide the funding and focus needed to strategically identify and permanently protect the state's most valuable remaining farmland and natural resource areas. Through this forward thinking land conservation program, the state can preserve land at a pace equal to that of development. With programs like Rural Legacy, Tennessee can insure a high quality of life with clean air and water, outdoor recreation, and a rich cultural heritage for future generations.

Voluntary Cleanup and Brownfields Programs - These types of programs can address industrial sites once buried in a haze of pollution and legal uncertainty. Private companies could use these programs to assess, cleanup and redevelop abandoned or underutilized sites so that they might once again be a productive part of the economy. Cleanup will make a marked difference in the quality of our air, water, and community life as a whole. Redevelopment of these sites takes the effort one step further by bringing jobs back to already developed but abandoned industrial areas and by increasing tax revenues.

Job Creation Tax Credit - Businesses can be encouraged to create full-time, permanent jobs by the availability of tax credits applicable to jobs created in smart growth areas. Typically these jobs must pay 150 percent of minimum wage, but often average between $30,000 to $35,000 per year. The success of this type of program means more family-supporting jobs for Tennesseans and the rejuvenation of our older neighborhoods. As additional businesses take advantage of this incentive, state and local governments will continue to save more taxpayer dollars by using infrastructure that is already in place rather than build costly new infrastructure to support sprawl development. Moreover, as businesses expand the economy will grow even stronger.

Live Near Work - This program would provide financial incentives for employees to live close to their place of work. In some states it is already possible for some employees to receive a minimum of $3,000 toward the purchase of their home if they meet the requirements of the Live Near Your Work Program. These funds can be made available through a partnership. The state can contribute $1,000, which is matched by the local jurisdiction and the employer, each of which may contribute a minimum of $1,000 to employees who purchase homes close to their places of work. The benefits of a live near your work program are clear: neighborhoods are strengthened through increased home ownership, commuting costs are reduced, and important relationships are forged between employers and their surrounding communities. Through this incentive, participating employers are offering their work force an improved quality of life that will in turn create a renewed sense of community within Tennessee's neighborhoods.

Through the type of programs mentioned above and many others addressing areas such as public education, public safety, transportation and preservation, Tennessee can create a tapestry of policies and programs to protect, preserve and economically develop established communities and valuable natural and cultural resources. Local and state governments would be encouraged to engage in a continuing effort to refine programs and policies to best meet their needs. There is a vast potential for smart growth concepts to improve the quality of life in Tennessee.

4.7 SUMMARY

It will be by the implementation of new technologies and energy sources that Tennessee will eventually be able to reduce its GHG emissions to and below levels targeted by the Kyoto Protocol. Chapter 4 of this report has discussed a number of these technologies that are currently under development and hold great promise to be the ones that will achieve significant market penetration in the next 10 to 20 years. New developments in transportation and electric power generation technologies are especially important to Tennessee as these sectors represent a large portion of the state's overall emissions. As new technologies become economically viable, the State of Tennessee should promote their implementation statewide to encourage stakeholders to make high return investments that will benefit their bottom line as well as the environment.

CHAPTER 5

PARTICIPATION IN FEDERAL PROGRAMS

5.1 INTRODUCTION

The State of Tennessee should encourage participation by all eligible organizations in federal energy conservation and pollution prevention programs. Programs such as U.S. Department of Energy sponsored Motor Challenge, Steam Challenge and Compressed Air Challenge and the U.S. Environmental Protection Agency's Energy Star and Green Lights provide significant free support materials, computer software and counseling to those who participate. All these programs and others are voluntary and encourage participants to make investments in energy conserving technologies that yield returns on investment in the 15 to 50 percent range. A brief synopsis of several programs follows.

5.2 THE MOTOR CHALLENGE PROGRAM

The United States Department of Energy's (DOE) Motor Challenge program is an industry/government partnership designed to help industry capture 2 billion kilowatt-hours per year of electricity savings by the year 2000. Initiated in 1993 as part of the Department's renewed effort to promote voluntary industry/ government partnerships to improve energy efficiency, economic competitiveness, and the environment, the program's official mission is to: "create a partnership with our allies to deliver products and services that assist our customers in gaining a competitive advantage in managing their electric motor systems while saving energy and enhancing environmental quality."

The primary goal of the program is to increase the market penetration of energy-efficient industrial electric motor-driven systems by encouraging the selection of efficient motors, pumps, fans, other motor driven equipment, and more importantly, by encouraging the most appropriate matching and integration of these system components.

The Motor Challenge is a network of resources. It exists to supply free, unbiased, reliable information tailored to help industries make key decisions about motor system purchasing and design. That unbiased reliable information comes from experts in motor systems, and peers in the field.

Motor Challenge's Primary Customers

Motor Challenge serves those organizations for whom the energy consumed by electric motors and driven equipment comprises a significant portion of their energy use. Examples of these types of organizations are:

- Industrial end-users/manufacturers
- Water and Waste Water Facilities
- Certain Federal Facilities

Motor Challenge can help motor system end-users increase the productivity and reliability of their systems, reduce energy costs, and improve their bottom line.

Motor Challenge recognizes the benefits of working with the existing market place of companies and organizations that routinely provide products and services to industry. Those companies are in an excellent position to educate industrial end-users about opportunities to improve the efficiency of their electric motor systems. To capture those benefits, Motor Challenge created an Allied Partnership that recruits companies interested in working with Motor Challenge to provide added benefit to their customers. Allied Partners will be able to complement their individual marketing materials, products and services with Motor Challenge technical fact sheets, training curriculum materials, and Software. In addition, Allied Partners will be able to obtain products that have been customized to their company organization. This type of leveraging will maximize the benefits of the Motor Challenge.

The formation of two distinct categories of partners - End-users and Allies - allows the program to more strategically focus resources and leverage the existing market structure.

The Benefits of Motor Challenge Partnership

By becoming a partner in the Motor Challenge, industries gain access to the latest information, delivered in a timely fashion. Besides live telephone and electronic access to experts, the Motor Challenge offers case histories, decision-making software, databases of products, publications, workshops and instructional programs. The Energy Savings Network provides:

- Regional training opportunities to keep companies up-to-date on the latest in equipment selection software, operations and maintenance approaches, auditing and testing, rewind approaches and much more.
- Directories to help industries locate the motor system products and provided needed services, and access to Allied Partners who provide training for Motor Challenge software and management policies.
- Case studies of how others have accomplished goals, made more profits, increased productivity, and solved specific problems.

5.3 THE STEAM CHALLENGE PROGRAM

Steam Challenge is a voluntary program that provides information and technical assistance to companies who have questions about their steam systems and are interested in pursuing opportunities to increase steam system efficiency.

Steam Challenge is dedicated to:

- Improve industrial competitiveness through enhanced productivity and lower production costs
- Provide steam plant operators with the tools and technical assistance they need to improve the efficiency of their steam plants, and
- Promote greater awareness of the energy and environmental benefits of efficient steam systems though improved technology and operation.

By offering a variety of tools and services the Steam Challenge program seeks to help companies identify and implement projects that will help enhance safety, save money, improve productivity, and lower emissions. Steam Challenge tools and services currently available are listed in Table 5.3.A.

TABLE 5.3.A STEAM CHALLENGE TOOLS AND SERVICES

Tools:	Services:
• Fact Sheets • Brochures • Checklists • Guidebooks • Software • Case Studies	• Demonstrations • Seminars • Training • Workshops • Conferences • Access to Steam Efficiency Experts • Answers to Your Steam-Related Questions • Referrals

For industrial steam system owners and operators, Steam Challenge is a voluntary program you can join that will give you access to targeted information on steam system efficiency.

For suppliers of steam-related technologies, there is the Steam Team, which will enable providers of steam products and services to provide input into the program and work together to promote "total steam system efficiency". DOE, the Alliance to Save Energy and a technical advisory committee reviews all material before recommending it for use by industry.

U.S. industry uses a lot of steam. In 1995, U.S. manufacturers consumed roughly 16.55 quadrillion Btu (quads) of energy for heat, power, and electricity generation. According to the Council of Industrial Boiler Owners, approximately two-thirds of all the fuel burned by these companies is consumed to raise steam, representing approximately 9.34 quadrillion Btu of the 1995 energy total.

The U.S. manufacturing economy depends on over 54,000 large boilers to produce steam for process use, to drive mechanical equipment (e.g., pumps and fans), and to generate electricity. It costs U.S. industry approximately $21 billion (1995 dollars) a year to feed these boilers.

After the fuels are burned, emissions are released into the atmosphere that cause air pollution and global climate change. Each year U.S. industry releases approximately 196 million metric tons of CO_2 while producing steam. These emissions represent over 40 percent of all U.S. industrial emissions of CO_2 and over 13 percent of total U.S. emissions.

Total demand for steam is projected to increase 20 percent in five major industries by 2015 (compared to 1990 levels), with demand in food processing and chemicals being even greater. Industrial requirements for steam are increasing most rapidly in the "other" category, which includes rubber, plastics, industrial machinery, and transportation equipment (See **Figure 5.3.A**).

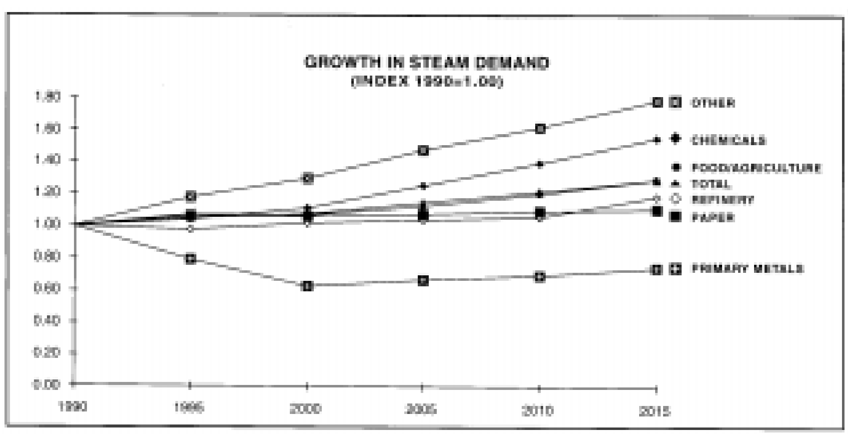


Figure 5.3.A Growth in Steam Demand by Industrial Sector from 1990 to 2015.

The seven industries represented in DOE-OIT's Industries of the Future Program are among the most energy and waste intensive in U.S. industry. When OIT examined the importance of steam in these industries, they found that on a weighted average basis, approximately 45 percent of their total energy consumption was used to raise steam.

The proportion of total energy used for steam was especially high in forest products, chemicals, petroleum refining, and steel (See Figure 5.3.B). There is a high degree of overlap between DOE's seven industries and the most steam-intensive industries, which include chemicals, pulp and paper, food and kindred products, and petroleum refining.

Energy efficient steam technologies can provide significant energy savings that lower costs and improve productivity. A more efficient steam system is also more reliable, enabling plant operators to focus on their work. Other non-energy benefits include: better steam system performance, longer life of equipment, better control, cost reduction, higher return on a large plant investment.

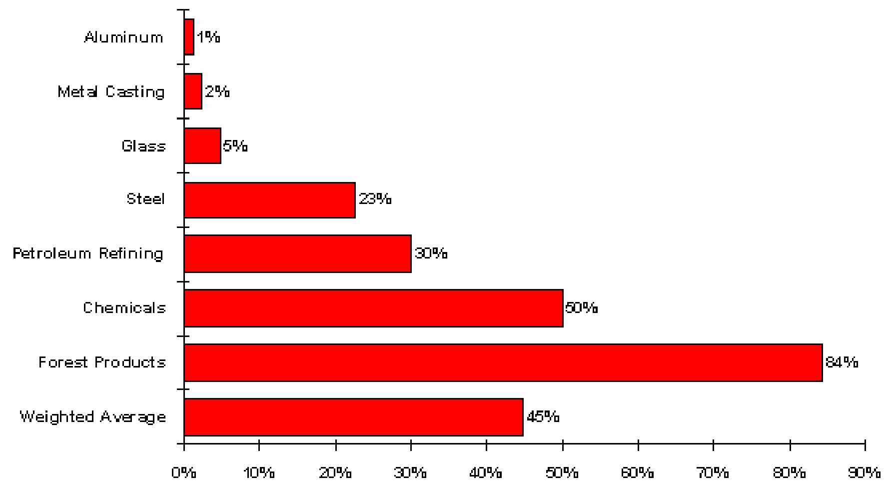


Figure 5.3.B Percent of Total Energy Used by DOE-OIT Focus Industries to Produce Steam

5.4 COMPRESSED AIR CHALLENGE PROGRAM

The "Compressed Air Challenge" has been recently announced by the U.S. DOE as a national effort designed to save industry $150 million per year, reduce energy and emissions, and improve productivity and competitiveness. The Compressed Air Challenge Program is a public-private partnership established to help U.S. manufacturers take advantage of the enormous cost-saving opportunities in efficient compressed air systems.Compressed air systems use $1.5 billion per year in electricity—equal to Connecticut's overall electricity consumption or one percent of total U.S. generation.

"The primary objective of the Compressed Air Challenge is to stimulate industry to reduce the inefficiencies in compressed air systems and capture the large energy savings and emissions reductions," said Dan Reicher, Assistant Secretary for Energy Efficiency and Renewable Energy.

Compressed air systems are considered industry's "fourth utility," after electricity, gas and water, and are a major cost in manufacturing plants. They are used extensively as a source of power for tools, equipment and industrial processes in the chemicals, plastics, glass, pulp and paper, electricity generation, textiles, petroleum, automobiles, and aircraft industries. Most compressed air systems do not operate efficiently. They are often modified over time, are frequently oversized and poorly maintained. Inefficient compressed air systems result in wasted energy, reduced quality control, and lower productivity.

Compressed air systems are often not well understood by plant operations staff and modifying a system is perceived as a risk to production. There is a tremendous need for reliable information to assist staff in improving compressed air systems. Optimization of these systems using existing technology could mean energy savings of 20 to 50 percent. The Compressed Air Challenge has set an initial goal of 10 percent improvement in efficiency—a savings to industry of $150 million per year (in 1997 dollars), greenhouse gas emission reductions of about 700,000 tons of carbon per year by 2010, equivalent to removing 130,000 cars from the road and tens of thousands of tons of reductions in criteria pollutants.

Compressed air system improvements can be achieved by: eliminating air supply leaks, lowering air supply pressures, and properly maintaining components, supply lines, and filters. More complex measures, such as better system control strategies and operating compressors to match process demands, can achieve further savings.

Manufacturers, representatives of the compressed air system industry, utilities, and research organizations have joined with the Department of Energy's Office of Energy Efficiency and Renewable Energy to sponsor this initiative with a mix of public and private funds. Each partner, including the department, will contribute $30,000 for a total of $300,000 to implement the challenge. The Compressed Air Challenge will:

- Develop and deliver information and training so that end users can target and capture, with existing technology, the large savings available in compressed air systems;
- Work to transform the market so high-efficiency is the norm; and
- Contribute to meeting U.S. Climate Change goals.

"The Compressed Air Challenge is clearly a win-win opportunity for industrial energy consumers, the compressed air system market, and the American public to save energy, create jobs, and benefit the environment," Mr. Reicher said.

In addition to the Department of Energy, other project sponsors include: the Compressed Air and Gas Institute; Compressor Distributors Association; Consortium for Energy Efficiency; Energy Center of Wisconsin; Honeywell Inc; Iowa Energy Center; NEES Companies; New York State Research and Development Authority; and Northwest Energy Efficiency Alliance. The Energy Center of Wisconsin will help implement the project, rather than offer financial support.

5.5 U.S. ENVIRONMENTAL PROTECTION AGENCY ENERGY STAR BUILDINGS PROGRAM

EPA's ENERGY STAR Buildings program is a voluntary energy-efficiency program for U.S. commercial buildings. The ENERGY STAR Buildings program focuses on profitable investment opportunities available in most buildings using proven technologies. A central component of the program is the five stage implementation strategy that takes advantage of building system interactions, enabling building owners to achieve additional energy savings while lowering capital expenditures. Through these actions, Partners can expect to reduce total building energy consumption by 30 percent on average.

Organizations that join the ENERGY STAR Buildings Program, called "Partners," sign a Memorandum of Understanding (MOU) that outlines the Partner's responsibilities and EPA's responsibilities.

The energy to operate buildings in the U.S. contributes to a host of environmental problems. By implementing EPA's ENERGY STAR Buildings Program, participants decrease their energy use and, at the same time, increase profits and prevent pollution.

Program participants receive multiple benefits by joining the program. These include:

- Savings
- Customer Support
- Public Recognition
- Workshops
- Publications
- Software
- Account Managers
- Information about Finance Opportunities
- The Energy Star Building Ally Program
- Ally Services and Products Directory (ASAP)
- The Energy Star Buildings Upgrade Manual

The program's five-stage implementation strategy provides a framework for making comprehensive efficiency upgrades in a range of commercial building types. Partners are encouraged to follow the five stage implementation strategy in upgrades of buildings they own. The strategy includes the following stages:

1) Green Lights
2) Building Tune-Up
3) Other Load Reductions
4) Fan System Upgrades
5) Heating and Cooling System Upgrades

A key advantage of this approach is that it can reduce the size of equipment and therefore its cost. Another advantage is that it is gradual. Partners can evaluate energy-efficiency options on a single stage at a time. They can also invest money in stages, rather than all at once.

Twenty-two companies agreed to complete comprehensive building efficiency upgrades in a single building over two years. These ENERGY STAR Showcase Partners demonstrated that the comprehensive ENERGY STAR Buildings strategy maximizes energy savings at a profit; rates of return ranged from 17 percent to 50 percent. Furthermore, the ENERGY STAR Showcase Building projects offered an opportunity to field-test and refine EPA's technical support materials.

5.6 GREEN LIGHTS

Green Lights is a voluntary, non-regulatory program sponsored by the U.S. EPA that enables participants to decrease atmospheric pollution while improving profitability, lighting quality and building efficiency. Green Light participants survey their facilities and upgrade lighting where it is profitable and where it maintains or improves lighting quality. Green Lights is the first step in the five-stage ENERGY STAR Buildings Program, which enables participants to maximize energy savings and minimize pollution emissions as they improve the efficiency of their building’s air distribution and heating and cooling systems.

Estimates show that if all U.S. facilities were upgraded to energy-efficient lighting where profitable, energy savings would exceed $12 billion a year, while decreasing air pollution by 5 percent. This would be equivalent to taking 15 million cars off the road, resulting in less smog, acid rain and a slowing of global climate change.

5.7 SUMMARY

The federal programs discussed in this chapter are well thought out and present sound engineering solutions that save energy and operating cost. Tennessee should support and encourage businesses to participate in these programs. Voluntary participation by business in energy conservation projects that present superior returns on investment should be encouraged by the State of Tennessee.

REFERENCES

Behura, N. and S. Evans. 1998. Compatibility of LED traffic signals with existing traffic signal field equipment. IMSA Journal (March/April): 34-39.

Bierman, A. 1995. Specifier Reports Supplements: Exit Signs (Supplement no. 1). Troy, NY: Rensselaer Polytechnic Institute.

Bierman, A. 1998a. Specifier Reports Supplements: Exit Signs (Supplement no. 2). Troy, NY: Rensselaer Polytechnic Institute.

Bierman, A. 1998b. LED Lighting Futures article. In preparation.

Boyce, P. R. 1981. Human Factors in Lighting. London: Applied Science Publishers.

Boyce, P. R. 1994. Specifier Reports: Exit Signs. Troy, NY: Rensselaer Polytechnic Institute.

Brown, Lester, Michael Renner, Christopher Flavin. *Vital Signs, 1998: The Environmental Trends That Are Shaping Our Future*, World Watch Institute, 1998.

CADDET: Centre for the Analysis and Dissemination of Demonstrated Energy Technologies, *Newsletter*, No. 3, September 1998.

Caneta Research Inc. (1993). Domestic hot water heat pumps for residential and commercial buildings, IEA Heat Pump Centre Analysis report no. HPC-AR2. .

[CBER]: Center for Business and Economic Research. *Tennessee Statistical Abstract: 1994-95*, College of Business Administration, University of Tennessee, Knoxville, 1994.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET) , "Learning from Experiences with Process Heating in the Metals Industry," Analysis Series No. 11, 1990.

Commission Internationale de l'Eclairage: Tutorial Workshop and Symposium, Vienna, Austria, October 22-23.

Conway, K. M., Y. He, P. R. Boyce and A. Bierman. 1997. Optimizing the use of LEDs in signs and signals for visually critical applications. CIE LED

Craig, K.R., Bain, R.L., and Overend, R.R (October 1995). "Biomass Power Systems Where are We, Where are We Going, and How Do We Get There? The Role of Gasification," EPRI Conference on New Power Generation Technology, October 25-27, 1995, San Francisco, California. Craig, K.R., Mann, M.K., and Bain R.L (October 1994) "Cost and Performance Potential of Advanced Integrated Biomass Combined Cycle Power Systems," ASME Cogen Turbo Power '94, 8th Congress & Exposition on Gas Turbines in Cogeneration and Utility, Industrial and Independent Power Generation, ISBN No. 07918-1213-8, Portland, OR.

Cunningham, Glenn and William Anderson. *Greenhouse Gas Emissions Inventory for Tennessee, 1990*, Center for Electric Power, Tennessee Technological University, Cookeville TN, 1995.

Deemer, S. 1997. Traffic signals getting energy-efficient bulbs. Los Angeles Times (November 26).

Delean, P. 1996. Popular abroad, ignored at home: Lachine start-up's final frontier - Quebec. Montreal Gazette (November 13).

Delong, M.M., (December 1995). "Economic Development Through Biomass System Integration," Northern States Power for the National Renewable Energy Laboratory, Golden, Colorado, NRELITP-430-20517.

Eaher, Daniel and R. Hatcher. *Ecology and Decline of Red Spruce in the Eastern United States*, (New York, Springer-Verlag), 1992.

Energy Information Administration, State Energy Data Report, 1994, 1996.

[EPRI]: Electric Power Research Institute, Field-Testing of High-Efficiency Supermarket Refrigeration, TR-100351, 1992.

Garay, P.N., *Handbook of Industrial Power and Steam Systems*, Fairmont Press, 1995.

Graham, R.L., Lichtenberg, E., Roningen, VO., Shapouri, H., and Walsh M.E. (August 1995). "The Economics of Biomass Production in the United States," Proceedings of the Second Conference of the Americas, NRELICP-2008098 (DE95009230).

Hall, D. 0., Rosillo-Calle, E, and de Groot, P. (January 1992). "Biomass Energy-Lessons from Case Studies in Developing Countries," Energy Policy, p 62-73.

Haussler, A. 1997. New bulbs for traffic signals get green light. Arizona Republic (July 18).

Hodapp, M. W. 1997. Applications for high-brightness light-emitting diodes. In High Brightness Light Emitting Diodes (G. Stringfellow and M. Craford, eds.). New York, NY: Academic Press.

Hoffman, M. S. 1990. World Almanac and Book of Facts. New York: Pharos Books.

Hollenbacher R.H. (1992). "Biomass Combustion Technologies in the United States," Biomass Combustion Conference, Reno, Nevada, U.S. DOE Western Regional Biomass Energy Program, Jan 28-30.

HOV Study: *High Occupancy Vehicle Land and Improved Accessibility Study*, prepared for the Tennessee Department of Transportation, Federal Highway Administration and the Nashville Area Metropolitan Planning Organization by Gresham, Smith, and Partners, 1993.

HOV Summary: *The Nashville Metropolitan Organization Area HOV Study: Executive Summary*," prepared by Gresham, Smith, and Partners, 1993.

Illuminating Engineering Society of North America (IESNA). 1993. Lighting Handbook: Reference and Application (M. Rea, ed.). New York, NY: IESNA.

Kiely, C. 1998. Green light for LEDs signalled: Solid state traffic lights may develop a market worldwide. Financial Times (January 13).

Kinoshita, C.M., Turn, S.Q., Overend, R.P, and Bain, R.L. (April 1996). "Power Generation Potential of Biomass Gasification Systems, Proceedings of the 1196 American Power Conference, Chicago, Illinois, April 9-11. Morrison, C.I. and Larson, E.D. (August 1995). "Cost Versus Scale for Advanced Plantation Based Biomass Energy Systems in the U.S.A. and Brazil," Proceedings of the Second Biomass Conference of the Americas, NRELICP-2008098 (DE95009230).

Klayton, Margaret. *The Impact of Telecommuting on the Supervisory Performance Appraisal Process*, Virginia Commonwealth University, Ph.D. dissertation, 1994.

McGowan, F (Marrh 1991). "Controlling the Greenhouse Effect-the Role of Renewables," Energy Policy, p 111118.

McGraw Hill, (May 10, 1995). "629 GW of New Electric Generating Capacity Scheduled Worldwide by 2003," UDI Press Release, Washington, D.C.

Miller, G. Tyler, *Environmental Science: Working With The Earth*, Wadsworth Publishing Co., Belmont CA, 1999.

Mokhtarian, Patricia. "A Synthetic Approach to Estimating the Impacts of Telecommuting on Travel," paper presented at the Conference on Urban Design, Telecommunications, and Travel Behavior; Williamsburg, Virginia, October 27-30, 1996.

Morris, G. (August 1995). "The California Power Industry in the Era of Restructuring," Proceedings of the Second Conference of the Americas, NRELICP-200-8098 (DE95009230).

[NAPAP]: National Acid Precipitation Assessment Program, 1990. *Integrated Assessment Report*, Washington D.C., NAPAP Office of the Director, November 1991.

Nilles, Jack. "Is Telecommuting Real?: The State of California Experience," in *Institute of Transportation Engineering Compendium Papers*, 1991.

Nolan, Carol. "Telecommuting Case History: Pacific Bell from 1985-1989," unpublished paper, 1989.

Nolt, John, Athena Bradley, et al. *What Have We Done?; The Foundation for Global Sustainability's State of the Biogreion Report for the Upper Tennessee Valley and the Southern Appalachian Mountains*, (Washburn, TN, Earth Knows Publications), 1997.

NRDC et al: Natural Resources Defense Council and the Public Service Electric and Gas Co., "Benchmarking Air Emissions of Electric Utility Generators in the United States: 1996 Emissions and Generation Data," (New York, NY, NRDC Publications Department), June 1998.

O'Callaghan, P., *Energy Management*, McGraw-Hill, England, 1993.

Olszweski, M. and E. C. Fontana. (1983). Heat pump desuperheaters for supplying domestic hot water - estimation of energy savings and economic viability for residential applications, Oak Ridge National Laboratory, report no. ORMUCON-114.

Oregon State University, AIRMaster Compressed Air System Audit and Analysis Software, "How to Take a Self-Guided Tour of Your Compressed Air System," 1996 revised in 1997.

Orlando, J.A., *Cogeneration Design Guide*, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 1996.

Pickrell, D. "Federal Tax Policy and Employer-Subsidized Parking," in the *Proceedings of the Commuter Parking Symposium*, U.S. Department of Transportation, DOT-T-91-14, 1990.

RTA: Regional Transportation Authority, *Regional Transportation Authority Middle Tennessee Park-and-Ride Lot Study*, September, 1993.

RTA et al: Regional Transportation Authority, Metropolitan Planning Organization, and Metropolitan Transit Authority. *Nashville Regional Commuter Rail Evaluation, Final Report*, 1996.

Rutgers University, Office of Industrial Productivity and Energy Assessment, *Modern Industrial Assessments: A Training Manual*, Version 1.0b, December 1995.

Stromberg, Jan, *Gas-Turbine-Based CHP in Industry*, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), 1993.

Talbott, E.M., *Compressed Air Systems: A Design Guidebook on Energy and Cost Savings*, 2nd Edition, Fairmont Press, 1992.

Talpin, H.R., *Boiler Plant and Distribution System Optimization Manual*, Fairmont Press, 1991.

[TMA]: Transportation Management Association Group. *Final Report: Telecommuting As a Travel Management And Workplace Tool In Middle Tennessee*, 1998.

Turner, W.C., *Energy Management Handbook*, 3rd Edition, Fairmont Press, 1997.

Turnure, J.T, Winnett, S., Shackleton, R., and Hohenstein, W. (August 1995). "Biomass Electricity: Long-Run Economic Prospects and Climate Policy Implications," Proceedings of the Second Biomass Conference of the Americas. NREUCP-200-8098 (DE95009230). Portland, OR.

[TVA]: Tennessee Valley Authority. *Energy Vision 2020: Integrated Resource Plan Environmental Impact Statement, Volume I,* (TVA), 1995.

[TVA]: Tennessee Valley Authority. *Energy Vision 2020: Integrated Resource Plan Environmental Impact Statement, Volume II, Technical Document* (TVA), 1995a.

[TVA]: Tennessee Valley Authority. "Climate Challenge Participation Accord Between Tennessee Valley Authority and U.S. Department of Energy," Attachment A, (TVA unpublished document), revised February 15, 1996.

[US EPA]: "Climate Wise: Wise Rules for Industrial Efficiency," EPA 231-R-98-014, July, 1998.

Weyerhauser (June 1995). "New Bern Biomass to Energy Project: Phase I Feasibility Study," for the National Renewable Energy Laboratory, Golden, Colorado.

WRI et al: World Resources Institute, The United Nations Environment Programme, The United Nations Development Programme, and the World Bank. *World Resources, A Guide To The Global Environment: The Urban Environment*, (New York: Oxford University Press), 1996.

Yen, Jin-Ru, H. Mahmassani and R. Herman. "Employer Attitudes and Stated Preference Towards Telecommuting: An Exploratory Analysis," 73rd Transportation.

APPENDIX

CO_2 Emissions from Coal Combustion

Coal Carbon Coefficient: 56.0

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*million tons*
1985	599.7	61.57
1986	605.7	62.19
1987	596.5	61.24
1988	610.6	62.69
1989	564.4	57.95
1990	600.3	61.63
1991	565.5	58.06
1992	590.6	60.63
1993	685.9	70.42
1994	622.9	63.95

Year	Projected Energy Consumption	CO_2 Emissions projection
	Trillion Btu	*million tons*
1995	626.79	64.35
1996	630.67	64.75
1997	634.56	65.15
1998	638.45	65.55
1999	642.33	65.95
2000	646.22	66.35
2001	650.11	66.74
2002	653.99	67.14
2003	657.88	67.54
2004	661.77	67.94
2005	665.65	68.34
2006	669.54	68.74
2007	673.43	69.14
2008	677.31	69.54
2009	681.2	69.94
2010	685.09	70.34
2011	688.97	70.73
2012	692.86	71.13
2013	696.75	71.53
2014	700.63	71.93
2015	704.52	72.33
2016	708.41	72.73
2017	712.29	73.13

CO_2 Emissions from Natural Gas

Natural Gas carbon coefficient: 31.9

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*Million Tons*
1985	196.7	11.5
1986	194	11.35
1987	207	12.11
1988	220.9	12.92
1989	228.6	13.37
1990	227.5	13.3
1991	234.6	13.72
1992	249.2	14.57
1993	263.1	15.39
1994	254	14.85

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*Million Tons*
1995	261.58	15.3
1996	269.16	15.74
1997	276.73	16.18
1998	284.31	16.63
1999	291.89	17.07
2000	299.47	17.51
2001	307.05	17.96
2002	314.63	18.4
2003	322.2	18.84
2004	329.78	19.29
2005	337.36	19.73
2006	344.94	20.17
2007	352.52	20.62
2008	360.09	21.06
2009	367.67	21.5
2010	375.25	21.95
2011	382.83	22.39
2012	390.41	22.83
2013	397.99	23.28
2014	405.56	23.72
2015	413.14	24.16
2016	420.72	24.61
2017	428.3	25.05

CO_2 Emissions from Asphalt

Asphalt Carbon Coefficient: 45.5

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*Million tons*
1985	29.3	2.44
1986	27.6	2.3
1987	30.3	2.53
1988	26.9	2.24
1989	37.8	3.15
1990	38.5	3.21
1991	35.5	2.96
1992	35	2.92
1993	32.7	2.73
1994	36.2	3.02

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*Million tons*
1995	37.1	3.09
1996	37.99	3.17
1997	38.89	3.24
1998	39.78	3.32
1999	40.68	3.39
2000	41.57	3.47
2001	42.47	3.54
2002	43.37	3.62
2003	44.26	3.69
2004	45.16	3.77
2005	46.05	3.84
2006	46.95	3.92
2007	47.84	3.99
2008	48.74	4.07
2009	49.64	4.14
2010	50.53	4.22
2011	51.43	4.29
2012	52.32	4.36
2013	53.22	4.44
2014	54.12	4.51
2015	55.01	4.59
2016	55.91	4.66
2017	56.8	4.74

CO_2 Emissions from Aviation Gasoline

Aviation Fuel Carbon Coefficient: 41.6

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*Million Tons*
1985	0.8	0.06
1986	1	0.08
1987	0.9	0.07
1988	0.9	0.07
1989	0.9	0.07
1990	0.9	0.07
1991	0.7	0.05
1992	1.7	0.13
1993	2	0.15
1994	2	0.15

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*Million Tons*
1995	2.13	0.16
1996	2.26	0.17
1997	2.39	0.18
1998	2.51	0.19
1999	2.64	0.2
2000	2.77	0.21
2001	2.9	0.22
2002	3.03	0.23
2003	3.16	0.24
2004	3.28	0.25
2005	3.41	0.26
2006	3.54	0.27
2007	3.67	0.28
2008	3.8	0.29
2009	3.93	0.3
2010	4.06	0.31
2011	4.18	0.32
2012	4.31	0.33
2013	4.44	0.34
2014	4.57	0.35
2015	4.7	0.36
2016	4.83	0.37
2017	4.96	0.38

CO_2 Emissions from Distillate Fuel

Distillate Fuel Carbon Coefficient: 44.0

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*million tons*
1985	129.8	10.47
1986	131.9	10.64
1987	131.6	10.62
1988	137.4	11.08
1989	135.9	10.96
1990	139.1	11.22
1991	131.8	10.63
1992	140.1	11.3
1993	139.7	11.27
1994	144.5	11.66

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*million tons*
1995	145.81	11.76
1996	147.12	11.87
1997	148.42	11.97
1998	149.73	12.08
1999	151.04	12.18
2000	152.35	12.29
2001	153.66	12.39
2002	154.96	12.5
2003	156.27	12.61
2004	157.58	12.71
2005	158.89	12.82
2006	160.19	12.92
2007	161.5	13.03
2008	162.81	13.13
2009	164.12	13.24
2010	165.43	13.34
2011	166.73	13.45
2012	168.04	13.56
2013	169.35	13.66
2014	170.66	13.77
2015	171.97	13.87
2016	173.27	13.98
2017	174.58	14.08

CO_2 Emissions from Jet Fuel

Jet Fuel Carbon Coefficient: 43.5

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*Million Tons*
1985	129.8	10.35
1986	131.9	10.52
1987	131.6	10.5
1988	137.4	10.96
1989	135.9	10.84
1990	139.1	11.09
1991	131.8	10.51
1992	140.1	11.17
1993	139.7	11.14
1994	144.5	11.52

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*Million Tons*
1995	145.81	11.63
1996	147.12	11.73
1997	148.42	11.84
1998	149.73	11.94
1999	151.04	12.05
2000	152.35	12.15
2001	153.66	12.25
2002	154.96	12.36
2003	156.27	12.46
2004	157.58	12.57
2005	158.89	12.67
2006	160.19	12.78
2007	161.5	12.88
2008	162.81	12.98
2009	164.12	13.09
2010	165.43	13.19
2011	166.73	13.3
2012	168.04	13.4
2013	169.35	13.51
2014	170.66	13.61
2015	171.97	13.71
2016	173.27	13.82
2017	174.58	13.92

CO_2 Emissions from Kerosene

Kerosene Carbon Coefficient: 43.5

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*Million Tons*
1985	6.3	0.5
1986	2.7	0.22
1987	3.8	0.3
1988	2.7	0.22
1989	3.8	0.3
1990	2.5	0.2
1991	1.9	0.15
1992	2.5	0.2
1993	2.3	0.18
1994	3.1	0.25

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*Million Tons*
1995	3.04	0.24
1996	2.97	0.24
1997	2.91	0.23
1998	2.84	0.23
1999	2.78	0.22
2000	2.71	0.22
2001	2.65	0.21
2002	2.59	0.21
2003	2.52	0.2
2004	2.46	0.2
2005	2.39	0.19
2006	2.33	0.19
2007	2.26	0.18
2008	2.2	0.18
2009	2.14	0.17
2010	2.07	0.17
2011	2.01	0.16
2012	1.94	0.15
2013	1.88	0.15
2014	1.81	0.14
2015	1.75	0.14
2016	1.69	0.13
2017	1.62	0.13

CO_2 Emissions from LPG

LPG carbon Coefficient: 37.8

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*million tons*
1985	8.2	0.57
1986	9.7	0.67
1987	9.6	0.67
1988	11.4	0.79
1989	12.8	0.89
1990	10.5	0.73
1991	11.6	0.8
1992	17.3	1.2
1993	12.9	0.89
1994	12.7	0.88

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*million tons*
1995	13.3	0.92
1996	13.91	0.96
1997	14.51	1.01
1998	15.12	1.05
1999	15.72	1.09
2000	16.33	1.13
2001	16.93	1.17
2002	17.53	1.22
2003	18.14	1.26
2004	18.74	1.3
2005	19.35	1.34
2006	19.95	1.38
2007	20.56	1.42
2008	21.16	1.47
2009	21.76	1.51
2010	22.37	1.55
2011	22.97	1.59
2012	23.58	1.63
2013	24.18	1.68
2014	24.78	1.72
2015	25.39	1.76
2016	25.99	1.8
2017	26.6	1.84

CO_2 Emissions from Lubricants

Lubricants carbon Coefficient: 44.6

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*Million tons*
1985	6.8	0.56
1986	6.7	0.55
1987	7.6	0.62
1988	7.3	0.6
1989	7.5	0.61
1990	7.7	0.63
1991	6.9	0.56
1992	7	0.57
1993	7.2	0.59
1994	7.5	0.61

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*Million tons*
1995	7.54	0.62
1996	7.57	0.62
1997	7.61	0.62
1998	7.64	0.62
1999	7.68	0.63
2000	7.71	0.63
2001	7.75	0.63
2002	7.78	0.64
2003	7.82	0.64
2004	7.85	0.64
2005	7.89	0.64
2006	7.92	0.65
2007	7.96	0.65
2008	7.99	0.65
2009	8.03	0.66
2010	8.06	0.66
2011	8.1	0.66
2012	8.13	0.66
2013	8.17	0.67
2014	8.2	0.67
2015	8.24	0.67
2016	8.27	0.68
2017	8.31	0.68

CO_2 Emissions from Motor Gasoline

Motor Gasoline carbon Coefficient: 42.8

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*million tons*
1985	304.8	23.92
1986	316.7	24.85
1987	330.9	25.96
1988	311.9	24.47
1989	315.3	24.74
1990	302.9	23.77
1991	294.9	23.14
1992	307.8	24.15
1993	321.5	25.23
1994	330.5	25.93

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*million tons*
1995	331.02	25.97
1996	331.54	26.02
1997	332.06	26.06
1998	332.58	26.1
1999	333.11	26.14
2000	333.63	26.18
2001	334.15	26.22
2002	334.67	26.26
2003	335.19	26.3
2004	335.71	26.34
2005	336.23	26.38
2006	336.75	26.42
2007	337.28	26.46
2008	337.8	26.51
2009	338.32	26.55
2010	338.84	26.59
2011	339.36	26.63
2012	339.88	26.67
2013	340.4	26.71
2014	340.92	26.75
2015	341.45	26.79
2016	341.97	26.83
2017	342.49	26.87

CO_2 Emissions from Residual Fuel

Residual fuel carbon Coefficient: 47.4

Year	Energy Consumption	CO_2 Emissions
	Trillion Btu	*million tons*
1985	3.4	0.3
1986	3.7	0.32
1987	2	0.17
1988	2.8	0.24
1989	2.9	0.25
1990	2	0.17
1991	2.65	0.23
1992	2.5	0.22
1993	3.3	0.29
1994	2.9	0.25

Year	Projected Energy Consumption	Projected CO_2 Emissions
	Trillion Btu	*million tons*
1995	2.86	0.25
1996	2.83	0.25
1997	2.79	0.24
1998	2.75	0.24
1999	2.71	0.24
2000	2.68	0.23
2001	2.64	0.23
2002	2.6	0.23
2003	2.56	0.22
2004	2.53	0.22
2005	2.49	0.22
2006	2.45	0.21
2007	2.42	0.21
2008	2.38	0.21
2009	2.34	0.2
2010	2.3	0.2
2011	2.27	0.2
2012	2.23	0.19
2013	2.19	0.19
2014	2.15	0.19
2015	2.12	0.18
2016	2.08	0.18
2017	2.04	0.18

CO_2 Emissions from Various Production Processes

Year	Total CO_2 Emission from Cement Production	Annual CO_2 Emission from Lime Manufacture	Total CO_2 Emission from Limestone Usage	Total CO_2 Emission from Soda Ash Production	Total CO_2 Emission Equiv from Aluminum Production	Total CO_2 Emissions From Various Production Processes
	tons	*tons*	*tons*	*tons*	*tons*	
	See Inventory	*See Inventory*	*See Inventory*	*See Inventory*	*ALCOA*	
1985	0.46	0.23	1.25	0	0.98	2.92
1986	0.46	0.23	1.25	0	0.98	2.92
1987	0.46	0.23	1.25	0	0.98	2.92
1988	0.46	0.23	1.25	0	0.98	2.92
1989	0.46	0.23	1.25	0	0.98	2.92
1990	0.46	0.23	1.25	0	0.98	2.92
1991	0.46	0.23	1.25	0	0.98	2.92
1992	0.46	0.23	1.25	0	0.98	2.92
1993	0.46	0.23	1.25	0	0.98	2.92
1994	0.46	0.23	1.25	0	0.98	2.92
1995	0.46	0.23	1.25	0	0.98	2.92
1996	0.46	0.23	1.25	0	0.98	2.92
1997	0.46	0.23	1.25	0	0.98	2.92
1998	0.46	0.23	1.25	0	0.98	2.92
1999	0.46	0.23	1.25	0	0.98	2.92
2000	0.46	0.23	1.25	0	0.98	2.92
2001	0.46	0.23	1.25	0	0.98	2.92
2002	0.46	0.23	1.25	0	0.98	2.92
2003	0.46	0.23	1.25	0	0.98	2.92
2004	0.46	0.23	1.25	0	0.98	2.92
2005	0.46	0.23	1.25	0	0.98	2.92
2006	0.46	0.23	1.25	0	0.98	2.92
2007	0.46	0.23	1.25	0	0.98	2.92
2008	0.46	0.23	1.25	0	0.98	2.92
2009	0.46	0.23	1.25	0	0.98	2.92
2010	0.46	0.23	1.25	0	0.98	2.92
2011	0.46	0.23	1.25	0	0.98	2.92
2012	0.46	0.23	1.25	0	0.98	2.92
2013	0.46	0.23	1.25	0	0.98	2.92
2014	0.46	0.23	1.25	0	0.98	2.92
2015	0.46	0.23	1.25	0	0.98	2.92
2016	0.46	0.23	1.25	0	0.98	2.92
2017	**0.46**	**0.23**	**1.25**	**0**	**0.98**	**2.92**

PCF Emissions – Recorded with CO_2

Year	Total CF4 Emission *tons* *See Inventory*	CO_2 Equivalent of CF4 Emissions *See Inventory*	Total C2F6 Emission *tons* *See Inventory*	CO_2 Equivalent of C2F6 Emissions *tons* *See inventory*	Total CO_2 Emission from Bakes *tons* *ALCOA*	Total PCF Emissions from Aluminum Production *tons* *C6+E6*	Total CO_2 Equivalent Emissions *tons* *ALCOA-recorded on CO_2 Emission Data*
1985	262800	854100	26280	120888	2320	289080	977462
1986	262800	854100	26280	120888	2320	289080	977462
1987	262800	854100	26280	120888	2320	289080	977462
1988	262800	854100	26280	120888	2320	289080	977462
1989	262800	854100	26280	120888	2320	289080	977462
1990	262800	854100	26280	120888	2320	289080	977462
1991	262800	854100	26280	120888	2320	289080	977462
1992	262800	854100	26280	120888	2320	289080	977462
1993	262800	854100	26280	120888	2320	289080	977462
1994	262800	854100	26280	120888	2320	289080	977462
1995	262800	854100	26280	120888	2320	289080	977462
1996	262800	854100	26280	120888	2320	289080	977462
1997	262800	854100	26280	120888	2320	289080	977462
1998	262800	854100	26280	120888	2320	289080	977462
1999	262800	854100	26280	120888	2320	289080	977462
2000	262800	854100	26280	120888	2320	289080	977462
2001	262800	854100	26280	120888	2320	289080	977462
2002	262800	854100	26280	120888	2320	289080	977462
2003	262800	854100	26280	120888	2320	289080	977462
2004	262800	854100	26280	120888	2320	289080	977462
2005	262800	854100	26280	120888	2320	289080	977462
2006	262800	854100	26280	120888	2320	289080	977462
2007	262800	854100	26280	120888	2320	289080	977462
2008	262800	854100	26280	120888	2320	289080	977462
2009	262800	854100	26280	120888	2320	289080	977462
2010	262800	854100	26280	120888	2320	289080	977462
2011	262800	854100	26280	120888	2320	289080	977462
2012	262800	854100	26280	120888	2320	289080	977462
2013	262800	854100	26280	120888	2320	289080	977462
2014	262800	854100	26280	120888	2320	289080	977462
2015	262800	854100	26280	120888	2320	289080	977462
2016	262800	854100	26280	120888	2320	289080	977462
2017	262800	854100	26280	120888	2320	289080	977462

Methane Emissions from Natural Gas and Oil Systems (1995)

Total Tennessee crude oil production (1995)	382,000 Barrels
Total Tennessee crude oil activity level (1995)	2,225,150 MMBtu
Total Tennessee oil refined (1995)	33,112,165 Barrels
Total Tennessee oil refined activity level (1995)	192,878,361 MMBtu
Total Oil Transported in the State of Tennessee(1995)	233,600,000 Barrels
Total Oil Transport activity level (1995)	1,360,720,000 MMBtu
Total Tennessee natural gas production (1995)	1,820 Million Cubic Feet
Total Tennessee natural gas activity level (1995)	1,820,000 MMBtu
Total Tennessee natural gas consumption (1995)	256,843 Million Cubic Feet
Total Tennessee natural gas consumption activity level (1995)	256,843,000 MMBtu

Sector	Activity Data (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)		
		Low	High	Median	Low	High	Median
Production (1995)							
Oil*	2,225,150	0.00070	0.01161	0.00615	0.78	12.92	6.84
Gas**	1,820,000	0.10677	0.19496	0.15087	97.16	177.41	137.29
Vented & Flared***	4,045,150	0.00696	0.03249	0.01973	14.08	65.71	39.91
Oil Transportation and Refinery (1995)							
Transportation*'	1,360,720,000	0.00173	0.00173	0.00173	1,177.02	1,177.02	1,177.02
Refining****	192,878,361	0.00021	0.00325	0.00173	20.25	313.43	166.84
Storage Tank****	192,878,361	0.00005	0.00058	0.00031	4.82	55.93	29.90
Natural Gas Processing, Transport and Distribution (1995)							
Natural Gas Consumption**	256,843,000	0.13230	0.27388	0.20309	16,990.16	35,172.08	26,081.12
TOTAL					**18,304.28**	**36,974.51**	**27,638.92**

* Energy Information Administration/Petroleum Supply Annual 1996

** Energy Information Administration/Natural Gas Annual 1995

*** Sum of the Total Oil and Gas Produced

**** Mapco Press Release @ http://www.mapcoinc.com

*' Transportation from 640,000 B/D piped through the state.(Private Communication)

Total Methane Emissions from Oil and Gas

Year	Emissions From Oil Production (tons Methane)		
	Low	High	Median
1996	0.72	11.91	6.31
1997	0.66	10.98	5.82
1998	0.61	10.12	5.36
1999	0.56	9.33	4.94
2000	0.52	8.60	4.56
2001	0.48	7.93	4.20
2002	0.44	7.31	3.87
2003	0.41	6.74	3.57
2004	0.37	6.21	3.29
2005	0.35	5.73	3.03
2006	0.32	5.28	2.80
2007	0.29	4.87	2.58
2008	0.27	4.49	2.38
2009	0.25	4.14	2.19
2010	0.23	3.81	2.02
2011	0.21	3.52	1.86
2012	0.20	3.24	1.72
2013	0.18	2.99	1.58
2014	0.17	2.76	1.46
2015	0.15	2.54	1.35
2016	0.14	2.34	1.24
2017	0.13	2.16	1.14

Year	Emissions From Gas Production (tons Methane)		
	Low	High	Median
1996	93.72	171.12	132.42
1997	90.39	165.06	127.73
1998	87.19	159.21	123.20
1999	84.10	153.56	118.84
2000	81.12	148.12	114.62
2001	78.24	142.87	110.56
2002	75.47	137.81	106.64
2003	72.79	132.92	102.86
2004	70.21	128.21	99.21
2005	67.72	123.66	95.70
2006	65.32	119.28	92.31
2007	63.01	115.05	89.03
2008	60.77	110.97	85.88
2009	58.62	107.04	82.83
2010	56.54	103.25	79.90
2011	54.54	99.59	77.06
2012	52.61	96.06	74.33
2013	50.74	92.65	71.70
2014	48.94	89.37	69.16
2015	47.21	86.20	66.70
2016	45.53	83.14	64.34
2017	43.92	80.20	62.06

Methane Emissions from Oil Production by Year for the State of Tennessee

1 Barrel of Oil = 5.825 Million Btu (MMBtu)

	Crude Oil Production* (Barrels/Yr)	Rate of Change From Prev. Year	Activity Data (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)		
				Low	High	Median	Low	High	Median
1995	382000	-9.26	2225150	0	0.01161	0.00615	0.7788	12.92	6.84
1994	421000	0.96	2452325	0	0.01161	0.00615	0.85831	14.24	7.54
1993	417000	-0.48	2429025	0	0.01161	0.00615	0.85016	14.1	7.47
1992	419000	-16.37	2440675	0	0.01161	0.00615	0.85424	14.17	7.51
1991	501000	-1.38	2918325	0	0.01161	0.00615	1.02141	16.94	8.97
1990	508000	-4.51	2959100	0	0.01161	0.00615	1.03569	17.18	9.1
1989	532000	-11.48	3098900	0	0.01161	0.00615	1.08462	17.99	9.53
1988	601000	-2.12	3500825	0	0.01161	0.00615	1.22529	20.32	10.77
1987	614000	-4.66	3576550	0	0.01161	0.00615	1.25179	20.76	11
1986	644000	-18.07	3751300	0	0.01161	0.00615	1.31296	21.78	11.54
1985	786000	-14.57	4578450	0	0.01161	0.00615	1.60246	26.58	14.08
1984	920000	-12.88	5359000	0	0.01161	0.00615	1.87565	31.11	16.48
1983	1056000	-6.71	6151200	0	0.01161	0.00615	2.15292	35.71	18.91
1982	1132000		6593900	0	0.01161	0.00615	2.30787	38.28	20.28

-7.81 % is the average rate of change from one year to the next.

* Energy Information Administration/Petroleum Supply Annual 1995-1982

Projections of Methane Emissions from Oil Production from 1996-2017 Based on -7.81% Yearly Decline

	Crude Oil Production* (Barrels/Yr)	Activity Data (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)		
			Low	High	Median	Low	High	Median
1996	352169	2051385	0.0007	0.01161	0.00615	0.72	11.91	6.31
1997	324668	1891190	0.0007	0.01161	0.00615	0.66	10.98	5.82
1998	299314	1743504	0.0007	0.01161	0.00615	0.61	10.12	5.36
1999	275940	1607352	0.0007	0.01161	0.00615	0.56	9.33	4.94
2000	254392	1481832	0.0007	0.01161	0.00615	0.52	8.6	4.56
2001	234526	1366113	0.0007	0.01161	0.00615	0.48	7.93	4.2
2002	216211	1259432	0.0007	0.01161	0.00615	0.44	7.31	3.87
2003	199327	1161081	0.0007	0.01161	0.00615	0.41	6.74	3.57
2004	183762	1070411	0.0007	0.01161	0.00615	0.37	6.21	3.29
2005	169411	986821	0.0007	0.01161	0.00615	0.35	5.73	3.03
2006	156182	909759	0.0007	0.01161	0.00615	0.32	5.28	2.8
2007	143985	838715	0.0007	0.01161	0.00615	0.29	4.87	2.58
2008	132741	773218	0.0007	0.01161	0.00615	0.27	4.49	2.38
2009	122375	712837	0.0007	0.01161	0.00615	0.25	4.14	2.19
2010	112819	657170	0.0007	0.01161	0.00615	0.23	3.81	2.02
2011	104009	605851	0.0007	0.01161	0.00615	0.21	3.52	1.86
2012	95887	558539	0.0007	0.01161	0.00615	0.2	3.24	1.72
2013	88399	514922	0.0007	0.01161	0.00615	0.18	2.99	1.58
2014	81495	474711	0.0007	0.01161	0.00615	0.17	2.76	1.46
2015	75131	437640	0.0007	0.01161	0.00615	0.15	2.54	1.35
2016	69264	403465	0.0007	0.01161	0.00615	0.14	2.34	1.24
2017	63855	371957	0.0007	0.01161	0.00615	0.13	2.16	1.14

Methane Emissions from Natural Gas Production by Year for the State of Tennessee

1 Million cubic feet of Gas (MMcf) = 0.001 Million Btu (MMBtu)

	Natural Gas Production * (Mmcf)	**Rate of Change From** Prev. Year	**Activity Data (MMBtu)**	**Emmision Factor (lbs CH4/MMBtu)**			**Methane Emissions (tons Methane)**		
				Low	High	Median	Low	High	Median
1995	1820	-8.54	1820000	0	0.19496	0.15087	97.1607	177.41	137.29
1994	1990	19.88	1990000	0	0.19496	0.15087	106.23615	193.99	150.12
1993	1660	-6.21	1660000	0	0.19496	0.15087	88.6191	161.82	125.22
1992	1770	-5.09	1770000	0	0.19496	0.15087	94.49145	172.54	133.52
1991	1865	-9.77	1865000	0	0.19496	0.15087	99.56303	181.8	140.69
1990	2067	8.79	2067000	0	0.19496	0.15087	110.3468	201.49	155.92
1989	1900	-9.52	1900000	0	0.19496	0.15087	101.4315	185.21	143.33
1988	2100	-22.42	2100000	0	0.19496	0.15087	112.1085	204.71	158.41
1987	2707	-21.85	2707000	0	0.19496	0.15087	144.5132	263.88	204.2
1986	3464	-26.08	3464000	0	0.19496	0.15087	184.92564	337.67	261.31
1985	4686	-6.69	4686000	0	0.19496	0.15087	250.16211	456.79	353.49
1984	5022	27.14	5022000	0	0.19496	0.15087	268.09947	489.54	378.83
1983	3950	32.73	3950000	0	0.19496	0.15087	210.87075	385.05	297.97
1982	2976		2976000	0	0.19496	0.15087	158.87376	290.1	224.49

-3.54 % is the average rate of change from one year to the next.

* Energy Information Administration/Natural Gas Annual 1995,1990 Volume II

Projections of Methane Emissions from Natural Gas from 1996-2017 based on -3.54% Yearly Decline

	Natural Gas Production (Mmcf)	Activity Data (MMBtu)	Emmision Factor (lbs CH4/ MMBtu) Low	High	Median	Methane Emissions (tons Methane) Low	High	Median
1996	1755	1755485	0.10677	0.19496	0.15087	93.72	171.12	132.42
1997	1693	1693257	0.10677	0.19496	0.15087	90.39	165.06	127.73
1998	1633	1633234	0.10677	0.19496	0.15087	87.19	159.21	123.2
1999	1575	1575340	0.10677	0.19496	0.15087	84.1	153.56	118.84
2000	1519	1519497	0.10677	0.19496	0.15087	81.12	148.12	114.62
2001	1466	1465634	0.10677	0.19496	0.15087	78.24	142.87	110.56
2002	1414	1413680	0.10677	0.19496	0.15087	75.47	137.81	106.64
2003	1364	1363568	0.10677	0.19496	0.15087	72.79	132.92	102.86
2004	1315	1315233	0.10677	0.19496	0.15087	70.21	128.21	99.21
2005	1269	1268611	0.10677	0.19496	0.15087	67.72	123.66	95.7
2006	1224	1223641	0.10677	0.19496	0.15087	65.32	119.28	92.31
2007	1180	1180266	0.10677	0.19496	0.15087	63.01	115.05	89.03
2008	1138	1138428	0.10677	0.19496	0.15087	60.77	110.97	85.88
2009	1098	1098073	0.10677	0.19496	0.15087	58.62	107.04	82.83
2010	1059	1059148	0.10677	0.19496	0.15087	56.54	103.25	79.9
2011	1022	1021604	0.10677	0.19496	0.15087	54.54	99.59	77.06
2012	985	985390	0.10677	0.19496	0.15087	52.61	96.06	74.33
2013	950	950460	0.10677	0.19496	0.15087	50.74	92.65	71.7
2014	917	916768	0.10677	0.19496	0.15087	48.94	89.37	69.16
2015	884	884271	0.10677	0.19496	0.15087	47.21	86.2	66.7
2016	853	852925	0.10677	0.19496	0.15087	45.53	83.14	64.34
2017	823	822691	0.10677	0.19496	0.15087	43.92	80.2	62.06

Projected Methane Emissions from Natural Gas Vented and Flared Based on Percentage of Yearly Changes

Year	Methane Emissions (tons Methane)		
	Low	High	Median
1996	0.08	0.37	0.22
1997	0.08	0.38	0.23
1998	0.09	0.40	0.24
1999	0.09	0.42	0.25
2000	0.09	0.44	0.27
2001	0.10	0.46	0.28
2002	0.10	0.48	0.29
2003	0.11	0.50	0.30
2004	0.11	0.52	0.31
2005	0.12	0.54	0.33
2006	0.12	0.56	0.34
2007	0.13	0.59	0.36
2008	0.13	0.61	0.37
2009	0.14	0.64	0.39
2010	0.14	0.67	0.41
2011	0.15	0.70	0.42
2012	0.16	0.73	0.44
2013	0.16	0.76	0.46
2014	0.17	0.79	0.48
2015	0.18	0.83	0.50
2016	0.18	0.86	0.52
2017	0.20	0.93	0.57

Methane Emissions from Oil Transportation
(Assumed Constant Due to Insufficient Data for Projection)

Year	Methane Emissions (tons Methane)		
	Low	High	Median
1996	1,177.02	1,177.02	1,177.02
1997	1,177.02	1,177.02	1,177.02
1998	1,177.02	1,177.02	1,177.02
1999	1,177.02	1,177.02	1,177.02
2000	1,177.02	1,177.02	1,177.02
2001	1,177.02	1,177.02	1,177.02
2002	1,177.02	1,177.02	1,177.02
2003	1,177.02	1,177.02	1,177.02
2004	1,177.02	1,177.02	1,177.02
2005	1,177.02	1,177.02	1,177.02
2006	1,177.02	1,177.02	1,177.02
2007	1,177.02	1,177.02	1,177.02
2008	1,177.02	1,177.02	1,177.02
2009	1,177.02	1,177.02	1,177.02
2010	1,177.02	1,177.02	1,177.02
2011	1,177.02	1,177.02	1,177.02
2012	1,177.02	1,177.02	1,177.02
2013	1,177.02	1,177.02	1,177.02
2014	1,177.02	1,177.02	1,177.02
2015	1,177.02	1,177.02	1,177.02
2016	1,177.02	1,177.02	1,177.02
2017	1,177.02	1,177.02	1,177.02

Methane Emissions from Oil and Natural Gas

1 Barrel of Oil = 5.825 Million Btu (MMBtu)

	Natural Gas Production* (Mmcf)	Rate of Change From Prev. Year	Activity Data (MMBtu)	USA Total Gross Withdrawals (Mmcf)	Rate of Change From Prev. Year	USA Total Vented & Flared (Mmcf)	Rate of Change From Prev. Year	USA Fraction Vented & Flared (MMBtu)
1995	1,820	-8.54	1,820,000	23,743,628	0.69	283,739	24.26	0.011950
1994	1,990	19.88	1,990,000	23,580,706	3.76	228,336	0.70	0.009683
1993	1,660	-6.21	1,660,000	22,725,642	2.68	226,743	35.35	0.009977
1992	1,770	-5.09	1,770,000	22,132,249	1.76	167,519	-1.41	0.007569
1991	1,865	-9.77	1,865,000	21,750,108	1.21	169,909	12.93	0.007812
1990	2,067	8.79	2,067,000	21,490,470	1.97	150,460	6.23	0.007001
1989	1,900	-9.52	1,900,000	21,074,425	0.36	141,642	-0.62	0.006721
1988	2,100	-22.42	2,100,000	20,999,255	4.27	142,525	15.21	0.006787
1987	2,707	-21.85	2,707,000	20,140,200	5.28	123,707	26.71	0.006142
1986	3,464	-26.08	3,464,000	19,130,711	-2.43	97,633	3.01	0.005103
1985	4,686	-6.69	4,686,000	19,606,699	-3.26	94,778	-12.17	0.004834
1984	5,022	27.14	5,022,000	20,266,522	8.61	107,913	13.64	0.005325
1983	3,950	32.73	3,950,000	18,659,046	-7.96	94,962	1.71	0.005089
1982	2,976		2,976,000	20,272,254		93,365		0.004606

-3.54 % is the average rate of change of Gas Production in Tennessee from one year to the next.
1.30 % is the average rate of change of the Total Gross Withdrawls in the USA
9.66 % is the average rate of change of the Total Gases Vented & Flared in the USA
8.18 % is the average rate of change of the Percent of Gas Vented & Flared in the USA

* Energy Information Administration/Natural Gas Annuals 1995,1990 Volume II

Vented and Flared in Tennessee by Year

1 Million cubic feet of gas (MMcf) = 0.001 Million Btu (MMBtu)

Rate of Change From Prev. Year	Tennessee Vented & Flared (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)		
		Low	High	Median	Low	High	Median
23.41	21,749	0.00696	0.03249	0.01973	0.0790	0.3533	0.2146
-2.95	19,270	0.00696	0.03249	0.01973	0.0671	0.3130	0.1901
31.82	16,562	0.00696	0.03249	0.01973	0.0576	0.2691	0.1634
-3.11	13,397	0.00696	0.03249	0.01973	0.0466	0.2176	0.1322
11.58	14,569	0.00696	0.03249	0.01973	0.0507	0.2367	0.1437
4.17	14,472	0.00696	0.03249	0.01973	0.0504	0.2351	0.1428
-0.97	12,770	0.00696	0.03249	0.01973	0.0444	0.2074	0.1260
10.50	14,253	0.00696	0.03249	0.01973	0.0496	0.2315	0.1406
20.36	16,627	0.00696	0.03249	0.01973	0.0579	0.2701	0.1640
5.58	17,678	0.00696	0.03249	0.01973	0.0615	0.2872	0.1744
-9.22	22,652	0.00696	0.03249	0.01973	0.0788	0.3680	0.2235
4.62	26,741	0.00696	0.03249	0.01973	0.0931	0.4344	0.2638
10.50	20,103	0.00696	0.03249	0.01973	0.0700	0.3266	0.1983
	13,706	0.00696	0.03249	0.01973	0.0477	0.2227	0.1352

Projections of Methane Emissions from Natural Gas Vented and Flared Based on Percent of Year Changes.

	Natural Gas Production (Mmcf)	Activity Data (MMBtu)	USA Total Gross Withdrawals (Mmcf)	USA Total Vented & Flared (Mmcf)	USA Fraction Vented & Flared (MMBtu)	Tennessee Vented & Flared (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)	
							Low	High	Median	Low	High
1996	1,755	1,755,485	24,053,170	311,142	0.012927	22,693	0.00696	0.03249	0.01973	0.08	0.37
1997	1,693	1,693,257	24,366,747	341,192	0.013984	23,679	0.00696	0.03249	0.01973	0.08	0.38
1998	1,633	1,633,234	24,684,412	374,144	0.015127	24,707	0.00696	0.03249	0.01973	0.09	0.40
1999	1,575	1,575,340	25,006,219	410,278	0.016364	25,779	0.00696	0.03249	0.01973	0.09	0.42
2000	1,519	1,519,497	25,332,221	449,903	0.017702	26,898	0.00696	0.03249	0.01973	0.09	0.44
2001	1,466	1,465,634	25,662,473	493,354	0.019149	28,066	0.00696	0.03249	0.01973	0.10	0.46
2002	1,414	1,413,680	25,997,030	541,001	0.020715	29,285	0.00696	0.03249	0.01973	0.10	0.48
2003	1,364	1,363,568	26,335,949	593,251	0.022409	30,556	0.00696	0.03249	0.01973	0.11	0.50
2004	1,315	1,315,233	26,679,286	650,546	0.024241	31,882	0.00696	0.03249	0.01973	0.11	0.52
2005	1,269	1,268,611	27,027,100	713,375	0.026223	33,267	0.00696	0.03249	0.01973	0.12	0.54
2006	1,224	1,223,641	27,379,447	782,272	0.028367	34,711	0.00696	0.03249	0.01973	0.12	0.56
2007	1,180	1,180,266	27,736,389	857,823	0.030686	36,218	0.00696	0.03249	0.01973	0.13	0.59
2008	1,138	1,138,428	28,097,983	940,671	0.033195	37,790	0.00696	0.03249	0.01973	0.13	0.61
2009	1,098	1,098,073	28,464,292	1,031,520	0.035909	39,431	0.00696	0.03249	0.01973	0.14	0.64
2010	1,059	1,059,148	28,835,376	1,131,143	0.038845	41,143	0.00696	0.03249	0.01973	0.14	0.67
2011	1,022	1,021,604	29,211,298	1,240,388	0.042021	42,929	0.00696	0.03249	0.01973	0.15	0.70
2012	985	985,390	29,592,121	1,360,183	0.045456	44,792	0.00696	0.03249	0.01973	0.16	0.73
2013	950	950,460	29,977,909	1,491,548	0.049173	46,737	0.00696	0.03249	0.01973	0.16	0.76
2014	917	916,768	30,368,726	1,635,600	0.053193	48,766	0.00696	0.03249	0.01973	0.17	0.79
2015	884	884,271	30,764,638	1,793,565	0.057542	50,883	0.00696	0.03249	0.01973	0.18	0.83
2016	853	852,925	31,165,711	1,966,785	0.062247	53,092	0.00696	0.03249	0.01973	0.18	0.86
2017	853	852,925	31,572,014	2,156,735	0.067336	57,433	0.00696	0.03249	0.01973	0.20	0.93

The Projections for Production of Natural Gas in Tennessee use a yearly average percent decrease of -3.54%.

Projections of Methane Emissions from Oil Refining from 1996-2017 Based on 4.80% Yearly Increase

	Crude Oil Production* (Barrels/Yr)	Activity Data (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)		
			Low	High	Median	Low	High	Median
1996	39906543	232455612	0.00021	0.00325	0.00173	24.41	377.74	201.07
1997	41821807	243612024	0.00021	0.00325	0.00173	25.58	395.87	210.72
1998	43828991	255303873	0.00021	0.00325	0.00173	26.81	414.87	220.84
1999	45932508	267556859	0.00021	0.00325	0.00173	28.09	434.78	231.44
2000	48136980	280397910	0.00021	0.00325	0.00173	29.44	455.65	242.54
2001	50447254	293855252	0.00021	0.00325	0.00173	30.85	477.51	254.18
2002	52868405	307958462	0.00021	0.00325	0.00173	32.34	500.43	266.38
2003	55405757	322738537	0.00021	0.00325	0.00173	33.89	524.45	279.17
2004	58064886	338227964	0.00021	0.00325	0.00173	35.51	549.62	292.57
2005	60851637	354460785	0.00021	0.00325	0.00173	37.22	576	306.61
2006	63772134	371472681	0.00021	0.00325	0.00173	39	603.64	321.32
2007	66832797	389301040	0.00021	0.00325	0.00173	40.88	632.61	336.75
2008	70040352	407985050	0.00021	0.00325	0.00173	42.84	662.98	352.91
2009	73401850	427565774	0.00021	0.00325	0.00173	44.89	694.79	369.84
2010	76924678	448086251	0.00021	0.00325	0.00173	47.05	728.14	387.59
2011	80616580	469591581	0.00021	0.00325	0.00173	49.31	763.09	406.2
2012	84485671	492129033	0.00021	0.00325	0.00173	51.67	799.71	425.69
2013	88540453	515748141	0.00021	0.00325	0.00173	54.15	838.09	446.12
2014	92789840	540500818	0.00021	0.00325	0.00173	56.75	878.31	467.53
2015	97243171	566441469	0.00021	0.00325	0.00173	59.48	920.47	489.97
2016	101910233	593627108	0.00021	0.00325	0.00173	62.33	964.64	513.49
2017	106801285	622117488	0.00021	0.00325	0.00173	65.32	1010.94	538.13

Methane Emissions from Oil Storage for the State of Tennessee*

1 Barrel of Oil = 5.825 million Btu (MMBtu)

	Crude Oil Production (Barrels/Day)	Crude Oil Production (Barrels/Yr)	Rate of Change From Prev. Year	Activity Data (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emi (tons Meth	
					Low	High	Median	Low	High
*1996***	104326	38078990	15	221810117	0	0.0006	0.0003	5.55	64.32
*1995***	90718	33112070	1.93	192877808	0	0.0006	0.0003	4.82	55.93
1994	89000	32485000	17.11	189225125	0	0.0006	0.0003	4.73	54.88
1993	76000	27740000	0	161585500	0	0.0006	0.0003	4.04	46.86
1992	76000	27740000	26.67	161585500	0	0.0006	0.0003	4.04	46.86
1991	60000	21900000	0	127567500	0	0.0006	0.0003	3.19	36.99
1990	60000	21900000	0	127567500	0	0.0006	0.0003	3.19	36.99
1989	60000	21900000	3.45	127567500	0	0.0006	0.0003	3.19	36.99
1988	58000	21170000	-3.33	123315250	0	0.0006	0.0003	3.08	35.76
1987	60000	21900000	0	127567500	0	0.0006	0.0003	3.19	36.99
1986	60000	21900000	0	127567500	0	0.0006	0.0003	3.19	36.99
1985	60000	21900000	0	127567500	0	0.0006	0.0003	3.19	36.99
1984	60000	21900000	0	127567500	0	0.0006	0.0003	3.19	36.99
1983	60000	21900000	21.21	127567500	0	0.0006	0.0003	3.19	36.99
1982	49500	18067500		105243188	0	0.0006	0.0003	2.63	30.52

4.8 % is the average rate of change from one year to the next.

* Energy Information Administration/Petroleum Supply Annual 1994-1982
** Mapco Press Release @ http://www.mapcoinc.com

Projections of Methane Emissions from Oil Storage from 1996-2017 based on 4.80% Yearly Increase

	Crude Oil Production* (Barrels/Yr)	Activity Data (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)		
			Low	High	Median	Low	High	Median
1996	39,906,543	232,455,612	0.00005	0.00058	0.00031	5.81	67.41	36.03
1997	41,821,807	243,612,024	0.00005	0.00058	0.00031	6.09	70.65	37.76
1998	43,828,991	255,303,873	0.00005	0.00058	0.00031	6.38	74.04	39.57
1999	45,932,508	267,556,859	0.00005	0.00058	0.00031	6.69	77.59	41.47
2000	48,136,980	280,397,910	0.00005	0.00058	0.00031	7.01	81.32	43.46
2001	50,447,254	293,855,252	0.00005	0.00058	0.00031	7.35	85.22	45.55
2002	52,868,405	307,958,462	0.00005	0.00058	0.00031	7.70	89.31	47.73
2003	55,405,757	322,738,537	0.00005	0.00058	0.00031	8.07	93.59	50.02
2004	58,064,886	338,227,964	0.00005	0.00058	0.00031	8.46	98.09	52.43
2005	60,851,637	354,460,785	0.00005	0.00058	0.00031	8.86	102.79	54.94
2006	63,772,134	371,472,681	0.00005	0.00058	0.00031	9.29	107.73	57.58
2007	66,832,797	389,301,040	0.00005	0.00058	0.00031	9.73	112.90	60.34
2008	70,040,352	407,985,050	0.00005	0.00058	0.00031	10.20	118.32	63.24
2009	73,401,850	427,565,774	0.00005	0.00058	0.00031	10.69	123.99	66.27
2010	76,924,678	448,086,251	0.00005	0.00058	0.00031	11.20	129.95	69.45
2011	80,616,580	469,591,581	0.00005	0.00058	0.00031	11.74	136.18	72.79
2012	84,485,671	492,129,033	0.00005	0.00058	0.00031	12.30	142.72	76.28
2013	88,540,453	515,748,141	0.00005	0.00058	0.00031	12.89	149.57	79.94
2014	92,789,840	540,500,818	0.00005	0.00058	0.00031	13.51	156.75	83.78
2015	97,243,171	566,441,469	0.00005	0.00058	0.00031	14.16	164.27	87.80
2016	101,910,233	593,627,108	0.00005	0.00058	0.00031	14.84	172.15	92.01
2017	106,801,285	622,117,488	0.00005	0.00058	0.00031	15.55	180.41	96.43

Methane Emissions from Natural Gas Processing, Transport, and Distribution by Year for the State of Tennessee

Numbers Based on Natural Gas Total Consumption for the State***
1 million cubic feet of Gas (MMcf) = 0.001 million Btu (MMBtu)

	Natural Gas Consumption	Rate of Change From	Activity Data (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)		
	(Mmcf)***	Prev. Year		Low	High	Median	Low	High	Media
1995*	256843	1	256843000	0	0.27388	0.20309	16990.16445	35172.08	26081.
1994*	254000	-3	254000000	0	0.27388	0.20309	16802.1	34782.76	25792.
1993*	263100	6	263100000	0	0.27388	0.20309	17404.065	36028.91	26716.
1992*	249200	6	249200000	0	0.27388	0.20309	16484.58	34125.45	25305.
1991*	234600	3	234600000	0	0.27388	0.20309	15518.79	32126.12	23822.
1990*	227500	0	227500000	0	0.27388	0.20309	15049.125	31153.85	23101.
1989*	228600	3	228600000	0	0.27388	0.20309	15121.89	31304.48	23213.
1988*	220900	7	220900000	0	0.27388	0.20309	14612.535	30250.05	22431.
1987*	207000	7	207000000	0	0.27388	0.20309	13693.05	28346.58	21019.
1986*	194000	-1	194000000	0	0.27388	0.20309	12833.1	26566.36	19699.
1985*	196700	-7	196700000	0	0.27388	0.20309	13011.705	26936.1	19973
1984*	211300	6	211300000	0	0.27388	0.20309	13977.495	28935.42	21456.
1983*	199100	-6	199100000	0	0.27388	0.20309	13170.465	27264.75	20217.
1982*	212100		212100000	0	0.27388	0.20309	14030.415	29044.97	21537.

1.59 % is the average rate of change from one year to the next.

* Energy Information Administration State Energy Data Report

** Energy Information Administration/Natural Gas Annual 1995

Emissions from Natural Gas Consumption
(tons Methane)

Year	Low	Median	High
1996	17,260.95	35,732.65	26,496.80
1997	17,536.06	36,302.16	26,919.11
1998	17,815.54	36,880.74	27,348.14
1999	18,099.49	37,468.54	27,784.01
2000	18,387.96	38,065.71	28,226.83
2001	18,681.02	38,672.40	28,676.71
2002	18,978.76	39,288.76	29,133.76
2003	19,281.24	39,914.94	29,598.09
2004	19,588.54	40,551.10	30,069.82
2005	19,900.74	41,197.40	30,549.07
2006	20,217.92	41,854.00	31,035.96
2007	20,540.15	42,521.07	31,530.61
2008	20,867.52	43,198.76	32,033.14
2009	21,200.11	43,887.26	32,543.68
2010	21,537.99	44,586.74	33,062.36
2011	21,881.26	45,297.36	33,589.31
2012	22,230.00	46,019.30	34,124.65
2013	22,584.30	46,752.75	34,668.53
2014	22,944.25	47,497.90	35,221.07
2015	23,309.94	48,254.91	35,782.43
2016	23,681.45	49,024.00	36,352.72
2017	24,058.88	49,805.34	36,932.11

Total Methane Emissions from Oil Refining, Oil Storage and Natural Gas Consumption
(tons Methane)

Year	Low	Median	High
	Low High	Median	
1996	18,562.71	37,538.23	28,049.89
1997	18,835.89	38,122.12	28,478.39
1998	19,113.64	38,716.40	28,914.38
1999	19,396.04	39,321.25	29,357.98
2000	19,683.16	39,936.85	29,809.31
2001	19,975.06	40,563.41	30,268.50
2002	20,271.83	41,201.11	30,735.70
2003	20,573.53	41,850.16	31,211.04
2004	20,880.24	42,510.77	31,694.66
2005	21,192.03	43,183.15	32,186.71
2006	21,509.00	43,867.52	32,687.33
2007	21,831.21	44,564.11	33,196.69
2008	22,158.76	45,273.16	33,714.94
2009	22,491.72	45,994.89	34,242.24
2010	22,830.18	46,729.57	34,778.76
2011	23,174.23	47,477.45	35,324.67
2012	23,523.96	48,238.78	35,880.14
2013	23,879.46	49,013.83	36,445.36
2014	24,240.82	49,802.89	37,020.51
2015	24,608.13	50,606.24	37,605.77
2016	24,981.50	51,424.16	38,201.35
2017	25,361.03	52,257.01	38,807.46

Projections of Methane Emissions from Gas Consumption from 1996 - 2017 based on 1.59% Yearly Increase

	Natural Gas Consumption (Mmcf)***	Activity Data (MMBtu)	Emmision Factor (lbs CH4/MMBtu)			Methane Emissions (tons Methane)		
			Low	High	Median	Low	High	Median
1996	260,937	260,936,546	0.13230	0.27388	0.20309	17,260.95	35,732.65	26,496.8
1997	265,095	265,095,334	0.13230	0.27388	0.20309	17,536.06	36,302.16	26,919.1
1998	269,320	269,320,405	0.13230	0.27388	0.20309	17,815.54	36,880.74	27,348.1
1999	273,613	273,612,814	0.13230	0.27388	0.20309	18,099.49	37,468.54	27,784.0
2000	277,974	277,973,636	0.13230	0.27388	0.20309	18,387.96	38,065.71	28,226.8
2001	282,404	282,403,960	0.13230	0.27388	0.20309	18,681.02	38,672.40	28,676.7
2002	286,905	286,904,895	0.13230	0.27388	0.20309	18,978.76	39,288.76	29,133.7
2003	291,478	291,477,565	0.13230	0.27388	0.20309	19,281.24	39,914.94	29,598.0
2004	296,123	296,123,114	0.13230	0.27388	0.20309	19,588.54	40,551.10	30,069.8
2005	300,843	300,842,703	0.13230	0.27388	0.20309	19,900.74	41,197.40	30,549.0
2006	305,638	305,637,513	0.13230	0.27388	0.20309	20,217.92	41,854.00	31,035.9
2007	310,509	310,508,742	0.13230	0.27388	0.20309	20,540.15	42,521.07	31,530.6
2008	315,458	315,457,609	0.13230	0.27388	0.20309	20,867.52	43,198.76	32,033.1
2009	320,485	320,485,350	0.13230	0.27388	0.20309	21,200.11	43,887.26	32,543.6
2010	325,593	325,593,223	0.13230	0.27388	0.20309	21,537.99	44,586.74	33,062.3
2011	330,783	330,782,504	0.13230	0.27388	0.20309	21,881.26	45,297.36	33,589.3
2012	336,054	336,054,493	0.13230	0.27388	0.20309	22,230.00	46,019.30	34,124.6
2013	341,411	341,410,506	0.13230	0.27388	0.20309	22,584.30	46,752.75	34,668.5
2014	346,852	346,851,882	0.13230	0.27388	0.20309	22,944.25	47,497.90	35,221.0
2015	352,380	352,379,983	0.13230	0.27388	0.20309	23,309.94	48,254.91	35,782.4
2016	357,996	357,996,190	0.13230	0.27388	0.20309	23,681.45	49,024.00	36,352.7
2017	363,702	363,701,909	0.13230	0.27388	0.20309	24,058.88	49,805.34	36,932.1

Methane Emissions from Coal Mining (1995)

	Production Million Short Tons	Emissions Coefficient (cf/ton) Low	Emissions Coefficient (cf/ton) High	CH4 Emissions (MMcf) Low	CH4 Emissions (MMcf) High
Underground Mines*	1.964	215	325	422	638
Surface Mines*	1.258	50	150	63	189
Post-Mining (underground)*	1.964	80	130	157	255
Post-Mining (surface)*	1.258	12	20	15	25
			Total	**657**	**1,107**
Total (Mmcf) CH4	**882**		**Average**	**882**	
Total (tCH4)	**18,226**		**Recovered**	**0**	

*Coal Industry Annual 1995

Total Methane Emissions From Coal Mining

Year	Underground Mining (MMcf)		Surface Mining (MMcf)		Post Underground (MMcf)		Post Surface (MMcf)		Total (MMcf)	
	Low	High	Low	High	Low	High	Low	High	Low	High
1996	400.5	605.4	60.1	180.2	149.0	242.2	14.4	24.0	624.0	1051.8
1997	379.9	574.2	57.3	172.0	141.3	229.7	13.8	22.9	592.3	998.9
1998	360.3	544.6	54.7	164.2	134.1	217.9	13.1	21.9	562.2	948.6
1999	341.7	516.6	52.3	156.8	127.2	206.6	12.5	20.9	533.7	900.9
2000	324.1	490.0	49.9	149.7	120.6	196.0	12.0	20.0	506.6	855.6
2001	307.4	464.7	47.6	142.9	114.4	185.9	11.4	19.1	480.9	812.6
2002	291.6	440.8	45.5	136.5	108.5	176.3	10.9	18.2	456.5	771.7
2003	276.6	418.1	43.4	130.3	102.9	167.2	10.4	17.4	433.3	732.9
2004	262.3	396.5	41.5	124.4	97.6	158.6	10.0	16.6	411.3	696.1
2005	248.8	376.1	39.6	118.8	92.6	150.4	9.5	15.8	390.5	661.1
2006	236.0	356.7	37.8	113.4	87.8	142.7	9.1	15.1	370.7	627.9
2007	223.8	338.3	36.1	108.3	83.3	135.3	8.7	14.4	351.8	596.4
2008	212.3	320.9	34.5	103.4	79.0	128.4	8.3	13.8	334.0	566.4
2009	201.3	304.4	32.9	98.7	74.9	121.7	7.9	13.2	317.1	538.0
2010	191.0	288.7	31.4	94.2	71.1	115.5	7.5	12.6	301.0	510.9
2011	181.1	273.8	30.0	90.0	67.4	109.5	7.2	12.0	285.7	485.3
2012	171.8	259.7	28.6	85.9	63.9	103.9	6.9	11.5	271.2	460.9
2013	162.9	246.3	27.3	82.0	60.6	98.5	6.6	10.9	257.5	437.8
2014	154.5	233.6	26.1	78.3	57.5	93.4	6.3	10.4	244.4	415.8
2015	146.6	221.6	24.9	74.8	54.5	88.6	6.0	10.0	232.0	395.0
2016	139.0	210.2	23.8	71.4	51.7	84.1	5.7	9.5	220.3	375.1
2017	131.9	199.3	22.7	68.2	49.1	79.7	5.5	9.1	209.1	356.3

Methane Emissions from Underground Coal Mining

Year	Production* Million Short Tons	Rate of Change from Prev. Year	Emissions Coefficient (cf/ton)		CH4 Emissions (MMcf)	
			Low	High	Low	High
1995	1.964	3.751	215	325	422	638
1994	1.893	-1.968	215	325	407	615
1993	1.931	-5.297	215	325	415	628
1992	2.039	-33.366	215	325	438	663
1991	3.060	-32.391	215	325	658	995
1990	4.526	-3.456	215	325	973	1,471
1989	4.688	-0.021	215	325	1,008	1,524
1988	4.689	-3.618	215	325	1,008	1,524
1987	4.865	-7.015	215	325	1,046	1,581
1986	5.232	1.651	215	325	1,125	1,700
1985	5.147	-0.943	215	325	1,107	1,673
1984	5.196	19.229	215	325	1,117	1,689
1983	4.358	-3.541	215	325	937	1,416
1982	4.518		215	325	971	1,468

* All Data From Coal Industry Annual 1995-1982 (UTK Library)

-5.15 % is the average rate of change from one year to the next.

Projections of Methane Emissions from Coal Mining from 1996 - 2017 based on -5.15% Yearly Decline

Year	Production* Million Short Tons	Emissions Coefficient (cf/ton)		CH4 Emissions (MMcf)	
		Low	High	Low	High
1996	1.863	215.000	325	400.50266	605
1997	1.767	215.000	325	379.86638	574
1998	1.676	215.000	325	360.29341	545
1999	1.589	215.000	325	341.72895	517
2000	1.508	215.000	325	324.12104	490
2001	1.430	215.000	325	307.4204	465
2002	1.356	215.000	325	291.58028	441
2003	1.286	215.000	325	276.55633	418
2004	1.220	215.000	325	262.3065	397
2005	1.157	215.000	325	248.79091	376
2006	1.098	215.000	325	235.97173	357
2007	1.041	215.000	325	223.81306	338
2008	0.987	215.000	325	212.28088	321
2009	0.936	215.000	325	201.34291	304
2010	0.888	215.000	325	190.96853	289
2011	0.842	215.000	325	181.1287	274
2012	0.799	215.000	325	171.79587	260
2013	0.758	215.000	325	162.94392	246
2014	0.719	215.000	325	154.54809	234
2015	0.682	215.000	325	146.58485	222
2016	0.647	215.000	325	139.03193	210
2017	0.613	215.000	325	131.86818	199

Methane Emissions from Surface Coal Mining

Year	Production* Million Short Tons	Rate of Change From Prev. Year	Emissions Coefficient (cf/ton)		CH4 Emissions (MMcf)	
			Low	High	Low	High
1995	1.258	15.096	50	150	63	189
1994	1.093	-1.973	50	150	55	164
1993	1.115	-22.408	50	150	56	167
1992	1.437	16.829	50	150	72	216
1991	1.230	-26.170	50	150	62	185
1990	1.666	-7.031	50	150	83	250
1989	1.792	-1.593	50	150	90	269
1988	1.821	15.472	50	150	91	273
1987	1.577	4.024	50	150	79	237
1986	1.516	-30.839	50	150	76	227
1985	2.192	8.838	50	150	110	329
1984	2.014	-8.786	50	150	101	302
1983	2.208	-20.260	50	150	110	331
1982	2.769		50	150	138	415

* All Data From Coal Industry Annual 1995-1982 (UTK Library)

-4.52 % is the average rate of change from one year to the next.

Projections of Methane Emissions from Surface Coal Mining from 1996 - 2017 based on -4.52% Yearly Decline

Year	Production* Million Short Tons	Emissions Coefficient (cf/ton)		CH4 Emissions (Mmcf)	
		Low	High	Low	High
1996	**1.201**	**50.000**	**150**	**60**	**180**
1997	**1.147**	**50.000**	**150**	**57**	**172**
1998	**1.095**	**50.000**	**150**	**55**	**164**
1999	**1.045**	**50.000**	**150**	**52**	**157**
2000	**0.998**	**50.000**	**150**	**50**	**150**
2001	**0.953**	**50.000**	**150**	**48**	**143**
2002	**0.910**	**50.000**	**150**	**45**	**136**
2003	**0.869**	**50.000**	**150**	**43**	**130**
2004	**0.829**	**50.000**	**150**	**41**	**124**
2005	**0.792**	**50.000**	**150**	**40**	**119**
2006	**0.756**	**50.000**	**150**	**38**	**113**
2007	**0.722**	**50.000**	**150**	**36**	**108**
2008	**0.689**	**50.000**	**150**	**34**	**103**
2009	**0.658**	**50.000**	**150**	**33**	**99**
2010	**0.628**	**50.000**	**150**	**31**	**94**
2011	**0.600**	**50.000**	**150**	**30**	**90**
2012	**0.573**	**50.000**	**150**	**29**	**86**
2013	**0.547**	**50.000**	**150**	**27**	**82**
2014	**0.522**	**50.000**	**150**	**26**	**78**
2015	**0.498**	**50.000**	**150**	**25**	**75**
2016	**0.476**	**50.000**	**150**	**24**	**71**
2017	**0.454**	**50.000**	**150**	**23**	**68**

Methane Emissions from Post-Mining Transportation and Handling from Underground Mines

Year	Production* Million Short Tons	Rate of Change From Prev. Year	Emissions Coefficient (cf/ton) Low	High	CH4 Emissions (MMcf) Low	High
1995	1.964	3.751	80	130	157	255
1994	1.893	-1.968	80	130	151	246
1993	1.931	-5.297	80	130	154	251
1992	2.039	-33.366	80	130	163	265
1991	3.060	-32.391	80	130	245	398
1990	4.526	-3.456	80	130	362	588
1989	4.688	-0.021	80	130	375	609
1988	4.689	-3.618	80	130	375	610
1987	4.865	-7.015	80	130	389	632
1986	5.232	1.651	80	130	419	680
1985	5.147	-0.943	80	130	412	669
1984	5.196	19.229	80	130	416	675
1983	4.358	-3.541	80	130	349	567
1982	4.518		80	130	361	587

* All Data From Coal Industry Annual 1995-1982 (UTK Library)

-5.15 % is the average rate of change from one year to the next.

Projections of Methane Emissions from Post-Mining Transportation and Handling from Underground Mines from 1996-2017 based on -5.15% Yearly Decline

Year	Production* Million Short Tons	Emissions Coefficient (cf/ton) Low	High	CH4 Emissions (MMcf) Low	High
1996	**1.863**	**80.000**	**130**	**149.02424**	**242**
1997	**1.767**	**80.000**	**130**	**141.34563**	**230**
1998	**1.676**	**80.000**	**130**	**134.06266**	**218**
1999	**1.589**	**80.000**	**130**	**127.15496**	**207**
2000	**1.508**	**80.000**	**130**	**120.60318**	**196**
2001	**1.430**	**80.000**	**130**	**114.38899**	**186**
2002	**1.356**	**80.000**	**130**	**108.49499**	**176**
2003	**1.286**	**80.000**	**130**	**102.90468**	**167**
2004	**1.220**	**80.000**	**130**	**97.60242**	**159**
2005	**1.157**	**80.000**	**130**	**92.573363**	**150**
2006	**1.098**	**80.000**	**130**	**87.803434**	**143**
2007	**1.041**	**80.000**	**130**	**83.279279**	**135**
2008	**0.987**	**80.000**	**130**	**78.988236**	**128**
2009	**0.936**	**80.000**	**130**	**74.918293**	**122**
2010	**0.888**	**80.000**	**130**	**71.058057**	**115**
2011	**0.842**	**80.000**	**130**	**67.396724**	**110**
2012	**0.799**	**80.000**	**130**	**63.924044**	**104**
2013	**0.758**	**80.000**	**130**	**60.630298**	**99**
2014	**0.719**	**80.000**	**130**	**57.506264**	**93**
2015	**0.682**	**80.000**	**130**	**54.5432**	**89**
2016	**0.647**	**80.000**	**130**	**51.73281**	**84**
2017	**0.613**	**80.000**	**130**	**49.067229**	**80**

Total Methane Generated by Large and Small Landfills Within Tennessee

	Methane Generation		
Year	Total tons/yr	max (+15%) tons/yr	min (-15%) tons/yr
1991	251,544.39	291,781.43	236,990.56
1992	254,517.73	295,242.02	239,750.54
1993	257,540.03	298,759.60	242,555.97
1994	260,612.09	302,335.10	245,407.59
1995	263,734.74	305,969.47	248,306.17
1996	266,848.21	309,593.17	251,196.23
1997	269,861.20	313,099.91	253,993.01
1998	272,815.37	316,538.19	256,735.20
1999	275,714.56	319,912.49	259,426.36
2000	278,444.33	323,089.59	261,960.24
2001	281,022.81	326,090.63	264,353.70
2002	283,435.50	328,898.70	266,593.26
2003	285,697.02	331,530.82	268,692.51
2004	287,807.30	333,986.93	270,651.36
2005	289,756.15	336,255.14	272,460.36
2006	291,568.61	338,364.62	274,142.77
2007	293,254.73	340,327.05	275,707.90
2008	294,801.78	342,127.63	277,143.94
2009	296,220.04	343,778.31	278,460.43
2010	297,628.51	345,417.59	279,767.83
2011	299,030.16	347,048.93	281,068.90
2012	300,407.01	348,651.42	282,346.96
2013	301,767.59	350,234.95	283,609.90
2014	303,097.17	351,782.42	284,844.08
2015	304,397.49	353,295.83	286,051.09
2016	305,667.66	354,774.16	287,230.12
2017	306,910.15	356,220.25	288,383.45

Methane Emmissions from Tennessee Landfills

Population Changes

Year	*Pop*	*Growth (%)*
1990	4,843,892.41	
1991	4,923,655.63	
1992	5,004,732.29	
1993	5,087,144.02	
1994	5,170,912.81	
1995	5,256,061.00	0
1996	5,340,959.00	1.62
1997	5,423,117.00	1.54
1998	5,503,671.00	1.49
1999	5,582,726.00	1.44
2000	5,657,161.00	1.33
2001	5,727,471.00	1.24
2002	5,793,260.00	1.15
2003	5,854,927.00	1.06
2004	5,912,470.00	0.98
2005	5,965,611.00	0.9
2006	6,015,033.00	0.83
2007	6,061,010.00	0.76
2008	6,103,195.00	0.7
2009	6,141,868.00	0.63
2010	6,180,274.00	0.63
2011	6,218,494.00	0.62
2012	6,256,038.00	0.6
2013	6,293,138.00	0.59
2014	6,329,393.00	0.58
2015	6,364,850.00	0.56
2016	6,399,485.00	0.54
2017	6,433,365.00	0.53
2018	6,466,193.00	0.51
2019	6,498,055.00	0.49
2020	6,528,653.00	0.47

Projected Waste-in-Place in Tennessee Landfills from Population Growth Numbers

	Generated		Average		WIP
Year	Total Tons	Growth (%)	1991-1995	1991-2017	88,400,000.00
1991	5,081,984.00	0	2.025472158	2.025472158	93,481,984.00
1992	5,032,461.77	-0.974466468			98,514,445.77
1993	5,412,597.13	7.553666126			103,927,042.90
1994	5,823,719.95	7.595666371			109,750,762.85
1995	5,588,004.58	-4.047505238			115,338,767.43
1996	5,701,188.06	2.025472158			121,039,955.49
1997	5,816,664.03	2.025472158			126,856,619.52
1998	5,934,478.94	2.025472158			132,791,098.46
1999	6,054,680.16	2.025472158			138,845,778.63
2000	6,177,316.02	2.025472158			145,023,094.65
2001	6,302,435.84	2.025472158			151,325,530.49
2002	6,430,089.92	2.025472158			157,755,620.42
2003	6,560,329.60	2.025472158			164,315,950.02
2004	6,693,207.25	2.025472158			171,009,157.27
2005	6,828,776.30	2.025472158			177,837,933.58
2006	6,967,091.27	2.025472158			184,805,024.84
2007	7,108,207.76	2.025472158			191,913,232.60
2008	7,252,182.53	2.025472158			199,165,415.13
2009	7,399,073.47	2.025472158			206,564,488.60
2010	7,548,939.64	2.025472158			214,113,428.24
2011	7,701,841.31	2.025472158			221,815,269.55
2012	7,857,839.96	2.025472158			229,673,109.51
2013	8,016,998.32	2.025472158			237,690,107.84
2014	8,179,380.39	2.025472158			245,869,488.23
2015	8,345,051.46	2.025472158			254,214,539.69
2016	8,514,078.16	2.025472158			262,728,617.85
2017	8,686,528.44	2.025472158			271,415,146.29

Projected Waste-in-Place in Tennessee Landfills from State Workbook Algorithm

Workbook	*Waste in place*	*Fraction*	
		Large landfills	***Small Landfills***
Year	*tons*	*tons*	*tons*
1991	89,265,716.52	65,163,973.06	24,101,743.46
1992	90,735,633.78	66,237,012.66	24,498,621.12
1993	92,229,755.83	67,327,721.75	24,902,034.07
1994	93,748,481.22	68,436,391.29	25,312,089.93
1995	95,292,215.11	69,563,317.03	25,728,898.08
1996	96,831,413.09	70,686,931.55	26,144,481.53
1997	98,320,934.96	71,774,282.52	26,546,652.44
1998	99,781,376.36	72,840,404.74	26,940,971.62
1999	101,214,640.94	73,886,687.89	27,327,953.05
2000	102,564,145.07	74,871,825.90	27,692,319.17
2001	103,838,863.09	75,802,370.05	28,036,493.03
2002	105,031,615.52	76,673,079.33	28,358,536.19
2003	106,149,636.22	77,489,234.44	28,660,401.78
2004	107,192,888.94	78,250,808.93	28,942,080.02
2005	108,156,333.55	78,954,123.49	29,202,210.06
2006	109,052,352.80	79,608,217.55	29,444,135.26
2007	109,885,914.32	80,216,717.45	29,669,196.87
2008	110,650,727.00	80,775,030.71	29,875,696.29
2009	111,351,867.23	81,286,863.08	30,065,004.15
2010	112,048,166.76	81,795,161.74	30,253,005.03
2011	112,741,094.12	82,300,998.71	30,440,095.41
2012	113,421,765.62	82,797,888.90	30,623,876.72
2013	114,094,387.41	83,288,902.81	30,805,484.60
2014	114,751,689.38	83,768,733.25	30,982,956.13
2015	115,394,523.64	84,238,002.26	31,156,521.38
2016	116,022,455.07	84,696,392.20	31,326,062.87
2017	116,636,698.37	85,144,789.81	31,491,908.56

Projected Waste-in-Place in Nonarid Small Landfills in Tennessee

	Classification Nonarid Range Methane Generated Small Landfills		
Year	tons/yr	max (+20%)	min (-20%)
1991	6507470.73	7808964.88	5205976.59
1992	6614627.7	7937553.24	5291702.16
1993	6723549.2	8068259.04	5378839.36
1994	6834264.28	8201117.14	5467411.42
1995	6946802.48	8336162.98	5557441.99
1996	7059010.01	8470812.02	5647208.01
1997	7167596.16	8601115.39	5734076.93
1998	7274062.34	8728874.8	5819249.87
1999	7378547.32	8854256.79	5902837.86
2000	7476926.18	8972311.41	5981540.94
2001	7569853.12	9083823.74	6055882.5
2002	7656804.77	9188165.73	6125443.82
2003	7738308.48	9285970.18	6190646.78
2004	7814361.6	9377233.92	6251489.28
2005	7884596.72	9461516.06	6307677.37
2006	7949916.52	9539899.82	6359933.22
2007	8010683.15	9612819.78	6408546.52
2008	8066438	9679725.6	6453150.4
2009	8117551.12	9741061.35	6494040.9
2010	8168311.36	9801973.63	6534649.09
2011	8218825.76	9862590.91	6575060.61
2012	8268446.71	9922136.06	6614757.37
2013	8317480.84	9980977.01	6653984.67
2014	8365398.16	10038477.79	6692318.52
2015	8412260.77	10094712.93	6729808.62
2016	8458036.97	10149644.37	6766429.58
2017	8502815.31	10203378.37	6802252.25

Projected Small Landfill Methane Generation Within Tennessee

		Range Methane Generated	
	Small Landfills	***max (+15%)***	***min (-15%)***
Year	tons/yr	tons/yr	tons/yr
1991	50,107.52	60,129.03	40,086.02
1992	50,932.63	61,119.16	40,746.11
1993	51,771.33	62,125.59	41,417.06
1994	52,623.83	63,148.60	42,099.07
1995	53,490.38	64,188.45	42,792.30
1996	54,354.38	65,225.25	43,483.50
1997	55,190.49	66,228.59	44,152.39
1998	56,010.28	67,212.34	44,808.22
1999	56,814.81	68,177.78	45,451.85
2000	57,572.33	69,086.80	46,057.87
2001	58,287.87	69,945.44	46,630.30
2002	58,957.40	70,748.88	47,165.92
2003	59,584.98	71,501.97	47,667.98
2004	60,170.58	72,204.70	48,136.47
2005	60,711.39	72,853.67	48,569.12
2006	61,214.36	73,457.23	48,971.49
2007	61,682.26	74,018.71	49,345.81
2008	62,111.57	74,533.89	49,689.26
2009	62,505.14	75,006.17	50,004.11
2010	62,896.00	75,475.20	50,316.80
2011	63,284.96	75,941.95	50,627.97
2012	63,667.04	76,400.45	50,933.63
2013	64,044.60	76,853.52	51,235.68
2014	64,413.57	77,296.28	51,530.85
2015	64,774.41	77,729.29	51,819.53
2016	65,126.88	78,152.26	52,101.51
2017	65,471.68	78,566.01	52,377.34

Projected Large Landfill Methane Generation Within Tennessee in Cubic Feet per Day

			Range Methane Generated	
Year	***Avg WIP Tons***	***Large Landfills*** ft³/day	***max (+15%)*** ft³/day	***min (-15%)*** ft³/day
1991	2,961,998.78	26,160,632.99	30,084,727.94	25,572,018.75
1992	3,010,773.30	26,439,623.29	30,405,566.79	25,844,731.77
1993	3,060,350.99	26,723,207.66	30,731,688.80	26,121,935.48
1994	3,110,745.06	27,011,461.74	31,063,181.00	26,403,703.85
1995	3,161,968.96	27,304,462.43	31,400,131.79	26,690,112.02
1996	3,213,042.34	27,596,602.20	31,736,092.53	26,975,678.65
1997	3,262,467.39	27,879,313.46	32,061,210.47	27,252,028.90
1998	3,310,927.49	28,156,505.23	32,379,981.02	27,522,983.87
1999	3,358,485.81	28,428,538.85	32,692,819.68	27,788,896.73
2000	3,403,264.81	28,684,674.73	32,987,375.94	28,039,269.55
2001	3,445,562.28	28,926,616.21	33,265,608.65	28,275,767.35
2002	3,485,139.97	29,153,000.63	33,525,950.72	28,497,058.11
2003	3,522,237.93	29,365,200.96	33,769,981.10	28,704,483.93
2004	3,556,854.95	29,563,210.32	33,997,691.87	28,898,038.09
2005	3,588,823.79	29,746,072.11	34,207,982.92	29,076,785.48
2006	3,618,555.34	29,916,136.56	34,403,557.05	29,243,023.49
2007	3,646,214.43	30,074,346.54	34,585,498.52	29,397,673.74
2008	3,671,592.30	30,219,507.98	34,752,434.18	29,539,569.05
2009	3,694,857.41	30,352,584.40	34,905,472.06	29,669,651.25
2010	3,717,961.90	30,484,742.05	35,057,453.36	29,798,835.36
2011	3,740,954.49	30,616,259.66	35,208,698.61	29,927,393.82
2012	3,763,540.40	30,745,451.11	35,357,268.78	30,053,678.46
2013	3,785,859.22	30,873,114.73	35,504,081.94	30,178,469.65
2014	3,807,669.69	30,997,870.65	35,647,551.24	30,300,418.56
2015	3,829,000.10	31,119,880.59	35,787,862.68	30,419,683.27
2016	3,849,836.01	31,239,061.97	35,924,921.27	30,536,183.08
2017	3,870,217.72	31,355,645.35	36,058,992.15	30,650,143.33

Projected Large Landfill Methane Generation Within Tennessee in Tons per Year

	Range Methane Generated		
Year	***Large Landfills tons/yr***	***max (+15%) tons/yr***	***min (-15%) tons/yr***
1991	201436.8741	231652.4052	196904.5444
1992	203,585.10	234,122.86	199,004.43
1993	205,768.70	236,634.00	201,138.90
1994	207,988.26	239,186.49	203,308.52
1995	210,244.36	241,781.01	205,513.86
1996	212,493.84	244,367.91	207,712.73
1997	214,670.71	246,871.32	209,840.62
1998	216,805.09	249,325.85	211,926.98
1999	218,899.75	251,734.71	213,974.50
2000	220,872.00	254,002.79	215,902.38
2001	222,734.94	256,145.19	217,723.41
2002	224,478.10	258,149.82	219,427.35
2003	226,112.05	260,028.85	221,024.53
2004	227,636.72	261,782.23	222,514.89
2005	229,044.76	263,401.47	223,891.25
2006	230,354.25	264,907.39	225,171.28
2007	231,572.47	266,308.34	226,362.09
2008	232,690.21	267,593.74	227,454.68
2009	233,714.90	268,772.13	228,456.31
2010	234,732.51	269,942.39	229,451.03
2011	235,745.20	271,106.98	230,440.93
2012	236,739.97	272,250.97	231,413.32
2013	237,722.98	273,381.43	232,374.22
2014	238,683.60	274,486.14	233,313.22
2015	239,623.08	275,566.54	234,231.56
2016	240,540.78	276,621.89	235,128.61
2017	241,438.47	277,654.24	236,006.10

Methane Emissions from Domesticated Animals

	Emissions Factor=257.7	*Emissions Factor= 155.9*		*Emissions Factor= 17.6*	*Emissions Factor= 11.0*	*Emissions Factor= 3.3*	*Emissions Factor= 39.6*	*Emissions Factor= 48.*
Year	**Methane Emissions from Dairy Cattle**	**Methane Emissions from Beef Cattle**	**Methane Emissions from Range Cattle**	**Methane Emissions from Sheep**	**Methane Emissions from Goats**	**Methane Emissions from Pigs**	**Methane Emissions from Horses**	**Methane Emission from Mules/Ass**
	Million Tons	*Million Tons*	*Million Tons*	*Million Tons*	*Million Tons*	*Million Tons*	*Million Tons*	*Million Ton*
1985	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1986	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1987	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1988	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1989	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1990	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1991	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1992	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1993	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1994	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1995	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1996	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1997	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1998	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
1999	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2000	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2001	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2002	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2003	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2004	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2005	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2006	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2007	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2008	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2009	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2010	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2011	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2012	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2013	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2014	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2015	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2016	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093
2017	0.03	0.12	0.06	0.000148	0.000173	0.001138	0.001223	0.000093

Emissions Factors for Various Domesicated Animals

	Animal Type	*Emission Factor*
Dairy Cattle	*Replacements 0-12 mo*	44.7
	Replacements 12-24 mo	135.7
	Mature	257.7
Beef Cattle	*Replacements 0-12 mo*	51.9
	Replacements 12-24 mo	148.9
	Mature	155.9
	Weanling Sutem Steers/Heifers	52.8
	Yearling System Steers/Heifers	104.7
	Bulls	220
Other	*Sheep*	17.6
	Goats	11
	Pigs	3.3
	Horses	39.6
	Mules/Asses	48.5

	Methane Emission from Manure Management							
Year	***Cattle***	***Pigs***	***Poultry***	***Sheep***	***Goats***	***Donkeys***	***Horses***	***Total Methane Emission from Manure Management***
	tons	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*
1985	23025	31858	2638	7	11	13	317	57869
1986	23025	31858	2638	7	11	13	317	57869
1987	23025	31858	2638	7	11	13	317	57869
1988	23025	31858	2638	7	11	13	317	57869
1989	23025	31858	2638	7	11	13	317	57869
1990	23025	31858	2638	7	11	13	317	57869
1991	23025	31858	2638	7	11	13	317	57869
1992	23025	31858	2638	7	11	13	317	57869
1993	23025	31858	2638	7	11	13	317	57869
1994	23025	31858	2638	7	11	13	317	57869
1995	23025	31858	2638	7	11	13	317	57869
1996	23025	31858	2638	7	11	13	317	57869
1997	23025	31858	2638	7	11	13	317	57869
1998	23025	31858	2638	7	11	13	317	57869
1999	23025	31858	2638	7	11	13	317	57869
2000	23025	31858	2638	7	11	13	317	57869
2001	23025	31858	2638	7	11	13	317	57869
2002	23025	31858	2638	7	11	13	317	57869
2003	23025	31858	2638	7	11	13	317	57869
2004	23025	31858	2638	7	11	13	317	57869
2005	23025	31858	2638	7	11	13	317	57869
2006	23025	31858	2638	7	11	13	317	57869
2007	23025	31858	2638	7	11	13	317	57869
2008	23025	31858	2638	7	11	13	317	57869
2009	23025	31858	2638	7	11	13	317	57869
2010	23025	31858	2638	7	11	13	317	57869
2011	23025	31858	2638	7	11	13	317	57869
2012	23025	31858	2638	7	11	13	317	57869
2013	23025	31858	2638	7	11	13	317	57869
2014	23025	31858	2638	7	11	13	317	57869
2015	23025	31858	2638	7	11	13	317	57869
2016	23025	31858	2638	7	11	13	317	57869
2017	23025	31858	2638	7	11	13	317	57869

Soil Management

Single-Nutrient Materials

Year	Amonium Nitrate						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
1996*	168520	33.5	56454	4.11	1.17	660.51	1037.95
1995*	161861	33.5	54223	25.18	1.17	634.41	996.94
1992**	129302	33.5	43316	20.54	1.17	506.80	796.40
1991**	107272	33.5	35936	18.66	1.17	420.45	660.71
1990**	90400	33.5	30284	-5.58	1.17	354.32	556.79
1989**	95745	33.5	32075	0.29	1.17	375.27	589.71
1988***	95465	33.5	31981	16.38	1.17	374.18	587.99
1987***	82029	33.5	27480	2.22	1.17	321.51	505.23
1985***	80248	33.5	26883		1.17	314.53	494.26

Year	Anhydrous Ammonia						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
1996*	15035	82	12329	17.60	1.17	144.25	226.67
1995*	12785	82	10484	-38.72	1.17	122.66	192.75
1992**	20862	82	17107	20.16	1.17	200.15	314.52
1991**	17362	82	14237	48.75	1.17	166.57	261.75
1990**	11672	82	9571	-18.38	1.17	111.98	175.97
1989**	14301	82	11727	10.30	1.17	137.20	215.61
1988***	12966	82	10632	-2.72	1.17	124.40	195.48
1987***	13328	82	10929	-13.58	1.17	127.87	200.94
1985***	15423	82	12647		1.17	147.97	232.52

Year	Nitrogen Solutions						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
1996*	52635	29.8	15685	28.81	1.17	183.52	288.38
1995*	40863	29.8	12177	32.49	1.17	142.47	223.89
1992**	30843	29.8	9191	-2.21	1.17	107.54	168.99
1991**	31540	29.8	9399	-26.97	1.17	109.97	172.81
1990**	43188	29.8	12870	33.67	1.17	150.58	236.62
1989**	32310	29.8	9628	-12.49	1.17	112.65	177.02
1988***	36921	29.8	11002	6.10	1.17	128.73	202.29
1987***	34799	29.8	10370	-15.26	1.17	121.33	190.66
1985***	41064	29.8	12237		1.17	143.17	224.99

Year	Urea						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
1996*	74749	46	34385	-4.24	1.17	402.30	632.18
1995*	78056	46	35906	-18.77	1.17	420.10	660.15
1992**	96088	46	44200	3.00	1.17	517.15	812.66
1991**	93291	46	42914	-23.08	1.17	502.09	789.00
1990**	121289	46	55793	11.47	1.17	652.78	1025.79
1989**	108806	46	50051	-3.68	1.17	585.59	920.22
1988***	112961	46	51962	5.91	1.17	607.96	955.36
1987***	106658	46	49063	5.63	1.17	574.03	902.05
1985***	100970	46	46446		1.17	543.42	853.95

* All data from "Commercial Fertilizers 1996"

** All data from TVA National Fertilizer and Environmental Research Summary Data 1992

*** All data from TVA National Fertilizer and Environmental Research Summary Data 1990

Soil Management

Year	Ammonium Sulfate						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced) Low	Emissons (tons N_2O - N) Low	Emissons (tons N_2O) Low
1996*	3331	21	700	50.05	1.17	8.18	12.86
1995*	2220	21	466		1.17	5.45	8.57
1992**	1325	21	278	-12.83	1.17	3.26	5.12
1991**	1520	21	319	-24.30	1.17	3.73	5.87
1990**	2008	21	422		1.17	4.93	7.75
1989**	1044	21	219		1.17	2.57	4.03
1988***	799	21	168		1.17	1.96	3.08
1987***	374	21	79		1.17	0.92	1.44
1985***	65	21	14		1.17	0.16	0.25

Year	Sodium Nitrate						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
1996*		16	0		1.17	0.00	0.00
1995*		16	0		1.17	0.00	0.00
1992**	5259	16	841	-12.84	1.17	9.84	15.47
1991**	6034	16	965	-11.91	1.17	11.30	17.75
1990**	6850	16	1096		1.17	12.82	20.15
1989**	4150	16	664	22.93	1.17	7.77	12.21
1988***	3376	16	540	-24.22	1.17	6.32	9.93
1987***	4455	16	713	31.92	1.17	8.34	13.11
1985***	3377	16	540		1.17	6.32	9.93

Year	Superphosphate 22% and Under						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
1996*	7	16	1		1.17	0.01	0.02
1995*	1	16	0		1.17	0.00	0.00
1992**	58	16	9		1.17	0.11	0.17
1991**	0	16	0		1.17	0.00	0.00
1990**	136	16	22		1.17	0.25	0.40
1989**	26	16	4	-52.73	1.17	0.05	0.08
1988***	55	16	9	34.15	1.17	0.10	0.16
1987***	41	16	7		1.17	0.08	0.12
1985***	2631	16	421		1.17	4.93	7.74

Year	Superphosphate over 22%						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
1996*	8621	45.8	3948	5.92	1.17	46.20	72.59
1995*	8139	45.8	3728	-37.20	1.17	43.61	68.54
1992**	12960	45.8	5936	15.42	1.17	69.45	109.13
1991**	11229	45.8	5143	-22.33	1.17	60.17	94.56
1990**	14457	45.8	6621	-12.96	1.17	77.47	121.74
1989**	16610	45.8	7607	-29.52	1.17	89.01	139.87
1988***	23567	45.8	10794	7.39	1.17	126.29	198.45
1987***	21946	45.8	10051	-2.52	1.17	117.60	184.80
1985***	22513	45.8	10311		1.17	120.64	189.57

* All data from "Commercial Fertilizers 1996"

** All data from TVA National Fertilizer and Environmental Research Summary Data 1992

*** All data from TVA National Fertilizer and Environmental Research Summary Data 1990

Soil Management

Year	Secondary and Micronutrients						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
*1996**	18546	0	0	27.56	1.17	0.00	0.00
*1995**	14539	0	0		1.17	0.00	0.00
*1992***	23581	0	0	46.00	1.17	0.00	0.00
*1991***	16151	0	0	11.32	1.17	0.00	0.00
*1990***	14509	0	0	-28.41	1.17	0.00	0.00
*1989***	20267	0	0		1.17	0.00	0.00
*1988****	7744	0	0	0.64	1.17	0.00	0.00
*1987****	7695	0	0	-25.11	1.17	0.00	0.00
*1985****	10275	0	0		1.17	0.00	0.00

Year	Potash Materials (Cloride)						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
*1996**	197686	0	0	2.58	1.17	0.00	0.00
*1995**	192723	0	0	18.58	1.17	0.00	0.00
*1992***	162531	0	0	14.11	1.17	0.00	0.00
*1991***	142430	0	0	-3.60	1.17	0.00	0.00
*1990***	147742	0	0	1.38	1.17	0.00	0.00
*1989***	145732	0	0	-12.67	1.17	0.00	0.00
*1988****	166884	0	0	-7.19	1.17	0.00	0.00
*1987****	179806	0	0		1.17	0.00	0.00
*1985****	151030	0	0		1.17	0.00	0.00

Year	Other						
	Consumption (tons)	% N	(tons N)	Rate of Change(%)	Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
*1996**	13325	20	2665	-2.24	1.17	31.18	49.00
*1995**	13630	20	2726	-60.56	1.17	31.89	50.12
*1992***	34562	20	6912	40.57	1.17	80.88	127.09
*1991***	24587	20	4917	64.48	1.17	57.53	90.41
*1990***	14948	20	2990	4.79	1.17	34.98	54.97
*1989***	14265	20	2853	18.44	1.17	33.38	52.45
*1988****	12044	20	2409	-46.63	1.17	28.18	44.29
*1987****	22566	20	4513		1.17	52.80	82.98
*1985****	4595	20	919		1.17	10.75	16.90

* All data from "Commercial Fertilizers 1996"

** All data from TVA National Fertilizer and Environmental Research Summary Data 1992

*** All data from TVA National Fertilizer and Environmental Research Summary Data 1990

Soil Management

Multiple-Nutrient Fertilizers

Year	***N-P-K***						
	Consumption			**Rate of**	**Emission Factors**	**Emissons**	**Emissons**
	(tons)	**% N**	**(tons N)**	**Change(%)**	**(% N_2O - N Produced)**	**(tons N_2O - N)**	**(tons N_2O)**
1997	144113.18	10.8	15564	-1.40	1.17	182.10	286.16
1998	142096.98	10.8	15346	-1.40	1.17	179.55	282.16
1999	140108.98	10.8	15132	-1.40	1.17	177.04	278.21
2000	138148.79	10.8	14920	-1.40	1.17	174.56	274.32
2001	136216.02	10.8	14711	-1.40	1.17	172.12	270.48
2002	134310.3	10.8	14506	-1.40	1.17	169.71	266.69
2003	132431.24	10.8	14303	-1.40	1.17	167.34	262.96
2004	130578.47	10.8	14102	-1.40	1.17	165.00	259.28
2005	128751.62	10.8	13905	-1.40	1.17	162.69	255.66
2006	126950.32	10.8	13711	-1.40	1.17	160.41	252.08
2007	125174.23	10.8	13519	-1.40	1.17	158.17	248.55
2008	123422.99	10.8	13330	-1.40	1.17	155.96	245.08
2009	121696.24	10.8	13143	-1.40	1.17	153.78	241.65
2010	119993.66	10.8	12959	-1.40	1.17	151.62	238.27
2011	118314.89	10.8	12778	-1.40	1.17	149.50	234.93
2012	116659.62	10.8	12599	-1.40	1.17	147.41	231.65
2013	115027.5	10.8	12423	-1.40	1.17	145.35	228.41
2014	113418.21	10.8	12249	-1.40	1.17	143.32	225.21
2015	111831.44	10.8	12078	-1.40	1.17	141.31	222.06
2016	110266.87	10.8	11909	-1.40	1.17	139.33	218.95
2017	108724.18	10.8	11742	-1.40	1.17	137.38	215.89

Year	***N-P***						
	Consumption			**Rate of**	**Emission Factors**	**Emissons**	**Emissons**
	(tons)	**% N**	**(tons N)**	**Change(%)**	**(% N_2O - N Produced)**	**(tons N_2O - N)**	**(tons N_2O)**
1997	170189.83	15.6	26550	3.84	1.17	310.63	488.13
1998	176723.19	15.6	27569	3.84	1.17	322.56	506.87
1999	183507.36	15.6	28627	3.84	1.17	334.94	526.33
2000	190551.96	15.6	29726	3.84	1.17	347.80	546.54
2001	197867	15.6	30867	3.84	1.17	361.15	567.52
2002	205462.85	15.6	32052	3.84	1.17	375.01	589.30
2003	213350.3	15.6	33283	3.84	1.17	389.41	611.93
2004	221540.54	15.6	34560	3.84	1.17	404.36	635.42
2005	230045.19	15.6	35887	3.84	1.17	419.88	659.81
2006	238876.32	15.6	37265	3.84	1.17	436.00	685.14
2007	248046.46	15.6	38695	3.84	1.17	452.73	711.44
2008	257568.64	15.6	40181	3.84	1.17	470.11	738.75
2009	267456.36	15.6	41723	3.84	1.17	488.16	767.11
2010	277723.65	15.6	43325	3.84	1.17	506.90	796.56
2011	288385.1	15.6	44988	3.84	1.17	526.36	827.14
2012	299455.82	15.6	46715	3.84	1.17	546.57	858.89
2013	310951.53	15.6	48508	3.84	1.17	567.55	891.86
2014	322888.55	15.6	50371	3.84	1.17	589.34	926.10
2015	335283.81	15.6	52304	3.84	1.17	611.96	961.65
2016	348154.91	15.6	54312	3.84	1.17	635.45	998.57
2017	361520.12	15.6	56397	3.84	1.17	659.85	1036.90

Soil Management

Projected Changes of Nitrous Oxide Emissions from Agricultural Soil Management from 1997-2017 based of average rates of change

Note that the rates of change for all emissions will be the same as those for the consumption.

Single-Nutrient Materials

Year	***Amonium Nitrate***						
	Consumption			**Rate of**	**Emission Factors**	**Emissons**	**Emissons**
	(tons)	**% N**	**(tons N)**	**Change(%)**	**(% N_2O - N Produced)**	**(tons N_2O - N)**	**(tons N_2O)**
1997	185752.14	33.5	62227	10.23	1.17	728.06	1144.09
1998	204746.37	33.5	68590	10.23	1.17	802.50	1261.08
1999	225682.87	33.5	75604	10.23	1.17	884.56	1390.03
2000	248760.24	33.5	83335	10.23	1.17	975.02	1532.17
2001	274197.41	33.5	91856	10.23	1.17	1074.72	1688.84
2002	302235.68	33.5	101249	10.23	1.17	1184.61	1861.53
2003	333141.02	33.5	111602	10.23	1.17	1305.75	2051.89
2004	367206.61	33.5	123014	10.23	1.17	1439.27	2261.70
2005	404755.6	33.5	135593	10.23	1.17	1586.44	2492.98
2006	446144.19	33.5	149458	10.23	1.17	1748.66	2747.90
2007	491765.01	33.5	164741	10.23	1.17	1927.47	3028.89
2008	542050.82	33.5	181587	10.23	1.17	2124.57	3338.61
2009	597478.64	33.5	200155	10.23	1.17	2341.82	3680.00
2010	658574.27	33.5	220622	10.23	1.17	2581.28	4056.30
2011	725917.29	33.5	243182	10.23	1.17	2845.23	4471.08
2012	800146.52	33.5	268049	10.23	1.17	3136.17	4928.27
2013	881966.11	33.5	295459	10.23	1.17	3456.87	5432.22
2014	972152.23	33.5	325671	10.23	1.17	3810.35	5987.69
2015	1071560.4	33.5	358973	10.23	1.17	4199.98	6599.97
2016	1181133.6	33.5	395680	10.23	1.17	4629.45	7274.86
2017	1301911.4	33.5	436140	10.23	1.17	5102.84	8018.75

Year	***Anhydrous Ammonia***						
	Consumption			**Rate of**	**Emission Factors**	**Emissons**	**Emissons**
	(tons)	**% N**	**(tons N)**	**Change(%)**	**(% N_2O - N Produced)**	**(tons N_2O - N)**	**(tons N_2O)**
1997	15474.843	82	12689	2.93	1.17	148.47	233.30
1998	15927.553	82	13061	2.93	1.17	152.81	240.13
1999	16393.507	82	13443	2.93	1.17	157.28	247.15
2000	16873.092	82	13836	2.93	1.17	161.88	254.38
2001	17366.707	82	14241	2.93	1.17	166.62	261.83
2002	17874.763	82	14657	2.93	1.17	171.49	269.49
2003	18397.682	82	15086	2.93	1.17	176.51	277.37
2004	18935.898	82	15527	2.93	1.17	181.67	285.48
2005	19489.86	82	15982	2.93	1.17	186.99	293.83
2006	20060.028	82	16449	2.93	1.17	192.46	302.43
2007	20646.876	82	16930	2.93	1.17	198.09	311.28
2008	21250.891	82	17426	2.93	1.17	203.88	320.38
2009	21872.577	82	17936	2.93	1.17	209.85	329.76
2010	22512.451	82	18460	2.93	1.17	215.98	339.40
2011	23171.043	82	19000	2.93	1.17	222.30	349.33
2012	23848.902	82	19556	2.93	1.17	228.81	359.55
2013	24546.592	82	20128	2.93	1.17	235.50	370.07
2014	25264.692	82	20717	2.93	1.17	242.39	380.90
2015	26003.8	82	21323	2.93	1.17	249.48	392.04
2016	26764.531	82	21947	2.93	1.17	256.78	403.51
2017	27547.516	82	22589	2.93	1.17	264.29	415.31

Soil Management

Year	Nitrogen Solutions						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	55538.82	29.8	16551	5.52	1.17	193.64	304.29
1998	58602.841	29.8	17464	5.52	1.17	204.32	321.08
1999	61835.9	29.8	18427	5.52	1.17	215.60	338.80
2000	65247.325	29.8	19444	5.52	1.17	227.49	357.49
2001	68846.954	29.8	20516	5.52	1.17	240.04	377.21
2002	72645.171	29.8	21648	5.52	1.17	253.28	398.02
2003	76652.932	29.8	22843	5.52	1.17	267.26	419.98
2004	80881.797	29.8	24103	5.52	1.17	282.00	443.15
2005	85343.964	29.8	25433	5.52	1.17	297.56	467.59
2006	90052.305	29.8	26836	5.52	1.17	313.98	493.39
2007	95020.4	29.8	28316	5.52	1.17	331.30	520.61
2008	100262.58	29.8	29878	5.52	1.17	349.58	549.33
2009	105793.97	29.8	31527	5.52	1.17	368.86	579.64
2010	111630.51	29.8	33266	5.52	1.17	389.21	611.62
2011	117789.05	29.8	35101	5.52	1.17	410.68	645.36
2012	124287.36	29.8	37038	5.52	1.17	433.34	680.96
2013	131144.17	29.8	39081	5.52	1.17	457.25	718.53
2014	138379.26	29.8	41237	5.52	1.17	482.47	758.17
2015	146013.5	29.8	43512	5.52	1.17	509.09	800.00
2016	154068.92	29.8	45913	5.52	1.17	537.18	844.13
2017	162568.75	29.8	48445	5.52	1.17	566.81	890.70

Year	Urea						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	72529.791	46	33364	-2.97	1.17	390.36	613.42
1998	70376.468	46	32373	-2.97	1.17	378.77	595.20
1999	68287.075	46	31412	-2.97	1.17	367.52	577.53
2000	66259.713	46	30479	-2.97	1.17	356.61	560.39
2001	64292.542	46	29575	-2.97	1.17	346.02	543.75
2002	62383.773	46	28697	-2.97	1.17	335.75	527.61
2003	60531.673	46	27845	-2.97	1.17	325.78	511.94
2004	58734.56	46	27018	-2.97	1.17	316.11	496.74
2005	56990.801	46	26216	-2.97	1.17	306.72	482.00
2006	55298.812	46	25437	-2.97	1.17	297.62	467.69
2007	53657.056	46	24682	-2.97	1.17	288.78	453.80
2008	52064.042	46	23949	-2.97	1.17	280.21	440.33
2009	50518.323	46	23238	-2.97	1.17	271.89	427.26
2010	49018.494	46	22549	-2.97	1.17	263.82	414.57
2011	47563.194	46	21879	-2.97	1.17	255.99	402.26
2012	46151.099	46	21230	-2.97	1.17	248.39	390.32
2013	44780.928	46	20599	-2.97	1.17	241.01	378.73
2014	43451.436	46	19988	-2.97	1.17	233.86	367.49
2015	42161.415	46	19394	-2.97	1.17	226.91	356.58
2016	40909.693	46	18818	-2.97	1.17	220.18	345.99
2017	39695.133	46	18260	-2.97	1.17	213.64	335.72

Soil Management

Year	Ammonium Sulfate						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	3474.3808	21	730	4.30	1.17	8.54	13.41
1998	3623.9333	21	761	4.30	1.17	8.90	13.99
1999	3779.9232	21	794	4.30	1.17	9.29	14.59
2000	3942.6276	21	828	4.30	1.17	9.69	15.22
2001	4112.3355	21	864	4.30	1.17	10.10	15.88
2002	4289.3483	21	901	4.30	1.17	10.54	16.56
2003	4473.9806	21	940	4.30	1.17	10.99	17.27
2004	4666.5602	21	980	4.30	1.17	11.47	18.02
2005	4867.4293	21	1022	4.30	1.17	11.96	18.79
2006	5076.9447	21	1066	4.30	1.17	12.47	19.60
2007	5295.4786	21	1112	4.30	1.17	13.01	20.45
2008	5523.4191	21	1160	4.30	1.17	13.57	21.33
2009	5761.1711	21	1210	4.30	1.17	14.16	22.24
2010	6009.1571	21	1262	4.30	1.17	14.76	23.20
2011	6267.8174	21	1316	4.30	1.17	15.40	24.20
2012	6537.6116	21	1373	4.30	1.17	16.06	25.24
2013	6819.0189	21	1432	4.30	1.17	16.75	26.33
2014	7112.5393	21	1494	4.30	1.17	17.48	27.46
2015	7418.694	21	1558	4.30	1.17	18.23	28.64
2016	7738.0269	21	1625	4.30	1.17	19.01	29.88
2017	8071.1054	21	1695	4.30	1.17	19.83	31.16

Year	Sodium Nitrate						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	5320.7627	16	851	1.17	1.17	9.96	15.65
1998	5383.2507	16	861	1.17	1.17	10.08	15.84
1999	5446.4726	16	871	1.17	1.17	10.20	16.02
2000	5510.437	16	882	1.17	1.17	10.32	16.21
2001	5575.1526	16	892	1.17	1.17	10.44	16.40
2002	5640.6282	16	903	1.17	1.17	10.56	16.59
2003	5706.8728	16	913	1.17	1.17	10.68	16.79
2004	5773.8954	16	924	1.17	1.17	10.81	16.99
2005	5841.7051	16	935	1.17	1.17	10.94	17.18
2006	5910.3112	16	946	1.17	1.17	11.06	17.39
2007	5979.723	16	957	1.17	1.17	11.19	17.59
2008	6049.95	16	968	1.17	1.17	11.33	17.80
2009	6121.0017	16	979	1.17	1.17	11.46	18.01
2010	6192.8879	16	991	1.17	1.17	11.59	18.22
2011	6265.6183	16	1002	1.17	1.17	11.73	18.43
2012	6339.2029	16	1014	1.17	1.17	11.87	18.65
2013	6413.6517	16	1026	1.17	1.17	12.01	18.87
2014	6488.9748	16	1038	1.17	1.17	12.15	19.09
2015	6565.1826	16	1050	1.17	1.17	12.29	19.31
2016	6642.2853	16	1063	1.17	1.17	12.43	19.54
2017	6720.2935	16	1075	1.17	1.17	12.58	19.77

Soil Management

Year	Superphosphate 22% and Under						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	6.3496674	16	1	-9.29	1.17	0.01	0.02
1998	5.7597537	16	1	-9.29	1.17	0.01	0.02
1999	5.2246458	16	1	-9.29	1.17	0.01	0.02
2000	4.7392519	16	1	-9.29	1.17	0.01	0.01
2001	4.2989533	16	1	-9.29	1.17	0.01	0.01
2002	3.8995605	16	1	-9.29	1.17	0.01	0.01
2003	3.5372732	16	1	-9.29	1.17	0.01	0.01
2004	3.208644	16	1	-9.29	1.17	0.01	0.01
2005	2.9105461	16	0	-9.29	1.17	0.01	0.01
2006	2.6401428	16	0	-9.29	1.17	0.00	0.01
2007	2.3948612	16	0	-9.29	1.17	0.00	0.01
2008	2.1723675	16	0	-9.29	1.17	0.00	0.01
2009	1.9705444	16	0	-9.29	1.17	0.00	0.01
2010	1.7874717	16	0	-9.29	1.17	0.00	0.01
2011	1.6214072	16	0	-9.29	1.17	0.00	0.00
2012	1.4707709	16	0	-9.29	1.17	0.00	0.00
2013	1.3341295	16	0	-9.29	1.17	0.00	0.00
2014	1.2101826	16	0	-9.29	1.17	0.00	0.00
2015	1.097751	16	0	-9.29	1.17	0.00	0.00
2016	0.9957649	16	0	-9.29	1.17	0.00	0.00
2017	0.9032537	16	0	-9.29	1.17	0.00	0.00

Year	Superphosphate over 22%						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	7804.1149	45.8	3574	-9.48	1.17	41.82	65.72
1998	7064.634	45.8	3236	-9.48	1.17	37.86	59.49
1999	6395.2227	45.8	2929	-9.48	1.17	34.27	53.85
2000	5789.2417	45.8	2651	-9.48	1.17	31.02	48.75
2001	5240.6806	45.8	2400	-9.48	1.17	28.08	44.13
2002	4744.0986	45.8	2173	-9.48	1.17	25.42	39.95
2003	4294.5703	45.8	1967	-9.48	1.17	23.01	36.16
2004	3887.6372	45.8	1781	-9.48	1.17	20.83	32.74
2005	3519.2631	45.8	1612	-9.48	1.17	18.86	29.63
2006	3185.7944	45.8	1459	-9.48	1.17	17.07	26.83
2007	2883.9236	45.8	1321	-9.48	1.17	15.45	24.28
2008	2610.6567	45.8	1196	-9.48	1.17	13.99	21.98
2009	2363.2832	45.8	1082	-9.48	1.17	12.66	19.90
2010	2139.3497	45.8	980	-9.48	1.17	11.46	18.01
2011	1936.6351	45.8	887	-9.48	1.17	10.38	16.31
2012	1753.1287	45.8	803	-9.48	1.17	9.39	14.76
2013	1587.0106	45.8	727	-9.48	1.17	8.50	13.36
2014	1436.633	45.8	658	-9.48	1.17	7.70	12.10
2015	1300.5044	45.8	596	-9.48	1.17	6.97	10.95
2016	1177.2748	45.8	539	-9.48	1.17	6.31	9.91
2017	1065.7218	45.8	488	-9.48	1.17	5.71	8.97

Soil Management

Year	*Secondary and Micronutrients*						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	19535.039	0	0	5.33	1.17	0.00	0.00
1998	20576.823	0	0	5.33	1.17	0.00	0.00
1999	21674.163	0	0	5.33	1.17	0.00	0.00
2000	22830.024	0	0	5.33	1.17	0.00	0.00
2001	24047.526	0	0	5.33	1.17	0.00	0.00
2002	25329.956	0	0	5.33	1.17	0.00	0.00
2003	26680.776	0	0	5.33	1.17	0.00	0.00
2004	28103.635	0	0	5.33	1.17	0.00	0.00
2005	29602.373	0	0	5.33	1.17	0.00	0.00
2006	31181.037	0	0	5.33	1.17	0.00	0.00
2007	32843.889	0	0	5.33	1.17	0.00	0.00
2008	34595.42	0	0	5.33	1.17	0.00	0.00
2009	36440.358	0	0	5.33	1.17	0.00	0.00
2010	38383.685	0	0	5.33	1.17	0.00	0.00
2011	40430.648	0	0	5.33	1.17	0.00	0.00
2012	42586.773	0	0	5.33	1.17	0.00	0.00
2013	44857.881	0	0	5.33	1.17	0.00	0.00
2014	47250.106	0	0	5.33	1.17	0.00	0.00
2015	49769.906	0	0	5.33	1.17	0.00	0.00
2016	52424.084	0	0	5.33	1.17	0.00	0.00
2017	55219.806	0	0	5.33	1.17	0.00	0.00

Year	*Potash Materials (Cloride)*						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	201410.04	0	0	1.88	1.17	0.00	0.00
1998	205204.24	0	0	1.88	1.17	0.00	0.00
1999	209069.92	0	0	1.88	1.17	0.00	0.00
2000	213008.41	0	0	1.88	1.17	0.00	0.00
2001	217021.1	0	0	1.88	1.17	0.00	0.00
2002	221109.39	0	0	1.88	1.17	0.00	0.00
2003	225274.68	0	0	1.88	1.17	0.00	0.00
2004	229518.45	0	0	1.88	1.17	0.00	0.00
2005	233842.16	0	0	1.88	1.17	0.00	0.00
2006	238247.32	0	0	1.88	1.17	0.00	0.00
2007	242735.46	0	0	1.88	1.17	0.00	0.00
2008	247308.16	0	0	1.88	1.17	0.00	0.00
2009	251966.99	0	0	1.88	1.17	0.00	0.00
2010	256713.59	0	0	1.88	1.17	0.00	0.00
2011	261549.61	0	0	1.88	1.17	0.00	0.00
2012	266476.73	0	0	1.88	1.17	0.00	0.00
2013	271496.66	0	0	1.88	1.17	0.00	0.00
2014	276611.17	0	0	1.88	1.17	0.00	0.00
2015	281822.02	0	0	1.88	1.17	0.00	0.00
2016	287131.03	0	0	1.88	1.17	0.00	0.00
2017	292540.06	0	0	1.88	1.17	0.00	0.00

Soil Management

Year	Other						
	Consumption (tons)	% N	(tons N)		Emission Factors (% N_2O - N Produced)	Emissons (tons N_2O - N)	Emissons (tons N_2O)
1997	13683.888	20	2737	2.69	1.17	32.02	50.32
1998	14052.443	20	2810	2.69	1.17	32.88	51.67
1999	14430.923	20	2886	2.69	1.17	33.77	53.06
2000	14819.598	20	2964	2.69	1.17	34.68	54.49
2001	15218.741	20	3044	2.69	1.17	35.61	55.96
2002	15628.634	20	3126	2.69	1.17	36.57	57.47
2003	16049.567	20	3210	2.69	1.17	37.56	59.02
2004	16481.838	20	3296	2.69	1.17	38.57	60.61
2005	16925.75	20	3385	2.69	1.17	39.61	62.24
2006	17381.619	20	3476	2.69	1.17	40.67	63.91
2007	17849.766	20	3570	2.69	1.17	41.77	65.64
2008	18330.522	20	3666	2.69	1.17	42.89	67.40
2009	18824.226	20	3765	2.69	1.17	44.05	69.22
2010	19331.228	20	3866	2.69	1.17	45.24	71.08
2011	19851.885	20	3970	2.69	1.17	46.45	73.00
2012	20386.564	20	4077	2.69	1.17	47.70	74.96
2013	20935.645	20	4187	2.69	1.17	48.99	76.98
2014	21499.514	20	4300	2.69	1.17	50.31	79.06
2015	22078.57	20	4416	2.69	1.17	51.66	81.19
2016	22673.222	20	4535	2.69	1.17	53.06	83.37
2017	23283.891	20	4657	2.69	1.17	54.48	85.62

Soil Management

Year	N-K						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	3296.6151	14.9	491	2.95	1.17	5.75	9.03
1998	3394.026	14.9	506	2.95	1.17	5.92	9.30
1999	3494.3152	14.9	521	2.95	1.17	6.09	9.57
2000	3597.5679	14.9	536	2.95	1.17	6.27	9.86
2001	3703.8716	14.9	552	2.95	1.17	6.46	10.15
2002	3813.3164	14.9	568	2.95	1.17	6.65	10.45
2003	3925.9951	14.9	585	2.95	1.17	6.84	10.76
2004	4042.0034	14.9	602	2.95	1.17	7.05	11.07
2005	4161.4396	14.9	620	2.95	1.17	7.25	11.40
2006	4284.4049	14.9	638	2.95	1.17	7.47	11.74
2007	4411.0038	14.9	657	2.95	1.17	7.69	12.08
2008	4541.3434	14.9	677	2.95	1.17	7.92	12.44
2009	4675.5345	14.9	697	2.95	1.17	8.15	12.81
2010	4813.6907	14.9	717	2.95	1.17	8.39	13.19
2011	4955.9293	14.9	738	2.95	1.17	8.64	13.58
2012	5102.3708	14.9	760	2.95	1.17	8.89	13.98
2013	5253.1395	14.9	783	2.95	1.17	9.16	14.39
2014	5408.3633	14.9	806	2.95	1.17	9.43	14.82
2015	5568.1737	14.9	830	2.95	1.17	9.71	15.25
2016	5732.7063	14.9	854	2.95	1.17	9.99	15.70
2017	5902.1006	14.9	879	2.95	1.17	10.29	16.17

Year	P-K						
	Consumption			Rate of	Emission Factors	Emissons	Emissons
	(tons)	% N	(tons N)	Change(%)	(% N_2O - N Produced)	(tons N_2O - N)	(tons N_2O)
1997	1208.0079	0	0	-9.38	1.17	0.00	0.00
1998	1094.7359	0	0	-9.38	1.17	0.00	0.00
1999	992.08523	0	0	-9.38	1.17	0.00	0.00
2000	899.05983	0	0	-9.38	1.17	0.00	0.00
2001	814.75719	0	0	-9.38	1.17	0.00	0.00
2002	738.35941	0	0	-9.38	1.17	0.00	0.00
2003	669.12526	0	0	-9.38	1.17	0.00	0.00
2004	606.38303	0	0	-9.38	1.17	0.00	0.00
2005	549.52398	0	0	-9.38	1.17	0.00	0.00
2006	497.99646	0	0	-9.38	1.17	0.00	0.00
2007	451.30056	0	0	-9.38	1.17	0.00	0.00
2008	408.98321	0	0	-9.38	1.17	0.00	0.00
2009	370.63386	0	0	-9.38	1.17	0.00	0.00
2010	335.88043	0	0	-9.38	1.17	0.00	0.00
2011	304.38575	0	0	-9.38	1.17	0.00	0.00
2012	275.84424	0	0	-9.38	1.17	0.00	0.00
2013	249.97901	0	0	-9.38	1.17	0.00	0.00
2014	226.53909	0	0	-9.38	1.17	0.00	0.00
2015	205.29707	0	0	-9.38	1.17	0.00	0.00
2016	186.04687	0	0	-9.38	1.17	0.00	0.00
2017	168.60171	0	0	-9.38	1.17	0.00	0.00

CO2 Emissions from Forest Management

Year	CO2 Emissions from Changes in Biomass Stock	CO2 Emissions from Forest and Grassland Conversion	CO2 Uptake from Abandoned Lands	Total CO2 Uptake from Forest management
	Million Tons	*Million Tons*	*Million Tons*	*Million Tons*
1985	-0.67	2.21	-6.43	-4.89
1986	-0.67	2.21	-6.43	-4.89
1987	-0.67	2.21	-6.43	-4.89
1988	-0.67	2.21	-6.43	-4.89
1989	-0.67	2.21	-6.43	-4.89
1990	-0.67	2.21	-6.43	-4.89
1991	-0.67	2.21	-6.43	-4.89
1992	-0.67	2.21	-6.43	-4.89
1993	-0.67	2.21	-6.43	-4.89
1994	-0.67	2.21	-6.43	-4.89

Year	CO2 Emissions from Changes in Biomass Stock	CO2 Emissions from Forest and Grassland Conversion	CO2 Uptake from Abandoned Lands	Projected Total CO2 Uptake from Forest management
	Million Tons	*Million Tons*	*Million Tons*	*Million Tons*
1995	-0.67	2.21	-6.43	-4.89
1996	-0.67	2.21	-6.43	-4.89
1997	-0.67	2.21	-6.43	-4.89
1998	-0.67	2.21	-6.43	-4.89
1999	-0.67	2.21	-6.43	-4.89
2000	-0.67	2.21	-6.43	-4.89
2001	-0.67	2.21	-6.43	-4.89
2002	-0.67	2.21	-6.43	-4.89
2003	-0.67	2.21	-6.43	-4.89
2004	-0.67	2.21	-6.43	-4.89
2005	-0.67	2.21	-6.43	-4.89
2006	-0.67	2.21	-6.43	-4.89
2007	-0.67	2.21	-6.43	-4.89
2008	-0.67	2.21	-6.43	-4.89
2009	-0.67	2.21	-6.43	-4.89
2010	-0.67	2.21	-6.43	-4.89
2011	-0.67	2.21	-6.43	-4.89
2012	-0.67	2.21	-6.43	-4.89
2013	-0.67	2.21	-6.43	-4.89
2014	-0.67	2.21	-6.43	-4.89
2015	-0.67	2.21	-6.43	-4.89
2016	-0.67	2.21	-6.43	-4.89
2017	-0.67	2.21	-6.43	-4.89

NOx Emissions from Burning of Agricultural Crop Wastes

Year	Soybeans	Wheat	Corn	Sorghum	Snap Beans	Total NOx Emissions from Burning of Agricultural Crop Wastes
	tons	*tons*	*tons*	*tons*	*tons*	*tons*
1985	432	25	200	102	4	763
1986	432	25	200	102	4	763
1987	432	25	200	102	4	763
1988	432	25	200	102	4	763
1989	432	25	200	102	4	763
1990	432	25	200	102	4	763
1991	432	25	200	102	4	763
1992	432	25	200	102	4	763
1993	432	25	200	102	4	763
1994	432	25	200	102	4	763

Year	Soybeans	Wheat	Corn	Sorghum	Snap Beans	Total NOx Emissions from Burning of Agricultural Crop Wastes
	tons	*tons*	*tons*	*tons*	*tons*	*tons*
1995	432	25	200	102	4	763
1996	432	25	200	102	4	763
1997	432	25	200	102	4	763
1998	432	25	200	102	4	763
1999	432	25	200	102	4	763
2000	432	25	200	102	4	763
2001	432	25	200	102	4	763
2002	432	25	200	102	4	763
2003	432	25	200	102	4	763
2004	432	25	200	102	4	763
2005	432	25	200	102	4	763
2006	432	25	200	102	4	763
2007	432	25	200	102	4	763
2008	432	25	200	102	4	763
2009	432	25	200	102	4	763
2010	432	25	200	102	4	763
2011	432	25	200	102	4	763
2012	432	25	200	102	4	763
2013	432	25	200	102	4	763
2014	432	25	200	102	4	763
2015	432	25	200	102	4	763
2016	432	25	200	102	4	763
2017	432	25	200	102	4	763

Methane Emissions from the Burning of Agricultural Crop Wastes

Year	Soybeans	Wheat	Corn	Sorghum	Snap Beans	Total Methane Emissions from Burning of Agricultural Crop Wastes	Total Equivalent CO2 Emissions
	tons	*tons*	*tons*	*tons*	*tons*	*tons*	
1985	210	75	288	145	2	720	15840
1986	210	75	288	145	2	720	15840
1987	210	75	288	145	2	720	15840
1988	210	75	288	145	2	720	15840
1989	210	75	288	145	2	720	15840
1990	210	75	288	145	2	720	15840
1991	210	75	288	145	2	720	15840
1992	210	75	288	145	2	720	15840
1993	210	75	288	145	2	720	15840
1994	210	75	288	145	2	720	15840

Year	Soybeans	Wheat	Corn	Sorghum	Snap Beans	Total Methane Emissions from Burning of Agricultural Crop Wastes	Total Equivalent CO2 Emissions
	tons	tons	tons	tons	tons	tons	
1995	210	75	288	145	2	720	15840
1996	210	75	288	145	2	720	15840
1997	210	75	288	145	2	720	15840
1998	210	75	288	145	2	720	15840
1999	210	75	288	145	2	720	15840
2000	210	75	288	145	2	720	15840
2001	210	75	288	145	2	720	15840
2002	210	75	288	145	2	720	15840
2003	210	75	288	145	2	720	15840
2004	210	75	288	145	2	720	15840
2005	210	75	288	145	2	720	15840
2006	210	75	288	145	2	720	15840
2007	210	75	288	145	2	720	15840
2008	210	75	288	145	2	720	15840
2009	210	75	288	145	2	720	15840
2010	210	75	288	145	2	720	15840
2011	210	75	288	145	2	720	15840
2012	210	75	288	145	2	720	15840
2013	210	75	288	145	2	720	15840
2014	210	75	288	145	2	720	15840
2015	210	75	288	145	2	720	15840
2016	210	75	288	145	2	720	15840
2017	210	75	288	145	2	720	15840

N2O Emissions from the Burning of Agricultural Crop Wastes

Year	Soybeans	Wheat	Corn	Sorghum	Snap Beans	Total N2O Emissions from Burning of Agricultural Crop Wastes	Equivalent CO2 Emissions
	tons	*tons*	*tons*	*tons*	*tons*	*tons*	
1985	25	1	12	6	0	44	11880
1986	25	1	12	6	0	44	11880
1987	25	1	12	6	0	44	11880
1988	25	1	12	6	0	44	11880
1989	25	1	12	6	0	44	11880
1990	25	1	12	6	0	44	11880
1991	25	1	12	6	0	44	11880
1992	25	1	12	6	0	44	11880
1993	25	1	12	6	0	44	11880
1994	25	1	12	6	0	44	11880

Year	Soybeans	Wheat	Corn	Sorghum	Snap Beans	Total N2O Emissions from Burning of Agricultural Crop Wastes	Equivalent CO2 Emissions
	tons	tons	tons	tons	tons	tons	
1995	25	1	12	6	0	44	11880
1996	25	1	12	6	0	44	11880
1997	25	1	12	6	0	44	11880
1998	25	1	12	6	0	44	11880
1999	25	1	12	6	0	44	11880
2000	25	1	12	6	0	44	11880
2001	25	1	12	6	0	44	11880
2002	25	1	12	6	0	44	11880
2003	25	1	12	6	0	44	11880
2004	25	1	12	6	0	44	11880
2005	25	1	12	6	0	44	11880
2006	25	1	12	6	0	44	11880
2007	25	1	12	6	0	44	11880
2008	25	1	12	6	0	44	11880
2009	25	1	12	6	0	44	11880
2010	25	1	12	6	0	44	11880
2011	25	1	12	6	0	44	11880
2012	25	1	12	6	0	44	11880
2013	25	1	12	6	0	44	11880
2014	25	1	12	6	0	44	11880
2015	25	1	12	6	0	44	11880
2016	25	1	12	6	0	44	11880
2017	25	1	12	6	0	44	11880

CO Emissions from the Burning of Agricultural Crop Wastes

Year	Soybeans	Wheat	Corn	Sorghum	Snap Beans	Total CO Emissions from Burning of Agricultural Crop Wastes
	tons	*tons*	*tons*	*tons*	*tons*	*tons*
1985	4196	1494	5755	2901	37	14383
1986	4196	1494	5755	2901	37	14383
1987	4196	1494	5755	2901	37	14383
1988	4196	1494	5755	2901	37	14383
1989	4196	1494	5755	2901	37	14383
1990	4196	1494	5755	2901	37	14383
1991	4196	1494	5755	2901	37	14383
1992	4196	1494	5755	2901	37	14383
1993	4196	1494	5755	2901	37	14383
1994	4196	1494	5755	2901	37	14383

Year	Soybeans	Wheat	Corn	Sorghum	Snap Beans	Total CO Emissions from Burning of Agricultural Crop Wastes
	tons	*tons*	*tons*	*tons*	*tons*	*tons*
1995	4196	1494	5755	2901	37	14383
1996	4196	1494	5755	2901	37	14383
1997	4196	1494	5755	2901	37	14383
1998	4196	1494	5755	2901	37	14383
1999	4196	1494	5755	2901	37	14383
2000	4196	1494	5755	2901	37	14383
2001	4196	1494	5755	2901	37	14383
2002	4196	1494	5755	2901	37	14383
2003	4196	1494	5755	2901	37	14383
2004	4196	1494	5755	2901	37	14383
2005	4196	1494	5755	2901	37	14383
2006	4196	1494	5755	2901	37	14383
2007	4196	1494	5755	2901	37	14383
2008	4196	1494	5755	2901	37	14383
2009	4196	1494	5755	2901	37	14383
2010	4196	1494	5755	2901	37	14383
2011	4196	1494	5755	2901	37	14383
2012	4196	1494	5755	2901	37	14383
2013	4196	1494	5755	2901	37	14383
2014	4196	1494	5755	2901	37	14383
2015	4196	1494	5755	2901	37	14383
2016	4196	1494	5755	2901	37	14383
2017	4196	1494	5755	2901	37	14383

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Methane Emissions From

Year	Population*	Growth(%)	Wastewater BOD Generation Rate (lbs BOD/capita/day)	BOD Generated (lbs BOD)	Fraction Anaerobically Treated
1995	5,256,061		0.200	1,051,212	0.150
1996	5,340,959	1.62	0.200	1,068,192	0.150
1997	5,423,117	1.54	0.200	1,084,623	0.150
1998	5,503,671	1.49	0.200	1,100,734	0.150
1999	5,582,726	1.44	0.200	1,116,545	0.150
2000	5,657,161	1.33	0.200	1,131,432	0.150
2001	5,727,471	1.24	0.200	1,145,494	0.150
2002	5,793,260	1.15	0.200	1,158,652	0.150
2003	5,854,927	1.06	0.200	1,170,985	0.150
2004	5,912,470	0.98	0.200	1,182,494	0.150
2005	5,965,611	0.90	0.200	1,193,122	0.150
2006	6,015,033	0.83	0.200	1,203,007	0.150
2007	6,061,010	0.76	0.200	1,212,202	0.150
2008	6,103,195	0.70	0.200	1,220,639	0.150
2009	6,141,868	0.63	0.200	1,228,374	0.150
2010	6,180,274	0.63	0.200	1,236,055	0.150
2011	6,218,494	0.62	0.200	1,243,699	0.150
2012	6,256,038	0.60	0.200	1,251,208	0.150
2013	6,293,138	0.59	0.200	1,258,628	0.150
2014	6,329,393	0.58	0.200	1,265,879	0.150
2015	6,364,850	0.56	0.200	1,272,970	0.150
2016	6,399,485	0.54	0.200	1,279,897	0.150
2017	6,433,365	0.53	0.200	1,286,673	0.150

* Tennessee Population Estimates--U.S. Census Bureau

Municiple Wastwater

Quantity of BOD Treated Anaerobically (lbsBOD/yr)	Methane Emissions Factor (lbs CH4/lb BOD)	CH4 Emissions (lbs CH4)	Methane Recovered (lbs CH4)	Net CH4 Emissions (tons CH4)	Equivalent CO2 (tons CO2)
57,553,868	0.220	12,661,851	0.000	6,331	0.139
58,483,501	0.220	12,866,370	0.000	6,433	0.142
59,383,131	0.220	13,064,289	0.000	6,532	0.144
60,265,197	0.220	13,258,343	0.000	6,629	0.146
61,130,850	0.220	13,448,787	0.000	6,724	0.148
61,945,913	0.220	13,628,101	0.000	6,814	0.150
62,715,807	0.220	13,797,478	0.000	6,899	0.152
63,436,197	0.220	13,955,963	0.000	6,978	0.154
64,111,451	0.220	14,104,519	0.000	7,052	0.155
64,741,547	0.220	14,243,140	0.000	7,122	0.157
65,323,440	0.220	14,371,157	0.000	7,186	0.158
65,864,611	0.220	14,490,214	0.000	7,245	0.159
66,368,060	0.220	14,600,973	0.000	7,300	0.161
66,829,985	0.220	14,702,597	0.000	7,351	0.162
67,253,455	0.220	14,795,760	0.000	7,398	0.163
67,674,000	0.220	14,888,280	0.000	7,444	0.164
68,092,509	0.220	14,980,352	0.000	7,490	0.165
68,503,616	0.220	15,070,796	0.000	7,535	0.166
68,909,861	0.220	15,160,169	0.000	7,580	0.167
69,306,853	0.220	15,247,508	0.000	7,624	0.168
69,695,108	0.220	15,332,924	0.000	7,666	0.169
70,074,361	0.220	15,416,359	0.000	7,708	0.170
70,445,347	0.220	15,497,976	0.000	7,749	0.170