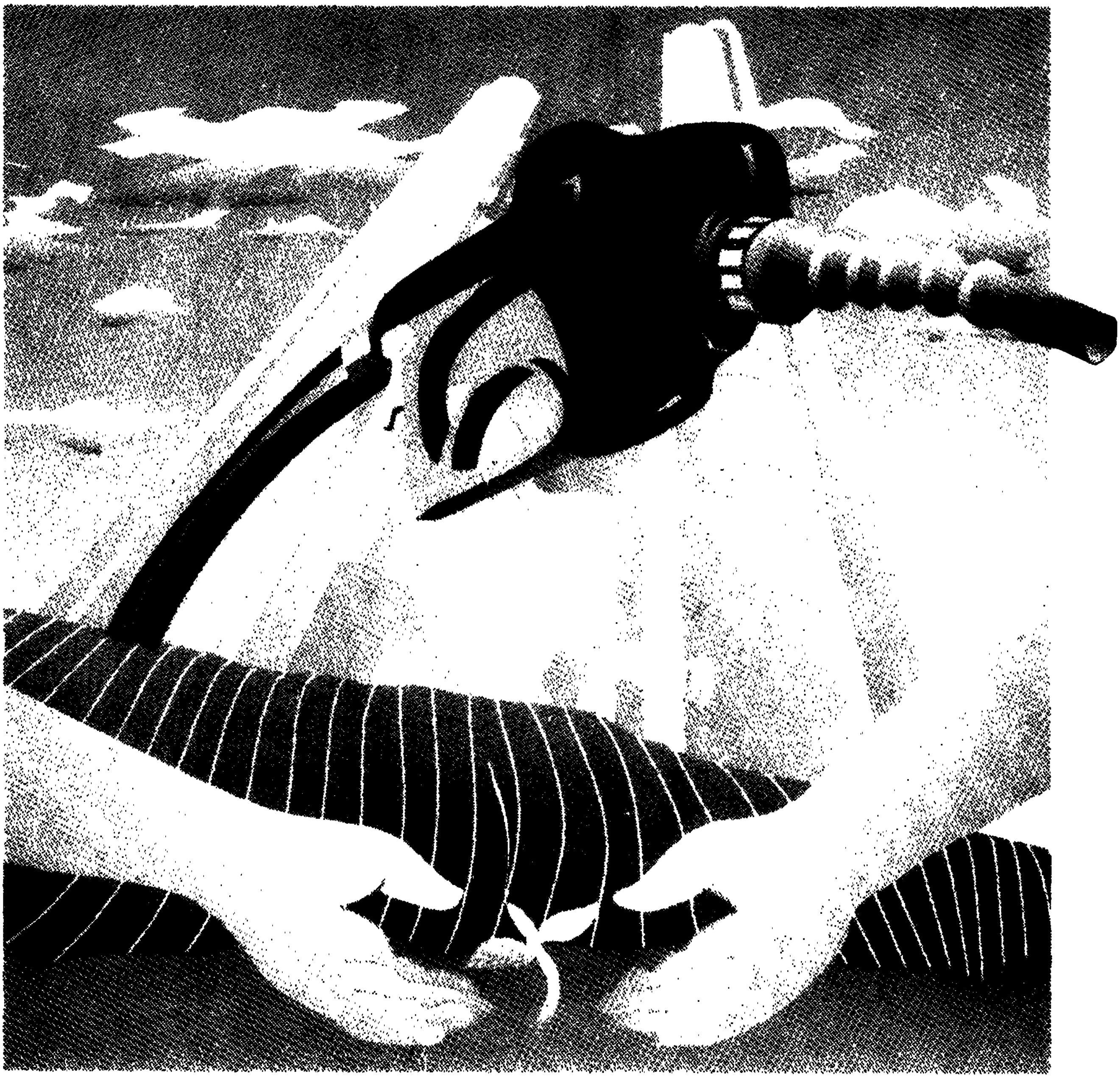
Fuel Cycle Evaluations Of Biomass – Ethanol And Reformulated Gasoline



Volume I

NREL

Fuel Cycle Evaluations of Biomass-Ethanol and Reformulated Gasoline

Volume I

Dr. K. Shaine Tyson
Cynthia J. Riley
Kenneth K. Humphreys

Prepared for:
Office of Transportation Technologies
and the Office of Planning and Assessment
Assistant Secretary for Energy Efficiency and Renewable Energy
U.S. Department of Energy
by the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401
and
Oak Ridge National Laboratory
Pacific Northwest Laboratory

NREL is a national laboratory of the U.S. Department of Energy.
NREL/TP-463-4950
DE94000227
November 1993

NOTICE

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01
Printed Copy A07

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issue of the following publications which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements and Index (GRA and I)*; *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

Printed on recycled paper

ACKNOWLEDGMENT

This report was undertaken in May 1991 at the request of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, with funding from the Office of Transportation Technologies and the Office of Planning and Assessment. The following participants are recognized for their contribution to this report:

Project Team Management

Cynthia Riley, *National Renewable Energy Laboratory*
K. Shaine Tyson, *National Renewable Energy Laboratory*
Brent Bailey, *National Renewable Energy Laboratory*
Ken Humphreys, *Pacific Northwest Laboratories*
Marylynn Placet, *Pacific Northwest Laboratories*
Lynn Wright, *Oak Ridge National Laboratories*

Other Project Participants

Dan Schell, *National Renewable Energy Laboratory*
Jack Ranney, *Oak Ridge National Laboratory*
R.D. Perlack, *Oak Ridge National Laboratory*
Jerry Tuskan, *Oak Ridge National Laboratory*
Meridian Corporation
Radian Corporation
CH2M Hill
EA Engineering, Science and Technology (formerly EA Mueller)
J.E. Sinor Consultants, Inc.

In addition, we would like to extend a special acknowledgement to the reviewers of this document (beginning on page 87). We want to thank these people for taking the time from their schedules to read and evaluate this work. They provided us with many helpful comments that have been invaluable. Where possible, we modified this work to reflect the information provided by the reviewers.

There were four types of comments that were not incorporated in this work and these deserve a brief description and explanation. Some comments were outside the scope of this effort. For example, some reviewers wanted us to characterize the corn-ethanol fuel cycles; however, our focus was to evaluate a new technology--producing ethanol from lignocellulosic biomass. Interested persons should contact the U.S. Department of Agriculture, Office of Energy, for information concerning corn ethanol.

Some comments reflected specific operating parameters of selected firms. Although this information was valuable and may be used in future studies, we had to use published information that is representative of the entire industry. This approach tends to discount the advances made by progressive companies. It was not our intent to imply that all firms operate in the manner described in this work.

Many of the comments addressed the validity of the ethanol technology described in this work. There are many possible configurations for the future biomass-ethanol technologies. The biomass conversion technology we described is one of many possible designs. The design used in this report is based on the results of more than 15 years of research and development by DOE and NREL. We believe that the hypothetical biomass-ethanol production system could operate as we described in this report. The authors never intended to examine policy or economic issues of industrial development. The intent of this work was to look at ethanol and RFG fuel cycles, as we envisioned they would function, for environmental releases that may have policy impacts. The ethanol technologies are in an early stage of development where they could be modified to alleviate unintentional damages. The systems approach sometimes reveals issues that are not seen when researchers examine small components of the system separately.

The reviewers pointed out many different assumptions that could have been used to define the boundaries of this study. There are many ways to define the boundaries, this study used a consistent approach accross each fuel cycle and provides the results of some sensitivity analyses of varying the assumptions used. Some of these boundaries are being addressed in the next generation of fuel cycle studies. The boundaries of the study can be modified to examine other assumptions to some extent. Copies of the original data are available in *Volume II: Appendices.* The readers could then manipulate these data to test alternative theories. Furthermore, these data could be modified by the reader's own information, which may differ from ours. For a copy of *Volume II: Appendices* please contact Dr. K. Shaine Tyson, National Renewable Energy Laboratory at 303-231-1316 or write to the laboratory at 1617 Cole Boulevard, Golden, Colorado, 80401.

Dr. K. Shaine Tyson
Senior Economist

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is using the total fuel cycle analysis (TFCA) methodology to evaluate energy choices. The National Energy Strategy (NES) identifies TFCA as a tool to describe and quantify the environmental, social, and economic costs and benefits associated with energy alternatives. A TFCA should quantify inputs and outputs, their impacts on society, and the value of those impacts that occur from each activity involved in producing and using fuels, cradle-to-grave. New fuels and energy technologies can be consistently evaluated and compared using TFCA, providing a sound basis for ranking policy options that expand the fuel choices available to consumers.

This study is limited to creating an inventory of inputs and outputs for three transportation fuels: (1) reformulated gasoline (RFG) that meets the standards of the Clean Air Act Amendments of 1990 (CAAA) using methyl tertiary butyl ether (MTBE); (2) gasohol (E10), a mixture of 10% ethanol made from municipal solid waste (MSW) and 90% gasoline; and (3) E95, a mixture of 5% gasoline and 95% ethanol made from energy crops such as grasses and trees.

The ethanol referred to in this study is produced from lignocellulosic material—trees, grass, and organic wastes—called biomass. The biomass is converted to ethanol using an experimental technology described in more detail later. Corn-ethanol is not discussed in this report.

This study is limited to estimating an inventory of inputs and outputs for each fuel cycle, similar to a mass balance study, for several reasons: (1) to manage the size of the project; (2) to provide the data required for others to conduct site-specific impact analysis on a case-by-case basis; (3) to reduce data requirements associated with projecting future environmental baselines and other variables that require an internally consistent scenario.

The E10 and RFG fuel cycles are compared for the year 2000; E95 and RFG fuel cycles are compared in 2010. Based on recent technological advances, ethanol-from-waste technology may be commercial by 2000; further advances should make ethanol-from-energy crops commercial by 2010. Ethanol will continue to be used as an additive to gasoline in the near future (e.g., the year 2000). By 2010, dedicated vehicles should be commercially available that run entirely off pure or nearly pure ethanol fuels such as E95. The fuels are consumed in light-duty passenger vehicles that reflect technology advances that are possible by 2000 or 2010.

When this study was initiated, 10% ethanol blends were common for financial reasons. Recent policy changes make the use of blends of less than 10% equally attractive financially and likely for environmental reasons. We chose to examine 10% blends because emission data were available. The fuel cycle results are presented in a format that the reader can use to examine other likely blends.

Five regional E95 fuel cycles were examined to evaluate the impact of different feedstock mixes on inventory input and output levels. The technology of producing ethanol from biomass was based on engineering designs, research trends, past industrial experience, and expert opinion. Projections of future crude oil mixes, refining product outputs, and organizational structure were used to characterize the future RFG industry.

Each fuel cycle is represented by a flow chart of activities based on a model industry. From this, an inventory of inputs (electricity, chemicals, materials, etc.) and outputs (fuel, emissions, wastes, etc.) was created for each fuel cycle. Only the operational phase of the fuel cycles was examined (Figure 1). Ranges are not provided for the estimated inputs and outputs because the model industry assumes that all firms have identical resources and technologies. Therefore, the results presented are point estimates that describe selected scenarios and are not projections of future industrial performance.

The industrial activities for each fuel cycle are divided into five stages: feedstock production, feedstock transportation, fuel production, fuel distribution, and end use. This convention is used to describe the fuel cycles and the results. All of the activities in a stage are detailed, with respect to equipment efficiency, capacity, and operating parameters that are common to the industry, or are expected to be technically feasible by 2000 or 2010.

Preconstruction and decommissioning phases of the fuel cycles are not included in this study. The discussion of results focuses on the gaseous, solid, and liquid fuel cycle emissions because environmental implications are the major issues influencing fuel use today (CAAA 1990, NES 1991).

Each fuel cycle accounts for all of the inventory characteristics associated with producing enough fuel to travel 1 billion vehicle miles (VMT). One billion VMT the data to be presented in common units, such as tons or gallons. To put one billion miles into perspective, Americans drove their passenger vehicles more than 1,769 billion VMT in 1990 and are expected to drive 2,177 billion VMT by 2000 and 2,814 billion VMT by 2010 (NES2 1991). The results are discussed in grams per mile as these are the standard units used by the industry.

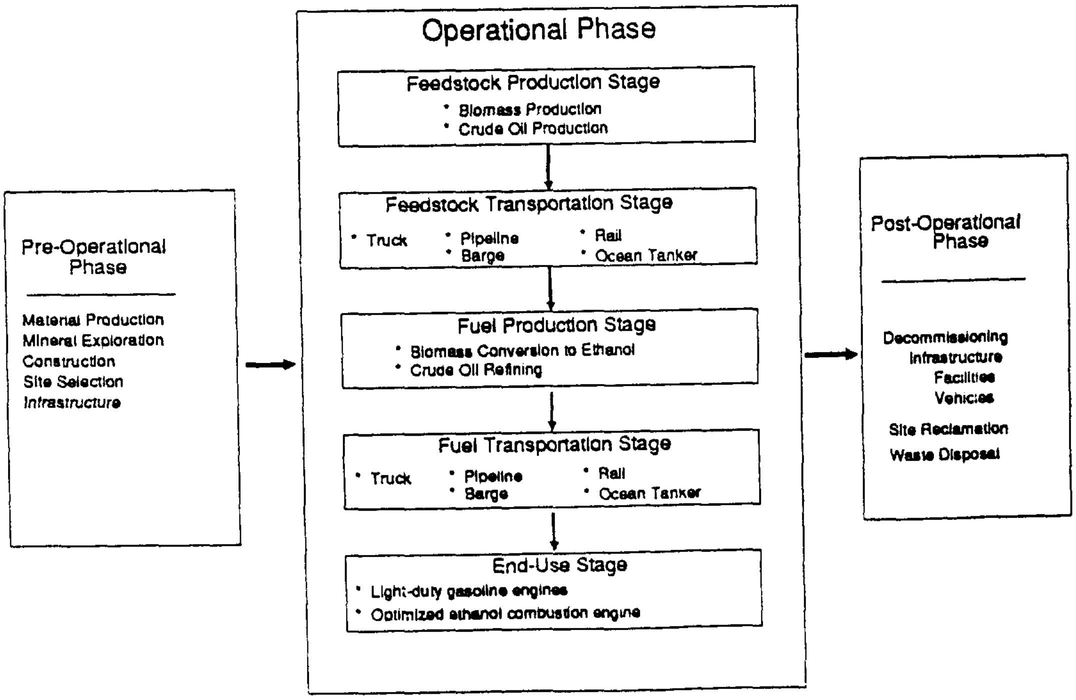


Figure 1. Fuel cycle boundaries

The conclusions drawn from this study are:

- Research and development towards reducing vehicle emissions can produce substantial benefits because the majority of fuel cycle emissions are produced in the end use stage
- RFG 2000 and 2010 emissions are underestimated because the fuel cycle emissions from producing MTBE were excluded, therefore, actual emissions would be higher than those shown in this report
- The E10 fuel cycle produces less carbon monoxide (CO), carbon dioxide (CO_2), and sulfur dioxide (SO_2), and creates substantial reductions in MSW sent to landfills compared to RFG 2000
- E95 fuel cycles produce 90% fewer CO_2, 67% less SO_2, and 14% less volitile organic carbon (VOC) emissions compared to the RFG fuel cycle
- When emissions associated with electricity production are included in the fuel cycle inventory for every kwh consumed or produced, E95 fuel cycles produce less of every criteria air emission except CO compared with RFG 2010
- Ethanol fuels can extend our fossil fuel resources in the transportation sector because they require fewer resources per Btu of fuel to produce
- This study can be used to rank fuels based on selected criteria, such as CO_2 emissions, but impact and valuation analysis is required to conclude that one fuel is preferred to another.

Most of the gaseous emissions are generated in the end-use and transportation stages. Improvements in engine performance, catalytic converters, and other vehicle emission controls will benefit both fuels. The CAAA set standards for vehicle emissions that will play a central role in determining the emission characteristics of fuel cycles because most of the emissions are produced by vehicles or stationary sources (fuel production facilities). Because of the lack of data on ethanol vehicle emissions, end-use emission estimates are based on the assumption that fuel and auto manufacturers will design systems to meet regulations. Thus, these regulations are critical focal points of the analysis.

There are only small differences between E10 and RFG inventory characteristics in 2000, because both RFG 2000 and E10 are composed of roughly 90% gasoline and the fuel cycle inventory associated with the gasoline is included in the E10 fuel cycle (Figure 2). If the emissions from producing MTBE were included in the RFG fuel cycles, E10 may produce fewer criteria air emissions than RFG.

E10 fuel cycles produce slightly less CO, SO_2, and CO_2 than RFG because of the ethanol component, but E10 also creates slightly more VOC, PM, NOx, and waste-water. Some emission reductions may offer valuable solutions to urban air quality in the short term. A major benefit of E10 is the opportunity to combine waste reduction with oxygenated fuel use in urban areas. Nearly 22 grams of MSW is diverted from landfills for every mile travelled on E10.

E95 fuel cycles produce less CO_2, SO_2, and nonbiogenic VOCs than the RFG 2010 fuel cycle (Figure 3). Biogenic VOCs are produced by growing plants during photosynthesis. The differences between E95 and RFG 2010 could be larger for some emissions shown because the emissions from producing MTBE have been omitted.

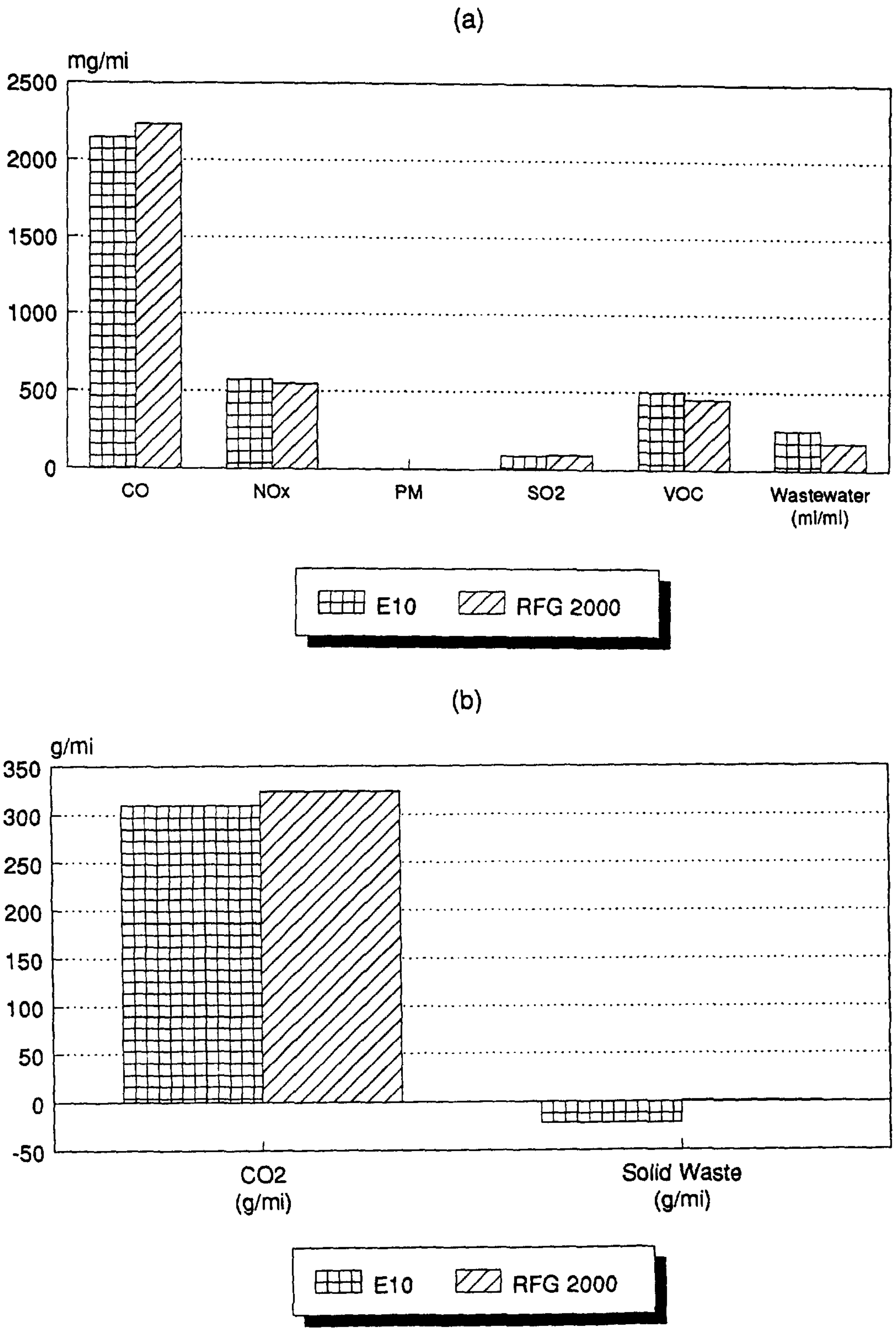


Figure 2. Fuel cycle emissions for E10 and RFG, 2000: (a) air emissions; (b) liquid and solid wastes

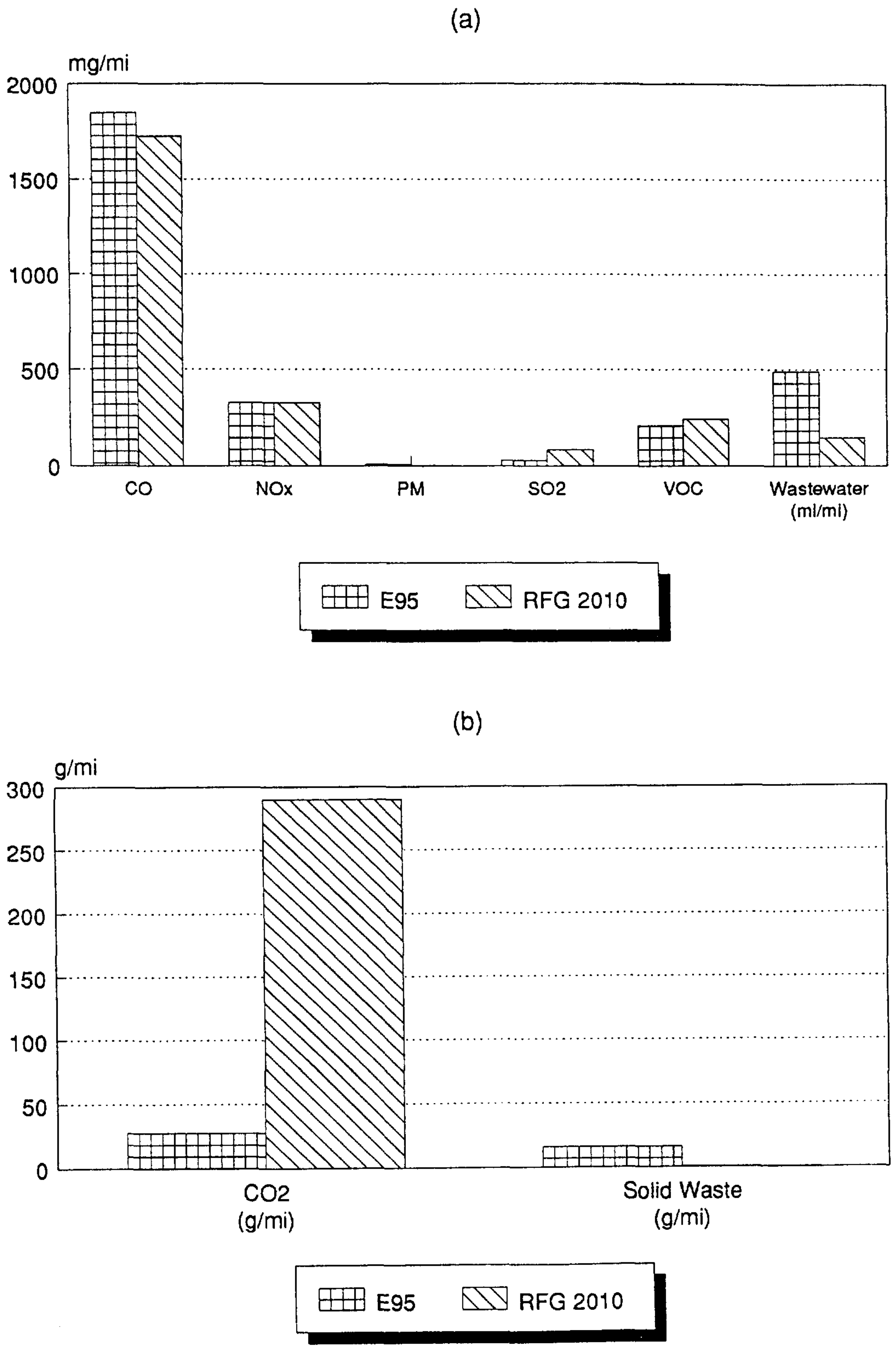


Figure 3. Fuel cycle emissions for E95 and RFG, 2010: (a) air emissions; (b) liquid and solid wastes

From this study, we can conclude that replacing a portion of the transportation fuel market with ethanol fuels can reduce global CO_2 emissions. Fossil fuel combustion accounts for all of the CO_2 produced in the E95 fuel cycles. E95 fuel cycles produce only 9% of the net CO_2 produced by the RFG fuel cycle.

Estimates of soil carbon accumulation are provided but not included in the fuel cycle inventory because they were treated as a long-term investments rather than a short-term operational characteristics. During the 30-year period required for soil carbon accumulation to reach an equilibrium, an average of 15.4 g/mi of CO_2 is sequestered in the soil each year. If annual soil carbon accumulation is included in the E95 fuel cycles, E95 produces only 4% of the total CO_2 produced by the RFG fuel cycle.

Generating electricity produces gaseous, liquid, and solid wastes. A sensitivity analysis examined the effect of including selected emissions from electricity generation or offsets. Electricity consumption creates emissions that are added to the appropriate stages of the fuel cycles. The ethanol production facility is a cogeneration plant, producing both ethanol and electricity. In the electricity sensitivity analyses, the ethanol fuel cycles are credited for the emissions that would be avoided if the utility purchased the ethanol company's electricity, rather than use their own fossil fuel capacity (emission per kWh x kWh sold). The ethanol fuels cycles were not allocated for the electricity sensitivity analysis (see section 3 for more details on allocations).

The addition of electricity emissions does not significantly change the results of the 2000 fuel cycles. However, significant changes occur when electricity emissions are included in the 2010 fuel cycles. E95 fuel cycles reduce all air emissions except CO. The differences could have been larger if the emissions from producing MTBE were included in the RFG 2010 fuel cycle.

The average E95 fuel cycle produces only 6.6 grams of CO_2 for every mile travelled. If E95 is substituted for RFG, E95 fuels could prevent the release of 301 g/mi of CO_2. In addition, producing electricity from ethanol plants offsets 32 mg/mi of SO_2. If E95 is substituted for RFG, the U.S. production of SO_2 would fall by 163 mg/mi.

Similarly, NOx, particulates, and VOC emissions are reduced by the electricity credit provided to the E95 fuel cycles. It is clear that E95 fuels provide substantial environmental benefits in emission reductions. This sensitivity analysis shows how the indirect impacts associated with a fuel cycle can be significant.

An energy analysis evaluated the non-renewable fossil fuel inputs required to produce each fuel. We found that one Btu of E10 requires 1.23 Btu of fossil fuel inputs while one Btu of RFG 2000 requires 1.25 Btu of fossil energy (Figure 4). One Btu of E95 requires only 0.25 Btu of fossil fuel energy to produce compared to 1.27 Btu to produce one Btu of RFG 2010.

The use of a renewable transportation fuel could extend our fossil fuel supplies over a longer period of time. During that time, other solutions could be developed to replace dependence on a declining resource.

In conclusion, the TFCA methodology can be used as a tool for ranking technological options for the DOE, even when the technology considered is experimental or the industry considered is distant in time. Information can be collected and organized in a manner that provides useful insights concerning both the technological development and its environmental implications.

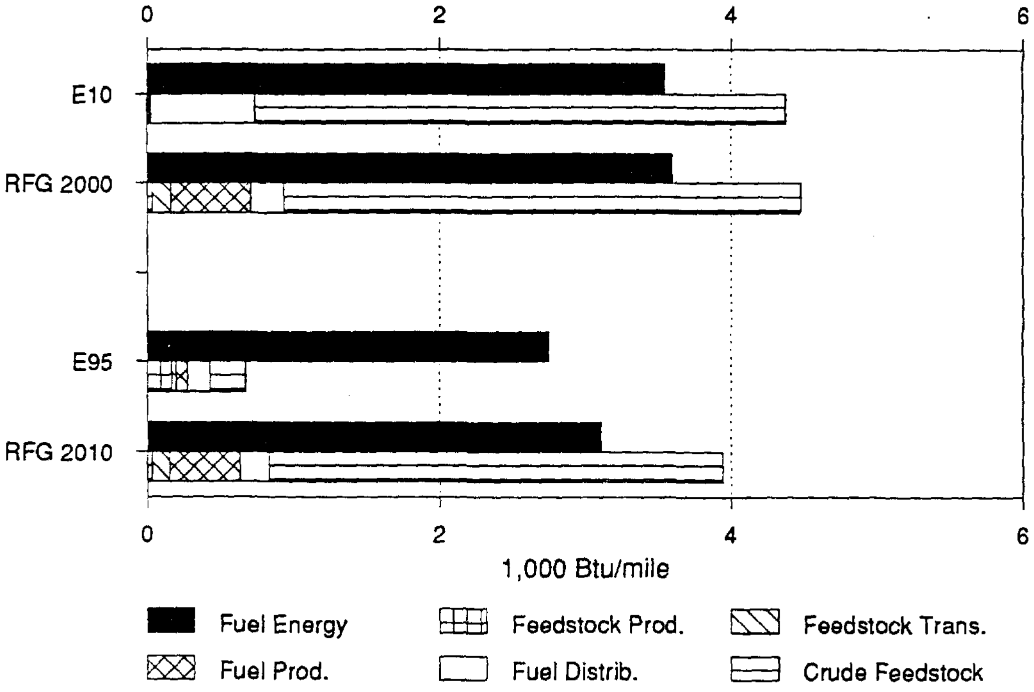


Figure 4. Energy input/output comparisons for ethanol and RFG fuel cycles

CONTENTS

CONTENTS

5.0 FINDINGS

TABLES

FIGURES

1.0 INTRODUCTION

The National Energy Strategy (NES 1991) presents a road map of policies that could lead to reduced dependence on imported fuels, more efficient use of domestic resources, economic growth, and a cleaner environment. To help reach these goals, the NES recommended using the total fuel cycle analysis (TFCA) as the methodology for the Department of Energy (DOE) and its agencies to use for evaluating fuels and energy technologies.

Motivating our technology and resource choices must be an improved understanding of total fuel cycle costs of all energy sources. Total fuel cycle costs are the entire costs of producing, transporting, dispensing, and using a given energy resource, including the costs of health and environmental impacts. Existing analytical tools are not capable of doing this with any reasonable precision; however, developing and sharing the capability to make total fuel cycle cost assessments is an NES priority (NES 1991, p. 17).

The NES proposes the following actions to better harmonize energy and environmental objectives:

- Use market mechanisms
- Increase efficiency
- Increase the use of natural gas
- Develop cost-competitive, renewable energy supplies
- Develop and use alternative transportation fuels
- Develop and use clean coal technologies
- Improve energy impact assessments
- Improve siting processes
- Minimize wastes.

The DOE is committed to using TFCA to evaluate these actions and supporting initiatives. One of the specific options, "Enhanced Transportation Biofuels Production R&D," proposes to accelerate the research and development of biofuel technologies in the hope that they may become commercial sooner, and thus, provide more benefits to the American public. The DOE's Office of Energy Efficiency and Renewable Energy (EERE) which funds Biofuels development, wants to enhance its ability to conduct credible evaluations of alternative fuel options by applying TFCA to biomass-ethanol and RFG. This report summarizes the findings of the TFCA for these fuels.

These fuel cycle analyses focused on measuring the amounts of inputs and outputs produced by three transportation fuels: E10, a blend of gasoline and 10% ethanol; E95, a blend of ethanol and 5% gasoline; and RFG made with MTBE. The ethanol is made from lignocellulosic feedstocks—trees, grasses, and organic wastes—that are converted to ethanol using an experimental technology. Industries that support the production and use of these fuels were assumed to exist by 2000 for E10 and by 2010 for E95. The RFG industry was modeled for both years. Ethanol made from corn is not discussed in this report.

The fuel cycles examined are a snapshot in time. Technology and industry are constantly changing. The technologies used to model the biomass-ethanol industry represent researchers' best assumptions about how this industry might function. These concepts changed between the time the study was initiated and completed, similar to how industries change over time. Technological progress can make the estimates provided in this paper obsolete; however, they provide us with a standard we can use today to measure progress and compare various options that could occur in the future.

These fuel cycle analyses provided us with a number of benefits:

1. Helped formulate future research agendas to answer questions that arose during this study and to provide data that did not exist for this study
2. Organized existing information
3. Improved the existing engineering design for biomass-ethanol production
4. Created a better understanding of how the biomass-ethanol industry may operate
5. Communicated what we know about biomass-ethanol to the public
6. Created a data base of emissions for site-specific impact studies
7. Established a basis for future cost-benefit studies.

These fuel cycle analyses focused on measuring the inputs and outputs of three fuel cycles, similar to a mass and energy balance. This report provides the information necessary to rank fuels by specific criteria, such as CO_2 emissions and also provides the information required to conduct impact studies. It does not include impact studies or estimates of the costs associated with impacts.

Impact studies require site-specific information. Environmental and social impacts are site specific and cannot be extrapolated to other situations with a high degree of accuracy. It is our hope that the data provided in this report can be used by other researchers to simulate site-specific impacts on a case-by-case basis. Local environmental policy, such as state incentives for fuel switching or vehicle conversion, should be based on site-specific data in order to correctly estimate the local benefit that could result from substituting fuels. This report contains the data that could be used to support such a study.

The remainder of the report is divided into several sections. Section 2 discusses the TFCA methodology and its implementation (including the rationale behind the choices of fuels evaluated). Section 3 briefly describes the industrial systems and technologies used to produce, deliver, and utilize the fuels. Section 4 discusses data quality. Section 5 presents the findings of the TFC analysis. Section 6 presents the conclusions drawn from this TFC analysis and discusses the implications. Section 7 lists some recommendations for future analysis and Section 8 lists the technical reviewers. Tables A through M present data summarizing the results of the fuel cycle analyses; they can be found at the end of this report.

The data presented are the tables and figures are reported or calculated data. The degrees of significance of the data is not reflected by the number of significant digits. These numbers have not been rounded so reviewers and other interested parties can verify these estimates by retracing the methodology and assumptions.

Appendices A through I, in Volume II, provide detailed descriptions of the technologies, industrial systems, data sources, and estimates used to support the information in this report. Appendices A through F summarize information relating one or more of the stages of the fuel cycles: feedstock production, feedstock transportation, fuel production, fuel transportation, and end-use. Appendix G describes the common assumptions used to coordinate emissions from transportation modes, and Appendix H describes the methodology developed to examine the secondary impacts of electricity production. Appendix I describes the assumptions and procedure used for the energy analyses.

Because of their length, Appendices A through I are available separately in Volume II: *Fuel Cycle Evaluations of Biomass Ethanol and Reformulated Gasoline: Appendices.* Please contact Dr. Tyson at the National Renewable Energy Laboratory for a copy.

2.0 TOTAL FUEL CYCLE ANALYSIS METHODOLOGY

Total fuel cycle analysis (TFCA) provides a systematic approach for evaluating fuel resources and technologies. The fuel cycle analysis is defined by the following steps:

1. Define the fuels or fuel cycles to be analyzed
2. Define the fuel cycle boundaries that will limit the analysis
3. Define the types of fuel cycle impacts to be analyzed (social, economic, technological, and environmental)
4. Define the data quality, sources, and management tools used in the fuel cycle.

Once the fuel cycle is defined and the information is collected, the results should be presented in a report for peer review.

The following discussion of boundary conditions and assumptions is critical to understanding how the information provided in this report should be used, and for understanding the lessons learned from applying TFCA.

2.1 Fuel Cycles

The DOE/EERE chose transportation fuels for the first fuel cycle study—specifically, ethanol fuels derived from biomass (organic lignocellulosic material) and reformulated gasoline fuels. Four fuel cycles selected were:

- E10 (gasohol), a blend of gasoline and 10% ethanol made from municipal solid waste (MSW) in 2000

- E95, 95% ethanol manufactured from energy crops in 2010 with 5% gasoline denaturant

- Reformulated gasoline (RFG) with 11% MTBE (methyl tertiary butyl ether) in 2000 and 2010.

DOE/EERE chose ethanol and RFG fuels because of their prominence in policies proposed by DOE and the Environmental Protection Agency (EPA).

One of the initiatives identified in the NES, "Enhanced Transportation Biofuels Production R&D," is an action that would stimulate production of alternative motor fuels from biomass. Biomass used to produce biofuels includes wood and wood wastes, agricultural residues and cellulosic energy crops, organic residues contained in MSW, and other types of organic wastes from industrial and food processing facilities. Biofuels can include ethanol, methanol, gasoline, diesel, or hydrogen.

Biomass-ethanol is identified in the NES as a cost-competitive, renewable energy supply that will play an increasingly important role over time as a viable alternative to gasoline from imported oil supplies. The NES projects that biofuels, primarily ethanol, could displace 200,000 barrels of oil per day by 2010 and displace 1.8 million barrels per day (MMBD) by 2030. By 2030, ethanol fuels could provide 14% of our transportation fuel needs (NES2, p. 51).

Producing ethanol from lignocellulosic biomass is not a commercial technology today. However, by 2000 a number of facilities could operate using low-cost feedstocks such as MSW. By 2010, cellulosic crop technologies, often referred to as energy crops, should be commercially available. In addition, the biomass-ethanol industry will rely on energy crops as its primary source of feedstock because the unused supply of cellulosic waste materials may dwindle as demand for these materials increases (recycled paper, electric power, ethanol, etc.).

The ethanol referred to in this study is produced from biomass—trees, grasses, and organic wastes—using an experimental technology. Corn-ethanol is not discussed in this report.

The NES projected that nearly all gasolines will be reformulated by 2000 (NES2 1991, p. 35). RFG using MTBE was selected because it is the most common RFG produced today. An RFG fuel cycle is developed for both 2000 and 2010 for comparisons with E10 and E95. ARCO EC-X is used as the prototype RFG for 2000 and 2010.

The CAAA require the use of RFG containing oxygenates (Title II, Part C) and clean fuels in fleets in serious, severe, and extreme ozone nonattainment areas and in serious CO nonattainment areas. Deadlines for adopting and using these fuels depend on the specific area and fuel considered. Specific clean fuels are not mandated but several alternative fuels are listed, including natural gas, methanol, ethanol (if the methanol and ethanol content of the fuel equals or exceeds 85% by volume), electricity, liquified petroleum gas, RFG or reformulated diesel, and hydrogen.

The EPA has issued regulations that will require all fuels in the year 2000 to meet CAAA Tier I standards in motor vehicles. Any fuel selected for this fuel cycle study should be one that could be designed to meet these standards. Gasohol and RFG were selected for the fuel cycle analysis because these fuels are available today and could meet the future standards with available technology. E10 is technically an RFG; the ethanol provides 3.7% oxygen compared with the 2.0% provided by MTBE. E10 can meet the CAAA standards on VOC emissions and Reid vapor pressure (RVP) if the ethanol is blended with a gasoline stock designed to produce a blended product with the desired properties. Thus, the fuel cycle for 2000 assumes that the lignocellulosic portion of MSW will be used to produce ethanol that will be consumed in conventional gasoline vehicles as an oxygenated fuel, E10.

The RFG fuel cycle was assumed to be substantially similar to a fuel cycle for the special gasoline base that would be mixed with ethanol to produce E10. (A study would be needed to evaluate the accuracy of this assumption.) The RFG fuel cycle characteristics are used to describe the fuel cycle for the gasoline base used in E10. The E10 fuel cycle will include both the RFG fuel cycle characteristics per gallon of gasoline and the characteristics associated with producing and using the ethanol portion of the fuel.

By 2010, Tier II standards will be promulgated with stricter limitations on air emissions from vehicles. Cleaner burning fuels will be required and ethanol is listed in the CAAA as a clean fuel alternative. Thus, the fuel cycle for 2010 assumes that ethanol is produced from energy crops and is consumed as a denatured fuel in dedicated ethanol vehicles.

E95 is ethanol denatured with 5% gasoline; neat ethanol has to be denatured according to existing regulations of the Bureau of Alcohol, Tobacco and Firearms, to control the collection of taxes on alcohol purchased for consumption and to discourage human consumption of fuel ethanol. Gasoline is a common denaturant today, although other denaturants are available.

All fuels are consumed by light-duty passenger vehicles. E10 and RFG are consumed in vehicles with conventional gasoline engines. E95 is consumed in dedicated ethanol vehicles with optimized technology; dedicated ethanol and methanol vehicles are assumed to be available by 2010, according to the NES and other industry sources. In 2010, ethanol vehicles get 28.25 miles per gallon (mpg) and conventional vehicles using RFG get 35.6 mpg; the gap between E10 and RFG is smaller—30.2 compared to 30.8 mpg, respectively.

The results of this study—the fuel cycle inventories—are presented in tons or gallons of inputs and outputs for every billion miles traveled by a light-duty passenger vehicle (billion VMT). The inventories are presented in Tables A through K at the end of this report.

Owing to the small values of some of the inputs and outputs on a per-mile basis, the inventories summed over 1 billion VMT create uniform units, in most cases tons (2,000 pounds). This is not to say that one light-duty passenger vehicle travels 1 billion VMT, but that many similar, if not identical vehicles, could travel a total of 1 billion VMT during the year.

The data inventory was managed by the Total Emission Model for Integrated Systems (TEMIS). TEMIS is an accounting tool and does not optimize or project variables. It does allow for a wide array of sensitivity analyses by altering major parameters such as engine efficiencies or crop yields to determine the effects on the total inventories.

No attempt was made to optimize technologies or markets represented by the fuel cycles based on economic or social criteria. Future economic parameters, such as costs and profits, will be affected by environmental issues, costs of environmental controls, and regulations. The industry structure examined is reasonable given what we know today about existing or similar industrial structures.

2.2 Fuel Cycle Boundaries

Only the operational phase of a fuel cycle (e.g., activities associated with producing and consuming the fuels) is documented in this study (Figure 1, p. vi). Emissions associated with construction and decommissioning of the infrastructure required to produce, deliver, or consume the fuels are not included in the inventories. Drilling and other activities associated with exploration for crude oil are not included in the fuel cycle analysis because these activities are generally one-time occurrences that resemble construction and development more than daily operational activities.

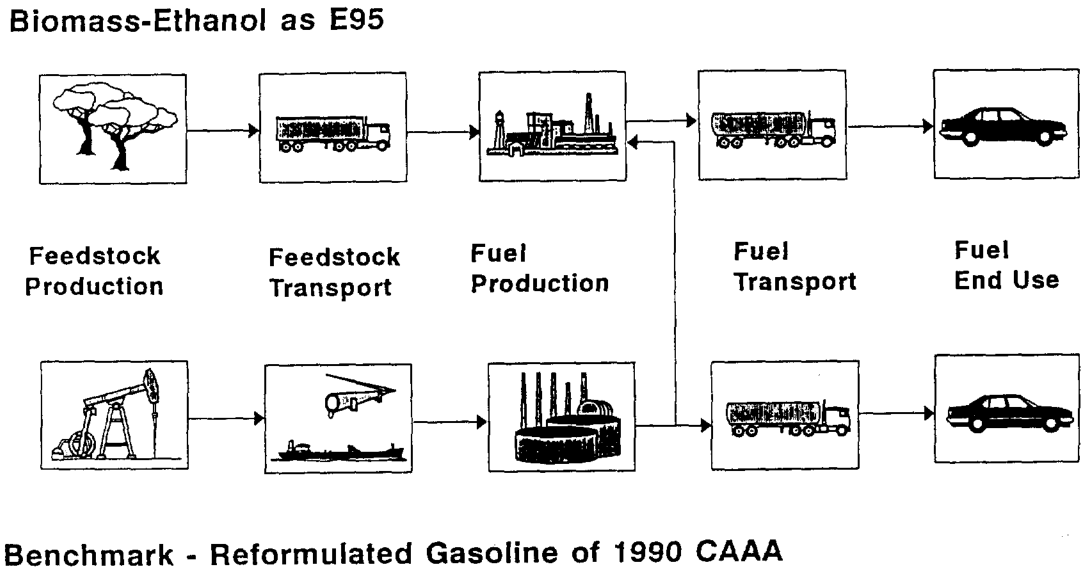
We examined a number of previous studies to determine the effect of excluding pre- and post-operational phases. Deluchi (1992) constructed ethanol and RFG fuel cycles to estimate energy consumption and greenhouse gas emissions. His analysis showed that 10 to 15% of fuel cycle energy inputs are used to produce the materials used in constructing vehicles and their infrastructure.

Deluchi assumed that 2 to 3% of the energy content of the end-use fuel is used in exploration, production, and drilling for onshore and offshore oil. The DOE Handbook (1983) estimates that the energy used to produce onshore oil in the lower 48 states is 1.5% of the energy in the crude produced, with about half of that used in development drilling and half for oil production.

The exclusion of construction activities may be a significant issue but would require more information on future biomass-ethanol industrial development than is currently available. The future size and location of

Table 1. Fuel Cycle Stages and Activities

Fuel Cycle Stage (Year)	E10 (2000)	E95 (2010)	RFG (2000 & 2010)
Feedstock production	Collect curbside MSW; deliver MSW to transfer stations; transport from station to sorting facility; sort and separate organics from recyclables.	Prepare land for planting; plant, tend, and harvest biomass crops and store on farm. Biomass Crops: perennial grasses annual grasses short rotation trees	Crude oil production from domestic sites, on-site processing and storage; imported crude oil production same as domestic. By-products: natural gas
Feedstock transportation	Load and transport sorted organic MSW to ethanol conversion plant via rail; store at conversion facility. Average distance: 100 mi	Load biomass into trucks, rail, or barge for transportation to ethanol conversion facility; unload. Average distance: 100 mi	Transport crude oil via truck, pipeline, barge, and tanker in U.S. boundary waters to storage facilities; store; deliver crude to refineries via pipeline, barge, and tanker; unload and store at refinery.
Fuel production	Convert organic MSW into E95 using 2000 technology. Gasoline fuel cycle inventory included (for 5% denaturant) in this stage. By-product: electricity	Lignocellulosic crops converted to E95 using 2010 technology. Gasoline fuel cycle inventory included (5% denaturant) in this stage. By-product: electricity	Crude oil converted to reformulated gasoline and other products. MTBE production is excluded; MTBE is treated as input. By-products: non-gasoline products
Fuel distribution	E95 is stored at conversion plant, loaded into railcars, transported to Chicago region, blended to E10 at local bulk terminals. E10 is transported by tank trucks to retailers. Gasoline fuel cycle inventory included for gasoline blended. E10 stored at retailers and pumped into passenger cars.	E95 stored at conversion plant, loaded into railcars, transported to dedicated bulk tanks in bulk terminals at major metro areas in region and unloaded, loaded into tank trucks and delivered to retailers, unloaded and stored at retail facilities, pumped into dedicated vehicles.	Reformulated gasoline is transported in pipelines, barges, tank trucks, and tankers to bulk terminals, stored, loaded into tank trucks for retail delivery, unloaded into retail storage, and pumped into passenger vehicles.
End use	Combustion in a light-duty passenger car, conventional gasoline engine.	Combustion in a light-duty passenger car, dedicated ethanol engine.	Combustion in a light-duty passenger car, conventional gasoline engine.



Does not include construction, exploration, and decommissioning

Figure 5. Fuel Cycle Stages

the biomass-ethanol industry have yet to be established and are highly controversial. This study was limited to the operational phase because it can be defined based on engineering principals and published information.

The operational phase of the fuel cycle is divided into five stages: feedstock production, feedstock transportation, fuel production, fuel distribution, and end-use, which is primarily the combustion of fuels in light-duty passenger vehicles (Figure 5). Table 1 summarizes the major activities included in each stage of the fuel cycles examined in this report. Figures 6 and 7 provide a flow diagram for each of the four fuel cycles, showing how the outputs from one activity become the inputs to the next. Detailed descriptions of the fuel cycle and related data are reported in Volume II: *Fuel Cycle Evaluations of Biomass Ethanol and Reformulated Gasoline: Appendices*.

The data reported in the appendices have not been allocated between co-products in most cases. The results reported Tables A through K and described in Sections 5 and 6 in this document have been allocated between coproducts. The descriptions of the fuel cycles themselves, in Section 3, go into more detail on allocation assumptions.

This study uses a three-part approach to evaluate a fuel cycle: (1) present detailed descriptions of the engineering systems that produce, transport, convert, and consume feedstocks and fuels; (2) construct a model industry that incorporates the activities defined in (1); and (3) build inventory of inputs and outputs for the four fuel cycles.

Estimates of fuel cycle inputs and outputs are based on theoretical engineering designs of the four fuel cycles studied. The future petroleum industry is assumed to be nearly identical to the existing petroleum industry.

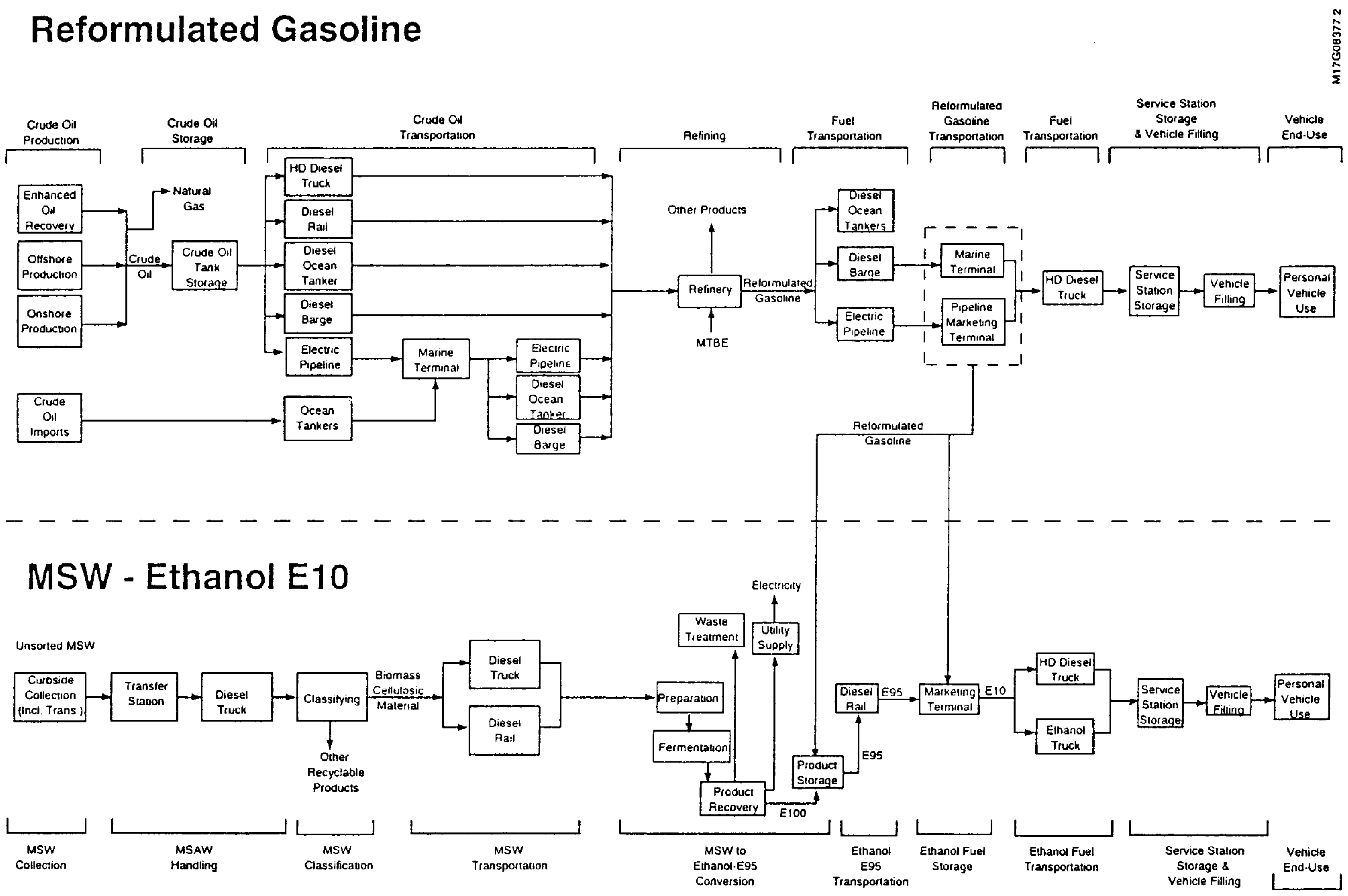


Figure 6. Fuel cycle activities, 2000

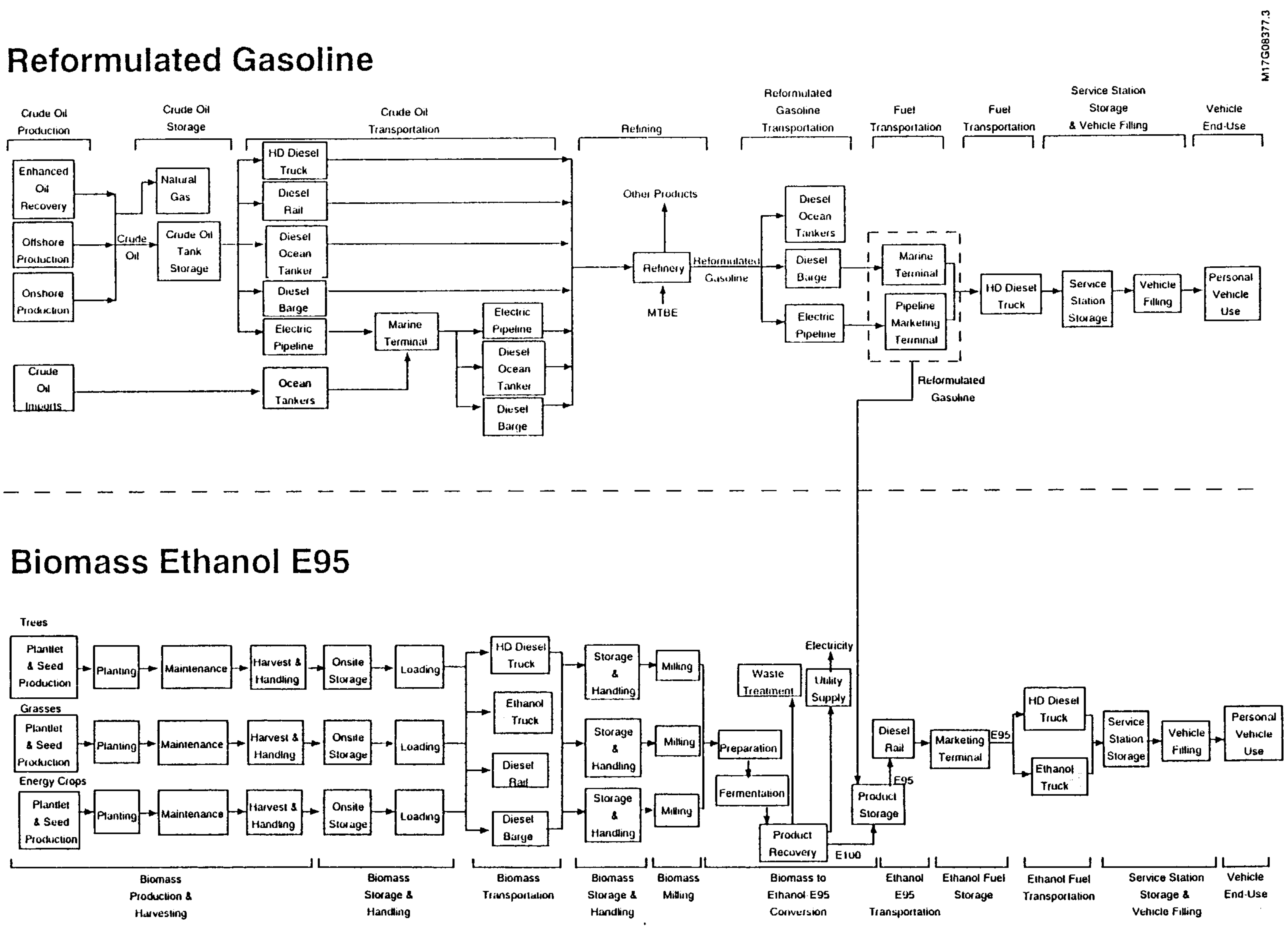


Figure 7. Fuel cycle activities, 2010

The biomass-ethanol industry is created from a hypothetical set of assumptions based on existing agricultural practices, transportation infrastructure, and engineering designs. Outputs include estimates of air pollutants, solid wastes, water effluent, and energy products such as fuel, electricity, and heat. Inputs include labor, electricity, feedstocks (crude oil and biomass), chemicals, water, fuels, and equipment. Tables A through K, at the end of this report, provide the reader with a clear picture of what information was collected for this study.

The fuel cycle scenarios are limited to characterizing the domestic industry, although the RFG fuel cycles include imported crude oil. We have assumed that imported crude has the same production emission characteristics as domestic crude oil production. This assumption can over- or underestimate actual inputs and outputs associated with international oil production, but the scope of estimating actual values is beyond this study (see Section 3.3 for more detail).

The emissions from transporting imported crude from the 200-mile economic trade boundary to U.S. ports are included but the emissions that occur before the oil reaches the 200-mile boundary are not included. The lack of readily available data and the modeling requirements involved to simulate crude oil transportation limited our treatment of this activity.

The location and volumes of domestic crude oil production are taken from NES projections, and refining and fuel consumption are assumed to be similar to patterns that exist today. All biomass and ethanol production is assumed to occur in the United States.

Eight fuel cycles were created. These base cases consist of one MSW-E10 for 2000, five energy crop-E95 fuel cycles for 2010, and reformulated gasoline fuel cycles for 2000 and 2010.

Only one site, the Chicago/Cook County area of Illinois, was selected to develop a fuel cycle for MSW-ethanol for 2000. MSW contains high amounts of cellulosic waste that can be converted into ethanol. Waste provides a number of benefits, such as low or negative costs, that make attractive feedstocks for the first facilities.

Very few sites generate enough waste to supply a large ethanol facility that produces 50 million gallons per year. A recent analysis revealed that only 20 potential ethanol sites could support a 50 million gallon per year facility (Tyson, 1993). The Chicago area provides a large volume of MSW, faces declining landfill capacity, and is a large urban area that could provide the necessary demand for E10.

Five sites for biomass-ethanol production were examined because we lacked information on what site characteristics, if any, affect the level of inputs and outputs of the biomass-ethanol fuel cycle (Figure 8). These five sites were chosen to reflect characteristics found in the surrounding regions. Regional variation in energy crop production inputs and outputs is very likely. Climate, soil characteristics, and other natural parameters affect which crops are produced, their yields, and agronomic practices and thus, affect the level of inputs and outputs required from biomass production. Different mixes of energy crops affect the yield of ethanol and thus, affect the inputs and outputs of the fuel production stage.

The five sites selected are: Peoria, IL; Lincoln, NE; Tifton, GA; Rochester, NY; and Portland, OR. Biomass production and conversion (fuel production) are located in the vicinity of these cities. Fuel was

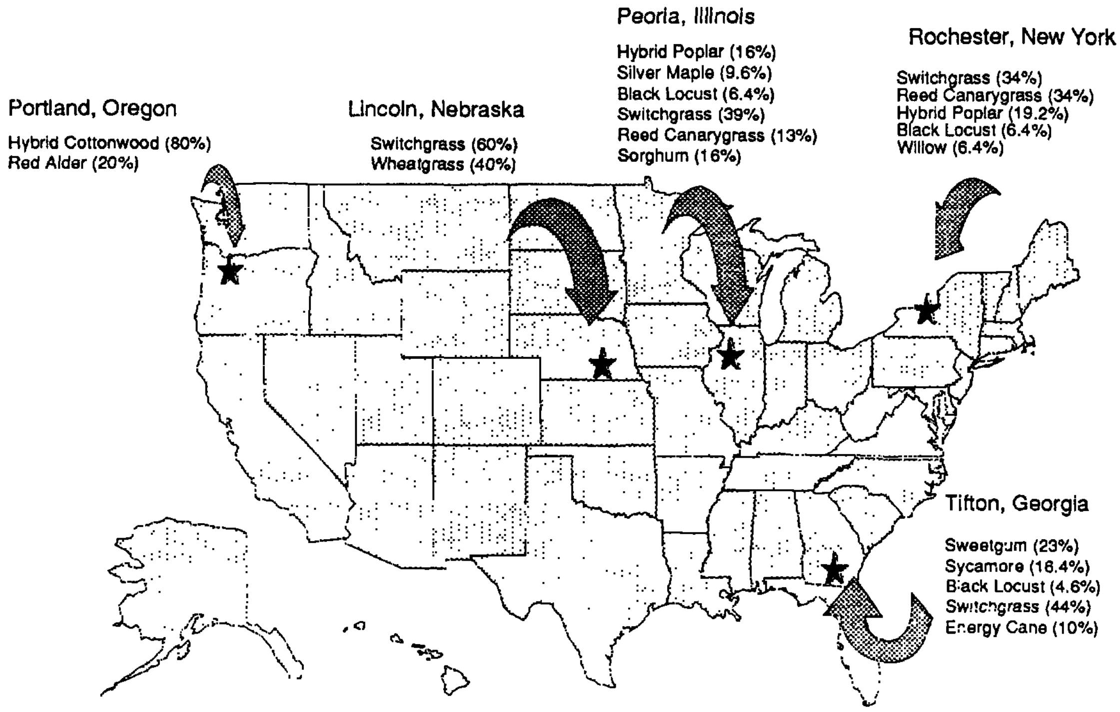


Figure 8. Ethanol fuel cycle locations

assumed to be consumed in the local area surrounding these cities. Future vehicle stocks (inventories) were not modelled.

2.3 Level of Impacts

This study creates an inventory of inputs and outputs that arise directly from the activities in the eight fuel cycles. This study does not examine any **impacts**, such as health or environmental damages or changes in urban air quality. Nor does this study attempt to quantify the emissions from manufacturing inputs consumed in the manufacture, transportation, or use of the ethanol and reformulated gasoline fuel (with a few exceptions). This study does not attempt to estimate the value of externalities. Analysts quantified inputs (e.g., electricity, fertilizers) and outputs (e.g., tons of SO_2 and cycloparaffins) but mainly excluded emissions produced from facilities that manufacture fertilizers and chemicals and the impacts the fuel industry is responsible for.

Other studies have examined the effects of including electricity and fertilizer production (Ho 1989 and 1990; Deluchi 1992). Fertilizer manufacturing and electricity generation have been identified as potentially significant activities, which, if included in a fuel cycle study, can have major effects on the results. In order to correctly identify and quantify the values associated with inputs, each input (such as fertilizer and electricity) should be the subject of a product life cycle analysis. The results from those analyses can then be used in fuel analyses such as this one.

To examine the effect of omitting these important secondary effects, published values for selected emissions from the regional production of electricity were incorporated into the fuel cycles in sensitivity analyses. These emission factors are not fuel cycle estimates; they only include the generation of electricity and not the mining or other activities that would also be involved in fossil fuel production. In addition, they do not reflect future technologies or the technologies that would be used to produce electricity.

The secondary emissions (other than energy requirements) associated with fertilizer are not estimated in this study; however, Deluchi's (1992) estimates of the energy required to mine, transport raw materials, and produce fertilizers are included in the discussion on energy balances. Fertilizer and electricity production emissions completely offset each other in a wood-ethanol fuel cycle examined by Deluchi. The electricity produced by the ethanol plant offsets fossil fuel-fired electricity, creating a reduction in fuel cycle emissions, which creates a savings that cancels out the fertilizer production emissions. For the fuel cycles examined in this study, electricity is also expected to offset all of the secondary emissions of fertilizer use.

If all of the emissions associated with major inputs (electricity, diesel, fertilizer, chemicals, concrete, steel, equipment, vehicles, etc.) to the fuel cycle are considered, fuel cycle estimates could increase by 10-15% (Deluchi 1992).

2.4 Data Quality and Sources

Published data are the foundation of the fuel cycle inventories. But because the biomass-ethanol fuel cycle is theoretical, there is a dearth of published information on the inputs and outputs of the fuel cycle. This report relies heavily on the expert opinion of researchers in these fields and on theoretical designs. That kind of data require verification through experimental design and operation of large-scale experimental biomass farms and ethanol production facilities. The data provided for the RFG fuel cycles were collected from existing publications. The existing crude oil/gasoline industry is a highly developed, complex, and diversified industry. To make the analysis manageable, a highly generalized version of the industry structure was created, one that is significantly less complex than the existing industry. As a result of this generalization, a degree of technical accuracy has been lost; however, this loss should not affect the major conclusions of this report.

Using published data creates a risk of overestimating future environmental emissions from both fuel cycles, because environmental regulations will drive pollution control equipment improvements, causing future environmental emissions to decline over time. The authors of this report believe that the fuel cycle inventories presented probably overestimate future environmental outputs. The bias probably affects all eight base case fuel cycles. The alternative approach is to project future environmental regulations and pollution control equipment efficiencies. This approach creates controversy that could detract from the value of the product and creates its own risk of under- or overestimating environmental emissions. Thus, it was not employed.

If published estimates of future characteristics are not available, information from the current industry is used. For example, particulate emission estimates from the boiler in the ethanol production facility are based on emission estimates from existing wood-fired power plant boilers. If published forecasts, projections, and regulations provide guidance on future inputs, outputs, and characteristics, they are used. For example, if reformulated gasoline used in light-duty passenger vehicles must meet specific tail pipe standards by 2003 according to the CAAA 1990, then these standards are assumed to be met. Estimates of future oil production technologies and volumes are provided by the NES.

Occasionally trends are used to extrapolate future technology or emission characteristics. For example, the characterization of future ethanol production efficiencies and biomass yields is based on current trends shown in biomass production trials.

In many cases, the estimates of outputs, especially airborne emissions of nitrous oxide (NOx), sulfur dioxide (SO_2), VOC, and other criteria pollutants, are based on air emission standards regulated by the EPA. If all vehicles must produce no more than 0.2 g/mi of NOx, then both the dedicated ethanol vehicle using E95 and the standard gasoline vehicle using RFG will emit 0.2 g/mi of NOx. Therefore, no uncertainty surrounds these estimates and no variation exists among fuels; the only uncertainty concerning the accuracy of the estimates whether vehicles and fuels will be designed that meet these standards. Stationary source emissions were handled in a similar way. Often, the basis for the estimates of air pollutants was based on EPA estimates from AP-42. Future improvements in pollution control equipment were not specifically forecasted. Thus, some improvements from the estimates provided in this report are possible.

The data in the appendices, in Volume II, are presented in familiar units, such as tons per year of solid wastes and units per million Btu of inputs processed. The information gathered and presented in the appendices was compiled so that the results could be easily aggregated and presented on a VMT basis.

An assessment of data quality is provided in the author's notes before each appendix in Volume II. Many estimates of the inputs and outputs of the biomass-ethanol and the reformulated gasoline fuel cycles are point estimates, the result of engineering designs or factors published by government agencies (EPA/AP-42, NES, etc.). Although there is uncertainty associated with any estimate, and uncertainty in applying those estimates to an industry that is either simplified (RFG) or does not exist (biomass-ethanol), the level of uncertainty was not quantified in this study.

2.5 Coordination and Peer Review

Fuel cycle stages were assigned to research teams based on expertise and common elements associated with activities or stages. Meridian Corporation studied MSW feedstock production. Oak Ridge National Laboratories (ORNL) analyzed energy crop production and transportation. NREL analyzed ethanol production. E. A. Mueller described ethanol and gasoline transportation and distribution for both 2000 and 2010 because the same infrastructure was assumed for both scenarios (with slight modifications). J. E. Sinor Consultants, Inc. characterized ethanol and RFG end use for 2000 and 2010. E. A. Mueller described crude oil production, transportation, and refining for both 2000 and 2010, assuming minor changes to industrial structure would occur between 2000 and 2010. Each team produced one report that is presented as an appendix in Volume II.

Pacific Northwest Laboratories (PNL) prepared two additional appendices documenting cross-cutting assumptions in the transportation sectors and assumptions made concerning the sensitivity study of secondary electricity emissions.

Appendices A and B cover energy crop production and MSW processing, respectively; ethanol production is summarized in Appendix C; ethanol distribution is described in Appendix D; and the end use characteristics of reformulated gasoline and ethanol fuels are found in Appendix E. Crude oil production, transportation, refining, and the distribution of reformulated gasoline are covered in Appendix F. Appendix G summarizes the transportation assumptions used for both fuel cycle analyses. The assumptions for vehicle efficiencies and emissions were coordinated to ensure consistent usage by the many analysts. Appendix H describes the assumptions and methodology used to estimate secondary electricity emissions. Appendix I summarizes the assumptions and methodology used to estimate energy balances.

Each team divided the assigned stages into linear flows of activities and focused on documenting the inputs and outputs associated with each activity (see Figures 6 and 7). These fuel cycle inventories can be characterized as material and energy balances. Water, natural resources, chemical, electricity, and other energy inputs are quantified. Similarly, the outputs of fuel production (electricity, water, air emissions, and solid wastes) are quantified. Environmental outputs are often reported as raw and treated wastes to account for the efficiency of pollution control equipment that may be required or employed in the future. Products of one stage of the fuel cycle are inputs into the next stage.

Each appendix has undergone a technical review process by experts in relevant scientific disciplines. A list of technical reviewers is provided in Section 8. In some cases, the data provided by the assigned teams are inadequate for the purposes of this study, or have been used in a manner that is not fully described in the appendix. When this occurs, an author's note will appear before the main body of the appendix.

All the team members, NREL, and DOE/EERE management, and invited technical experts, met monthly for a problem-solving and coordination meeting. These meetings refined the direction of the ongoing analyses, ensured consistent assumptions across the entire project, and promoted the level of coordination and cooperation required to produce a report made from many people's contributions.

This report has undergone a thorough peer review, consisting of industry leaders in both the ethanol and petroleum industry, government offices in the EPA, OTA, USDA, and DOE, and respected scientists that are involved in the transportation industry. Their comments were extremely helpful and mostly supportive; they have been integrated into this report whenever possible. A complete list of reviewers is available in Section 8.

3.0 FUEL CYCLE SCENARIOS

This section summarizes the major activities of the eight base case fuel cycles and their variations. The eight base cases are:

- E10 made with ethanol produced from MSW in Peoria/Chicago area in 2000
- RFG industry in 2000
- E95 made with ethanol produced from energy crops in Tifton, GA, in 2010
- E95 made with ethanol produced from energy crops in Peoria, IL, in 2010
- E95 made with ethanol produced from energy crops in Rochester, NY, in 2010
- E95 made with ethanol produced from energy crops in Portland, OR, in 2010
- E95 made with ethanol produced from energy crops in Lincoln, NE, in 2010
- RFG industry in 2010.

Because the actual fuel cycles are complex, involve numerous assumptions, and generate a large amount of information that cannot be presented in summary form, readers should familiarize themselves with the appendices in Volume II. Figures 6 and 7 (on pages 8 and 9, respectively) depict the ethanol and reformulated fuel cycles used for the years 2000 and 2010, respectively.

Sections 3.1 and 3.2 provide a discussion of the activities associated with the feedstock production, transportation, fuel production, and fuel distribution stages of the biomass-ethanol and reformulated gasoline fuel cycles, respectively. The end-use stage of the fuels will be discussed separately in Section 3.3. The sensitivity analyses are summarized in Section 3.4.

3.1 Biomass-Ethanol Fuel Cycles

The six biomass-ethanol scenarios are differentiated by feedstock, location, and year: one MSW feedstock scenario for the year 2000 and five regional energy crop scenarios for the year 2010. The feedstocks and plant locations are designed to bracket a range of potential scenarios that could lead to variations in environmental outputs from feedstock production, transportation, and conversion. The major differences between the 2000 and 2010 scenarios are the choice of feedstock—MSW or dedicated energy crops—and the type of fuel produced—E10 or E95.

We assumed each bioethanol production facility requires 2,000 dry tons of feedstock per day (tpd) to provide consistent scenarios for comparative purposes. The ethanol plant in 2000 produces 71.8 million gallons of E95 and 681 million gallons of E10. The ethanol plants in 2010 produce between 78 and 85 million gallons of E95. The ethanol yields vary according to feedstock composition.

Fuel distribution varies between scenarios; ethanol fuels are distributed among regional cities based on a weighted average of population distribution in the region.

The feedstock production and transportation stages of the fuel cycle are described first, followed by a summary of biomass-ethanol conversion and fuel distribution. MSW and energy crop production are described separately because there are significant differences in the activities used to produce these feedstocks.

3.1.1 MSW Feedstock Supply

By 2000, the first ethanol facilities may locate where low-cost waste feedstocks, such as MSW, crop and forest residues, and other organic waste streams are abundant. The first facility was assumed to use MSW feedstocks because large amounts of cellulosic material are present in MSW, tipping fees provide a monetary incentive, and an ethanol facility may be a socially acceptable solution to the waste disposal problem.

The Chicago/Cook County area was selected as a representative site for the MSW scenario in 2000. The area produces more than 1 million dry tons of MSW per year from a 50-mile radius, has a declining landfill capacity, a large population, and is an ozone nonattainment area (Chicago) where cleaner-burning fuels may be required to meet the requirements of the CAAA.

Most of the inputs associated with acquiring MSW consists of the feedstock itself and diesel fuel used in the collection and transportation vehicles. A block flow diagram of the entire MSW collection and sorting process is provided in Figure 9. The MSW is collected as curbside garbage using compaction garbage trucks. Approximately 3,540 wet tons of MSW per day will be collected from residential and commercial establishments. The MSW will be transported an average of 4 miles in Chicago or 6 miles in Cook County to transfer stations where it will be consolidated and compacted into larger loads. After compaction it will be transported in semi-tractor trailers or rail cars 50 miles to a sorting/preparation facility. Operations at the transfer facility include unloading collection vehicles, compacting MSW, and loading semi-trailers. Equipment use produces the bulk of air emissions.

In the base case, all of the activities that occur before the MSW leaves the transfer facility are eliminated from the fuel cycle because these activities would occur in the absence of an ethanol industry (Figure 10). The inclusion of these activities was considered as a sensitivity analysis. A full account of all of the activities involved in MSW collection is available in Appendix B, MSW Collection, Transportation and Separation, in Volume II.

Nearly 71% (by dry weight) of the material entering the sorting/preparation facility is wastepaper and other lignocellulosic material suitable for ethanol production. The remainder of the material is recycled or taken to a landfill for disposal. We prefer to believe that markets for these materials will be available in the future, and these materials can be recycled. In either case, this study did not include the activities of handling the non-organic wastes leaving the sorting facility. We recognize that these studies are important, but characterizing the variety of options for disposing or recycling non-organic wastes were beyond the scope and resources available for this work.

The input/output inventory associated with operating the sorting facility is prorated between the two output streams: lignocellulosic biomass, and recyclable products and wastes. Only 71% of all of the inputs (such as electricity and fuel consumed by the sorting facility) are allocated to the biomass; similarly, 71% of all the emissions from the facility are associated with the biomass produced. A sensitivity analysis was conducted to consider the effects of allocating all of the sorting emissions to the cellulosic fraction of the sorted waste. This last case would be appropriate if the wastes were disposed in local landfills.

The cellulosic waste is loaded onto rail cars and transported 100 miles to the ethanol facility. Rail is the most likely transportation option between the preparation facility and the ethanol production plant in Peoria, given the available infrastructure. Rail cars also provide an advantage of short-term storage

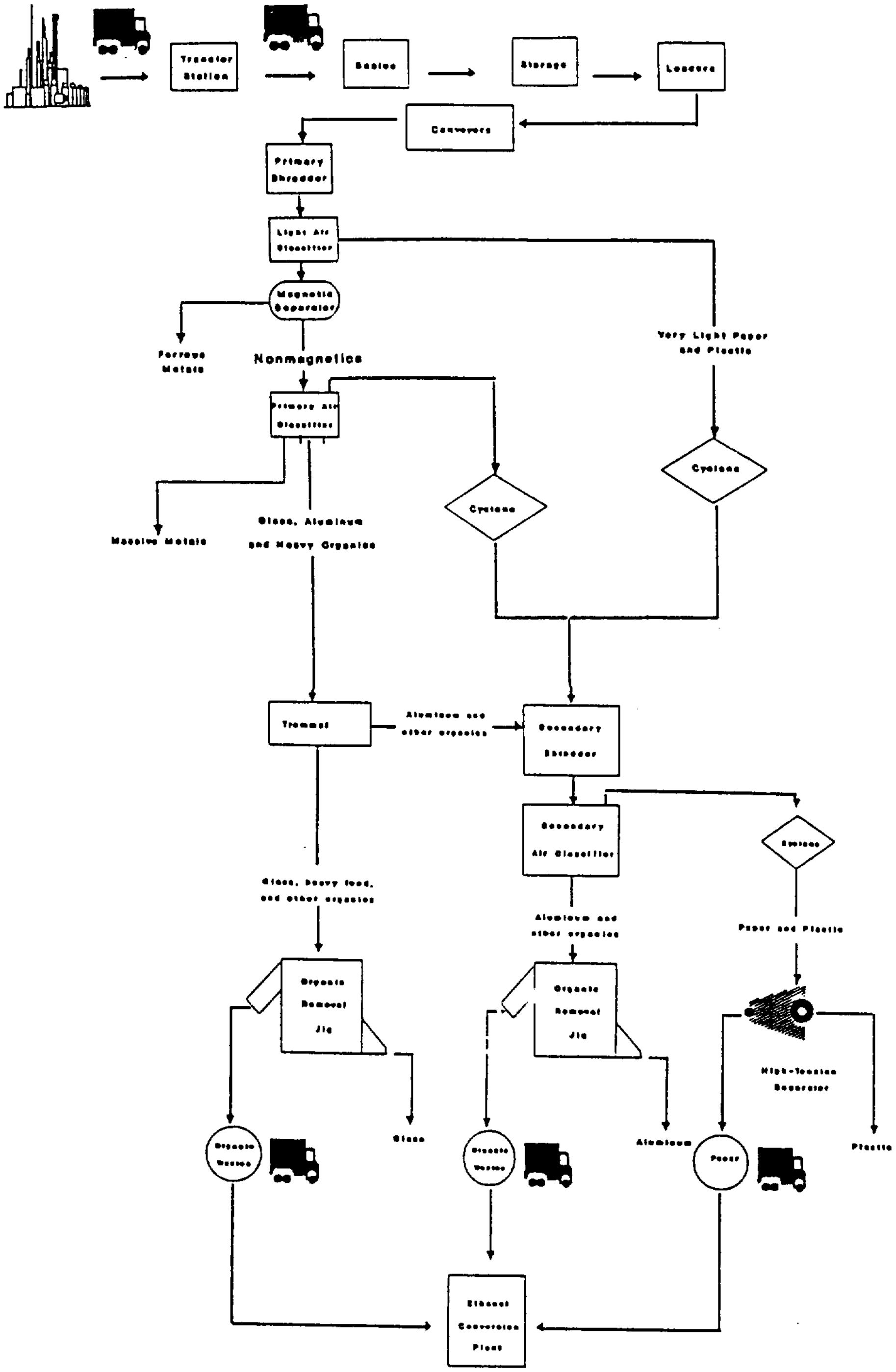


Figure 9. Process flowchart for MSW collection, sorting, and preparation

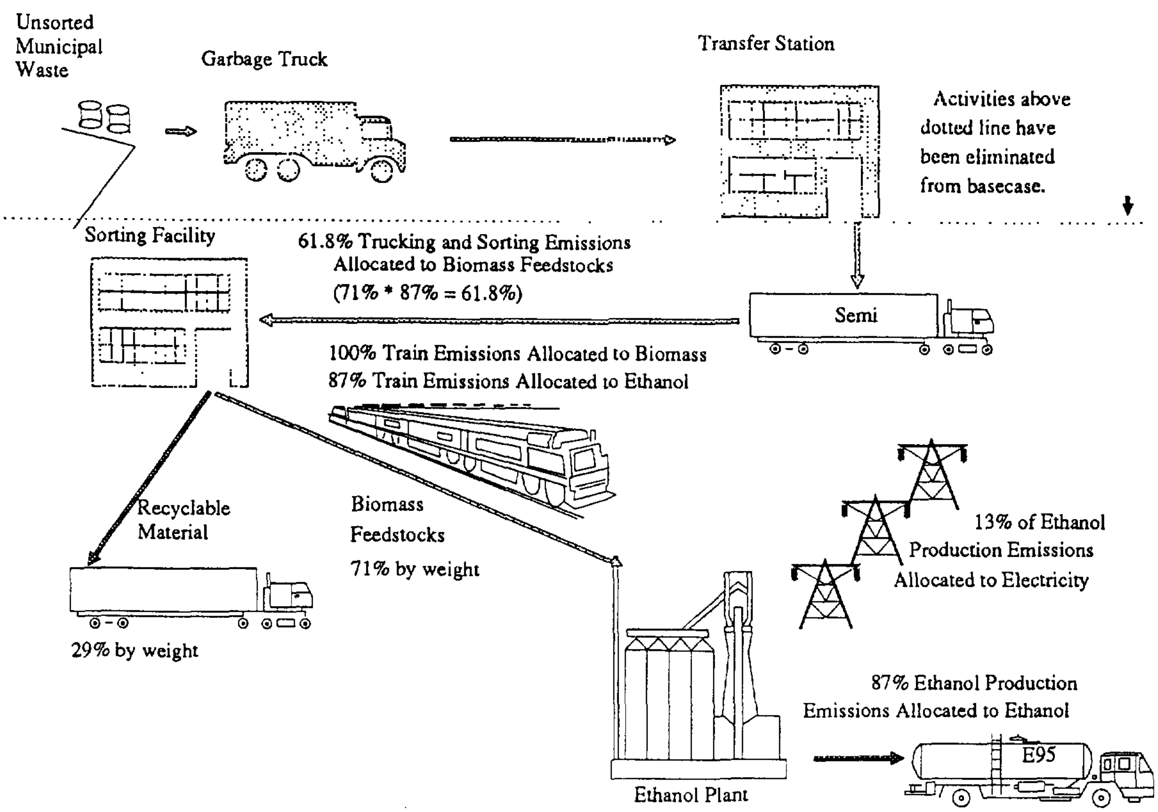


Figure 10. MSW-E10 fuel cycle allocation diagram

at the preparation facility or at the ethanol production plant.

Nearly 315,400 tons of organic carbon are sequestered in the cellulose delivered to the ethanol facility. If the organic material is transformed into ethanol, all of the carbon is released during the ethanol manufacturing process and the combustion of the fuel ethanol. Most of the cellulose is paper, food wastes, and yard wastes that are produced and consumed within a year. The trees to make paper and the plants that produce food sequester atmospheric carbon during their growing cycle, representing an offset of 1.15 million tons of CO_2 per year.

3.1.2 Dedicated Energy Crop Supply

In 2010, waste markets could be limited by expanding recycling industries, waste reduction technologies, and other energy industries that consume wastes for feedstocks. The biomass-ethanol industry of 2010 will rely primarily on energy crops. Improved varieties of energy crops will probably be available by 2010.

Biomass production, transportation, conversion, fuel distribution, and end use were assumed to occur in the vicinity of the five locations selected: Peoria, IL; Lincoln, NE; Tifton, GA; Rochester, NY; and Portland, OR (Figure 8, p. 12). Biomass crops produced at each location were selected based on soil characteristics, climate, harvesting time schedules, storage characteristics, and available data from field trials. Data from field trials were projected to 2010 based on recent trends. These projections involved yield estimates, input requirements, and cultural practices possible by 2010. Researchers assumed that farmers will be employing more low-impact, environmental practices by 2010.

Crop establishment, cultural management, harvesting, and storage operations vary among the three broad classes of cellulosic energy crops: woody crops, perennial herbaceous crops, and annual herbaceous crops. Farmers in different regions were assumed to use similar practices for each type of crop.

The land available for energy crop production includes the counties within a 100-mile radius of each of the five ethanol manufacturing facilities, with the conversion facilities located in the approximate center of the areas. The total acreage used for energy crops is limited to a maximum of 7% of the "suitable" land (defined in Appendix A, Energy Crop Production, Storage, and Transportation, Volume II), across all land quality designations. This assumption would make energy crop production the fifth most important crop in each area. This approach minimizes land competition. An alternative approach, not used in this report, is to minimize transportation distance and increase the concentration of biomass crop acreage close to the facility. Transportation emissions would be lower under the second methodology.

Energy crop yields were expected to grow over time as scientists select and breed energy crops for desirable traits, and hybridize and propagate exceptional plant material (genetic research). Moreover, breeding superior crops is also expected to reduce management requirements; faster growth will reduce the frequency of weed control, and greater tolerance to stresses will reduce the need for pest control. Estimates of future yields were solicited from energy crop researchers in several regions. These estimates are believed to be conservative and based on expert opinion.

Soil conservation practices, such as reduced tillage methods (plowing), are assumed to be sufficiently advanced so that biomass crops maintain high survival rates and yields. Reduced tillage will minimize soil erosion in the early years of tree crop establishment and reduce soil losses associated with annual crops. The major assumptions regarding the establishment, management, and harvesting of each major class of energy crops can be found in Appendix A.

A unique characteristic of energy crop production systems is that they capture carbon dioxide from the atmosphere, release oxygen, and convert much of the carbon to useable energy feedstocks. Some of the carbon sequestered is returned to the atmosphere through the decomposition of the biomass—harvesting residues, storage losses, leaf litter, and small roots that die each year. Some of the carbon initially captured by the growing biomass is accumulated as organic matter in the soil until an equilibrium condition is reached, which may take 30 to 50 years. The net change of carbon in the soil and in aboveground tree stems and branches (which are not yet used for fuel production) represent pools of carbon that are "sequestered" or removed from the atmosphere for relatively longer periods of time, and thus represent a benefit of the biofuels system. Soil carbon is not included in the base cases; however, we will describe the effects of including soil carbon on the final analysis.

Harvested energy crops are stored on the farm until they are transported to an ethanol facility. Trees and thin-stemmed grasses are baled and can be stored covered or uncovered. Thick-stem grasses are harvested as forage and stored in silage facilities. Varying harvest schedules allow energy crops to be delivered to the ethanol facility year-round, minimizing conflicts with local demands for harvesting equipment and labor. Storage losses are accounted for in the transportation stage of the fuel cycle.

Transportation distances depend on the distribution of cropland, geography, and available routes. Where bulk commodity transportation modes, such as rail and barge, are available, it is assumed that biomass is transported an average of 25 miles to the rail terminal or port and loaded. The extensive network of canals near Rochester, NY, allows for barge transportation. The geographical distribution of energy cropland in the Portland location suggests that rail transportation is a rational alternative. The other sites rely on truck transportation. Truck transportation distances were calculated by proportional relationships between the acreage required and the amount of land available in a radius from the ethanol production facility.

3.1.3 Ethanol Production

The conceptual design for the lignocellulosic biomass-to-ethanol production process is based on research and process development work sponsored by the DOE Ethanol Program. The major drawback in this design is the lack of actual experimental data that would support the estimates of processing inputs, system efficiency, and system outputs. The inventory characteristics used in this study are the result of a mass-and-energy engineering balance, which scales processes and requirements using conversion factors. Experimental data are used for specific assumptions or to model specific processes; however, the effects of running the process on a totally integrated basis (i.e., running all the process steps in series using effluent from one step as the feed to the next step) are uncertain. More information will be available when the experimental process development unit (scaled to 1 tpd) starts up in late 1993. A large-scale process development unit may be operating soon after. If these experimental units are successful, the biomass-ethanol conversion technology should be commercial by 2000.

A block flow diagram of the process and a map of the inputs, outputs, and environmental releases is provided in Figure 11. Further detail on the process is available in Volume II, Appendix C, Biomass Conversion. The overall process is very similar for both 2000 and 2010. Feedstock compositions and the material and energy balance consequences cause the major differences.

The compositions of the various feedstocks, the organic fraction of MSW, and the 13 energy crops were estimated based on data from the literature. For some of the feedstocks, full composition information was not available in the literature. In these cases, estimates were made, which then became part of the design basis for the conversion facilities.

Energy crops or wastes enter the plant and are stored and processed in the feedstock handling area. After size reduction, the biomass is treated with a dilute sulfuric acid solution. This step increases the digestibility of the cellulose fraction and hydrolyzes the hemicellulosic fraction into sugars. This solution is neutralized and prepared for fermentation. Enzymes are used to hydrolyze the cellulose into glucose, then microorganisms ferment the sugars to ethanol and carbon dioxide. The hydrolization and fermentation is combined into one system, called the simultaneous saccharification and fermentation process, a new technological advancement, which is the foundation of this engineering design. Other designs are possible, and modifications to this design were suggested by the results of this study. Each different design

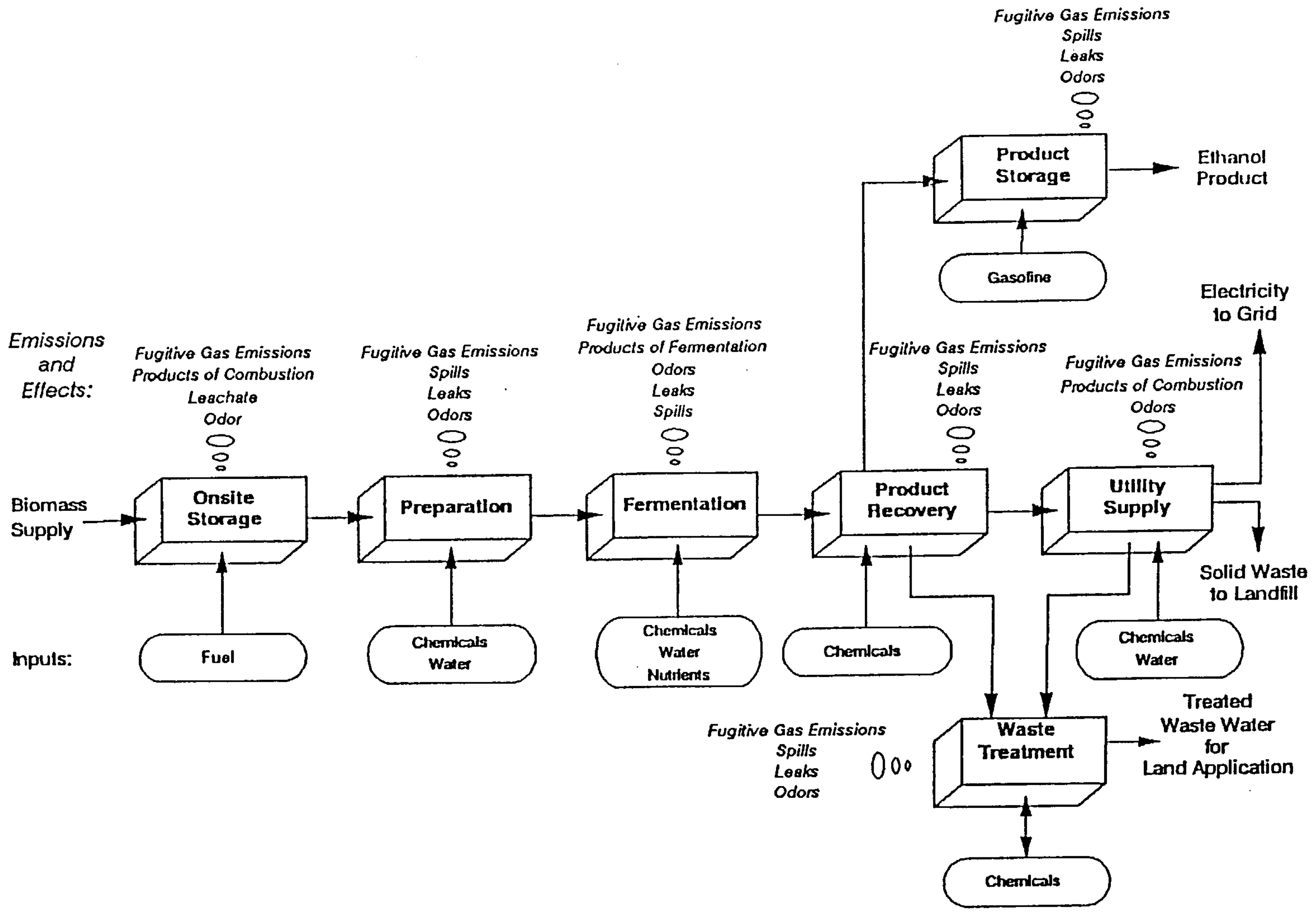


Figure 11. Process flow diagram of ethanol production process

would produce different fuel cycle inventories.

Ethanol produced from the fermentation steps is recovered, dehydrated, denatured with 5% (by volume) gasoline, and sold as fuel grade ethanol. The fuel cycle inventory associated with gasoline production is added to the ethanol inventories in this stage. Thus, inventory characteristics for the ethanol production stage shown in Tables A, C, D, E, F, and G include full fuel cycle inventory characteristics for gasoline. A limited amount of on-site storage is included in the design. Tank cars (railroad) provide an alternative short-term storage mechanism.

Solid wastes from fermentation and ethanol recovery are dewatered and sent to a fluidized bed boiler where high pressure steam is generated. The recovered solids are mostly lignin and insoluble protein that entered the plant as part of the feedstock. These components have substantial heating value and are a major source of fuel for the boiler. Other liquid and gaseous waste streams are also sent to the boiler for energy recovery. The high pressure steam is let down through a steam turbine, which generates electricity for the plant and provides lower pressure steam for internal process users. Excess electricity is produced and sold to the local utility grid in all six base cases. The capacity of the cogeneration facilities ranges from 13-21 MW for the energy crop cases and equals 8.2 MW in the MSW case.

Liquid separated from the solids after ethanol recovery is processed in a wastewater treatment system. The wastewater is assumed to be treated to the standards required for industrial wastewater pretreatment; effluent is assumed to be sent to a publicly owned treatment works (POTW). The exact nature of the effluent is unknown, although it is believed to be substantially similar to effluent from corn-ethanol plants.

Ash and uncombusted material recovered from the boiler are solid wastes that require disposal. The solid waste is assumed to be nonhazardous and suitable for disposal in a licensed landfill. The ash from the five base cases using energy crops should be similar to ash from power plants fired by wood and agricultural residues. The ash produced from the MSW feedstocks is assumed to be nonhazardous because the MSW feedstock has been sorted to remove plastics and other contaminates. Even refuse derived fuels (RDF) have higher levels of plastics that increase fuel heating values, and thus, ash from RDF-fired and MSW-fired power plants are not comparable to ash from the ethanol facilities. Ash from biomass-fired power plants is generally alkaline and can be used to control acid formation in landfills.

Sludge, the other source of solid waste, is produced in the wastewater treatment system. In the MSW case, this material is dewatered and sent to the boiler as a low-value fuel. In the five energy crop cases, the sludge is assumed to be either land applied as a soil amendment or disposed in a landfill on site.

For each of the six cases evaluated, a detailed material and energy balance was estimated, complete with utility summaries and chemical summaries. A boiler manufacturer provided performance data and emissions estimates for all cases. Steam turbine performance was estimated by a steam turbine manufacturer. An engineering company provided design and performance information for the wastewater treatment system for each of the cases.

In all six scenarios (five energy crop scenarios and one MSW scenario), the biomass production, transportation, and

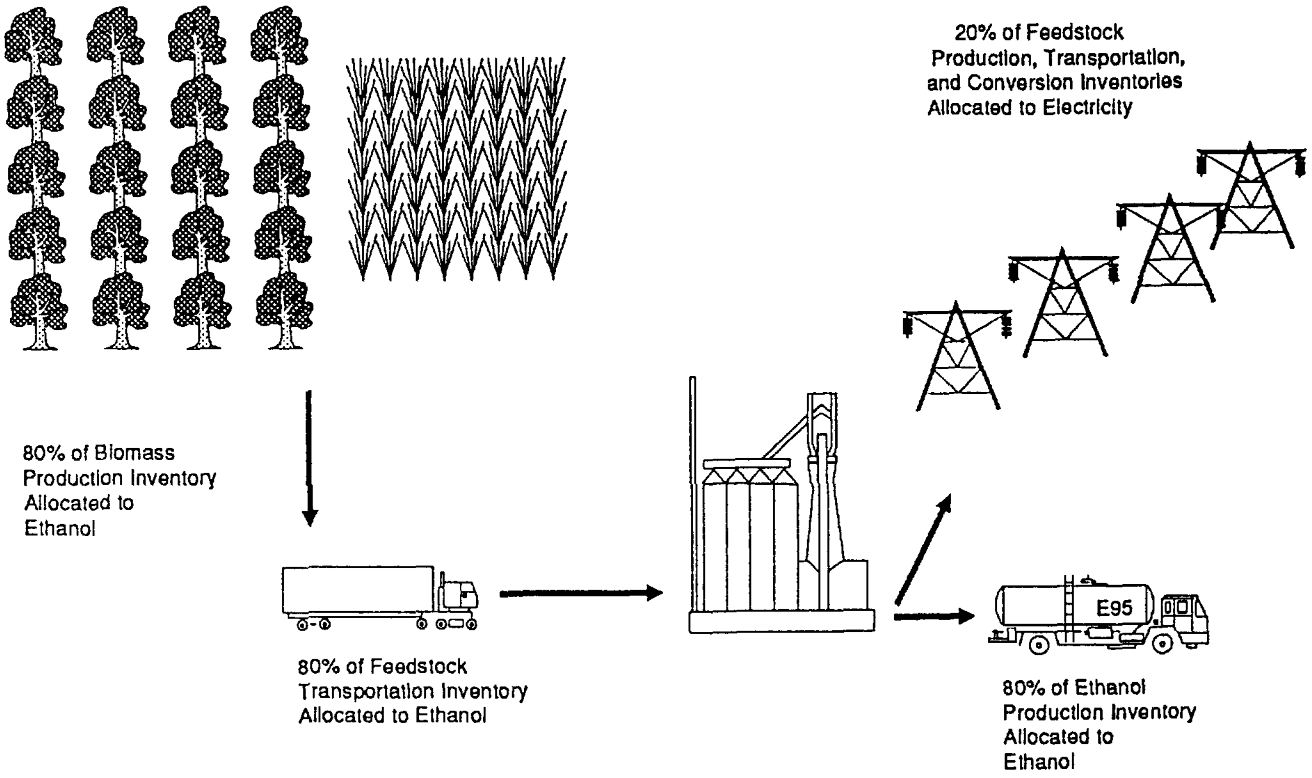


Figure 12. E95 fuel cycle allocation diagram

conversion inventory inputs and outputs were divided between two products: ethanol and electricity. This apportionment varied in each case; on the average, 80% of all the inputs and outputs of the conversion stage and the previous stages was allocated to the ethanol product and 20% was allocated to the electricity product (Figure 10, p. 19 and Figure 12). Similar methodology is used for the refinery allocation in the reformulated gasoline scenarios to account for the fact that only a fraction of a barrel of oil actually ends up in the final liquid fuel product (Figure 15, p. 30). The data provided in Appendix C, Volume II, are not allocated. The results of the base cases (Tables A through K, at the end of this report) include the allocation.

3.1.4 Ethanol Fuel Distribution

The MSW-ethanol facility in Peoria, IL, produces 71.8 million gallons per year of E95. The five ethanol facilities modeled in 2010 produce between 78 and 85 million gallons of E95 per year. An average of the five E95 base cases were used for general comparisons between E95 and RFG fuel cycles.

A complete account of the original assumptions used to characterize ethanol transportation is available in Volume II, Appendix D, Ethanol Fuel Transportation and Distribution. As explained in the authors' notes to appendix D and in this section, many changes were made to the

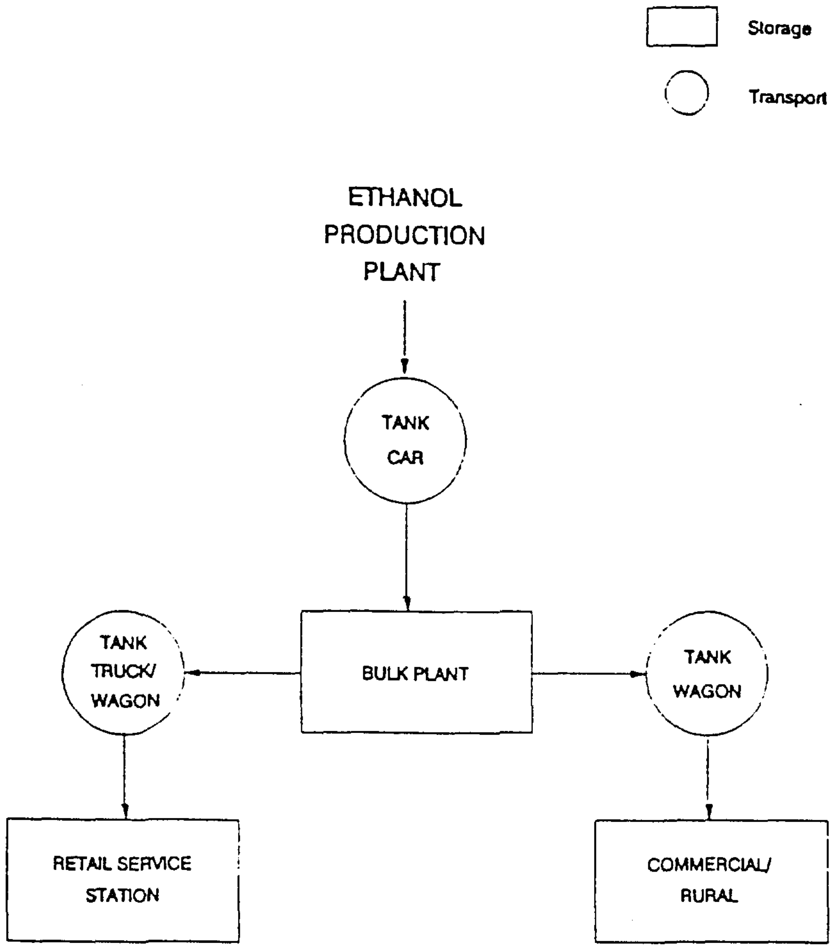


Figure 13. Flow diagram of ethanol fuel distribution

original assumptions. Only those assumptions actually used to characterize ethanol fuel distribution are described here.

We have assumed that the gasoline transportation and storage facilities could be used for ethanol with minor modifications. To simplify the types of transportation available and types of fuels used in them, all locomotives and trucks are assumed to be identical and use #2 diesel fuel. Ocean tankers and barges use #6 diesel. However, ocean tankers and barges were not used to distribute ethanol fuels. Fuel pumps at bulk facilities and retail terminals are assumed to be all electric. While we recognize that the industry is more complex and uses a variety of equipment and fuels, these simplifications are necessary for this analysis.

Transportation mode efficiencies are based on published statistics. Vapor losses from storage tanks are based on an assumption of uniform tank design and size. All storage tanks are equipped with vapor recovery systems.

The distribution stage begins at the ethanol plant when the E95 is loaded onto rail cars (Figure 13). In all six cases (one MSW case and five energy crop cases), railroad tank cars transport E95 from the ethanol plant. The ethanol plants are located in regions that support a railroad infrastructure allowing the E95 fuel to be transported to the surrounding major cities by rail. A major city was defined as a population center of 50,000 or more.

E95 is stored at the ethanol plant by loading it into waiting rail cars. In 2000, E95 will be transported 157 miles to Chicago's bulk terminals for blending to produce E10. The rail cars unload the E95 at a bulk storage plant located at or near the rail line. Storage tank designs are assumed to be similar to those of today. Vapor recovery systems reduce VOC emissions from the tank cars while in transit, during unloading, and on the storage tanks during refilling. Only minor modifications will be needed for transporting E95 in tank cars as E95 is transported in rail cars today.

In each major city, the storage tanks used for E95 are assumed to be dedicated to that purpose to avoid contamination with water and petroleum products. The number of times the tanks are refilled depends on the volume of the tanks, the capacity of a bulk facility, and the amount of fuel transported to each major city.

In 2000, E95 is blended with a gasoline base designed to produce an E10 that meets CAAA requirements. The fuel cycle inventory associated with the gasoline added to the E95 to produce E10 is added to the E10 fuel cycle in the distribution stage (compare Tables A, J, and K at the end of this report).

Quality and vapor pressure control were ensured by assuming that E95 and the gasoline base was pumped into tank trucks using a metered commingling of the two fuels during the loading of tank trucks.

Tank trucks loaded with E10 travel an average round-trip distance of 50 miles to retail and commercial stations. Evaporative VOC emissions are controlled with vapor recovery systems during loading of the tank truck and refilling retail storage tanks. Evaporative VOC emissions from E10 were assumed to be equal to those from RFG. The constituents of the emission vapors would be different but that information was not available. Ethanol spills are based on recent spill data for gasoline.

In 2010, the E95 is transported to major cities located in a 200-mile radius around the ethanol plant. Table 2 is an extract from Appendix D, Ethanol Fuel Transportation and Distribution, in Volume II, that shows how the distribution of ethanol is allocated regionally. The amount of E95 delivered to each major metropolitan area depends on the ratio of the number of people in that city to the total number of people in the 200-mile radius. This mechanism was used to approximate a regional distribution system.

E95 is not blended in 2010; it is used as a fuel in dedicated ethanol-fuel vehicles. From the storage tanks, the E95 is loaded into tank trucks and delivered directly to retail stations. The average truck travels 50 miles round-trip between the bulk plant and the retail stations. Rural accounts and commercial storage are also included in the analysis.

Both E10 and E95 are unloaded into retail or commercial storage tanks, where they are pumped on demand into customers' cars. All pumps are assumed to be electric. Electricity estimates may include electricity used to support retail building requirements as well as the pumps.

3.2 Reformulated Gasoline Fuel Cycles

The NES assumes that RFG will be the primary fuel used by 2000. The RFG fuel cycle constructed for this study assumes

Table 2. E95 distribution for Rochester, NY

Destination	E95 delivered (mil. gal/yr)	Percent of production (%)	Distance transported (miles)	Transport mode
Rochester, NY	18.1	23.1	0	——
Buffalo, NY	26.7	34.1	69	rail
Niagara Falls, NY	5.3	6.8	74	rail
Syracuse, NY	12.7	16.2	77	rail
Erie, PA	8.9	11.4	150	rail
Scranton, PA	6.5	8.4	170	rail
Totals	78.2	100.0	72[1]	rail

[1] weighted average of transportation distance

that the future gasoline industry is substantially similar to the gasoline industry today. The RFG in these fuel cycles has a composition that is consistent with CAAA standards for an RFG containing 2% oxygen by weight (11% MTBE). MTBE is the oxygenate used in the RFG fuel cycle. Technically, E10 qualifies as an RFG. However, the desired benchmark to compare with biomass-ethanol fuels is a 100% fossil fuel-based product, in this case, RFG with MTBE additives.

This fuel cycle study assumes that RFG is the only gasoline produced by the petroleum industry, despite contrary projections. We did not attempt to model the future petroleum industry with all of its infinite variations. This study creates a fuel cycle inventory for one particular fuel, an MTBE-based RFG.

The NES provides a recent forecast of the petroleum oil industry for the years 2000 and 2010. The strategy scenario, used for this fuel cycle study, includes advances in petroleum production and utilization technologies, and enough information to construct hypothetical slates of crude oil qualities and refinery characteristics.

Most of the existing infrastructure and industrial practices are assumed to remain unchanged for 2010. No substantial difference exists between 2010 and 2000 RFG fuel cycles, except the characteristics of the crude and product slates. Figure 14 depicts a schematic of the proposed RFG industry described in the following sections 3.2.1 through 3.2.4.

3.2.1 Crude Oil Production

Crude oil production begins with the wellhead. Exploration and drilling are assumed to be pre-operation activities and are not included in the fuel cycle. Conventional crude oil production technology will remain essentially similar to current technologies through 2010. Speculative resources, such as oil shale or gas hydrates, are not included because their

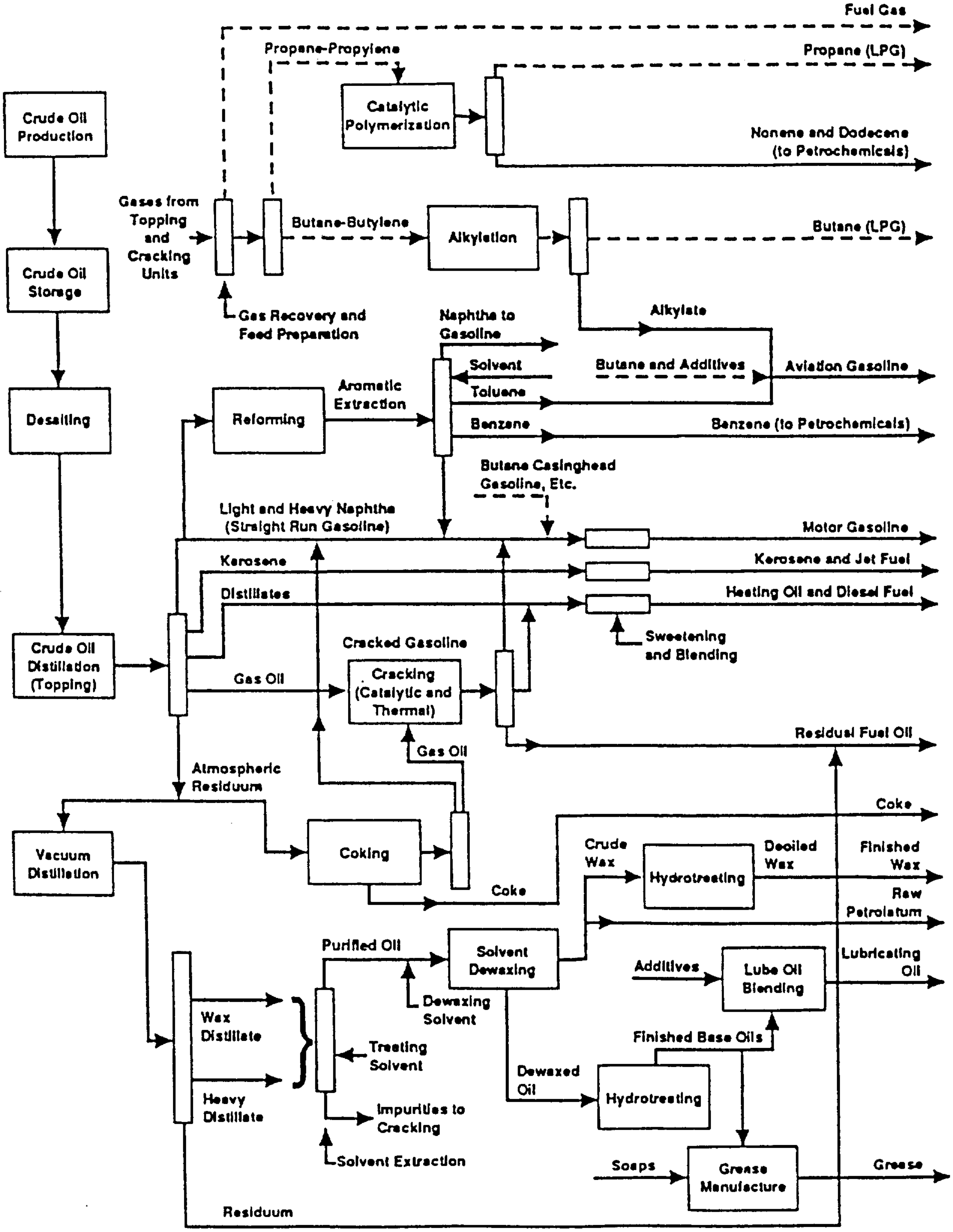


Figure 14. RFG fuel cycle schematic

economic exploitation is considered unlikely by 2010, given the expected economic conditions and anticipated technological development. The NES assumption that controversial resources (such as the Arctic National Wildlife Refuge and Outer Continental Shelf areas) will be developed and producing by 2000 or 2010 is incorporated into this analysis.

The techniques that produce crude oil vary according to the properties of the crude, the geology of the underground reservoir, the age of the field, and its location (onshore or offshore). Most of the current domestic production of crude oil is from onshore oil fields using primary recovery technologies. However, these methods are expected to shift toward secondary and tertiary techniques as fields age. Secondary and tertiary techniques are more energy intensive than primary ones and employ gases, steam, and mechanical means of enhancing the flow of crude oil from the reservoir as the field becomes depleted. By 2000 and 2010, heavier crudes will be produced and secondary and tertiary production methods will account for a larger portion of the total production. Thus, the characteristics of the hypothetical slate of crude oil available to refineries and the inputs and outputs associated with crude oil production are projected to change over time.

The inputs and outputs associated with crude oil production are allocated between the two coproducts produced from a wellhead (natural gas and crude oil) on a contained-Btu basis (Figure 15). Therefore, only 58% of the emissions created during crude oil production are assigned to the crude oil that is transported to the refinery. A sensitivity analysis assigned 100% of the wellhead emissions to the crude oil to evaluate the influence of this assumption on the results. See the refinery description for a description of other allocation assumptions.

Imported crude oil characteristics are added to the fuel cycle production stage. Even with the domestic oil production incentives present in the NES, more than 44% of the oil demanded by refineries will be imported in 2000, falling to 37% in 2010. Estimating foreign oil production characteristics is the best approach to the RFG fuel cycle inventory; however, collecting this information was beyond the scope of this study.

The base case constructed for the RFG fuel cycle assumes that imported oil is assigned the same production characteristics as domestically produced oil. A sensitivity analysis tested the alternative assumption that imports should be assigned a zero inventory balance to determine how sensitive the fuel cycle inventory totals are to the inclusion or exclusion of imported oil emissions.

3.2.2 Crude Oil Transportation

Domestic crude oil is stored in tankage near the wellhead; then it is transported via pipeline, barge, (ocean) tanker, rail car, or truck to crude storage tanks at the refineries. Offshore and Alaskan crude is assumed to be transported by pipeline to a marine tank storage facility; from there it is transported by ocean tanker to coastal refineries or to refinery storage facilities. Current transportation patterns are assumed to be relatively stable throughout the next two decades. National average statistics of the portion of crude oil transported in each mode are used to derive weighted average transportation estimates. Specific transportation assumptions are detailed in Volume II, Appendix F.

Only the characteristics associated with transporting imported crude oil from the

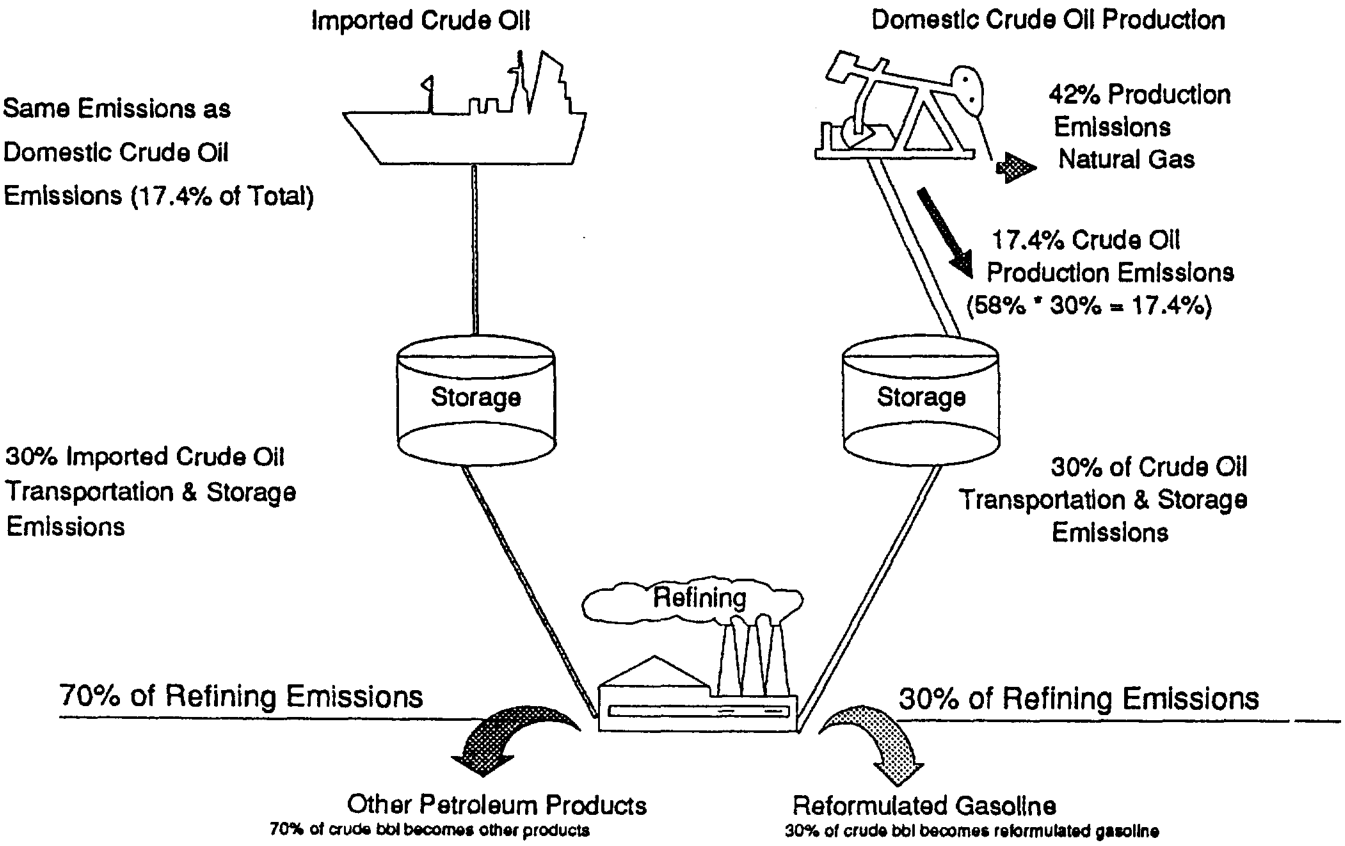


Figure 15. RFG fuel cycle allocation diagram, 2010

200-mile economic boundary to the port are included in the fuel cycle study. Transportation characteristics for the beginning of the journey are not included. Imported crude oil is unloaded into storage tanks at existing port facilities. The majority of the imported oil is transported by pipeline to refineries. Because most refineries that depend on imported crude oil are located at ports, imported crude oil is not transported the same distances as domestic crude oil.

The inventory characteristics for crude oil transportation are subject to an allocation assumption, which is described in detail in the following section on refining.

3.2.3 Refining

The petroleum refining industry provides the link between crude oil and finished products. The major variables that affect refinery operations (with respect to the production of RFG) are: (1) crude oil characteristics, (2) crude oil refining technology, and (3) RFG specifications. The characteristics of the hypothetical crude oil slate available to refineries will influence U.S. refinery operations. Similarly, the specifications for the major refinery outputs (gasoline and diesel) will certainly affect refinery operations.

For the purposes of this study, a simplifying assumption was made that the U.S. crude refining system can be characterized by two geographical components: one east of the Rocky Mountains that encompasses crude oils processed in the Petroleum Administration for Defense Districts (PADDs) I through IV; and the other west of the Rockies encompassing refining in PADD V. API (refers to standard grades defined by the American Petroleum Institute) gravities and sulfur contents were forecast for both geographical regions. These values are in Table F-18 of Appendix F, Volume II. Four refinery scenarios were investigated:

- West Coast (PADD V), average crude slate, year 2000
- West Coast (PADD V), average crude slate, year 2010
- United States less West Coast (PADDs I through IV), average crude slate, year 2000
- United States less West Coast (PADDs I through IV), average crude slate, year 2010.

The second step was to define the RFG product specifications. The following list describes the average RFG composition and property characteristics expected in the years 2000 and 2010.

- Aromatic content: 25% by volume
- Benzene content: 1.0% by volume
- Olefin content: 15% by volume
- Oxygen content: 2.0% by weight
- Summer RVP (Reid vapor pressure): 8.5 psi
- Sulfur content: 100 ppm.

The study's approach formulates the gasoline pool to meet these specifications on a nationwide average basis, using a plausible scenario based mainly on changes to catalytic reforming operations. MTBE is assumed to be the oxygenate in the U.S. gasoline pool in the years 2000 and 2010. Eleven percent MTBE corresponds to 2% oxygen by weight. MTBE may be manufactured in a refinery; but for purposes of this study, MTBE is considered a separate input to the gasoline refining process, and no environmental releases associated with its production were calculated. As a result, the fuel cycle inventory provided in Tables B and H, at the end of this report, underestimate total fuel cycle inputs and outputs.

National average refining and blending scenarios are developed based on the four individual refinery scenarios listed previously, along with projected crude production rates, API gravities, sulfur content, and reformulated gasoline product specifications. The scenarios developed assumed that more than 98% of the fuel is produced by complex/integrated refineries. The scenarios proposed are not an attempt to achieve the optimum, but are intended to be plausible on an average nationwide basis. In reality, each refinery will try to achieve an optimum strategy for its individual situation. The refining scenarios evaluated in this study include

- Reducing reformate severity and therefore reformate volume
- Reducing alkylate and butane volumes in the pool
- Diverting butanes to maximize production of isobutylene, used to make MTBE
- Increasing FCC light olefins production in 2010. (Up to that date, the United States may be able to import worldwide supplies of isobutylene or MTBE.)
- Extracting benzene from reformate
- Eliminating deliberate blending of other aromatics
- Increasing the manufacture of hydrogen to make up for reduced production of catalytic reforming hydrogen.

At the same time, the scenarios include increased vacuum distillation and coking volumes to contend with the trend toward heavier crude oils, and include increased hydrotreating and caustic washing to contend with higher sulfur contents of crude oils. A simplified block flow diagram of a typical complex refinery is provided in Figure 16.

The annual charge volumes of each refining process are quantified for 2000 and 2010, with West Coast (PADD V) vacuum distillation, coking, and crude oil gravity distinguished from the rest of the United States (PADDs I through IV). Table F-17, in Appendix F, shows annual U.S. refinery unit operation charges for both years.

Environmental releases (air emissions, water releases, and solid wastes) are based on published factors (release/barrel throughput). Environmental releases are calculated by multiplying the annual throughput volumes for each refining step by the emission factors. Major inputs to the refinery includes the crude oil, natural gas, electricity, and MTBE for blending with the final gasoline product. Although there are many different types of chemical inputs in refining, they were not included in this study because characterization was difficult. Major outputs include RFG and "other refinery products," such as LPG (liquid petroleum gas), aviation gasoline, benzene, kerosene, jet fuel, heating oil, diesel fuel, fuel oil, coke, and miscellaneous specialty oils and waxes.

All the fuel cycle characteristics for the crude oil production, transportation, and refining stages reported in the base cases are weighted by the ratio of the gasoline base (gasoline without MTBE) to total refinery product based on the Btu content of the product streams (Figure 15, p. 30). In 2000, 35% of the fuel cycle characteristics associated with crude oil production, transportation, and refining are assigned to RFG; 30% are assigned in 2010. Only a fraction of a barrel of oil ultimately becomes RFG; the remaining fraction becomes other petroleum products. The allocation of the crude oil production, transportation, and refining characteristics reflects the fraction of crude oil used to produce gasoline. As the characteristics of the crude oil slate and the product slate change, the ratio of gasoline to total refinery output changes. U.S. production of gasoline is projected to fall from 7 million barrels per day (bpd) in 2000 to 6.3 million bpd in 2010; whereas, crude oil demand increases from 12.3 million bpd to 13.7 million bpd between 2000 and 2010 (NES2, p.121).

Air emissions are estimated using factors for criteria pollutants, aldehydes, and ammonia obtained from AP-42 (EPA 1985) and modified when appropriate to include control technologies expected to be in place by 2000. Emission factors for 2000 are assumed to be the same through year 2010, except for adjustments required by regulations. The emission factors for greenhouse gases (such as carbon dioxide and methane) are derived from energy consumption and combustion data. Mandatory data reporting requirements under California legislation AB2588 for air toxics and the EPA Toxic Release Inventory System are used to help quantify toxics.

3.2.4 RFG Distribution

The RFG transportation infrastructure in 2010 is expected to resemble the existing infrastructure because major changes are not considered in the NES. The volume of RFG transported declines from 7 million bpd in 2000 to 6.3 million bpd in 2010. Therefore, the percentage of fuel that travels through one or another mode of transportation is assumed to remain constant.

RFG can be transported via pipeline, barge, rail, and truck from the refinery to bulk terminals or marine terminals. From bulk terminals the fuel is usually transported to

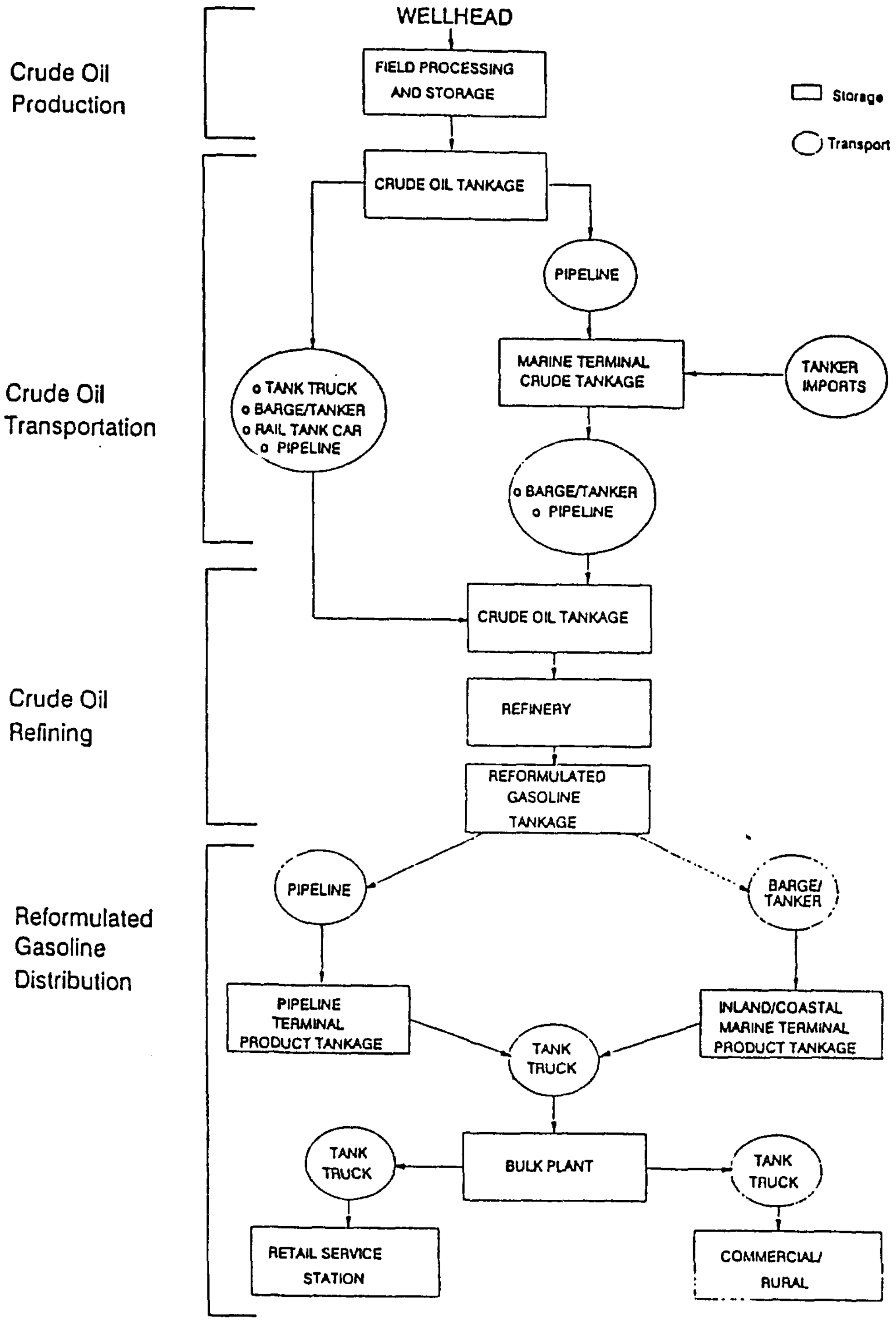


Figure 16. Simplified flow chart of a complex refinery

bulk plants in local metropolitan areas using tanker trucks. Trucks are used to transport the fuel from bulk plants to retail outlets. Fuel consumption for transporting gasoline is reported for the nation as a whole. Thus, it is not necessary to develop detailed estimates of how much gasoline is transported by each mode for any given distance. The lack of distances could be confusing, but keep in mind that if national estimates of fuel use in gasoline transportation are available, they are preferred to detailed modeling of a complex system in the time period allotted.

Number 2 diesel is assumed to be the only fuel used in trucks, rail, and inland barges. Number 6 diesel is assumed to be the only fuel used in ocean tankers and barges. Pipeline pumps and pumps at storage facilities are assumed to be all electrically driven.

The primary sources of emissions are vehicle emissions, primarily from rail and trucks because pipeline pumps are assumed to be electric. Stage I and II vapor recovery controls are assumed to be universally employed by 2000, with a recovery efficiency of 95% by 2000. Vapor recovery systems are assumed to be used at the pumps in all retail stations. National data on spills (as a fraction of throughput) are assumed to remain constant over time.

3.3 Fuel End Use Characteristics

E10, E95, and RFG are consumed in light-duty, spark-ignition passenger vehicles that represent technology available in 2000 and 2010. The end-use characteristics used for vehicles and fuels are presented in Appendix E, Ethanol and Reformulated Fuel End Use.

Information on other fuels and vehicles used in the fuel cycle are provided in Volume II, Appendix G, Accounting of Transportation Emissions. The assumptions used throughout these fuel cycle analyses concerning vehicle and equipment performance, fuels, and emissions were coordinated with assumptions and guidelines provided in Volume II, Appendix G.

Fuel composition and vehicle performance are estimated for the years 2000 and 2010 using an engineering analysis based on the technical literature. The emission values are generated from published EPA data. Changes in emission levels expected from vehicles using ethanol fuels are projected from identified changes in emissions from vehicles using reformulated gasoline. Ethanol vehicle performance is based on a theoretical analysis of the physical and chemical property differences between RFG and ethanol fuels. The theoretical analysis is then supported through a comparison with empirical data on actual engine performance measurements presented in the literature.

Vehicle emissions from RFG are based on a scenario of proposed Tier I standards being met by 2000 and proposed Tier II standards being met by 2010. Evaporative emission standards have not been proposed by EPA for either year, and therefore, they are projected to equal the exhaust VOC levels as currently observed. Carbon dioxide and sulfur dioxide emissions are based on fuel carbon and sulfur content, respectively, and on projected fuel economy for each fuel. Projections of toxic VOC emissions are based on relative reductions in total VOC emissions from data published for recent years.

The fuel economy projections are based on NES estimates for a compact vehicle. Fuel economy projections for RFG are based on changes in fuel energy content resulting from the hydrocarbon distribution in an RFG.

3.3.1 E10

E10 is assumed to be sold in 2000 in exactly the same way it is today—as an undifferentiated product for use by any standard gasoline-burning vehicle. Widespread vehicle technology changes, such as the use of variable valve timing, may be adopted but would not experience different effects for different fuels. Variable compression engines would be able to derive additional benefits from ethanol, but are less likely to be widespread by 2000. By 2000, 95.7% of new autos will use fuel injection systems rather than carburetion.

When E10 is burned in a gasoline-optimized engine, the only large efficiency effects should be the increase in volume of combustion products and the effect of charge-air cooling. The charge-air cooling effect of 12° F should produce about 2% to 3% more power from a given engine, but would have a much smaller effect on thermal efficiency. The increased volume of combustion products should increase efficiency about 1%. In total, the theoretical expectation would be for about a 1% to 2% increase in miles per million Btu when switching from gasoline to E10.

Generally speaking, the enleanment effect of oxygen in E10 or RFG reduces CO emissions while slightly increasing NOx emissions. The effect is greater for CO than for NOx and therefore, NOx emission differences between E10 and RFG with MTBE are expected to be negligible. All light-duty passenger vehicles are assumed to meet future Tier I federal standards by 2000. Therefore, the level of vehicle NOx emissions are predicted to be near the Tier I targets while also recognizing available benefits of the respective fuel formulations for hydrocarbons and CO emissions.

Both E10 and RFG (with MTBE) have a

gasoline, and vehicles achieve fewer miles per gallon with these fuels. Light-duty passenger vehicles using E10 are projected to get similar mileage, 30.2 miles per gallon of E10 and 30.8 miles per gallon of RFG 2000.

3.3.2 E95

By the year 2010, fully optimized engines for ethanol fuels should be available. They could take the form of dedicated-fuel, high-compression engines designed to run specifically on E85 or E95, or they could be variable-fuel, variable-compression engines with highly sophisticated engine control systems able to optimize engine performance for a variety of fuels.

The theoretical analysis suggests a 15% efficiency advantage for ethanol over gasoline, including the effect of greater tank and fuel weight. On a proportional basis this would translate to a 13% advantage for E85 and a 14% advantage for E95. Not enough experimental data are available to confirm these percentages. On a constant compression ratio basis, the theoretical advantage for ethanol would be 7%. The available data indicates an assumption that a 15% advantage for an optimized engine is a reasonable estimate of future potential. This theoretical value is assumed as the correct measure of potential by 2010.

Because of its lower energy density, light-duty passenger vehicles are assumed to get 28.25 miles per gallon on E95 and 35.6 miles per gallon on reformulated gasoline.

3.3.3 RFG

The CAAA require that RFG be sold in the nine worst ozone nonattainment areas starting in 1995. Other cities can elect to be included. States or cities can also elect to use RFG to satisfy local environmental goals. The NES projects that RFG will replace conventional gasoline by 2000 (NES2, p. 35). RFG with MTBE is assumed to be the predominate fuel in 2000 and 2010.

Future vehicle efficiency projections are based on the NES projections of new car efficiency ratings for the years 2000 and 2010—32.1 and 37.1 miles per gallon, respectively. These projections are based on 1990 gasoline composition (see Table E-17 in Volume II, Appendix E). The estimated energy density of RFG containing 15% MTBE, plus enough added alkylate to replace aromatics and olefins, is approximately 4% less than the energy density of conventional gasoline today. Converting the NES data points to miles per million Btu yields a fleet average mileage projection of 30.8 miles per gallon in 2000 and 35.6 miles per gallon in 2010 using RFG. This corresponds to 194 and 244 miles per million Btu, respectively.

3.4 Sensitivity Analyses

Two types of sensitivity analyses are examined: (1) different fuel cycle boundaries and (2) allocation methodologies. The fuel cycle boundary analyses evaluate the changes that occur when specific activities are included or excluded from the inventories and changes that occur from including or excluding secondary emissions from input production. Including or excluding oil imports or MSW collection are examples of activities; including or excluding emissions from electricity generation are examples of treatment of secondary emissions.

An allocation methodology divides the fuel cycle inventory for a stage or an activity between multiple products; e.g., ethanol and electricity, gasoline and other petroleum products. For example, emissions from an ethanol production facility are divided between ethanol and electricity based on the energy value of the outputs. A list of sensitivity studies and their variations appears in Table 3.

3.4.1 Boundary Analysis

We sifted through the various assumptions that had to be made about which activities to include, how to handle secondary emissions, and how to allocate the inventories between coproducts to develop a set of eight base cases. The rationale and the assumptions made for the base cases are described in Sections 2 and 3 and in Table 3 as R1 through R8. In this section we identify some opportunities to alter our assumptions to test alternative theories. There are two questions asked about the base cases: (1) How did the boundaries definitions affect the fuel cycle results; and (2) Should secondary emissions from input manufacturing be included? The first question arose from the treatment of imported oil and garbage collection activities. The second arose from a general concern that limiting a fuel cycle to quantifying primary inputs and outputs overlooked secondary characteristics of potential significance, namely, emissions from manufacturing electricity and gasoline used in ethanol fuels. The following discussions of sensitivity analyses were designed to examine these questions.

Oil Import Boundary Treatment. In the RFG base cases (2000 and 2010), imported oil was assigned the same inventory characteristics (on a per barrel and per Btu basis) as domestic crude oil production. Alternatively, foreign oil production characteristics could be ignored and the fuel cycle could be restricted to characterizing domestic activities. Nearly half of the crude oil used in domestic refineries is imported and the composition of the imported oil influences how U.S. refineries operate. Without the data to characterize foreign oil

Table 3. Descriptions of Fuel Cycle Base Case and Sensitivity Analyses

Ref. No.	Year	Base Case Descriptions
R1	2000	RFG with inputs/outputs of crude oil production, transportation, and refining allocated between RFG and other products. Imported crude oil is assigned the same inputs/outputs as domestic crude oil production.
R2	2000	E10 from MSW with inputs/outputs of sorting allocated between cellulose and other recyclables. Includes inputs/outputs of R1 for 90% gasoline content. Fuel cycle begins as MSW leaves the transfer station. Inputs/outputs associated with sorting, transporting, and converting lignocellulose to E95 and electricity allocated between ethanol and electricity.
R3	2010	RFG with inputs/outputs of crude oil production, transportation, and refining allocated between RFG and other products. Imported crude oil is assigned the same inputs/outputs as domestic crude oil production.
R4	2010	E95 from Tifton biomass, includes inputs/outputs of R3 for the 5% gasoline content. Feedstock conversion, transportation, and production characteristics allocated between ethanol and electricity products.
R5	2010	E95 from Peoria biomass, includes inputs/outputs of R3 for the 5% gasoline content. Feedstock conversion, transportation, and production characteristics allocated between ethanol and electricity products.
R6	2010	E95 from Lincoln biomass, includes inputs/outputs of R3 for the 5% gasoline content. Feedstock conversion, transportation, and production characteristics allocated between ethanol and electricity products.
R7	2010	E95 from Portland biomass, includes inputs/outputs of R3 for the 5% gasoline content. Feedstock conversion, transportation, and production characteristics allocated between ethanol and electricity products.
R8	2010	E95 from Rochester biomass, includes inputs/outputs of R3 for the 5% gasoline content. Feedstock conversion, transportation, and production characteristics allocated between ethanol and electricity products.

Table 3. continued

Ref. No.	Year	Sensitivity Cases Description
R9	2000	RFG with the inputs/outputs of crude oil production, transportation, and refining allocated between RFG and other products. Imported crude oil production activities are assigned zero inputs/outputs values.
R10	2000	RFG with inputs/outputs of crude oil production, transportation, and refining allocated between RFG and other products. Imported crude oil is assigned the same inputs/outputs as domestic crude oil production. Emissions associated with electricity production and use in the fuel cycle are included.
R11	2000	RFG is assigned all of the emissions associated with production, transportation, and refining of crude oil. By-products and coproducts are "free" of emissions. Imported crude oil is assigned the same emissions as domestic crude oil production.
R12	2000	E10 from MSW with inputs/outputs of sorting, transporting, and converting lignocellulosic material allocated between ethanol and electricity. Includes inputs/outputs of R1 for 90% gasoline content. Fuel cycle begins with curbside garbage collection.
R13	2000	E10 from MSW with inputs/outputs of sorting, transporting, and converting lignocellulosic material assigned 100% to ethanol. Recyclables from sorting and electricity are "free" of emissions. Includes inputs/outputs of R1 for 90% gasoline content. Fuel cycle begins as MSW leaves the transfer station.
R14	2000	E10 from MSW with inputs/outputs of sorting, transporting, and converting lignocellulosic material assigned 100% to ethanol. Recyclables from sorting and electricity are "free" of emissions. Includes inputs/outputs of R1 for 90% gasoline content. Fuel cycle begins with curbside garbage collection.
R15	2000	E10 from MSW with inputs/outputs of sorting, transporting, and converting lignocellulosic material allocated between ethanol and electricity. Excludes inputs/outputs of R1 for 90% gasoline content. Fuel cycle begins as MSW leaves the transfer station.

Table 3. continued

Ref. No.	Year	Sensitivity Cases Description
R16	2000	E10 from MSW with inputs/outputs of sorting, transporting, and converting lignocellulosic material allocated between ethanol and electricity. Excludes inputs/outputs of R1 for 90% gasoline content. Fuel cycle begins with curbside garbage collection.
R17	2010	RFG with the inputs/outputs of crude oil production, transportation, and refining crude oil allocated between RFG and other products. Imported crude oil production activities are assigned zero inputs/outputs values.
R18	2010	RFG with inputs/outputs of crude oil production, transportation, and refining crude oil allocated between RFG and other products. Imported crude oil is assigned the same inputs/outputs as domestic crude oil production. Emissions associated with electricity production and use in the fuel cycle are included.
R19	2010	RFG is assigned all of the emissions associated with production, transportation, and refining crude oil. By-products and coproducts are "free" of emissions. Imported crude oil is assigned the same emissions as domestic crude oil production.
S1	2010	One case that inventories the inputs/outputs associated with the 5% of gasoline in E95. Subtracting these data from R4, R5, R6, R7, and R8 will provide inventories for the E95 cases, excluding inputs/outputs associated with the fuel cycle of the gasoline contained in the E95.
R25	2010	E95 from Tifton biomass, includes inputs/outputs of R3 for the 5% gasoline content; feedstock production, transportation, and conversion inputs/outputs allocated between ethanol and electricity; and emissions credits/debits for electricity generation/use.

Table 3. continued

Ref. No.	Year	Sensitivity Cases Description
R26	2010	E95 from Peoria biomass, includes inputs/outputs of R3 for the 5% gasoline content; feedstock production, transportation, and conversion inputs/outputs allocated between ethanol and electricity; and emissions credits/debits for electricity generation/use.
R27	2010	E95 from Lincoln biomass, includes inputs/outputs of R3 for the 5% gasoline content; feedstock production, transportation, and conversion inputs/outputs allocated between ethanol and electricity; and emissions credits/debits for electricity generation/use.
R28	2010	E95 from Portland biomass, includes inputs/outputs of R3 for the 5% gasoline content; feedstock production, transportation, and conversion inputs/outputs allocated between ethanol and electricity; and emissions credits/debits for electricity generation/use.
R29	2010	E95 from Rochester biomass, includes inputs/outputs of R3 for the 5% gasoline content; feedstock production, transportation, and conversion inputs/outputs allocated between ethanol and electricity; and emissions credits/debits for electricity generation/use.
S2	2000	One case that inventories the difference between the input/output inventories of R3 and R19 for the 5% of gasoline in E95. Subtracting these data from cases R4, R5, R6, R7, and R8 will provide inventories for the E95 cases, reflecting gasoline fuel cycle inputs and outputs for gasoline content of E95 that are not allocated on a product basis in the RFG fuel cycle.
R45	2000	E10 from MSW with inputs/outputs of sorting, transporting, and converting lignocellulosic material allocated between ethanol and electricity. Includes inputs/outputs of R1 for 90% gasoline content. Fuel cycle begins as MSW leaves the transfer station. Includes emission debits/credits for electricity used and produced in the fuel cycle.

production, the initial decision was to assign imported oil zero input and output values; e.g., foreign oil did not have any emissions or energy inputs associated with production. On further reflection, this approach was abandoned because it diluted the production emissions for all crude oil used in domestic refineries, obscuring the actual resource and emission costs. Lacking better data, imported crude oil production activities were assigned the same characteristics as domestic oil production. This is an imperfect proxy; this fuel cycle analysis could be improved by better characterization of foreign oil production characteristics.

Two sensitivity analyses examined the effects of setting the foreign oil production inventory to zero for the two reformulated gasoline base cases (see descriptions of R9 and R17 in Table 3).

Curbside Collection of MSW Boundary Treatment. Initially, all the activities that contributed to E10 production were identified and characterized. This included quantifying inputs and outputs associated with collecting curbside garbage, taking it to a transfer station for compaction, then delivering it to a sorting facility. As the analysis progressed, it became clear that some of these activities would occur whether an ethanol industry existed or not; the only difference is the compacted garbage would be taken to a landfill, rather than a sorting facility. The base case for E10 begins at the transfer station, ignoring the activities to bring the MSW to that point. A sensitivity analysis includes curbside collection (R12).

Secondary Emissions Boundaries. In a strictly defined fuel cycle inventory, all of the inputs and outputs associated with each activity are quantified to the extent possible. Emissions associated with producing inputs are not quantified. Using this strict definition, the ethanol used to produce E10 would be considered an input and the number of gallons involved would be estimated, but none of the fuel cycle characteristics associated with the production of ethanol would be included in the E10 fuel cycle. Similarly, the fuel cycle emissions associated with the gasoline in E95 would not be considered in the ethanol fuel cycle. This approach does not accurately reflect the cost to society for producing E10 (e.g., cost in terms of amounts of resources consumed and wastes produced).

This brings up a difficult issue to resolve: if the production emissions (secondary emissions) associated with one input (10% ethanol or 5% gasoline) are included, then the secondary emissions for all inputs should be included for consistency. This approach requires information of the life-cycle emissions for every input to a fuel cycle. This approach becomes an unbounded problem with an infinite and expanding amount of analysis. The most common alternative is to limit the boundaries to include secondary emissions associated with the production of inputs, if those emissions are large relative to the primary emissions of the total fuel cycle. If the analyst bases the inclusion of secondary emissions on this methodology, how does the analyst know in *advance* if an input has major secondary emissions associated with its production without performing a fuel cycle analysis on every input?

The approach taken here is based on recent fuel cycle analyses (Deluchi 1992) and other environmental assessments (Ho 1989). Diesel fuel, electricity, and fertilizer have been identified as inputs whose production emissions significantly affect analytical conclusions. The only published data on emissions from fertilizer manufacturing facilities are uncontrolled emission estimates from AP-42 (EPA 1985). Because fertilizer production facilities use emission controls, these data would have overestimated fertilizer emissions. For this reason, fertilizer emissions were not incorporated into this report. Deluchi (1992) found that greenhouse gas emissions from fertilizer and electricity production cancelled each other out in a study of a wood-ethanol fuel cycle.

The emissions from the RFG fuel cycle are added to the E10 and E95 fuel cycles based on the amount of gasoline used because data would be available from this report. Secondary emissions from electricity are also examined.

Secondary Emissions: Electricity. Electricity emissions depend on the fuel and the technology used to produce electricity, which vary regionally as a result of resource endowments and environmental regulation. We have assumed that the regional mix of electric generating resources will determine the quantities of emissions associated with producing electricity. The activities that consume or produce electricity in each stage of the fuel cycles have to be characterized regionally for the electricity sensitivity analysis. The methodology and assumptions used in the electricity sensitivity analyses are summarized below. More detail is provided in Volume II, Appendix H, Environmental Factors Associated with Electricity.

Analysts examined two types of fuel cycles: national fuel cycles for the RFG and regional fuel cycles for the ethanol fuels. All of the activities associated with the ethanol fuel cycles are limited to one region. In the RFG fuel cycles, the regional concentration of fuel cycle activities are more complex. Some stages of the national fuel cycle are regionally concentrated (crude oil production), whereas others are spread more uniformly over the country (fuel distribution).

The current regional distribution of oil-related activities—crude oil production, transportation, refining, and fuel distribution—are regionally characterized based on existing infrastructure patterns. Crude oil production occurs in many states, but the bulk of crude oil production is concentrated in the Texas-Louisiana-Oklahoma area, the north central U.S. (Kansas, Wyoming, Colorado), and the West Coast, including California, Washington, and Alaska. Refinery capacity is concentrated in similar regions. Crude transportation is obviously related to the location of crude oil producing areas and refineries, whereas fuel distribution is a more dispersed activity. National data on existing capacity and throughput were coupled with NES projections on oil production estimates to develop estimates of future regional activities. Census data were used to develop estimates on population concentrations and regional distribution throughput.

Only five emissions were assigned to electricity use: CO_2, NOx, SO_2, total suspended solids (TSP or particulates), and solid waste. Other emissions were not as thoroughly documented and were not used for this study. Emission estimates are derived from published sources (described in Appendix H). These estimates depend on the type of fossil fuel used to produce electricity and the mix of fossil fuel-generating capacity available in each federal region in the future.

Regional estimates of the amount of electricity consumed or produced in each stage of the fuel cycle are developed based on what portion of each production stage occurs in each region. The electricity used (or produced) in each region is assigned a debit (or credit) based on the regional electricity-generating characteristics and their emissions. The regional emissions are weighted and averaged based on the portion of the total activities occurring in a particular region.

All eight base cases were evaluated for their sensitivity to secondary electricity emissions (see Table 3: R10, R18, R25, R26, R27, R28, R29, and R45).

Secondary Emissions: RFG. The emissions associated with the 5% of gasoline in E95 were isolated to evaluate how their inclusion affects the E95 fuel cycles (R20-R24). Similarly, the emissions associated with the 90% gasoline in E10 were also isolated to evaluate just the emissions associated with producing ethanol as a gasoline additive (R15).

Secondary Emissions: Diesel Fuel. A diesel fuel cycle has the same initial stages and activities as a gasoline fuel cycle: crude oil production, imports, transportation, and refining. The activities associated with diesel fuel distribution are not significantly different from those of gasoline. Emissions from the combustion of diesel fuel in transportation vehicles and other engines are included in the base cases. Because the allocation methodology was based on the ratio of Btus in gasoline compared to the total product of a refinery, the data provided in the base cases can be adjusted to reflect the addition of fuel cycle characteristics for diesel consumed in the fuel cycle.

This analysis was not conducted due to time limitations. However, by assigning 100% of the crude oil production, transportation, and refining emissions to RFG (e.g., other refinery products are not associated with production emissions), an upper bound on the possible effects of including the fuel cycle emissions associated with diesel production can be calculated. This procedure is described in the following section.

3.4.2 Allocation Methodology

Fuel cycle characteristics for a stage or activity were divided among the coproducts of that stage or activity in four areas: MSW sorting facility, crude oil production, crude oil refining, and ethanol production. In addition, prior activities were also subject to the allocation (Figures 10, p. 19; Figure 12, p. 23; and Figure 15, p. 28). Analysts assigned inventory characteristics on the basis of the ratio of energy in the final product compared to the energy of the total outputs or dry weight of final product compared to the dry weight of the total outputs, whichever is most reasonable for the case examined.

MSW Sorting Facility Allocation. When MSW is sorted, two streams of products issue: lignocellulosic organic waste and nonorganic wastes. Many of the nonorganic wastes can be sold to recyclers: glass, metal, plastic, etc. Regardless of their disposition, the emissions associated with separating MSW should be divided among the coproducts (lignocellulosic material and wastes). In the MSW-E10 base case fuel cycle, 71% of the input/output inventory from sorting MSW is assigned to the lignocellulosic output; the remainder (29%), is allocated to the coproduct recyclables. The allocation was based on dry weights. This allocation would apply to MSW collec-tion and transportation activities in sensitivity cases in which they are included. A sensitivity analysis evaluated the effect of assigning 100% of the sorting, transportation, and conversion characteristics to the lignocellulosic feedstock.

Coproduction of Crude Oil and Natural Gas. Natural gas is often produced with crude oil. It is referred to as associated gas. If the input/output inventory from producing crude oil is assigned to crude oil, the natural gas produced is "free" to society;

there are no inputs or outputs associated with its production. The RFG base cases (2000 and 2010) assume that the inventory associated with crude oil production is divided between the natural gas and crude oil, on a Btu basis. In 2010, crude oil is assigned 58% of the production characteristics and natural gas is assigned the remaining 42%. A sensitivity study examined unallocated emissions; e.g., assigning all the inputs and outputs associated with crude oil production, transportation, and refining to RFG (Table 3, analyses R11 and R19).

Coproduction of Multiple Refinery Products. Only a fraction of a barrel of crude oil is transformed into RFG; the remainder is transformed into diesel, propane, chemicals, plastics, coke, asphalt, and other products. In the RFG base cases (R1 and R3), the refinery characteristics are divided between RFG and "all other products" based on a Btu equivalent value of total output. In 2000, 35% of the refinery emissions are assigned to RFG; by 2010 that percentage falls to 30% (less gasoline produced in product slate).

The characteristics of the crude oil production and transportation stages are similarly allocated; only a portion of the barrel of crude produced and transported becomes RFG. The remaining crude oil production, transportation, and refining inventory characteristics are assigned to "other petroleum products." Therefore, only 35% of the transportation emissions in 2000 and 30% in 2010 are assigned to RFG in the base cases; only 20% of the crude oil production inventory is reflected in the RFG fuel cycle in 2000 (0.58 x 0.35), falling to 17.4% (0.58 x 0.30) in 2010 (Figure 15 on page 28).

The sensitivity analysis of crude oil allocation examined the effect of assigning all of the refinery emissions (and thus 100% of the transportation emissions and 100% of the crude oil production emissions) to RFG.

Biomass-Ethanol Conversion Process. The biomass conversion facility yields two products: E95 and electricity. Based on economic value, these products are considered coproducts. The characterization of the activities that produce, transport, and convert biomass needs to reflect only the portion that actually contributes to ethanol production, rather than electricity. Therefore, the base cases reflect an allocation of the characteristics of feedstock production, transportation, and conversion based on the ratio of energy content in the ethanol to that of the total products. Each regional case is slightly different, because different feedstocks yield different proportions of ethanol and electricity. The average of the allocation characteristics of the five 2010 cases is 80% to ethanol, 20% to electricity.

The sensitivity analyses reexamine the six biomass-ethanol base cases without any allocation.

4.0 DATA QUALITY

4.1 Data Sheets

Each research team that was responsible for preparing an appendix for the fuel cycle was asked to assess the quality of the data used for their report. A generic format was developed to ensure consistency. Data assessment sheets (Figures 17 - 19) provided a qualitative assessment of the data quality.

In general, the quality of the data could be improved with additional work; however, the improvements may not significantly change the conclusions of the analysis. The experimental data used to characterize the ethanol fuel cycles can be verified through research and development trials. The experimental results could improve the engineering design used in this study. It is important to remember that this fuel cycle analysis documents the characteristics of one combination of technological designs among many possible combinations. Each different combination of technologies will result in different fuel cycle inventories.

The quality of data used to characterize the existing and future petroleum industry could be substantially improved. Future regulations and trends could be characterized, improving the accuracy of the projections made in this report. Data from selected processes indicate that improvements in technologies, such as waste minimization, are very likely. However, these data were not used to characterize the future industry because evaluating the myriad of technologies used in the industry was beyond the scope of the work. Researchers were directed to collect published data that best characterized the industry. Published data that typifies an industry, or attempts to project some "average" operating parameter, underestimate the achievements of progressive firms that have surpassed average levels.

Analysts recognized these limitations in the quality of data collected from published sources and theoretical engineering designs but decided to use the available information in this fuel cycle study because it could be documented. Once the implications of fuel cycle results are assessed, the cost of investing in better data can be weighed against the projected benefits.

4.2 Appendices

Information provided by team participants and contractors that appear in Volume II, _Fuel Cycle Evaluations of Biomass-Ethanol and Reformulated Gasoline: Appendices_, has been substantially modified in some cases. Because of the preliminary nature of this fuel cycle analysis—the first of its kind with respect to the level of detail—it was not believed to be cost effective to have either the team members or the consultants make major modifications to their methodology or data sources until the whole project could be evaluated.

The appendices that were modified the most were: Appendix D, Ethanol Transportation; Appendix B, MSW Collection, Transportation, and Separation; Appendix F, the Benchmark Reformulated Gasoline Fuel Cycle; and Appendix C, Biomass Conversion. Authors' notes appear before each Appendix, describing how the information contained in the appendix was used or altered in the TFCA. A brief description of the major changes is provided here.

In Appendix D, Ethanol Transportation, the authors assumed that only the differences between the environmental emissions associated with transporting gasoline and

	Materials									Energy				Chemicals					Prod		Wastes					Air Releases																Water Releases							Land Concerns							
	Labor	Steel	Aluminum	Concrete	Asphalt	Plastics	Gen. Equipment	Electronics	Other	Electricity	Crude Oil	Natural Gas	Diesel Fuel	Water	Fertilizer	Insecticide	Herbicide	Other	Ethanol	By-products	Hazardous	Radioactive	Mixed	Combustible	Other	SO2	NOx	CO	PM-Total	Pb	VOC-Total	VOC-Breakdown	CO2	CH4	Other Greenhouse	Acetaldehyde	Formaldehyde	Other Toxics	Fertilizer	Insecticide	Herbicide	Fertilizer	Insecticide	Herbicide	Suspended Solids	Oil & Grease	Priority Pollutants	Thermal	Land Area	Land Conversion	Soil Productivity	Erosion	Noise	Odors	Aesthetics	Health/Safety
MSW Col/Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Collection	▨	▨	▨	▨	▨	▨	▨	▨	▨	NA	NA	NA	●	NA	NA	NA	NA	◒	NA	NA	NA	NA	NA	NA	NA	●	●	●	●	○	●	◒	●	NA	○	●	◒	◒	○	○	○	NA	NA	NA	NA	○	○	NA	●	◒	○	○	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
MSW Classification: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportn	▨	▨	▨	▨	▨	▨	▨	▨	▨	●	NA	NA	NA	◒	○	○	◒	◒	NA	NA	◒	○	◒	◒	○	●	●	●	●	●	◒	◒	●	○	○	NA	NA	●	○	○	○	○	○	○	◒	○	○	NA	●	◒	○	○	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
MSW Conv: Facility Constctn	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	▨	▨	▨	▨	▨	▨	▨	▨	▨	◒	NA	NA	◒	◒	NA	NA	NA	◒	◒	◒	NA	NA	NA	NA	◒	◒	◒	◒	◒	◒	◒	◒	◒	○	○	◒	◒	○	NA	NA	NA	NA	NA	NA	◒	●	○	NA	○	NA	○	○	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Ethanol Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportn	▨	▨	▨	▨	▨	▨	▨	▨	▨	●	●	NA	NA	NA	NA	NA	NA	NA	●	NA	NA	NA	NA	NA	NA	●	●	●	◒	NA	●	◒	●	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	○	◒	NA	NA	NA	NA	NA	NA	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
End-Use: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	▨	▨	▨	▨	▨	▨	▨	▨	▨	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	◒	NA	NA	●	◒	●	●	●	◒	●	●	◒	●	◒	◒	●	●	●	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	▨	▨	▨	▨
Disposal	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

Legend

▨ Qualitative discussion included in analysis, as relevant.
NA Data are not applicable.
○ Data are not available.
◒ Data quality could be improved through more detailed analysis and/or research.
● Data quality is good.

12/12/91

Figure 17. Availability and quality of E10 TFCA quantitative data

	Materials									Energy					Chemicals				Prod	
	Labor	Steel	Aluminum	Concrete	Asphalt	Plastics	Gen. Equipment	Electronics	Other	Electricity	Crude Oil	Natural Gas	Diesel Fuel	Water	Fertilizer	Insecticide	Herbicide	Other	Ethanol	By-products
Bio Prod: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Cropping/Harvstng	▨	▨	▨	▨	▨	▨	▨	▨	▨	●	●	●	◒	●	◒	○	◒	◒	NA	NA
Land Retirement	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Bio Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportn	▨	▨	▨	▨	▨	▨	▨	▨	▨	●	●	NA	◒	●	NA	NA	NA	○	NA	NA
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Bio Conv: Facility Constcln	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	▨	▨	▨	▨	▨	▨	▨	▨	▨	◒	NA	NA	◒	◒	NA	NA	NA	◒	◒	◒
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Ethanol Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportn	▨	▨	▨	▨	▨	▨	▨	▨	▨	●	●	NA	NA	NA	NA	NA	NA	NA	●	NA
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
End-Use: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	▨	▨	▨	▨	▨	▨	▨	▨	▨	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Disposal	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

	Wastes					Air Releases															
	Hazardous	Radioactive	Mixed	Combustible	Other	SO2	NOx	CO	PM - Total	Pb	VOC-Total	VOC-Breakdown	CO2	CH4	Other Greenhouse	Acetaldehyde	Formaldehyde	Other Toxics	Fertilizer	Insecticide	Herbicide
Bio Prod: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Cropping/Harvstng	NA	NA	NA	●	NA	●	◒	●	●	●	◒	◒	●	○	○	◒	◒	○	◒	○	◒
Land Retirement	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Bio Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportn	NA	NA	NA	●	◒	●	●	●	●	●	●	◒	●	◒	◒	◒	◒	◒	NA	NA	NA
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Bio Conv: Facility Constcln	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	NA	NA	NA	NA	◒	◒	◒	◒	◒	◒	◒	◒	◒	○	○	◒	◒	○	NA	NA	NA
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Ethanol Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportn	NA	NA	NA	NA	NA	●	●	●	◒	NA	●	◒	●	NA	NA	NA	NA	NA	NA	NA	NA
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
End-Use: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	◒	NA	NA	●	◒	●	●	●	◒	●	●	◒	●	◒	◒	●	●	●	NA	NA	NA
Disposal	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

	Water Releases							Land Concerns							
	Fertilizer	Insecticide	Herbicide	Suspended Solids	Oil & Grease	Priority Pollutants	Thermal	Land Area	Land Conversion	Soil Productivity	Erosion	Noise	Odors	Aesthetics	Health/Safety
Bio Prod: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Cropping/Harvstng	◒	○	◒	◒	○	◒	NA	●	◒	◒	◒	▨	▨	▨	▨
Land Retirement	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Bio Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportn	NA	NA	NA	NA	NA	NA	●	NA	NA	NA	NA	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Bio Conv: Facility Constcln	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	NA	NA	NA	◒	●	○	NA	○	NA	○	○	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Ethanol Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportn	NA	NA	NA	○	◒	NA	NA	NA	NA	NA	NA	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
End-Use: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	▨	▨	▨	▨
Disposal	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

Legend

▨ Qualitative discussion included in analysis, as relevant.
NA Data are not applicable.
○ Data are not available.
◒ Data quality could be improved through more detailed analysis and/or research.
● Data quality is good.

12/12/91

Figure 18. Availability and quality of E95 TFCA quantitative data

	Materials									Energy				Chemicals					Prod		Wastes					Air Releases																Water Releases							Land Concerns							
	Labor	Steel	Aluminum	Concrete	Asphalt	Plastics	Gen. Equipment	Electronics	Other	Electricity	Crude Oil	Natural Gas	Diesel Fuel	Water	Fertilizer	Insecticide	Herbicide	Other	Ethanol	By-products	Hazardous	Radioactive	Mixed	Combustible	Other	SO2	NOx	CO	PM-Total	Pb	VOC-Total	VOC-Breakdown	CO2	CH4	Other Greenhouse	Acetaldehyde	Formaldehyde	Other Toxics	Fertilizer	Insecticide	Herbicide	Fertilizer	Insecticide	Herbicide	Suspended Solids	Oil & Grease	Priority Pollutants	Thermal	Land Area	Land Conversion	Soil Productivity	Erosion	Noise	Odors	Aesthetics	Health/Safety
Oil Production: Explore/Drill	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Produce	▨	▨	▨	▨	▨	▨	▨	▨	◒	◒	●	◒	◒	●	◒	NA	NA	NA	NA	●	◒	◒	◒	◒	◒	●	◒	◒	◒	○	◒	◒	◒	◒	NA	●	●	◒	NA	NA	NA	NA	NA	NA	◒	●	○	●	●	◒	◒	◒	▨	▨	▨	▨
Plug	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Oil Trans: Infrastructure Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	▨	▨	▨	▨	▨	▨	▨	▨	NA	●	●	NA	●	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	●	●	●	●	NA	●	◒	●	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	○	◒	NA	NA	NA	NA	NA	NA	▨	▨	▨	▨
Decommissioning	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Refining: Facility Construction	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	▨	▨	▨	▨	▨	▨	▨	▨	NA	●	●	●	NA	NA	NA	NA	NA	NA	NA	●	NA	NA	NA	NA	NA	●	●	●	◒	NA	◒	○	◒	◒	○	○	○	○	NA	NA	NA	NA	NA	NA	●	●	○	○	●	NA	NA	NA	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Gasoline Trans: Infrastr Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Transportation	▨	▨	▨	▨	▨	▨	▨	▨	NA	●	NA	NA	●	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	●	●	●	◒	NA	●	◒	●	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	○	◒	NA	NA	NA	NA	NA	NA	▨	▨	▨	▨
Decom	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
End-Use: Infrastructure Dvlpt	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Operation	▨	▨	▨	▨	▨	▨	▨	▨	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	◒	NA	NA	●	◒	●	●	●	◒	●	●	◒	●	◒	◒	●	●	●	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	▨	▨	▨	▨
Disposal	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

Legend

- ▨ Qualitative discussion included in analysis, as relevant.
- NA Data are not applicable.
- ○ Data are not available.
- ◒ Data quality could be improved through more detailed analysis and/or research.
- ● Data quality is good.

12/12/91

Figure 19. Availability and quality of RFG TFCA quantitative data

pure ethanol were required. The fuel cycle actually examines the environmental emissions associated with transporting specific fuels—in this case E10 and E95—neither of which is pure ethanol. Incremental emissions from transporting pure ethanol cannot be added to the emissions of transporting RFG because of the differences in the distribution network for the regional biomass and national RFG scenarios.

Although there were several errors in the formulas provided—generally using parameters for crude or RFG instead of those for E10, E95, or pure ethanol—the basic formulas were not in error. Therefore, the formulas were reconstructed on a spread sheet, and the environmental emissions associated with distributing E10 and E95 were recalculated. The recalculated numbers shown in the authors notes at the beginning of Appendix D were used as input to the ethanol fuel cycle scenarios.

Appendix D characterized ethanol distribution as an average of five sites; it did not characterize each site. Also, the inputs and outputs reported for ethanol distribution were calculated on a net basis, e.g., the incremental emissions from distributing pure ethanol compared to distributing RFG. Distribution and emissions characteristics were recalculated for each site and for each fuel.

In Appendix B, MSW Collection, Transportation, and Separation, the toxic air emissions reported in Table B-15 were for a small facility operating 8 hours per day. Analysts prorated these estimates to reflect a larger facility operating 24 hours per day. The sorting allocation, the treatment of curbside collection and garbage truck movements, and the derived allocation of conversion characteristics (between ethanol and electricity) were not described in Appendix B. However, they were introduced into the TEMIS accounting framework.

In many cases, the information provided in Appendix F, Benchmark Reformulated Gasoline Fuel Cycle, is not allocated between coproducts. The information provided for crude oil production is prorated between crude oil and associated gas. The refinery information is also allocated between gasoline base (RFG without MTBE) and other petroleum products. However, the refinery allocation was not applied to the characterization of crude oil production, transportation, or imports. The allocation was performed on the data in the TEMIS accounting framework.

In Appendix C, Biomass Conversion, the particulate emission levels did not reflect the available pollution control equipment that might be required by 2000 and 2010, only that pollution control equipment required today. Specifically, the engineering design included a baghouse for boiler emissions and a cyclone separator for emissions from the feedstock preparation and handling systems. The emissions reported from the engineering design could be reduced through the use of available technology such as electrostatic precipitators for the boiler emissions, which have an average efficiency of 90%, and a wet scrubber on the feedstock preparation system. If both of these technologies are employed in the conversion facility, particulate emissions could be reduced by as much as 90% compared to the value reported in Appendix C. The values used in the ethanol base cases assumed that additional pollution control equipment is employed and PM emissions are reduced by 90%.

Also, Appendix C does not discuss the allocation of characteristics between ethanol and electricity products. This allocation was applied to the data produced by the TEMIS system.

4.3 Fuel Cycles Inconsistencies

As a result of variations in approaches adopted by each team and gaps in transferring information among teams, some minor variations occur in the accounting of volumes or fuel characteristics among reports for the stages of the fuel cycles.

- The RFG fuel cycle was based on national averages, with some disaggregation to capture regional differences in crude oil and refinery characteristics.

- The biomass feedstock analyses were site specific, accounting for land distribution, transportation networks, and infrastructure. An average of the biomass production scenarios was calculated to compare biomass-ethanol estimates with the national RFG estimates.

- Minor variations (1%) in reported biomass feedstock volumes occurred; the outputs of the feedstock production analyses (MSW and crops) did not exactly match the input volumes at the conversion facility. No significant effects were anticipated from this mismatch.

- The refinery and gasoline distribution analysis assumed that RFG would have an RVP of 9 psi, whereas the end-use stage assumed an RFG with an RVP of 6.7. As a result, the environmental emissions and required input to the refinery stage that would occur to produce low-RVP fuels were not accurately reflected in the fuel cycle. Differences in refinery emissions could be significant.

- During the transformation of TEMIS data into spreadsheets, inconsistencies in the data have been introduced. The most obvious inconsistency can be seen in the end use emissions for E95 fuels, the values for CO, NOx, SOx, PM, etc., should all be equal because E95 fuel is being used to drive one mile in each case (or a billion VMT if Tables C through G are examined). The variation is generally less than 1 percent, but it is clear that no variation should occur. PNL was unable to correct the errors in the time available. Therefore, we have to assume that similar variations occur in the remaining data and we have found several instances of this effect. In general then, the values reported are close approximations of the actual figures that should result from calculations but probably vary 1% to 5% from the true value. NREL has concluded from this exercise that TEMIS and PNL's proceedures should be improved and this inconsistency issue resolved before any it is used for future fuel cycle analysis.

The values provided in the spreadsheets have been checked against the original data in every case. Extensive data verification was enlisted and NREL believes that the data provided in Tables A through M at the end of this report provides an accurate representation of fuel cycle inputs and emissions, given the 1% to 5% variation described above.

5.0 FINDINGS

The TEMIS accounting framework stores, manipulates, and displays the data presented here. Tables A through H, at the end of this report, provide summary data for the eight base cases. The tables summarize all of the inputs and outputs that would occur to produce enough fuel to travel 1 billion VMT. Each ethanol plant produced between 78 and 85 million gallons of E95, enough fuel for 2.21 to 2.41 billion VMT (assuming it is used in light-duty passenger vehicles). One billion VMT is 40 to 45% of the total mileage possible from the fuel produced from each ethanol plant in 2010, 4.5% of the total amount of E10 produced. The standard (1 billion VMT) was created to compare different fuels and different vehicle efficiencies on a common basis of mobility. One billion VMT is only 0.045% of the 2,177 billion passenger vehicle miles projected for 2000, or 0.036% of the 2,814 billion VMT projected by 2010 (NES 1991).

The fuel cycle data reported in Tables A through J have been adjusted by the efficiencies of the vehicles consuming a particular fuel. The reader cannot multiply the gasoline fuel cycle by 0.90 to estimate the portion of the gasoline fuel cycle that is implicit in the E10 fuel cycle. The vehicle efficiencies of each type of fuel must be considered separately and will adjust the inventory estimates on a miles traveled basis.

The eight base cases—two RFG cases and six biomass-ethanol cases—and several sensitivity analyses are described in Section 3. Further details are available in the appendices in Volume II. The base cases include:

- RFG fuel cycles for the years 2000 and 2010
- E10 base case for 2000, transforming sorted MSW into ethanol that is used to produce E10, a blend of 10% ethanol and 90% gasoline
- Five regional biomass-ethanol scenarios in 2010, assuming E95 (95% ethanol and 5% gasoline) is used in dedicated ethanol vehicles.

RFG 2000 and E10 are used in conventional gasoline engines.

The discussion of results focuses on the gaseous, solid, and liquid emissions because environmental implications are the major issues revolving around fuel use today (CAAA 1990, NES 1991). The inventories of all of the activities involved with producing enough fuel to power a car for 1 billion VMT are aggregated into totals for each stage of the fuel cycle and for the fuel cycle as a whole. Secondary emissions, when they are included in the base cases (e.g., for the gasoline fractions of ethanol fuels) or in the sensitivity cases (electricity generation emissions), are reflected in the stages of the fuel cycles where these inputs are consumed (or outputs produced). For example, E10 blending occurs in the distribution stage; denaturing ethanol with gasoline occurs in the ethanol production stage.

5.1 E10 and Reformulated Gasoline Fuel Cycles: 2000

Both E10 and RFG 2000 produce more of some emissions and less of others when compared to each other (Table 4 and Tables A and B at the end of the report). The benefit of one fuel compared to the other needs to be based on which emissions are important. Both fuels consist of roughly 90% gasoline and therefore, emissions levels are similar because the fuel cycle emissions associated with gasoline are reflected in both fuel cycles.

Table 4. 2000: MSW-E10 and RFG fuel cycle emissions (mg/mi unless noted)

Emission	Fuel	End Use	Fuel Distrib.	Fuel Prod.	Feedstock Transport.	Feedstock Prod.	Total
CO	E10 RFG	2,097 2,195	38[a] 4.5	9.6[a] 8.1	0.8 13.6	0.8 7.3	2,145.6 2,229.0
NOx	E10 RFG	399 400	163[a] 8.1	6.4[a] 61.7	2.4 30.8	1.6 45.4	572.0 546.1
PM	E10 RFG	0[b] 0[b]	4.5[a] 0.3	0.5[a] 2.1	0.0 1.5	0.0 0.5	5.0 4.4
SO_2	E10 RFG	40.8 49.9	44.7[a] 0.3	2.6[a] 39.9	0.0 0.9	0.0 2.7	88.2 93.8
CO_2[c]	E10 RFG	262,515 279,690	46,244[a] 1,179	258.0[a] 25,764.5	157.8 4,263.8	236.7 12,973.0	309,411.0 323,870.0
VOC[d]	E10 RFG	380 380	116[a] 43	1.7[a] 8.1	0.0 14.5	0.0 13.6	497.6 459.0
Waste-water ml/mi	E10 RFG	n/a n/a	178[a] 0	61.3[a] 52.1	n/a —	13.7 122.7	253.3 174.8
Solid Waste	E10 RFG	n/a n/a	740.2[a] n/a	5,055.0[a] 635.1	n/a n/a	-27,624.0 90.7	-21,828.8 725.8

[a] Includes gasoline fuel cycle emissions for gasoline added to ethanol in this stage.

[b] Particulate emissions from passenger vehicles not available for E10 or reformulated gasoline.

[c] Fossil CO_2, does not include CO_2 sequestered in biomass or released from fermentation or ethanol combustion.

[d] Biogenic VOC emissions.

Gasoline-related emissions are accounted for in two stages of the E10 fuel cycle: when 5% gasoline is added at the conversion facility to denature the ethanol, and when the balance of the gasoline is blended with E95 to make E10 in the distribution stage. Thus, the distribution stage of the E10 fuel cycle reflects the gasoline-related inputs and outputs and overshadows any transportation emissions associated with distributing E10. When the gasoline fuel cycle emissions are excluded from the E10 fuel cycle (Table J at the end of the report), distribution emissions for E10 are similar to those for RFG.

The E10 fuel cycle produces 4% less CO than RFG, 6% less SO_2, and 4.5% less CO_2 (the organic portions of MSW were assumed to have been sequestered from atmospheric CO_2). E10 also produces 5% more NOx than RFG, 14% more PM, and 8% more VOCs. Although these differences may seem small, substituting E10 for RFG can provide signficant benefits in terms of CO, CO_2, and SO_2 reductions in regional air quality basins.

5.1.1 Carbon monoxide emissions (CO)

Nearly 98% of the CO emissions originate from the tail pipes of light-duty passenger cars for both fuels in 2000 (Figure 20). Both RFG and E10 are oxygenated fuels, and as such, produce lower CO emissions than conventional gasoline. Analysts assumed that vehicle emissions equal 2.2 grams per mile for RFG and 2.1 grams per mile for E10. This assumption was the largest single factor contributing to the end result that E10 produces 4% less CO than RFG.

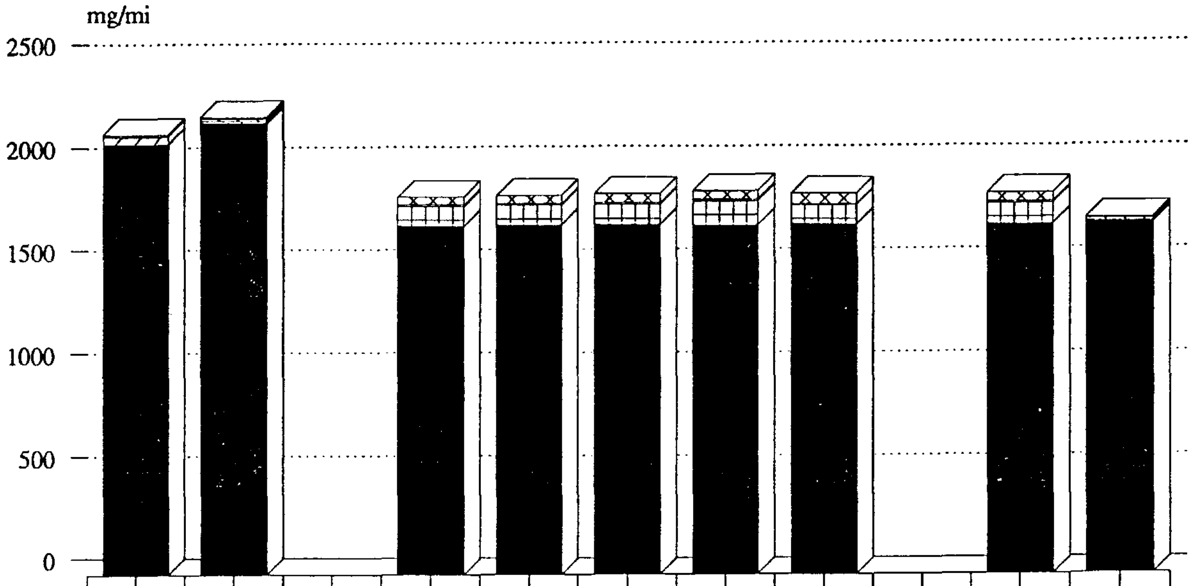
Generally speaking, vehicles using E10 produce 4.5% less CO emissions than conventional gasoline, but NOx emissions increase by 2.9%. The differences between E10 and RFG made with MTBE are expected to be smaller because both fuels contain oxygenates that provide similar benefits. The benefit of CO reduction is slightly higher for E10 because of the higher oxygen content of the fuel, 3.7% versus 2.0; E10 should burn more completely. The effect of increasing the oxygen content of gasoline has a larger impact on CO emissions than on NOx emissions. Thus, a slight benefit is assumed for CO emissions while the difference in NOx end use emissions is assumed to be negligible.

5.1.2 Nitrogen oxide emissions (NOx)

Roughly 70% of the NOx in the year 2000 is produced from the passenger vehicles, the end-use stage (Figure 21). Crude oil production, transportation, and refining contribute 30% of the NOx emissions to the RFG fuel cycle, while E10 distribution seems to produce 28% of the NOx generation in the E10 fuel cycle. However, approximately 90% of the NOx emissions from distribution and production in the E10 fuel cycle are emissions from the crude oil production, transport and refining and the distribution of gasoline; this distorts the true emissions associated with E10 distribution activities. Only 13.6 mg/mi of NOx are produced by vehicles transporting E95 to blending facilities and E10 to retailers. Less than 1% of the NOx emissions produced in the E10 fuel cycle stages, excluding end use, are generated during MSW collection, sorting, and transportation.

5.1.3 Sulfur dioxide emissions (SO_2)

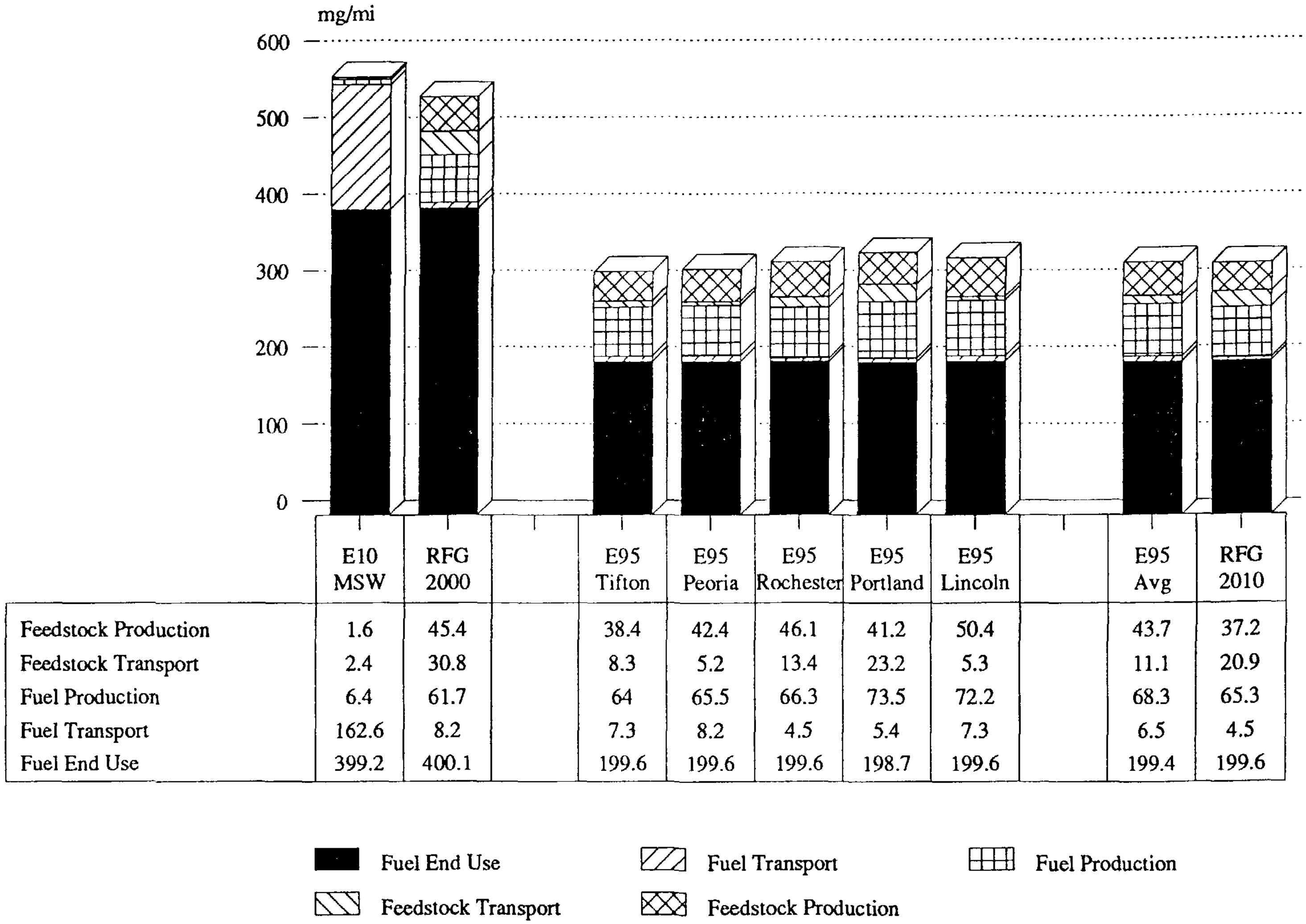
Passenger vehicles (the end use stage) are a major source of SO_2 from both fuel cycles (Figure 22). Gasoline contains sulfur, but pure ethanol does not. Blending 10% ethanol into gasoline reduces SO_2 emissions proportionately. New research shows that reducing the sulfur content of RFG also reduces CO, NOx, nonmethane hydrocarbons, and selected air toxics emissions from passenger vehicles (CRC, 3-92). Regulations that will cause reductions in the sulfur content of #2 diesel fuel were not reflected in this study. However, the impact of the low-sulfur diesel will reduce the fuel cycle estimates of SO_2 emissions in the transportation and distribution stages. The



	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Feedstock Production	0.8	7.3		38.4	42.4	46.1	41.2	50.4		43.7	6.4
Feedstock Transport	0.8	13.6		8.3	5.2	8.2	9	5.3		7.2	9.1
Fuel Production	9.6	8.2		95.2	95.5	97	117.1	92.1		99.4	7.3
Fuel Transport	37.9	4.5		1.8	2.7	1.8	1.8	2.7		2.2	2.7
Fuel End Use	2096.5	2195.4		1693.7	1697.4	1697.4	1693.7	1697.4		1695.9	1700

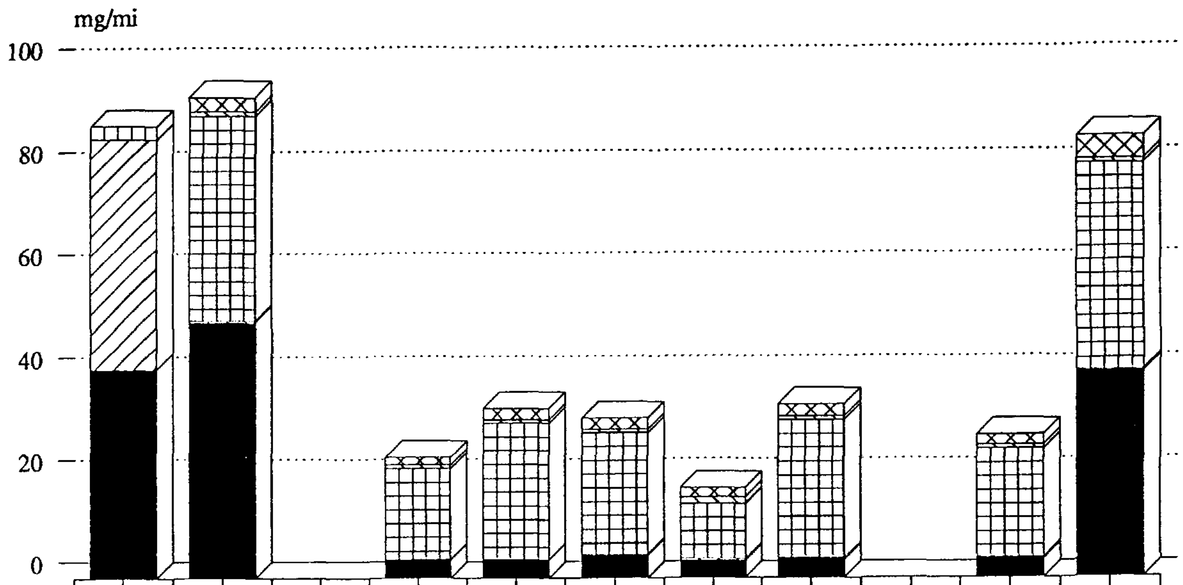
■ Fuel End Use
▨ Fuel Transport
⊞ Fuel Production
▧ Feedstock Transport
⊠ Feedstock Production

Figure 20. Fuel cycle emissions of carbon monoxide, base cases



	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Feedstock Production	1.6	45.4		38.4	42.4	46.1	41.2	50.4		43.7	37.2
Feedstock Transport	2.4	30.8		8.3	5.2	13.4	23.2	5.3		11.1	20.9
Fuel Production	6.4	61.7		64	65.5	66.3	73.5	72.2		68.3	65.3
Fuel Transport	162.6	8.2		7.3	8.2	4.5	5.4	7.3		6.5	4.5
Fuel End Use	399.2	400.1		199.6	199.6	199.6	198.7	199.6		199.4	199.6

Figure 21. Fuel cycle emissions of nitrogen oxides, base cases



	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Feedstock Production	0	2.7		1.5	2.2	2.2	1.9	2.3		2	4.5
Feedstock Transport	0	0.9		0.7	0.7	0.7	1.3	0.8		0.8	0.9
Fuel Production	2.6	39.9		17.8	26.6	23.7	10.7	26.9		21.1	39.9
Fuel Transport	44.8	0.3		0	0	0.2	0.3	0.3		0.2	0.3
Fuel End Use	40.8	49.9		3.6	3.6	4.4	3.4	3.5		3.7	40

■ Fuel End Use ▨ Fuel Transport ⊞ Fuel Production

▧ Feedstock Transport ⊠ Feedstock Production

Figure 22. Fuel cycle emissions of sulfur dioxide, base cases

primary sources of SO_2 in these stages are heavy-duty trucks and trains that use diesel #2 and #6, respectively.

Only 2.6% of the SO_2 emissions from the E10 fuel cycle are produced by ethanol-related activities (Table J at the end of this report). The majority of SO_2 emissions are created by train engines hauling feedstock to the conversion plant and trucks that distribute fuel. Most of the SO_2 emissions reflected in the E10 fuel cycle are emissions associated with the gasoline that is blended with E95 in the distribution stage.

5.1.4 Particulate matter emissions (PM)

Nearly 50% of the PM emissions in the RFG fuel cycle are produced during refining (Figure 23). The remaining emissions are produced by transportation vehicles using diesel fuels. In the E10 fuel cycle, 90% of the PM emissions are attributed to the gasoline fuel cycle emissions associated with the gasoline used in E10. The remaining PM emissions are created by the ethanol production facility (Table J at the end of the report). Not enough data were available to determine the composition of the particulates produced in either fuel cycle or to estimate emissions from passenger vehicles.

5.1.5 Volatile organic compounds (VOC)

E10 fuel cycles create about 8% more VOCs than RFG fuel cycles for two reasons (Figure 24). First, not only must the gasoline travel through its regular distribution system, but there is an additional burden of heavy-duty vehicle emissions caused by moving the E95 to the blender's location. Second, E10 is a more volatile fuel than RFG and the evaporative VOC losses from tank trucks and retail storage will be higher for E10 compared to RFG. There are also the evaporative and fugitive emissions associated with moving the E95 to the blenders and storing it there. Different blends of ethanol, now economically feasible, should be evaluated in the future.

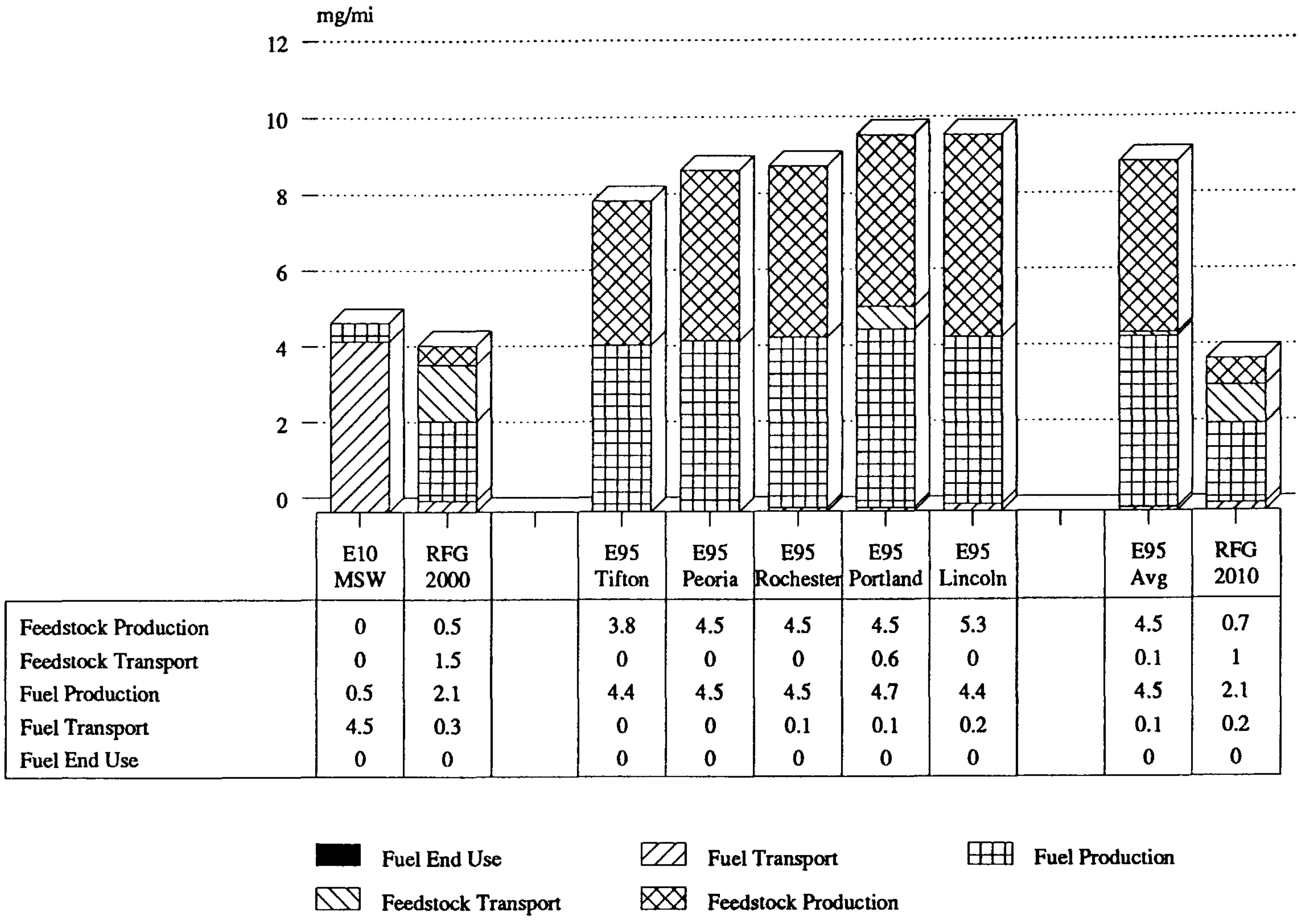
Roughly 80% of the fuel cycle VOC emissions in the year 2000 are created in the end use stage—engine exhaust and evaporation losses. Once again, the analysts assumed the emissions were identical for both fuels since vehicle and fuel manufacturers will attempt to meet CAAA standards. Not enough data were available to provide detailed composition of the VOCs produced in either fuel cycle. Detailed VOC compositions were available for some stages or activities, unavailable for others, and for yet others, only reported as an aggregate sum of VOCs without any detail.

5.1.6 Carbon dioxide emissions (CO_2)

Although 10% of E10 is made from a renewable fuel (lignocellulose), the E10 fuel cycle creates 4.5% less CO_2 emissions than RFG (Figure 25). The lignocellulosic material in the organic fraction of MSW was created by trees and other plants that sequestered CO_2. Trees are used to make paper and lumber, vegetables are grown to make food, grass produces lawn clippings, etc. Because fossil fuel is used to collect and process MSW feedstocks, and transport E95, the E10 fuel cycle emissions are only 4.5% less than those for the RFG fuel cycle, instead of the full 10% fraction of ethanol in the fuel.

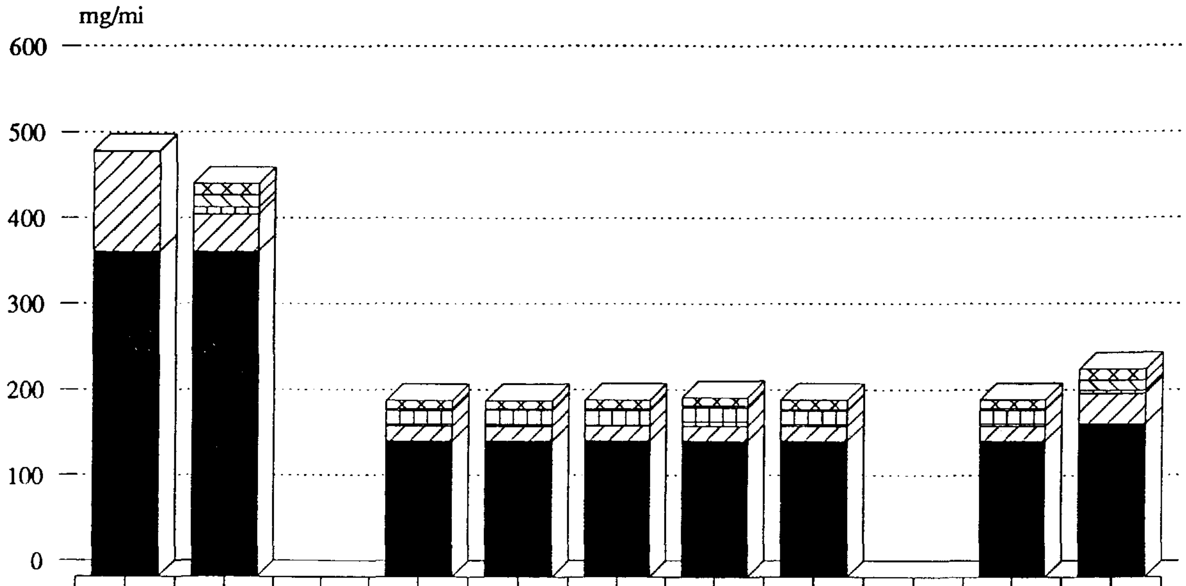
5.1.7 Wastewater emissions

Because the contaminants in the wastewater produced are not strictly comparable (grease, salts, metals, etc.), only the quantities of wastewater can be compared (Figure 26). The Appendices in Volume II provide more detail on the composition of effluent streams. Liquid wastes were only produced in two stages of the fuel cycles—fuel production and crude oil production. Fuel spills were



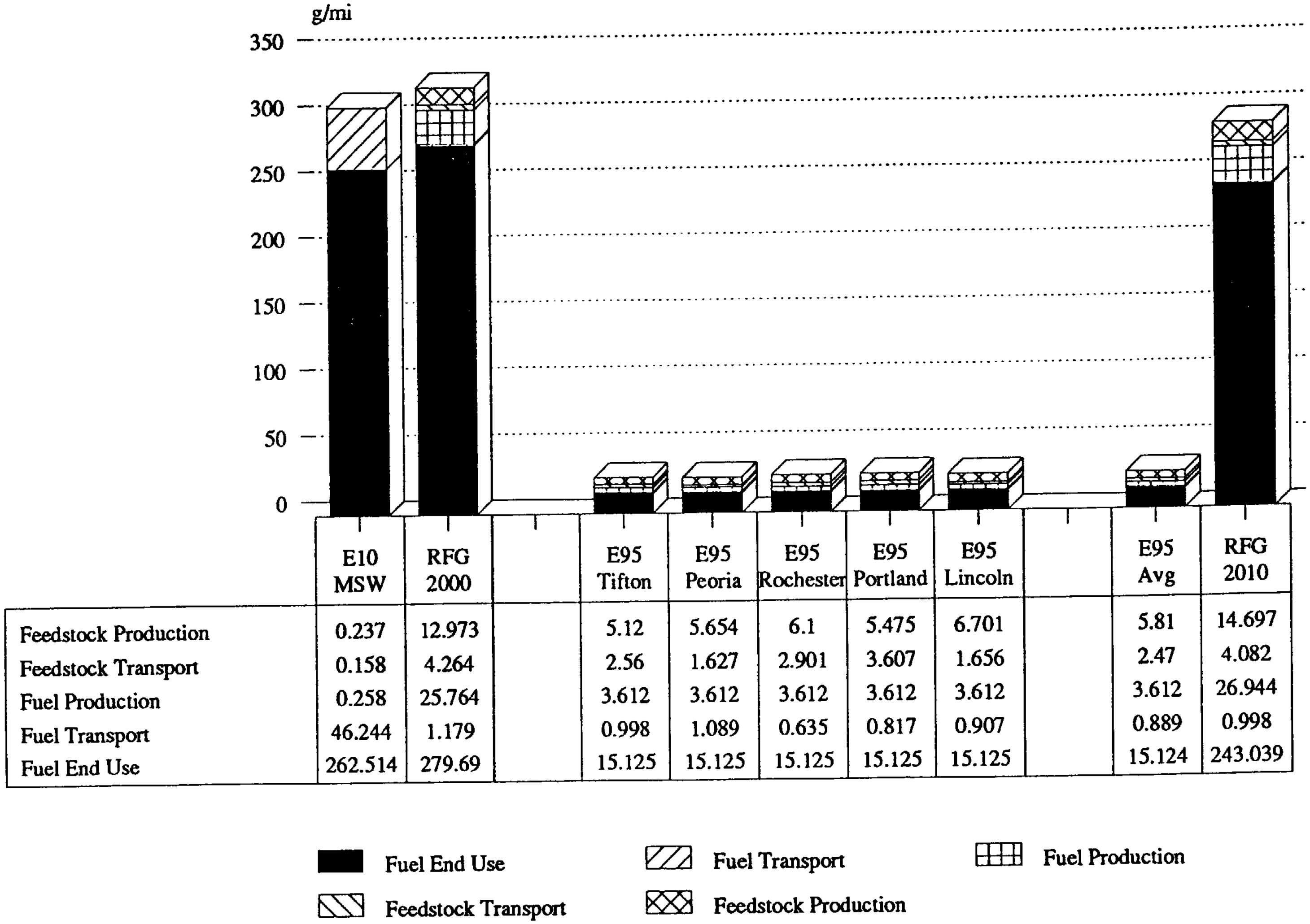
	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Feedstock Production	0	0.5		3.8	4.5	4.5	4.5	5.3		4.5	0.7
Feedstock Transport	0	1.5		0	0	0	0.6	0		0.1	1
Fuel Production	0.5	2.1		4.4	4.5	4.5	4.7	4.4		4.5	2.1
Fuel Transport	4.5	0.3		0	0	0.1	0.1	0.2		0.1	0.2
Fuel End Use	0	0		0	0	0	0	0		0	0

Figure 23. Fuel cycle emissions of particulate matter, base cases



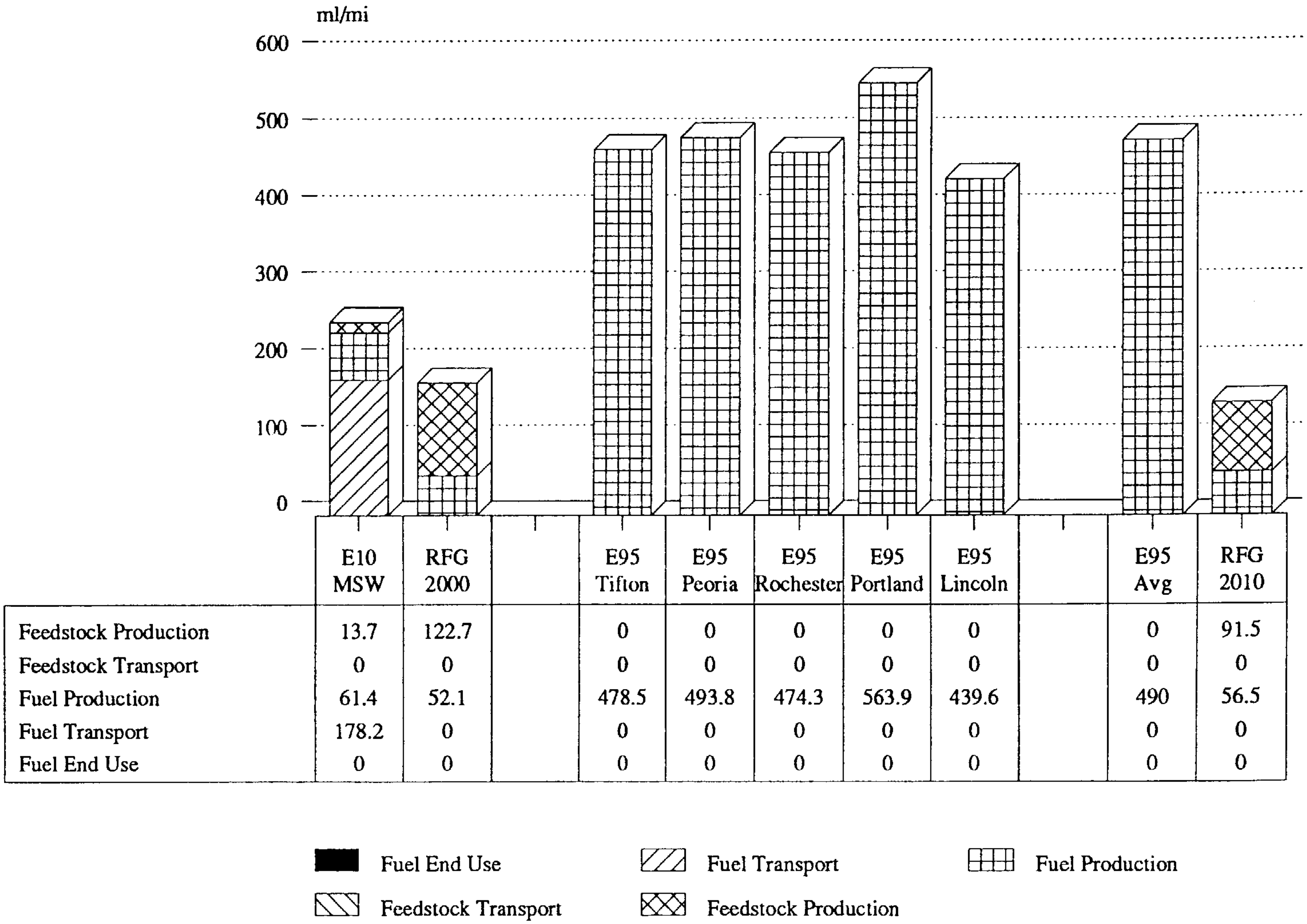
	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Feedstock Production	0	13.6		9.2	9.7	10.4	9.7	11.3		10.1	12.7
Feedstock Transport	0	14.5		2.3	1.5	2.2	2.6	1.5		2	11.8
Fuel Production	1.7	8.1		18	18.6	17.8	21.5	18		18.8	3.6
Fuel Transport	115.7	42.6		17.2	17.2	17.2	17.2	17.2		17.2	35.4
Fuel End Use	380.1	380.1		159.7	159.7	159.7	159.6	159.7		159.7	179.6

Figure 24. Fuel cycle emissions of volatile organic compounds, base cases



	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Feedstock Production	0.237	12.973		5.12	5.654	6.1	5.475	6.701		5.81	14.697
Feedstock Transport	0.158	4.264		2.56	1.627	2.901	3.607	1.656		2.47	4.082
Fuel Production	0.258	25.764		3.612	3.612	3.612	3.612	3.612		3.612	26.944
Fuel Transport	46.244	1.179		0.998	1.089	0.635	0.817	0.907		0.889	0.998
Fuel End Use	262.514	279.69		15.125	15.125	15.125	15.125	15.125		15.124	243.039

Figure 25. Fuel cycle emissions of carbon dioxide, base cases



	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Feedstock Production	13.7	122.7		0	0	0	0	0		0	91.5
Feedstock Transport	0	0		0	0	0	0	0		0	0
Fuel Production	61.4	52.1		478.5	493.8	474.3	563.9	439.6		490	56.5
Fuel Transport	178.2	0		0	0	0	0	0		0	0
Fuel End Use	0	0		0	0	0	0	0		0	0

Figure 26. Fuel cycle emissions of wastewater, base cases

negligible and not included in wastewater estimates.

Most of the process water from ethanol production can be treated by city sanitation plants to produce potable water. The wastewater stream produced by the ethanol production facility is an optimal environment for growing organisms and is perfectly suited to agricultural uses, such as irrigation. Wastewater produced by the MSW sorting facility is treated to standards necessary to dispose of the water in POTWs. Roughly 90% of the wastewater produced in the RFG fuel cycle is reflected in the E10 distribution stage, creating the appearance of substantial water use and disposal in a stage where water is not used.

Almost 70% of the liquid effluent produced in the RFG fuel cycle is formation water—water produced with the crude oil—which contains a wide variety of salts, metals, and radionuclides. Most of the formation water is reinjected into the oil bearing formation or other zones. Water that is used in enhanced oil recovery (EOR) processes and formation water that is reinjected is not considered to be wastewater. If they were, estimated wastewater produced during crude oil production would be approximately 20 times higher than reported. Pollution caused by abandoned wells is not included in this study.

5.1.8 Solid wastes

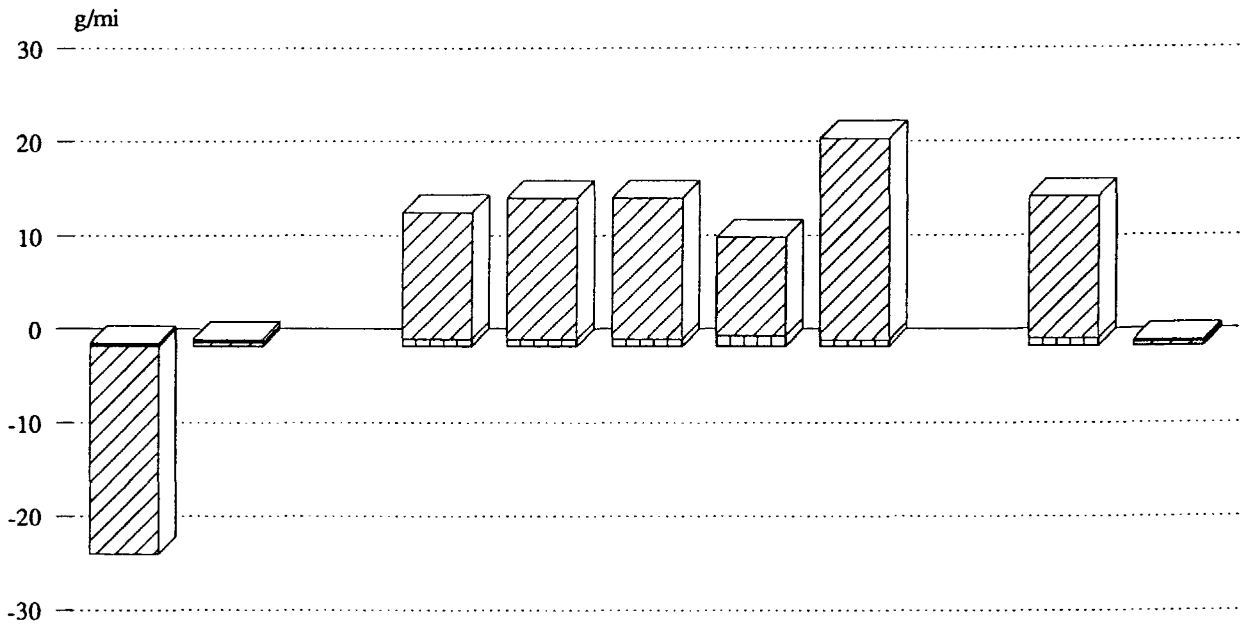
The E10 fuel cycle actually reduces solid wastes that would otherwise be discarded into landfills by turning it into ethanol and ash (Figure 27). Gypsum is produced in the pretreatment stage from neutralizing sulfuric acid used to pretreat the cellulosic material. Approximately 15% of the solid waste produced in the fuel production stage is gypsum; the remainder is ash from the combustion of the nonfermentable portions of the MSW feedstock. The fraction of MSW that is diverted to the ethanol plant reduces the amount of MSW sent to landfills by 71%, creating a potential benefit for local landfills. The entire facility reduced the amount of MSW by 720,000 tons per year, or 21.8 g/mi on a net basis, including solid wastes created during the production of ethanol.

Depending on the amounts of foreign constituents in the biomass ash, most of the solid waste produced in the ethanol fuel cycle should be relatively innocuous. On the other hand, nearly half of the solid waste produced in the RFG fuel cycle is composed of dangerous (hazardous, toxic, carcinogenic, mutagenic, etc.) materials (see Table B at the end of this report). The dangerous wastes in the E10 fuel cycle are those associated with producing the gasoline fraction of E10.

5.2 E95 and RFG Fuel Cycles: 2010

One RFG and five regional E95 fuel cycles were evaluated for 2010. With a few exceptions, there is little difference in emission characteristics from each stage of the five E95 fuel cycles (Table 5 and Tables C through H at the end of the report). Different emission characteristics that occur among the E95 cases are caused by different types of feedstocks and different feedstock transportation characteristics.

CO emissions are 6% to 8% higher for E95 compared with RFG. NOx emissions for E95 range from -4% to +4% of NOx emissions from RFG, and SO_2 emissions are 60% to 80% lower for E95 fuels. Particulate emissions are 100% to 146% higher for E95, and VOC emissions (excluding biogenic emissions) are 13% to 15% less than RFG. E95 produces only 9% of the CO_2 emissions that RFG produces. If soil carbon accumulation is included in the E95 fuel cycles, E95 produces only 4% of the CO_2 produced in the RFG fuel cycle. All of the emissions associated with producing and transporting feedstocks and



	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Dangerous Solids	0.372	0.363		0.022	0.022	0.022	0.022	0.022		0.022	0.272
Benign Solids	-22.2	0.363		13.582	15.13	15.13	10.592	21.489		15.184	0.363
Sludge	0	0		0.753	0.744	0.744	1.095	0.678		0.803	0

▦ Sludge ▨ Benign Solids ■ Dangerous Solids

Figure 27. Fuel cycle emissions of solid wastes, base cases

producing ethanol have been allocated between the two products produced—ethanol and electricity. The base cases only reflect the emissions associated with ethanol production. Similarly, only emissions associated with the RFG fraction of a barrel of crude are shown here.

5.2.1 Carbon monoxide emissions (CO)

As with the fuel cycles examined for the year 2000, 91% of the CO emissions from the E95 fuel cycles and 98% of the CO emissions from the RFG fuel cycle come from passenger vehicles, in the end-use stage (Figure 20, p. 53). Vehicle emissions are 1.7 grams of CO per mile for both fuels. Analysts have assumed that vehicles and fuels will be designed for cars to ensure that the proposed Tier II standards of the CAAA are met. Technologies, such as improved catalytic convertors and other pollutant traps, could benefit both fuels.

E95 fuel cycles produce 6% to 8% more CO than the RFG fuel cycle because of the combustion of solid wastes in the boiler of the ethanol production facility. Refineries were assumed to purchase excess power needs, and the emissions associated with that electricity are not included in the base cases; however, they are included in the electricity sensitivity cases (discussed later). Although biomass combustion is perceived as a mature technology, many technological advances in boiler efficiency are being examined by NREL and others. More efficient biomass boilers could be developed by 2010, which could diminish boiler emissions.

5.2.2 Nitrogen oxides emissions (NOx)

There is no significant difference in the amount of NOx produced by either fuel cycle (Figure 21, p. 54). Surprisingly, the emissions from the average E95 fuel cycle and the RFG fuel cycle for 2010 are roughly the same for each stage. NOx emissions for crude oil transportation are higher than those of biomass transportation because of the longer distances involved.

The passenger vehicles, in the end-use stage, produce about 61% of the NOx emissions in both fuel cycles. Vehicle emissions were 0.2 g/mi NOx for both fuels. Analysts assumed that both fuels and vehicles are designed to meet the proposed Tier II standards of the CAAA.

Fuel production is the second largest NOx source for both fuel cycles, producing 20% of the total emissions. NOx is produced during the combustion of the waste biomass in the ethanol plants' boilers and the combustion of petroleum by-products in the refinery. Analysts assumed that ammonia injection is used to control NOx emissions from the ethanol plant's boiler. The NOx emissions from the boilers are a combination of thermal NOx from the air consumed in the boiler, unreacted ammonia, and the combustion of the protein content in the waste biomass.

The other major NOx source is feedstock production. NOx emissions are produced by farm vehicles using diesel fuel. Farm vehicle use is correlated with biomass yields—lower yields require more land under cultivation and more diesel fuel, and the types of biomass grown—some management and harvesting activities are more energy intensive than others. Because land quality affects biomass yields and the management practices required, it is difficult to draw any conclusions about specific crops having a major influence on the volume of NOx emissions. The variability in NOx emissions for the feedstock transportation stage is due to different modes of transportation (truck, rail, and barge). NOx emissions are higher when rail and barge are used to move feedstocks (Portland, OR, and Rochester, NY, respectively). The other cases relied on truck transportation.

Table 5. 2010: E95 and RFG Fuel Cycle Emissions (mg/mi unless noted)

Emission	Fuel	End Use	Fuel Distrib.	Fuel Prod.	Feedstock Transport.	Feedstock Prod.	Total
CO	E95 RFG	1,695.9 1,700.0	2.2 2.7	99.4[a] 7.3	7.2 9.1	43.7 6.4	1,848.2 1,725.5
NOx	E95 RFG	199.4 199.6	6.5 4.5	68.3[a] 65.3	11.1 20.9	43.7 37.2	329.0 327.5
PM	E95 RFG	0.0[b] 0.0[b]	0.1 0.2	4.5[a] 2.1	0.1 1.0	4.5 0.7	9.2 3.9
SO_2	E95 RFG	3.7 40.0	0.2 0.3	21.1[a] 39.9	0.8 0.9	2.0 4.5	27.8 85.6
CO_2[c]	E95 RFG	15,124.0 243,039.0	889.0 998.0	3,612.0[a] 26,944.0	2,470.0 4,082.0	5,810.0 14,697.0	27,905.0 289,760.0
VOC[d]	E95 RFG	160 180	17.2 35.4	18.8[a] 3.6	2.0 11.8	10.1 12.7	207.8 243.1
VOC[e]	E95 RFG	n/a n/a	n/a n/a	n/a n/a	n/a n/a	1,629.2 n/a	1,629.2 n/a
Waste-water ml/mi	E95 RFG	n/a n/a	— —	490.0[a] 56.5	n/a —	0.0 91.5	490.0 148.0
Solid Wastes	E95 RFG	n/a n/a	n/a n/a	16,009.0[a] 544.3	n/a n/a	0.0 90.7	16,009.0 635.0

[a] Includes gasoline fuel cycle emissions for gasoline added to ethanol in this stage.
[b] Particulate emissions from passenger vehicles not available for E95 or reformulated gasoline.
[c] Fossil CO_2, does not include CO_2 sequestered in biomass or released from fermentation or ethanol combustion.
[d] VOC totals, excluding biogenic emissions.
[e] Biogenic VOC emissions.

5.2.3 Sulfur dioxide emissions (SO_2)

SO_2 is produced from two sources: transportation vehicle emissions (diesel-fueled and passenger) and stationary sources, such as the conversion facility and the refinery (Figure 22, p. 55). Even if the level of sulfur in RFG is reduced from 350 to 50 ppm, reducing emissions in the end-use stage by 86%, total fuel cycle SO_2 emissions from the RFG fuel cycle will still exceed those from E95 fuel cycles.

Pure ethanol does not contain sulfur; however, the denaturant gasoline contains sulfur. Since the denaturant represents only 5% by volume, E95 provides a significant reduction in SO_2 emissions from passenger vehicle exhaust over RFG.

More than 75% of the SO_2 produced in the E95 fuel cycles results from combusting organic wastes at the conversion facility. The proteins in biomass contain sulfur, which is the source of SO_2 emissions from the boiler. Most of the regional variation in SO_2 production in the E95 fuel cycles is the result of differences in the protein content of the feedstocks used. The Portland, OR, conversion facility produces the least SO_2 because wood feedstocks do not contain high levels of protein (100% wood feedstocks at Portland); the Lincoln, NE, plant produces the most SO_2 because grass feedstocks contain relatively high levels of protein (100% grass feedstocks at Lincoln). SO_2 emissions from the conversion facility boilers at other facilities fall between these extremes because feedstocks are composed of both wood and grass biomass.

Air emissions from future ethanol facilities would be controlled by New Source Performance Standards (NSPS). If an ethanol facility is located in an attainment area, the facility design would typically be required to apply best available control technology (BACT) under a prevention of significant deterioration (PSD) new source review. The design of the ethanol production facility used in this study meets current NSPS PSD new source review requirements. Facilities that are proposed in nonattainment areas may have to purchase SO_2 credits for PSD new source review approval.

Sulfur contained in the crude oil is the source of SO_2 emissions from the refinery. Refineries may be required to reduce their SO_2 emissions in the future if CAAA regulations affecting electric utility plants are expanded to include major industrial facilities. Major retooling of refinery operations that would be required to produce RFG may require NSPS review of existing facilities. Therefore, future SO_2 emissions from refineries could be less than those presented in this study.

Feedstock production and transportation activities create SO_2 from diesel fuel used in tractors, trucks, and other equipment. Reducing sulfur content of diesel will affect the total SO_2 emissions from both fuel cycles in direct proportion to the amount of diesel fuel consumed in both fuel cycles.

5.2.4 Particulate matter emissions (PM)

Approximately half of the particulates produced in the E95 fuel cycles are tail pipe emissions from diesel-fueled farm and feedstock transportation vehicles; the other half are emissions from the conversion facility (Figure 23, p. 57). In the RFG fuel cycle, 53% of the particulates are produced from the refinery, followed by another 25% from crude oil transportation (diesel use in tankers, railroads, etc.) and the remainder produced from production and processing equipment at the wellhead. Data on the quantity and composition of particulates from passenger vehicles fueled by E95 or RFG were not available.

The particulate emissions from the conversion facility are divided equally between boiler fly ash emissions and dust from the feedstock handling and preparation activities. The fly ash emissions are a function of the total heating value of the material fed to the boiler. Higher particulate emissions from the Portland plant are the result of the high lignin content of wood and higher levels of waste fed to the boiler.

Particulate emissions from feedstock and fuel transportation are positive but very low. In most cases, these estimates are shown as zero. The exception of the E95 Portland fuel cycle is caused by transporting biomass feedstock by rail, which is responsible for the relatively high levels of particulate emissions in the feedstock transportation stage.

If airborne soil erosion, fertilizers, and pesticides are included in the accounting of particulates, total particulate emissions in the E95 fuel cycles would increase by many thousandfold. Particulate emissions increase to 0.86 g/mi in the Portland E95 fuel cycle; 1.8 g/mi in the Tifton fuel cycle, 4.6 g/mi in the Rochester fuel cycle; 14.8 g/mi in the Peoria fuel cycle; and 39.1 g/mi in the Lincoln fuel cycle. This compares with only 3.9 mg/mi for the RFG fuel cycle. An impact analysis is required to determine if some or all of these airborne farm emissions would have occurred in the absence of a biomass-ethanol industry, and if so, how much of these emissions are the direct result of the biomass-ethanol industry.

5.2.5 Volatile organic compound emissions (VOC)

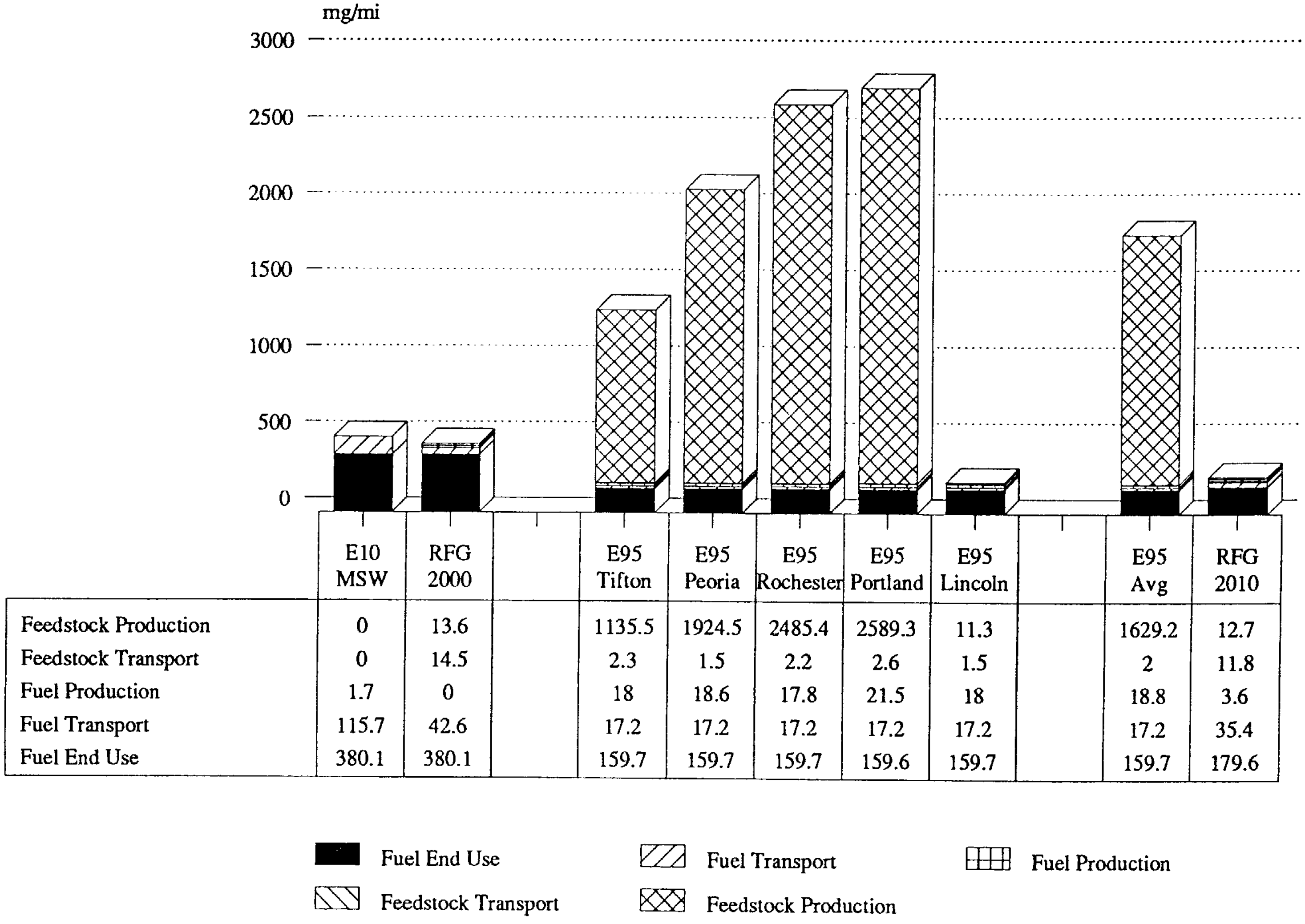
VOC emissions were divided into two source categories: (1) biogenic VOC emissions produced by growing organisms and (2) nonbiogenic VOC emissions produced during the use or combustion of fossil fuels and volatile chemicals. This allows us to compare the quantities of nonbiogenic VOC emissions of the two types of fuel cycles—E95 and RFG. RFG fuel cycles do not produce any biogenic VOC emissions.

Approximately 75% of the nonbiogenic VOC emissions produced from the E95 and RFG fuel cycles are evaporative and exhaust emissions from the passenger vehicles used in the end-use stage (Figure 24, p. 58). Exhaust emissions were assumed to be identical for both fuels (0.09 g/mi). Evaporative engine losses were less for E95 (0.07 grams per mile) compared to RFG (0.09 grams per mile). This difference caused end-use emissions from dedicated passenger vehicles using E95 to be 11% less than emissions from vehicles using RFG.

The remaining VOC emissions are produced from the combustion of diesel fuel in equipment used to produce and transport feedstocks and fuels. VOC emissions from the biomass conversion processes also produce significant amounts of VOCs from the utility boilers.

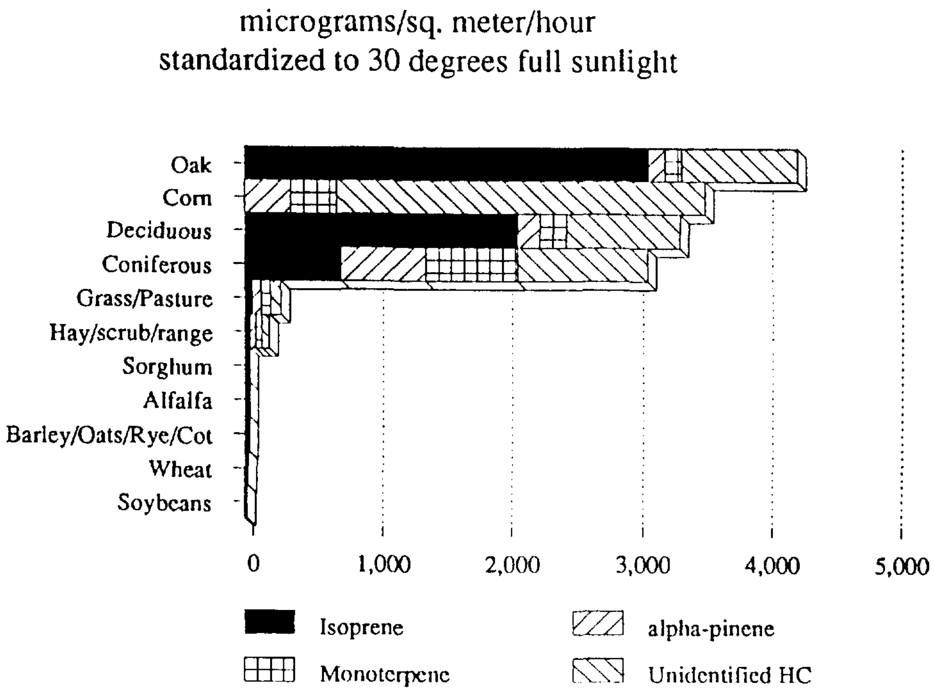
If biogenic VOC emissions are included in the VOC accounting framework, total VOC emissions in the E95 fuel cycles increase 600 to 1600%, depending on the proportion of trees produced in the biomass feedstock mix (Figure 28). Deciduous trees produce nearly 10 times more biogenic VOCs than any other agricultural crop except corn (Figure 29). Analysts assumed that herbaceous biomass crops did not produce biogenic VOC emissions, although it is likely that these emissions will be produced in small quantities.

Not enough information was available to characterize biogenic emissions from herbaceous crops. The thin-stemmed herbaceous biomass crops, such as switchgrass, may produce quantities of biogenic VOCs similar to other grass-type crops, such as wheat, alfalfa, hay, pasture, and small grains. Energy sorghum may produce biogenic emissions similar to grain



	E10 MSW	RFG 2000		E95 Tifton	E95 Peoria	E95 Rochester	E95 Portland	E95 Lincoln		E95 Avg	RFG 2010
Feedstock Production	0	13.6		1135.5	1924.5	2485.4	2589.3	11.3		1629.2	12.7
Feedstock Transport	0	14.5		2.3	1.5	2.2	2.6	1.5		2	11.8
Fuel Production	1.7	0		18	18.6	17.8	21.5	18		18.8	3.6
Fuel Transport	115.7	42.6		17.2	17.2	17.2	17.2	17.2		17.2	35.4
Fuel End Use	380.1	380.1		159.7	159.7	159.7	159.6	159.7		159.7	179.6

Figure 28. Fuel cycle emissions of volatile organic compounds including biogenic emissions, base cases



Source: Pierce et al 1990

Figure 29. Biogenic volatile organic compound emissions, by source

sorghum, although with the growth rate envisioned these emissions may be as high as those from corn crops. The estimates of biogenic VOC emissions for short-rotation woody crops are probably in the range of those for deciduous trees, but exact values for these types of crops are not known with certainty. Corn produces more VOCs than most deciduous trees. The extent that tree crops displace corn and other crops will determine the net changes in localized biogenic VOC emissions. This net analysis should be undertaken in the future.

Not enough data exist to completely define the components of the biogenic and nonbiogenic VOC emissions in sufficient detail to perform ozone impact studies. Each specific VOC compound has a different reactivity and chemical signature in the atmosphere. Some decompose rapidly and others have complex reaction chains. The differences in the composition of VOC emissions will influence the timing, persistence, and impacts of ozone creation in a locality.

5.2.6 Carbon dioxide emissions (CO_2)

E95 fuel cycles produce 30 g/mi of fossil CO_2, on the average; the RFG fuel cycle produces 290 g/mi of CO_2 (Figure 25, p. 59). CO_2 emissions from the E95 fuel cycles are positive because diesel vehicles that burn fossil fuel are used in transportation, farming, and other minor activities, and because 5% of E95 consists of RFG. Thus, a portion of the RFG fuel cycle is added to the E95 fuel cycle, reflecting the fuel cycle emissions associated with the denaturant.

On average, 16 g/mi of CO_2 are sequestered annually as soil carbon over a 30-year period.

At some point, the oxidation of soil carbon becomes equal to the net annual additions to soil carbon, and sequestration ceases. Analysts assumed 30 years would be required for equilibrium to be attained for the soils used to produce biomass. If the soil carbon sequestered each year in the 30-year period is included in the E95 fuel cycle base cases, E95 would produce only 4% of the CO_2 produced by the RFG fuel cycle.

Displacing gasoline with ethanol fuels is a policy option that appears to have a substantial impact on transportation-related CO_2 emissions. More than 90% of the CO_2 emissions associated with RFG can be avoided by replacing gasoline with E95.

5.2.7 Wastewater emissions

The E95 fuel cycles produce 490 ml/mi of wastewater, on average, compared with only 148 ml/mi in the RFG fuel cycle (Figure 26, p. 60). The wastewater produced in the E95 fuel cycle comes from the conversion facility, except for the water that is reflected in the 5% gasoline contained in E95. The wastewater in ethanol plants could be reduced by as much as 60% with more sophisticated water recycling designs.

The process water from ethanol production can be treated by city sanitation plants to produce potable water. The wastewater stream is an optimal environment for growing organisms and as such is perfectly suited to other agricultural uses.

Most of the wastewater produced in the RFG fuel cycle is formation water that is produced during oil production. It commonly contains salts, metal, oil, radionuclides, and other hazardous materials. Most of the formation water is reinjected into the oil reservoir or other geological zones. The formation water reinjected and the process water that is used for EOR is not considered wastewater. If they were, estimated wastewater produced during crude oil production would be approximately 20 times higher than reported. Pollution caused by abandoned wells is not included in this study.

5.2.8 Solid waste emissions

The E95 fuel cycles produce 16 g/mi of solid waste; of this waste, half is gypsum produced from neutralizing sulfuric acid used in the pretreatment process and half is the ash remaining after the organic wastes and nonfermentable residues are combusted (Figure 27, p. 62). If another method of biomass pretreatment could be used that did not require acid prehydrolysis, solid waste production could be cut in half. The solid waste produced by an ethanol plant is not considered hazardous. Currently, biomass ash from combustion boilers is in demand as a landfill amendment to control acidity. It can also be used as a soil amendment.

Approximately half of the 0.6 g/mi of solid waste produced in the RFG fuel cycle is considered dangerous—hazardous, toxic, cancerogenic, etc. (see Table H at the end of this report). Future waste reduction technologies, high-temperature combustion, and other alternatives are being explored that could reduce petroleum industry wastes.

5.3 Sensitivity Studies

These sensitivity studies provide information about the impacts of boundary assumptions and allocation methodologies, and the effects of fuel substitution on total fuel cycle inventories. The sensitivity analyses are described in Section 3.4. Allocation methodologies had significant impacts on the all the fuel cycle results. The inclusion or exclusion of activities relating to feedstock sources (curbside collection of MSW or oil imports) had minor impacts on the E10 fuel cycle results. The substitution of E95 for diesel fuel for vehicles entering or leaving the ethanol plant had negligible impacts on the E95 fuel cycle results. Including secondary electricity emissions had very significant effects on all the fuel cycles.

5.3.1 Impact of including garbage collection and transportation to the transfer facility and the activities that occur at the transfer facility in the MSW base case

Curbside garbage collection and the transportation of the MSW to a transfer station where it is unloaded, compacted, and reloaded into larger vehicles was excluded from the E10 base case (Figure 10, p. 19). These activities were excluded because they would occur, relatively unchanged, whether the MSW was delivered to a landfill or an ethanol facility. Less than a 1% increase in emissions results from including these activities in the base case fuel cycle, except for NOx and SO_2, which increase 2.3%, and 1.9%, respectively.

Only about 10% of the emissions in the MSW base case scenario are directly derived from the ethanol fuel cycle; the rest are emissions from the RFG fuel cycle. If the emissions from the ethanol-related activities are isolated (delete RFG fuel cycle emissions from the E10 fuel cycle [see Table J at the end of this report]), the effect of including the activities that occur before the MSW leaves the transfer station causes a 70% increase in CO and NOx emissions, a 180% increase in CO_2 emissions, and a 20% increase in VOC emissions. If a fuel cycle of E95 from MSW was constructed, excluding emissions from the activities prior to the MSW leaving the transfer station, total emissions would be underestimated.

5.3.2 Impact of excluding inventory characteristics for foreign oil production from RFG fuel cycles for 2000 and 2010

In the base cases, analysts assigned foreign oil imports the same inventory characteristics for the production stage as domestic crude oil. The projected effect of excluding foreign oil emissions (treating them as "free" goods) was to dilute the environmental characteristics of oil production by spreading the domestic oil production emissions over a larger pool of oil delivered to the refineries. Thus, it was no surprise that when the environmental inventories for foreign oil are excluded from the analysis, the emissions for crude oil production fall roughly by half (approximately half of the future oil supply will be imported to meet the demands of domestic refineries).

Environmental emissions (air emissions) from crude oil production are only a fraction of the total fuel cycle emissions, because end use creates the bulk of the emissions (see Table 4, p. 51 and Table 5, p. 64). However, when end-use emissions are disregarded, crude oil production creates 20% to 30% of total emissions. By assuming that imported oil has no emission characteristics, fuel cycle emissions (excluding end use) are reduced by 10% to 15%, compared with the same emissions in the base case.

5.3.3 Impact of assigning 100% of the inventory characteristics from crude oil production, transportation, and refining to the RFG fuel cycles for 2000 and 2010

In the RFG base cases, crude oil production emissions were allocated between natural gas and crude oil (42% and 58%, respectively). In addition, the refinery emissions were allocated between RFG and all other products. In 2000, 35% of the refinery emission characteristics were allocated to RFG. By 2010 this portion fell to 30% because of changes in the quality of crude oils and the mix of products produced. The refinery emission allocation accounts for the fact that only a fraction of a barrel of crude becomes RFG (Figure 15, p. 30).

Using this logic, only a fraction of the crude production and transportation emissions should be allocated to gasoline production; the remainder should be allocated to the production of other petroleum products. Only 20.3% of crude oil production emissions in 2000 were allocated to the RFG fuel cycle (0.58 x 0.35); 17.4% of production emissions were allocated to RFG in 2010. Similarly, only 35% and 30% of the crude oil transportation and refining emissions were represented in the RFG base cases for 2000 and 2010, respectively.

The alternative is to assign 100% of the crude oil production, transportation, and refining emissions to the RFG fuel cycle because gasoline is the driving economic force of the industry, and the coproducts such as associated natural gas and diesel are free goods. Predictably, this causes the refinery emissions to increase by 180% (1/0.35) in 2000 and 233% (1/0.30) in 2010. Similar increases occur for crude oil transportation emissions. Crude oil production emissions increase 400% in 2000 and nearly 500% in 2010 (1/0.203 and 1/0.174, respectively).

CO emissions only increased by 2.9% because end-use emissions dominated total CO emissions. By excluding end-use emissions from the total, CO emissions rose 200% when a 100% allocation system was used.

Total NOx, PM, SOx, CO_2, and VOC emissions, from the 2000 RFG base case, rose 66%, 198%, 95%, 33%, and 21%, respectively. Slightly higher increases were observed for the 2010 scenario. If end-use emissions are excluded, NOx emissions increased 245% over the base case, SOx emissions increased 205%, CO_2 emissions increased 245%, and VOC emissions increased 117%.

If the refinery and crude oil production allocations had not been made, RFG would create two to three times more air pollutants than ethanol fuel cycles, even when ethanol fuel cycle characteristics are not allocated between products (ethanol and electricity) themselves. Only 20% of the feedstock production, transportation, and conversion emissions are assigned to electricity produced from the biomass conversion facility. Thus, ethanol fuel cycle emissions from pre-fuel distribution stages would only increase 25% on the average (1/0.8) if 100% of all the fuel cycle emissions were assigned to the ethanol produced.

This sensitivity analysis shows that different assumptions for allocating emissions among by-products and activities can significantly affect the outcome of the fuel cycle analysis. The conclusions drawn from a fuel cycle analysis are more often a function of the allocation methodology than anything else. The key to evaluating the conclusions and the methodology is the reasonableness of the assumptions and allocation method selected. Although this is an obvious conclusion, it is worth pointing out the differences in outcomes that could occur under different assumptions.

5.3.4 Impact of excluding the RFG fuel cycle inventory characteristics from the E95 and E10 base cases

Table I, at the end of this report, provides the data that are included in the E95 base case scenarios to account for the fuel cycle activities of producing and using RFG as a denaturant in ethanol production. These emissions are added to the stages of ethanol fuel cycles when gasoline is mixed with ethanol. Levels of toxic air, land, and water emissions that are uniquely associated with gasoline fall to zero when the emissions associated with RFG are removed from the fuel cycle. In the future, another denaturant may be found that does not produce toxic emissions.

Obviously, excluding what essentially is 90% of the fuel in the MSW-E10 scenario would be misleading. Table J, at the end of this report, shows the E10 fuel cycle emission that can be attributed to the **ethanol** portion of the fuel.

5.3.5 Impact of adding the secondary emissions associated with electricity consumption/production to the appropriate fuel cycle stages

If one assumes that the by-product electricity sold by the ethanol plant offsets or partially eliminates the need for a utility company to produce electricity, then the avoided emissions can be viewed as emission "credits" for the electricity produced from the ethanol plant. Similarly, when electricity is consumed in a fuel cycle, the emissions associated with producing that electricity should be included in the fuel cycle (debits).

For the eight base cases, NOx, SO_2, CO_2, particulates, and solid waste emissions per kWh were subtracted as credits when electricity was produced and added to the fuel cycle inventories when kWhs were consumed. The allocations between ethanol and electricity had to be removed to account for the emissions and inputs associated with the co-product electricity in the E95 fuel cycles. The incremental changes to the basecases shown in Table 6 includes the emissions associated with producing electricity from the ethanol plant and the debits and credits associated with electricity consumption and production.

The ethanol fuel cycles are regional. Some stages of the RFG fuel cycle have activities in them that are regionally concentrated (like refining and oil production), whereas other stages are national in character (fuel distribution). Utilities also have regional characteristics, depending on local resource endowments and environmental air quality regulations. Therefore, analysts estimated regional electricity generation emissions characteristics for each federal region.

Characteristic electricity generation emissions for a region where an ethanol fuel cycle is located are added to the fuel cycle when electricity is consumed and credited against emissions when it is produced. For crude oil production, transportation, and refining, the activities are apportioned to various regions, depending on where they occur today. Thus, the emission debits and credits for these stages of the fuel cycle were weighted by the proportion of the activity that occurred in each region. Appendix H, Environmental Factors Associated with Electricity Inputs, in Volume II, describes the weighting process and the emission values.

National average emissions are applied to electricity consumption in the RFG fuel cycles for fuel distribution. This may not accurately portray actual emissions if specific electric usage for distribution fuel is examined regionally. However, since national average statistics were used to estimate electricity consumption in fuel distribution, using national average electric generation emissions was appropriate for this study.

E10 and RFG 2000 both show increases in all emissions considered in the electricity sensitivity study because both fuel cycles consume large amounts of electricity. Only 5% of the electricity produced by the ethanol plant is reflected in the E10 fuel cycle because only 10% of E10 is ethanol. The one ethanol plants produces enough ethanol for 20.6 billion miles.

All the emissions considered in the electricity sensitivity analysis of the E95 fuel cycles are reduced because more electricity is produced by the ethanol facility than is consumed in the

Table 6. Electricity Sensitivity Analysis
(Add these emissions to the respective base cases[a])
(mg/mi unless noted)

Emission	Fuel Cycle	Fuel Distribution	Fuel Production	Feedstock Transport	Feedstock Production	Total Change
NO_x	E10	82.0	- 7.5	0.4	3.3	78.1
	RFG 2000	31.8	7.3	11.8	6.4	57.2
	E95	23.6	- 70.9	0.0	0.0	-47.4
	RFG 2010	28.1	4.5	10.0	4.5	47.2
SO_2	E10	99.2	-10.9	1.0	5.1	94.5
	RFG 2000	44.5	7.3	8.2	4.5	64.4
	E95	22.7	-82.8	0.0	0.0	-60.1
	RFG 2010	30.8	5.4	6.4	2.7	45.4
CO_2	E10	28,860	- 2,529	229	1,266	27,825
	RFG 2000	11,430	2,722	4,264	2,177	20,593
	E95	7,584	-28,861	0	0	-21,277
	RFG 2010	10,160	2,449	3,901	1,996	18,507
PM	E10	6.1	-0.9	0	0	5.2
	RFG 2000	2.8	0.5	0.8	0.5	4.6
	E95	1.8	-5.3	0	0	-3.4
	RFG 2010	2.3	0.5	0.7	0.4	3.8
Solid Waste	E10	5,063	192	0	205	5,461
	RFG 2000	1,995	454	635	363	3,447
	E95	1,433	-3,169	0	0	-1,735
	RFG 2010	1,905	363	635	272	3,175

[a] The numbers shown should be added to the values presented in Tables 4 and 5 to calculated TFC emissions for these sensitivity analyses.

entire fuel cycle. In some cases, the electricity production credit offsets more than the total amount of SO_2 and CO_2 produced throughout the entire fuel cycle, including emissions associated with the electricity consumed.

All the emissions examined in the electricity sensitivity analysis of RFG 2010 increase because a large amount of electricity is consumed in refining and fuel distribution and no electricity is produced. Most of the increase occurs in fuel distribution in which a large amount of electricity is consumed to pump gasoline into and out of storage tanks. Total NOx emissions increase 14%, SO_2 and PM emissions double, solid waste emissions increase 500%, and CO_2 emissions increase 6%.

If E95 is substituted for RFG, it will offset all of the RFG fuel cycle CO_2 emissions--308 g/mi-while only creating 7 g/mi of CO_2. This is a savings of 301 g/mi, which could signficantly reduce atmospheric accumulation.

When the results of the electricity sensitivity cases are compared for E95 and RFG, E95 provides a net benefit to society by significantly reducing the amount of air pollutants produced by its fuel cycle compared with RFG. This type of analysis is the primary reason that TFCA is important to policy makers because it provides a mechanism in which the many costs and benefits associated with a fuel can be compared equally. This comparison is limited to an inventory of selected physical inputs and outputs. Economic and social impacts should be included in the future for a complete analysis.

5.3.6 Impact of replacing emission characteristics of diesel with those for E95 used in heavy-duty transportation trucks to evaluate the effect of fuel substitution within the E95 fuel cycles

Because transporting biomass and fuels (E95 and E10) on diesel trucks contributes such a small percentage of the total fuel cycle emissions (generally less than 10%), substituting E95 for diesel in heavy-duty engines was not expected to produce large benefits. The emissions from heavy duty diesel trucks using E95 and #2 diesel (presented in Tables G-5 and G-8 in Volume II, Appendix G, Accounting of Transportation Emissions), are summarized in Table 7. Other information that supports these assumptions and summarizes existing data and tests are presented in Volume II, Appendix E, Ethanol and Reformulated Fuel End Use. From the data presented it appears that if E95 was substituted for #2 diesel fuel in trucks that transport biomass and E95, total PM, SO_2, CO, and NOx would be reduced, whereas VOC emissions would increase considerably. The CO_2 produced is recycled as organic matter; CO_2 emissions should be considered zero in the end-use stage of the heavy-duty truck emission cycles.

Only one E95 scenario was examined. The results confirmed that the benefits of substituting E95 for diesel in heavy-duty trucks used in the fuel cycle were positive; however, the end-use stage emissions from the passenger vehicles still obscured changes in the feedstock and fuel transportation stages.

5.4 Energy Efficiency

There are many different ways to evaluate energy efficiency. This study uses three methods to address the issues of process efficiency, fossil fuel use (depletable resources), and total energy efficiency (Table 8). Throughout the energy analysis, lower heating values are assumed for all the fuels except for biomass. Biomass heating values are estimated on a dry weight basis. The heat rate of 10,400 Btu per kWh for electricity captured the efficiencies of electricity production.

Table 7. Emission Assumptions for High-Speed, Heavy-Duty Trucks for the year 2010, (g/bhp-hr)[a]

	#2 Diesel[b]	E95[c]
Exhaust VOCs[d]	0.5	3.0
Aldehydes	n/a	0.05
Evaporative VOCs	nil	1.0
CO	2.0	1.2
NOx	2.0	1.5
Total PM	0.08	0.04
CO_2	1448	1447
SO_2	0.45	0.002

[a] Grams per brake-horse power hour.
[b] Projections based on emissions data in EPA Report AP-42, future heavy-duty diesel engine standards, and research goals now set by engine industry (SRI 1991).
[c] Year 2010 truck with catalytic converter.
[d] Poly Nuclear Aromatic (PNA) compounds are components of diesel exhaust emissions, but they have not been sufficiently characterized to report on a quantitative basis.

Energy embodied in fertilizer, chemicals, MTBE, and electricity is included. Tables L and M at the end of this report contain more detailed information on the energy balances.

5.4.1 Process Energy Requirements

Process energy includes diesel, electricity, natural gas, chemicals (including fertilizer), and additives used in the fuel cycle of each fuel. The end-use stage is not included in this category since the only operation that occurs in that stage is the combustion of the fuel to provide mobility; it is shown below under *Fuel energy*. Process energy does not include feedstocks (not even the feedstocks consumed to provide process energy in refineries and ethanol production facilities—e.g., shrinkage). Feedstocks are shown seperately.

The E10 fuel cycle consumes 20% less process energy compared to the RFG fuel cycle. The differences is mostly caused by redundant fuel transportation requirements, transporting

Table 8. Total Energy Cycles
Base Cases

	E10	RFG 2000	E95	RFG 2010
Process energy inputs (Btu/mi)				
Feedstock production	16.6	38.6	167.8	34.8
Feedstock transportation	4.4	126.4	31.3	121.5
Fuel production	7.2	546.6	81.0	484.2
Fuel distribution	714.2	226.3	150.7	194.9
Subtotal process energy inputs	742.3	937.9	430.9	835.4
Feedstock energy inputs (Btu/mi)				
Biomass feedstock	372.8	n/a	4,659.6	n/a
Crude oil feedstock	3,632.5	3,540.4	245.4	3,105.8
Subtotal feedstock energy	4,005.3	3,540.0	4,905.0	3,105.8
Fuel energy (Btu/mi)				
End-use fuel energy value	3,546.3	3,594.5	2,751.6	3,107.9
Energy ratios				
Process energy inputs/fuel output	0.21	0.26	0.16	0.27
Total fossil inputs/fuel output	1.23	1.25	0.25	1.27
Total inputs/fuel output	1.34	1.25	1.94	1.27

both the ethanol and the gasoline blended with the ethanol. E95 fuel cycles are more efficient than RFG 2010, consuming fewer Btus of process energy inputs per Btu of output (Figure 30(a)). On the whole, the differences in process energy consumed per Btu of energy output is relatively similar for the three fuels considered; however, some interesting differences among the stages are noteworthy.

Feedstock production is almost three times more energy intensive (Btu of energy consumed per Btu of energy feedstock produced) for both E95 and the ethanol component of E10 than for RFG. This is the result of producing a relatively diffuse, low-Btu fuel. Half of the energy required in feedstock production for E95 is used to fuel farm equipment (diesel) and half is embodied in the production of nitrogen fertilizer. Most of the energy used in biomass production in the E10 fuel cycle is electricity to operate the MSW sorting facility. Because ethanol is only 10% of the fuel, this number is low compared to the energy required to produce and process crude oil. If MSW was the feedstock for an E95 fuel cycle, the energy consumed in the feedstock production stage would be similar to energy crop production (e.g., approximately ten times higher).

The energy consumed in feedstock transportation is four to five times higher for RFG than for ethanol fuels on basis of Btu of energy consumed per Btu of feedstock moved. Nearly 60% of the energy requirements in crude transportation are electricity inputs for pipeline transportation. The remainder is diesel for tanker, barge, rail, and truck transportation. Crude oil is transported longer distances (average 615 miles) compared with biomass (26 to 48 miles), which offsets any benefits of moving a more condensed energy product.

Crude oil refining is more energy intensive per Btu of final product than biomass conversion to E100 (pure ethanol without denaturants) when only the process energy inputs are considered. Neither analysis included shrinkage or combustion of biomass as process energy for fuel production.

Almost 85% of the energy inputs reported in the E10 distribution stage are the energy consumed in the fuel cycle activities for producing RFG, which is blended with E95 in the distribution stage. The remainder is the energy required to transport E95 to the blenders and deliver E10 to local retailers. When the energy required to distribute RFG is combined with the energy required to distribute E95 to the bulk facilities and E10 to retail users, total energy consumed in the E10 distribution stage is 3 times higher than for RFG distribution alone.

The E95 fuel cycles consume less energy in the distribution stage compared with the RFG fuel cycles, because RFG distribution is based on national average transportation distances and E95 distribution is based on regional distribution infrastructure patterns.

5.4.2 Fossil fuel energy

Focusing on fossil fuel inputs provides an insight into the effects of an ethanol fuel industry on our depletable resources. The total impact of consuming fossil fuels is examined by adding the crude feedstocks to the process energy; this includes the crude feedstocks that are transformed into gasoline and added to the ethanol fuel cycles in the conversion and distribution stages. Figure 30(b) provides a breakdown of process energy inputs and outputs by stage with crude oil feedstocks as a separate input.

E10 provides a small benefit compared with RFG in 2000; one Btu of process energy can produce 4.76 Btu of E10 or 3.85 Btu of RFG. In 2010, only 0.25 Btu of fossil energy is required to produce 1 Btu of E95, whereas 1.27 Btu of fossil energy is required to produce 1 Btu of RFG. Clearly, a biomass-ethanol industry could extend our fossil fuel supply over a longer period of time if the ethanol is used as a dedicated fuel to augment or displace future gasoline demand. The energy balance for RFG in 2010 shows some improvement over the ratio of the fuel in 2000, but it still requires more fossil energy input than output produced.

5.4.3 All energy sources

The third method of calculating energy ratios reflects the sum of all of the inputs (fossil and organic) associated with fuel production. Ethanol fuel cycles appear to be less efficient than RFG fuel cycles. One Btu of input produces 0.52 Btu of E95 or 0.79 Btu of RFG 2010. The difference is that over 80 percent of the Btu input for E95 is renewable energy.

In Table 8, only a fraction of total energy inputs are shown in each of the fuel cycles—the portion required to produce, transport, and convert feedstocks into liquid fuel. The allocations discussed in Section 3, and revisited in some of the previous sensitivity analyses, have been applied to the the base case scenarios. The excluded energy inputs are transformed into other products, like diesel, electricity, or asphalt. If the electricity produced from the ethanol plant and the other refinery products are included in the fuel cycle analysis, the feedstocks and other inputs are not allocated among coproducts. Table 9 shows the unallocated energy inputs, energy contained in the by-products, and resulting energy ratios. The energy required to distribute coproducts or byproducts is not included.

Including all of the feedstock inputs and all of the resulting coproducts does not significantly alter the energy balances reported in Table 8. The ratio of inputs to outputs changes very little when the fuel production allocations are removed, because the allocations are based on the ratio of energy in the fuel (ethanol, RFG) to the energy contained in the coproducts. Thus, both the inputs and the outputs increase in similar proportions when the allocations are removed. The slight changes are due to the fact that the allocations are not applied to the distribution stage.

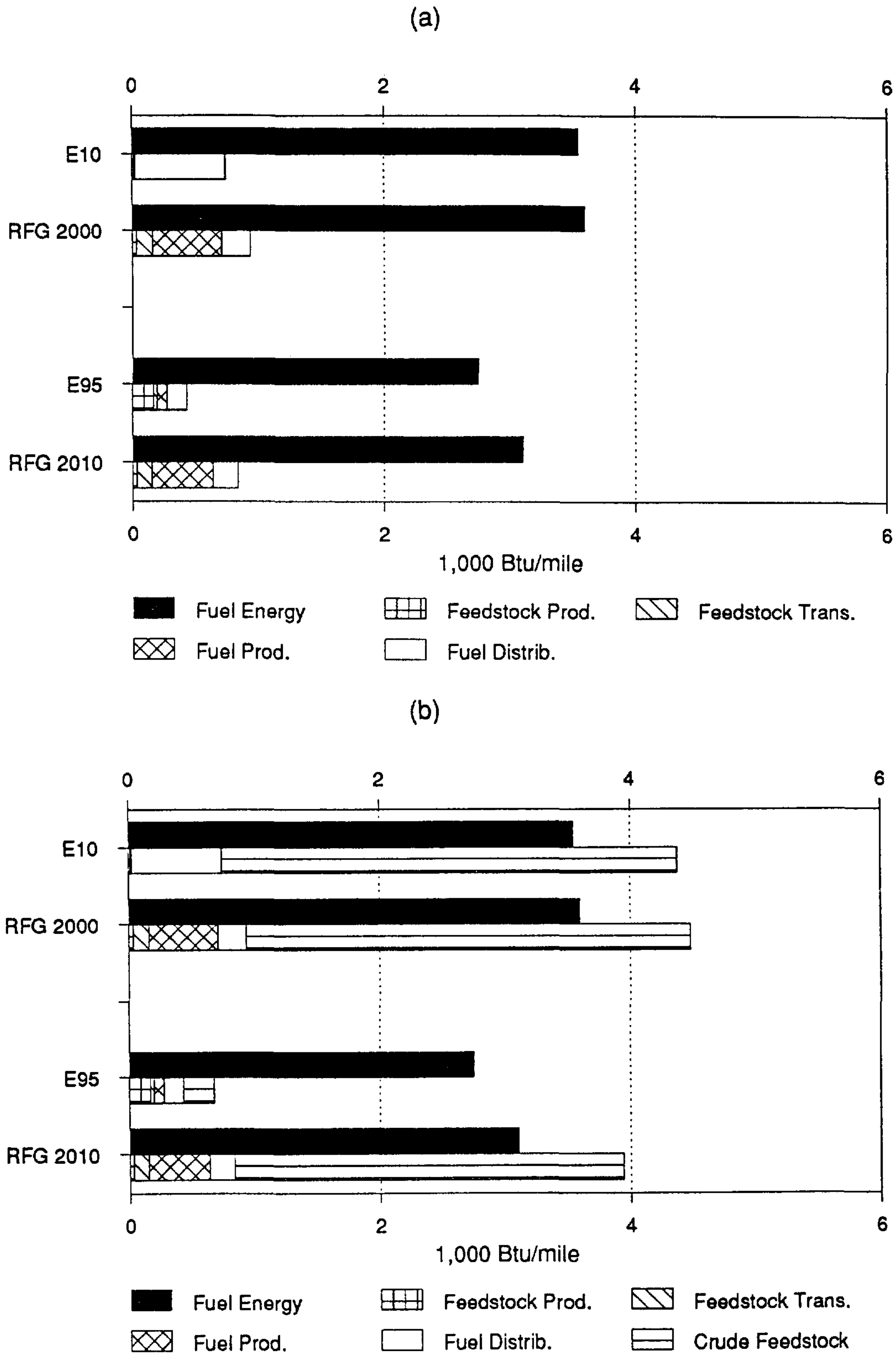


Figure 30. Total energy cycles: (a) process energy, (b) fossil energy

Table 9. Total Energy Cycles
Without Coproduct Allocations

	E95	RFG 2010
Process energy inputs (Btu/mi)		
Feedstock production	204.8	116.1
Feedstock transportation	39.2	405.0
Fuel production	93.3	929.1
Fuel distribution	150.7	194.9
Subtotal process energy inputs	488.1	1,645.2
Feedstock energy inputs (Btu/mi)		
Biomass feedstock	5,811	n/a
Crude oil feedstock	245.4	10,352
Subtotal feedstock energy:	6,056.4	10,352
Fuel and other outputs (Btu/mi)		
End-use fuel energy value	2,751.6	3,107.9
Electricity	655.1	n/a
Other petroleum refinery products	n/a	7,251.7
Subtotal energy value of outputs	3,406.7	10,359.6
Energy ratios		
Process energy inputs/energy outputs	0.14	0.16
Total fossil inputs/energy outputs	0.22	1.16
Total energy inputs/energy outputs	1.92	1.16

6.0 CONCLUSIONS AND DISCUSSION

This study presents data on environmental emissions produced by four fuel cycles: E10, E95, RFG 2000, and RFG 2010 that can be used to support impact studies, cost/benefit studies, and economic analyses. Providing the best possible estimates of the quantities of emissions created by an industry is necessary to conduct credible and useful studies of environmental impacts and their benefits or costs. Without quality data, impact studies are either worthless or misleading. This study focuses on providing quality information for further analysts.

The results of this work, presented in Tables A through M and described in the previous sections, can be used to evaluate limited policy objectives. If decision makers need to reduce a particular emission, such as carbon monoxide, then this report provides information that can be used to evaluate the benefits of substituting gasoline for E10, E95, and RFG. For example, this report indicates that E95 reduces CO_2 emissions, which could reduce or forestall global warming, if substituted for RFG. However, we have only quantified CO_2, and not necessarily included other greenhouse gases such as N_2O (nitrous oxide) and methane. This information contained in this report and the appendices in Volume II are powerful tools, but not the only tools needed to evaluate policy options for transportation.

Each fuel examined in this report has some advantages that the other fuels do not have; e.g, reduces CO, VOC, or other emissions. No one fuel examined can be characterized as better or worse than its alternatives based on the results of this study alone, because benefits of reducing some emissions are offset by increases in other emissions. Future analysis of economic, environmental, and health impacts of the volumes of emissions reported are required to support this type of conclusion.

This study revealed a number of interesting results:

- Vehicle emissions create the bulk of most of the gaseous emissions.
- Increasing our use of E95 is a promising option for reducing CO_2 emissions from the transportation sector because E95 fuel cycles produce 4 to 10% of the CO_2 emissions produced by the RFG fuel cycle.
- When emissions from electricity generation are added to the fuel cycle analysis, E95 fuels produce significantly less NOx, SO_2, particulates, and CO_2 emissions than RFG.
- Ethanol fuels can extend our fossil fuel resources in the transportation sector until a permanent solution is found for our dependency on petroleum, since ethanol fuels use fewer fossil fuel resources in their production than RFG.
- Assumptions concerning technology performance, particularly emission control equipment, environmental regulation, and allocation assumptions, heavily influence the results of this study.

These conclusions are not new; this study reaffirms these conclusions and provides supporting documentation.

Vehicle emissions dominated total fuel cycle gaseous emissions in all the fuel cycles. Improvements in engine performance, catalytic converters, and other vehicle emission controls will benefit both fuels. CAAA standards for vehicle emissions will play a central role in determining the emission characteristics of the fuel cycles because most of the emissions are either vehicle emissions or point-source emissions (fuel production facilities). Because of the lack of data on ethanol fuel emissions, many emission estimates are based on the assumption that fuel and auto manufactures will design systems to meet regulations. Thus, these regulations are critical focal points of the analysis.

E95 fuels are promising options for reducing CO_2 emissions from the transportation sector. Used in sufficient quantitites, fuel substitution policies can be effective policy tools for mitigating global warming because most of the CO_2 produced from the ethanol fuel cycle is recycled each year in new growth of trees and grasses. The positive balance of CO_2 emissions for E95 fuel cycles reflects CO_2 produced by fossil fuel inputs.

There are further benefits of E95 substitution when the electricity from the ethanol facility is considered and soil carbon accumulation is included. Soil carbon accumulation was not accounted for in the base cases because it was treated as a long-term investment, rather than a short-term operational characteristic. During the 30-year period required for soil carbon accumulation to reach an equilibrium, approximately 15.9 g/mi of CO_2 is sequestered in the soil annually. If annual soil carbon accumulation is included in the E95 fuel cycles, E95 produces only 4% of the total CO_2 produced by the RFG fuel cycle. If electricity offsets are included in the analysis, E95 fuel cycles produce only 6.6 g/mi of CO_2.

If E95 vehicles captured 10% of the passenger vehicle market by 2010, U.S. CO_2 emissions could be reduced by 35 million tons per year. This reduction level would require the construction and operation of 122 ethanol plants. In order for these CO_2 benefits to be realized, the production of gasoline would have to fall; U.S. refineries cannot be selling the excess gasoline overseas.

In addition, E95 can reduce the production of SO_2 emissions in the utility sector by 32.3 mg/mi. If E95 is substituted for RFG, the U.S. production of SO_2 will fall 163 mg/mi. Similarly, when E95 is substituted for RFG, NOx, particulates, and solid waste emissions are also reduced. It is clear that E95 fuels provide substantial environmental benefits in emission reductions once the electricity produced from the ethanol facility is factored into the analysis.

This last result further emphasizes the impact of assumptions on fuel cycle estimates. Excluding secondary emissions, such as the emissions from producing electricity, can underestimate the total impact a fuel creates on society. The readers should keep this in mind and recall that the emissions of other inputs, such as fertilizer and MTBE, are not included in this study. Previous work by Deluchi indicates that electricity credits and fertilizer emissions offset each other in biomass-ethanol fuel cycles (Deluchi only examined greenhouse gases). If this remains true, then the base cases shown in this report are the most accurate estimates of emission inventories.

Approximately 80% of the energy inputs used to make E95 are renewable. The fossil fuel energy consumed in the E95 fuel cycle is equal to 25% of the fuel energy produced. Regardless of the end use of E95—as a dedicated fuel or blended with gasoline to produce E10—ethanol fuels can prolong our limited petroleum resources and reduce dependence on imported oil.

Each year the world's consumption of petroleum increases and the exhaustable reserves shrink. Someday, in our lifetime, we could see the effects of rationed supplies of petroleum. Therefore, the fact that ethanol made from crops and trees does not require large amounts of fossil fuels to produce, and is made from a renewable resource will become a large benefit in the future. A renewable resource is not limitless; our future production of ethanol will be limited by land use policies. However, this country will be able to produce a constant amount of fuel, whether it is 10% or 50% of the gasoline demand, year after year after year. The availability of a fuel that can be substitutued for gasoline could be very important for our future generations.

The issues at stake often become obscured by more immediate concerns, clean air, more fuel efficient vehicles, testing and demonstration of new technologies, and current economic conditions. Information is needed to address all these concerns, and provide a basis for tradeoffs. The TFCA methodology has proven to be a useful analytical tool for the DOE to the extent that it can be used to develop detailed estimates of emission inventories. This information can be used to rank future technologies or fuels in a consistent manner based on specific emission criteria.

In addition, the TFCA demonstrated that useful information can be collected and organized in a manner that provides insights concerning both the development of new technologies and their environmental implications. The process in which scientists and engineers were asked to develop their best estimate of one specific combination of technologies needed to produce ethanol from biomass, and estimate the required inputs and wastes produced, led to many questions concerning the technologies selected and several improvements in the overall design. Several new lines of research were developed as a result of this work.

This study describes only one unique combination of technologies used to produce ethanol from biomass. Many others are possible. Because the biomass-ethanol technology has been examined in minute detail, changes to the process can be integrated into the data base developed for this project, and the impacts of new technologies or engineering designs can be examined in the future.

Readers who would like to examine the fuel cycle inventories for E10, E95, RFG, or other combinations of ethanol and gasoline can use the basic framework and detailed information provided in this document and Volume II, The Appendices, to create their own fuel cycle inventories.

We believe that the TFCA methodology has been a useful tool for the DOE and will provide the type of environmental information needed to assess future technologies and energy fuels.

7.0 RECOMMENDATIONS FOR THE FUTURE

This study is a starting point for future analyses that could take many directions. Only a limited portion of a total fuel cycle analysis was examined; pre- and post-operational phases need to be defined and included. Different fuel mixes could be examined. The lifecycle emissions of materials used to produce fuels could be included. Social, environmental, and economic impacts need to be estimated in a way that will assist political leaders in making well informed decisions. Comparisons between the total net value of alternative fuels can hopefully provide answers to policy questions. However, much remains to be done. Future research should continue to expand our understanding of how renewable energy technologies impact society.

Future fuel cycle analyses would benefit from characterizing future environmental control technology and regulations. We based emissions on published data that in turn are based on the efficiency of existing pollution control equipment. These figures overestimate emissions because future environmental regulation and pollution control equipment will probably reduce emissions.

Technological systems can be designed to meet environmental standards. The environmental standards projected for the future will influence the design of the renewable energy technologies and their impact on the environment. Thus, a well-defined set of potential regulations and standards for air emissions, water quality, and waste disposal will be required for future fuel cycle analysis to ensure consistency among the studies. These regulations and standards should be provided to the scientists and researchers directly involved in technology design so the technology meets the challenge of the future.

In the process of estimating inventory characteristics and evaluating the fuel cycle results, potential research areas needing more attention were discovered. For example, once the results of the E95 fuel cycles were compiled and reviewed, it became clear that the ethanol conversion facility used 12 times more nitrogen fertilizer than the amount used in biomass farming.

The research staff reexamined nitrogen fertilizer (ammonia and urea) needs in the ethanol facility. Ammonia is used for three major purposes: (1) pH control of xylose fermentation, (2) nitrogen source (fertilizer) for microorganisms, and (3) NOx control of boiler emissions. The largest portion of the total ammonia used is for pH control (80 to 95%). The amount of ammonia required for pH control is a function of the quantity of organic acids produced by the xylose fermenting organisms (*E. coli*). The organic acid production assumed for this study was high, based on existing organisms available to NREL. Future research could produce highly specific organisms that minimize acidic levels. The research design was reevaluated, and analysts assumed that existing strains of organisms that did not produce acidic effluent would be cultivated and utilized. A research program is under way in this area today.

Similar revelations occurred with respect to water recycling in conversion facility. Our initial facility design did not use existing technology that could reduce water demand and effluent through more efficient recycling systems. Solid waste produced from the ethanol facility could be cut in half if a pretreatment step was developed that does not use acids during pretreatment or that increases the efficiency of recycling acids. Land used for biomass production could have been modeled differently. The existing system assumes that the land is dispersed in the area around the ethanol plant. A more realistic version may have been an assumption that a trade-off between lower transportation costs and higher profits would encourage farmers in the immediate vicinity of the plant to produce biomass, concentrating biomass directly around the ethanol plant. The activity of performing a fuel cycle analysis of such detail improved the technical understanding of processes and systems involved in fuel production.

A better characterization of the refinery stage of the reformulated gasoline fuel cycle is needed. By improving the environmental model of refinery activities, estimates of diesel fuel cycles, and a better inventory of the environmental characteristics of reformulated gasoline production can be produced.

Diesel characterization also is needed because diesel consumption is a major source of air emissions in both fuel cycles and should be characterized the same way as electricity or the gasoline inputs to the fuel cycles. The characterization of fuel cycle emissions associated with the production and use of other inputs (fertilizer, MTBE, etc.) into the fuel cycle should also be considered.

The bulk of the future research should focus on the environmental and economic questions that will arise from this work. The regional implications of the fuel cycle inventories and the relative changes that would occur if ethanol fuels displaced gasoline fuels have far-reaching policy impacts. This study does not go far enough to address these questions directly from the inventories produced.

The logical extension of this study is to apply the data to baseline environmental concentrations, determine the changes, and estimate how these changes will affect human and environmental systems. The costs and benefits of those changes need to be valued to provide a conclusion about the benefit of a particular fuel.

8.0 AUTHORS AND TECHNICAL REVIEWERS

Volume I: Fuel Cycle Evaluations of Biomass-Ethanol and Reformulated Gasoline

K. Shaine Tyson	Author	National Renewable Energy Laboratory
Martin Andreas	Reviewer	Senior Vice President and Assistant to CEO Archer Daniels Midland Company
Mike Bacca	Reviewer	Simpson Timber Company
Andrew Baker	Reviewer	USDA Forest Service, Forest Products Laboratory
Mitch Beaver	Reviewer	Illinois Department of Energy & Natural Resources
Mike Bryan	Reviewer	Ethanol/Sweetener Manager, National Corn Growers Association
Dwayne Buxton	Reviewer	Field Crops Research Unit, USDA ARS
A. Barry Carr	Reviewer	Specialist in Agricultural Policy, Congressional Research Service, Library of Congress
Roger Conway	Reviewer	U.S. Department of Agriculture, Energy Office
Michael Czeskleba	Reviewer	Senior Business Analyst, Ashland Petroleum Company
Brian Davis	Reviewer	Sun Co. & Brand Marketing
Bob Dinneen	Reviewer	Legislative Director, Renewable Fuels Association
Norman Dudey	Reviewer	Vice President, Quadrex Corporation
Mark Dungan	Reviewer	U.S. Department of Agriculture
Douglas Durante	Reviewer	Washington Representative, Clean Fuels Development Coalition
Richard Gadomski	Reviewer	Chairman and CEO, The PSI Group of Companies
Earle Gavett	Reviewer	Consultant
Karel Grohmanm	Reviewer	U.S. Department of Agriculture, ARS-SAA
David Hallberg	Reviewer	Executive Vice President, Revolution Fuels of America, Inc.
Robert Harris	Reviewer	Director of Nebraska Energy Office
Bruce Heine	Reviewer	New Energy Company of Indiana
Ben Henneke	Reviewer	EnvironFuels
Howard Hinton	Reviewer	Midwest Grain Products
William Holmberg	Reviewer	Terra Plex
Jack Huggins	Reviewer	President and CEO, Pekin Energy Company
Evan Hughes	Reviewer	Electric Power Research Institute
Thomas Jeffries	Reviewer	Supervisory Microbiologist, USDA-FS, Forest Products Laboratory
Bruce Jordan	Reviewer	EnvironFuels
Raphael Katzen	Reviewer	President, Raphael Katzen Associates Intn'l, Inc.
Don Klass	Reviewer	EnTech International, Inc.
Jeffrey Knight	Reviewer	Transportation Director, State of Wisconsin
Michael Ladisch	Reviewer	LORRE, Purdue University
Pat Layton	Reviewer	Scott Worldwide, Inc.
Hyunok Lee	Reviewer	U.S. Department of Agriculture
Annette Liebe	Reviewer	Environmental Defense Fund

Robert Yuhnke	Reviewer	National Transportation Program Manager, Environmental Defense Fund
John McClelland	Reviewer	U.S. Department of Agriculture
Frederick Potter	Reviewer	President, Information Resources, Inc.
Steve Rosen	Reviewer	Refined Planning, Clark Oil Refining Corporation
Lawrence Russo	Reviewer	Project Development Manager, New Energy Company of Indiana
Subir Sarkar	Reviewer	Technical Director, South Point Ethanol
Victor Shaio	Reviewer	Chairman and President, New Energy Company of Indiana
Kenneth E. Skog	Reviewer	USDA Forest Service Products Laboratory
Hal Smedley	Reviewer	Colorado Corn Admin. Committee
Wayne Smith	Reviewer	Director, Center for Biomass Energy Systems, University of Florida
Todd Sneller	Reviewer	Administrator, Nebraska Gasohol Committee
Eric Vaughn	Reviewer	President, Renewable Fuels Association
Robert Walker	Reviewer	Amoco Corporation, Alternative Feedstock Development
James Whitehead	Reviewer	Badger Engineers, Inc.
Michael Graboski	Reviewer	Colorado School of Mines, Director, Colorado Institute for Fuels and High Altitudes Engineering Research
Bob Reynolds	Reviewer	President, Downstream Alternatives
Lou Shrier	Reviewer	Cambridge Energy Research Associates
John Boatwright	Reviewer	Company Economist, Exxon Company, USA
James McKenzie	Reviewer	World Resources Institute
Ken Riley	Reviewer	VP of Business Management, ARCO Products Company
David Doniger	Reviewer	Natural Resources Defense Council
David Fry	Reviewer	Tosco Refining Company
Terry Higgins	Reviewer	National Petroleum Refiners Association
Gary Jones	Reviewer	Senior Vice President, Marketing, Total Petroleum, Inc.
Ronald L. Jones	Reviewer	Refinery Director, American Petroleum Institute
Jay Juby	Reviewer	Manager of Quality Control, Williams Pipeline Company
W. L. Leffler	Reviewer	Shell Oil Company
Jerry Levine	Reviewer	Amoco Oil Company
R. M. Moore	Reviewer	Assistant to the President, Chevron Research Company
Bob Pahl	Reviewer	Phillips Petroleum
William Piel	Reviewer	Mgr. of Business Development, ARCO Chemical Company
Larry Williams	Reviewer	President and CEO, National Cooperative Refinery Association
Michael Adler	Reviewer	Environmental Protection Agency
Mark Deluchi	Reviewer	Institute of Transportation Studies, University of California-Davis
Gordon Mac Donald	Reviewer	Vice President and Chief Scientist, MITRE Corporation
Dick Hurn (RFA)	Reviewer	RH Technical Services
Thomas Ryan	Reviewer	Southwest Research Institute
Bill Becker	Reviewer	Executive Director, State & Territorial Air Pollution Program Administrators
Jerry Gallagher	Reviewer	Colorado Department of Health

David E. Gushee	Reviewer	Senior Specialist in Environmental Policy, Congressional Research Service, Library of Congress
Charles Gray	Reviewer	Director of Regulatory Program and Technology, Environmental Protection Agency
Richard Rykowski	Reviewer	Sr. Project Manager, US Environmental Protection Agency
Jerry Sinor	Reviewer	Editor, J.E. Sinor Consultants, Inc.
Dan Sperling	Reviewer	Transportation Research Group, University of California Davis
Dick Stern	Reviewer	Environmental Protection Agency
Dexter Sutterfield	Reviewer	Director of Fuels Research Department, National Institute for Petroleum Research
Dennis Tirpak	Reviewer	Director, Office of Policy Analysis, U.S. Environmental Protection Agency
Catherine R. Zoi	Reviewer	Senior Environmental Scientist, Office of Air and Radiation, Environmental Protection Agency
Henry Kelley	Reviewer	Office of Technology Assessment
Ben Massell	Reviewer	U.S. Department of Energy
Barry McNutt	Reviewer	U.S. Department of Energy

Volume II: Fuel Cycle Evaluations of Biomass-Ethanol and Reformulated Gasoline, Appendices

K. Shaine Tyson	Editor	National Renewable Energy Laboratory

Appendix A: Energy Crop Production, Storage and Transportation

Robert Perlack	Author	Oak Ridge National Laboratory
Jack Ranney	Author	Oak Ridge National Laboratory
Lynn Wright	Author	Oak Ridge National Laboratory

John McClelland	Technical Reviewer	USDA Office of Energy
Jim Cook	Technical Reviewer	Audubon Society
Robert Williams	Technical Reviewer	Princeton University
Steve Hubbell	Technical Reviewer	Princeton University
Shaine Tyson	Technical Reviewer	National Renewable Energy Laboratory
Janet Joseph	Technical Reviewer	New York Energy Research and Development Authority
Jane Turnbull	Technical Reviewer	Pacific Gas and Electric
Jeff Lee	Technical Reviewer	EPA Global Land Use/Productivity Project
Ken Andrasko	Technical Reviewer	EPA Office of Policy
Anthony Turhollow	Technical Reviewer	Oak Ridge National Laboratory
Gregg Marland	Technical Reviewer	Oak Ridge National Laboratory
Kathleen Dripchak	Technical Reviewer	JAYCOR
Dave Ostlie	Technical Reviewer	Energy Performance Systems
Bruce Gold	Technical Reviewer	Tennessee Valley Authority, R&D Division

Tom Strand	Technical Reviewer	Energy Foundation

Appendix B: MSW Collection, Transportation, and Separation

Meridian Corp.	Author	
Don Walter	Technical Reviewer	DOE/CE Director, Waste Material Management Division
Charlotte Frola	Technical Reviewer	Project Officer, Solid Waste Association of North America
Barbara Goodman	Technical Reviewer	National Renewable Energy Laboratory, Program Manager, Waste Management

Appendix C: Biomass Conversion

Cindy Riley	Author	National Renewable Energy Laboratory
Dan Schell	Author	National Renewable Energy Laboratory
Ed Hertzel	Technical Reviewer	Proctor and Gamble
Bruce Jordan	Technical Reviewer	Corn-ethanol Industry Consultant
Ed Dahlgren	Technical Reviewer	Forest Products Consultant

Appendix D: Ethanol Fuel Transportation and Distribution
and
Appendix E: Benchmark Reformulated Gasoline Fuel Cycle

E. A. Mueller	Author	
Ronald Jones	Technical Reviewer	American Petroleum Institute, Director of Refinery and Environmental Research
Dexter Sutterfield	Technical Reviewer	National Institute for Petroleum Energy Research, Director of Fuels Research Department

Appendix E: Ethanol and Reformulated Fuel End Use

J. Sinor Associates	Author	
Brent Bailey	Author	National Renewable Energy Laboratory
Daniel Sperling	Technical Reviewer	University of California Davis
Jeff Alson	Technical Reviewer	EPA, Ann Arbor, MI
Tim Belian	Techncial Reviewer	Coordinating Research Council
David Lax	Technical Reviewer	American Petroleum Institute
Lisa Snapp	Techncial Reviewer	EPA, Ann Arbor, MI
Richard Windsor	Technical Reviewer	Detroit Diesel Corporation

Appendix G: Accounting of Transportation Emissions

Ken K. Humphreys	Author	Pacific Northwest Laboratory
Brent Bailey	Author	National Renewable Energy Laboratory
E.A. Mueller	Author	

Appendix H: Environmental Factors Associated with Electricity Inputs

Marylynn Placet	Author	Pacific Northwest Laboratory
Ken K. Humphreys	Author	Pacific Northwest Laboratory

Appendix I: Assumptions and Calculations for Energy Ratios

K. Shaine Tyson	Author	National Renewable Energy Laboratory
Cynthia J. Riley	Author	National Renewable Energy Laboratory

9.0 REFERENCES

Clean Air Act Amendments of 1990. 42 United States Code, Title II, Sections 201 - 235.

Coordinating Research Council, February 1992. Effects of Fuel Sulfur on Mass Exhaust Emissions, Air Toxics, and Reactivity. Technical Bulletin No. 8. Auto/Oil Air Quality Improvement Research Program.

DeLuchi, Mark A. November 1991. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity. Volume I. Main Text and Volume II. Appendices. Center for Transportation Research, Agronne National Laboratory. ANL/ESD/TM-22, Vol. I and II.

Environmental Protection Agency. September 1985. Compilation of Air Pollutant Emission Factors. Volume I. Stationary Point and the Areas Sources. (AP-42). Fourth Edition. Research Triangle Park.

Ho, S.P. 1989. "Global Warming Impact of Ethanol Versus Gasoline," presented at Clean Air Issues and America's Motor Fuel Buiness. Washington D.C., October 3-5, 1989.

Ho, S.P. and Renner, T.A. 1990 "Global Warming Impact of Gasoline versus Alternative Transportation Fuels," SAE Technical Paper Series, no. 901489.

Humphreys, Kenneth. May 1992. CE Total Energy Cycle Analysis: A Background Paper. Draft. Batelle Pacific Northwest Laboratory.

Koomey, J. April 1990. Comparative Analysis of Monetary Estimates of External Environmental Costs Associated with Combustion of Fossil Fuels. Lawrence Berkeley Laboratory.

Pierce, Thomas E; Lamb, Brain K. and Allan R. Van Meter. June 1990. "Development of a Biogenic Emissions Inventory System for Regional Scale Air Pollution Models." presented at the 83rd Annual Air and Waste Management Association Meeting and Exhibition. June 24-29, 1990. 90-94.3

U.S. Department of Energy. February 1991. National Energy Strategy. U.S. Government Printing Office, DOE/S-0082P.

U.S. Department of Energy. February 1991. National Energy Strategy: Technical Annex 2. Integrated Analysis Supporting the National Energy Strategy: Methodology, Assumptions, and Results. (NES2) U.S. Government Printing Office, DOE/S-0082P.

U.S. Department of Energy. 1988. Annual Energy Review. U.S. Government Printing Office.

Table A. Fuel Cycle Inventory: E10

Inputs or Outputs	Units	End-Use	E10/ E95 Dist.	E95 Prodtn.	MSW Trans	MSW Sort	MSW Collctn	Grand Total
Inputs								
Crude oil	bbls	0	681360	4008	0	0	0	685368
Diesel	gallons	0	94120	4386	16530	6090	18270	139396
Diesel (No. 6)	gallons	0	442680	2268	0	0	0	444948
Ethanol-10	gallons	33100000	0	0	0	0	0	33100000
Ethanol-95	gallons	0	3484210	0	0	0	0	3484210
Gasoline	gallons	0	29615790	174210	0	0	0	29790000
Insecticides	tons	0	0	0	0	0	0	0
MTBE	gallons	0	0	21678	0	0	0	21678
Natural gas	mmscf	0	163.2	0.96	0	0	0	164.16
Refinery Products	gallons	0	0	0	0	0	0	0
Water	gallons	0	143820	30829296	0	0	0	30973116
Electricity	kWh	0	45962400	-3406200	214890	1295430	0	44066520
Herbicides	tons	0	0	0	0	0	0	0
K2O-Fertilizer	tons	0	0	0	0	0	0	0
N-Fertilizer	tons	0	0	0	0	0	0	0
P2O5-Fertilizer	tons	0	0	0	0	0	0	0
Antifoam	tons	0	0	3.48	0	0	0	3.48
CS Liquor	tons	0	0	57.42	0	0	0	57.42
Glucose	tons	0	0	69.6	0	0	0	69.6
H2SO4	tons	0	0	522	0	0	0	522
Lime	tons	0	0	382.8	0	0	0	382.8
Limestone	tons	0	0	78.3	0	0	0	78.3
NH3	tons	0	0	84	0	0	0	84
Nutrients	tons	0	0	16.53	0	0	0	16.53
BFW Chemicals		0	0	0	0	0	0	
Amine	tons	0	0	0.0609	0	0	0	0.0609
Hydrazine	tons	0	0	0.174	0	0	0	0.174
Na2PO4	tons	0	0	0.0174	0	0	0	0.0174
CW Chemicals		0	0	0	0	0	0	
Orthophosphate	tons	0	0	0.2001	0	0	0	0.2001
Phosphonate	tons	0	0	0.0609	0	0	0	0.0609
Polyphosphate	tons	0	0	0.2001	0	0	0	0.2001
Silicate	tons	0	0	0.1653	0	0	0	0.1653
Zinc	tons	0	0	0.087	0	0	0	0.087
WWT Chemicals		0	0	0	0	0	0	
Phosphate	tons	0	0	10.8	0	0	0	10.8
Polymer	tons	0	0	0	0	0	0	0
Urea	tons	0	0	28	0	0	0	28
					0	0	0	
Air Releases					0	0	0	
CO	tons	2311	41.74	10.632	0.87	0	0.87	2365.112
NOx	tons	440	179.22	7.002	2.61	0.87	0.87	630.572
PM (total)	tons	0	4.998	0.54948	0	0	0	5.54748
SOx	tons	45	49.3476	2.898	0	0	0	97.2456
CO_2 Fossil	tons	289368	50974	284.4	174	87	174	341061.4
CO_2 Organic	tons	17432	0	30798	0	0	0	48230

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table A. Fuel Cycle Inventory: E10 continued

Inputs or Outputs	Units	End-Use	E10/ E95 Dist.	E95 Prodtn.	MSW Trans	MSW Sort	MSW Collctn	Grand Total
Air Releases								
NH3 (air)	tons	0	0	1.044	0	0	0	1.044
Cd (air)	tons	0	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0	0
HCl	tons	0	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0	0	0
K2O-Fertilizer (air)	tons	0	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	0	0	0
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	0	0	0
Herbicides (air)	tons	0	0	0	0	0	0	0
VOC (total)	tons	419	127.56	1.926	0	0	0	548.486
VOC-exhaust	tons	209	21.18	0.042	0	0	0	230.222
VOC-engine evap	tons	209	0	0	0	0	0	209
Crude oil (air)	tons	0	9.18	0.054	0	0	0	9.234
Diesel (air)	tons	0	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	34	0	0	0	0	34
Ethanol-100 (air)	tons	0	0	0	0	0	0	0
Ethanol-95 (air)	tons	0	2	0	0	0	0	2
Gasoline (air)	tons	0	45.9	0	0	0	0	45.9
Hydrocarbons	tons	0	9.18	0.054	0	0	0	9.234
Acetaldehyde (air)	tons	0.46	0	0.0261	0	0	0	0.4861
Acetone (air)	tons	0	0.0204	0.00012	0	0	0	0.02052
Benzene	tons	0.94	0.0204	0.00012	0	0	0	0.96052
Butadiene (air)	tons	0.12	0	0	0	0	0	0.12
Butane (iso) (air)	tons	0	0.0612	0.00036	0	0	0	0.06156
Butane (n) air	tons	0	1.1832	0.00696	0	0	0	1.19016
Cycloparaffins (C-7)	tons	0	0.255	0.0015	0	0	0	0.2565
Cycloparaffins (C-8)	tons	0	0.969	0.0057	0	0	0	0.9747
Ethane (air)	tons	0	1.02	0.006	0	0	0	1.026
Formaldehyde (air)	tons	0.53	0.2346	0.01878	0	0	0	0.78338
Heptane (air)	tons	0	1.8462	0.01086	0	0	0	1.85706
Hexane (air)	tons	0	1.3974	0.00822	0	0	0	1.40562
Isoprene (air)	tons	0	0	0	0	0	0	0
Methane (air)	tons	0	5.712	0.0336	0	0	0	5.7456
Monoprene (air)	tons	0	0	0	0	0	0	0
Octane (air)	tons	0	1.224	0.0072	0	0	0	1.2312
Pentane (air)	tons	0	0.8874	0.00522	0	0	0	0.89262
Propane (air)	tons	0	1.6116	0.00948	0	0	0	1.62108
					0	0	0	
Water Releases					0	0	0	
Arsenic (water)	tons	0	0	0	0	0	0	0
Benzene (water)	tons	0	0.0612	0.00036	0	0	0	0.06156

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table A. Fuel Cycle Inventory: E10 continued

Inputs or Outputs	Units	End-Use	E10/ E95 Dist.	E95 Prodtn.	MSW Trans	MSW Sort	MSW Collctn	Grand Total
Boron (water)	tons	0	1.3566	0.00798	0	0	0	1.36458
Chloride (water)	tons	0	999.6	5.88	0	0	0	1005.48
Cr (water)	tons	0	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0	0	0
Insecticides (water)	tons	0	0	0	0	0	0	0
Mobile ions (water)	tons	0	3151.8	18.54	0	0	0	3170.34
NO3N (water)	tons	0	0.0306	0.00018	0	0	0	0.03078
N-Fertilizer (water)	tons	0	0	0	0	0	0	0
Oil & Grease (water)	tons	0	7.2318	0.04254	0	0	0	7.27434
P2O5-Fertilizer (water)	tons	0	0	0	0	0	0	0
Phenols (water)	tons	0	0	0	0	0	0	0
Sodium (water)	tons	0	1326	7.8	0	0	0	1333.8
Soil (water)	tons	0	0	0	0	0	0	0
Sulfides (water)	tons	0	0	0	0	0	0	0
Susp. Solids (water)	tons	0	1.122	33.3276	0	0	0	34.4496
Thermal (water)		0	0	0	0	0	0	0
BOD (water)	tons	0	0.204	0.0012	0	0	0	0.2052
COD (water)	tons	0	2.142	39.6846	0	0	0	41.8266
K2O-Fertilizer (water)	tons	0	0	0	0	0	0	0
TOC (water)	tons	0	1.734	0.0102	0	0	0	1.7442
					0	0	0	
Groundwater Releases					0	0	0	
Herbicides (gw)	tons	0	0	0	0	0	0	0
Insecticides (gw)	tons	0	0	0	0	0	0	0
K2O-Fertilizer (gw)	tons	0	0	0	0	0	0	0
N-Fertilizer (gw)	tons	0	0	0	0	0	0	0
P2O5-Fertilizer (gw)	tons	0	0	0	0	0	0	0
Soil (gw)	tons	0	0	0	0	0	0	0
					0	0	0	
Land Concerns					0	0	0	
Herbicides (land)	tons	0	0	0	0	0	0	0
Insecticides (land)	tons	0	0	0	0	0	0	0
K2O-Fertilizer (land)	tons	0	0	0	0	0	0	0
N-Fertilizer (land)	tons	0	0	0	0	0	0	0
P2O5-Fertilizer (land)	tons	0	0	0	0	0	0	0
Formation Water	gallons	0	33061260	194478	0	0	0	33255738
Sludge	tons	0	0	0	0	0	0	0
Soil (land)	tons	0	0	0	0	0	0	0
Solid Waste	tons	0	408	5570.4	0	-30450	0	-24471.6
Solid Waste (Haz.)	tons	0	408	2.4	0	0	0	410.4
Wastewater (Treated)	gallons	0	14040300	15995760	0	3630423	0	33666483

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table B. Fuel Cycle Inventory: Reformulated Gasoline, 2000

Input or Output	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Inputs							
Crude oil	bbls	0	0	0	0	668000	668000
Diesel	gallons	0	50000	0	6000	0	56000
Diesel (No. 6)	gallons	0	56000	0	378000	0	434000
Ethanol-10	gallons	0	0	0	0	0	0
Ethanol-95	gallons	0	0	0	0	0	0
Gasoline	gallons	28925000	0	0	0	0	0
Insecticides	tons	0	0	0	0	0	0
MTBE	gallons	3610000	0	3.61E+06	0	0	3.61E+06
Natural gas	mmscf	0	0	160	0	0	160
Refinery Products	gallons	0	0	0	0	0	0
Water	gallons	0	0	0	0	141000	141000
Electricity	kWh	0	2.04E+07	4.52E+06	7.08E+06	3.71E+06	3.57E+07
Herbicides	tons	0	0	0	0	0	0
K2O-Fertilizer	tons	0	0	0	0	0	0
N-Fertilizer	tons	0	0	0	0	0	0
P2O5-Fertilizer	tons	0	0	0	0	0	0
Antifoam	tons	0	0	0	0	0	0
CS Liquor	tons	0	0	0	0	0	0
Glucose	tons	0	0	0	0	0	0
H2SO4	tons	0	0	0	0	0	0
Lime	tons	0	0	0	0	0	0
Limestone	tons	0	0	0	0	0	0
NH3	tons	0	0	0	0	0	0
Nutrients	tons	0	0	0	0	0	0
BFW Chemicals							
Amine	tons	0	0	0	0	0	0
Hydrazine	tons	0	0	0	0	0	0
Na2PO4	tons	0	0	0	0	0	0
CW Chemicals							0
Orthophosphate	tons	0	0	0	0	0	0
Phosphonate	tons	0	0	0	0	0	0
Polyphosphate	tons	0	0	0	0	0	0
Silicate	tons	0	0	0	0	0	0
Zinc	tons	0	0	0	0	0	0
WWT Chemicals							
Phosphate	tons	0	0	0	0	0	0
Polymer	tons	0	0	0	0	0	0
Urea	tons	0	0	0	0	0	0
Air Releases							
CO	tons	2420	5	9	15	8	2457
NOx	tons	441	9	68	34	50	602
PM (total)	tons	0	0.32	2.32	1.68	0.58	4.9
SOx	tons	55	0.38	44	1	3	103.38
CO_2 Fossil	tons	308300	1300	28400	4700	14300	357000
CO_2 Organic	tons	0	0	0	0	0	0

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table B. Fuel Cycle Inventory: Reformulated Gasoline, 2000 continued

Input or Output	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Air Releases							
NH3 (air)	tons	0	0	0	0	0	0
Cd (air)	tons	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0
HCl (air)	tons	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0	0
K2O-Fertilizer (air)	tons	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	0	0
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	0	0
Herbicides (air)	tons	0	0	0	0	0	0
VOC (total)	tons	419	47	0	16	15	497
VOC-exhaust	tons	210	2	0	7	0	219
VOC-engine evap	tons	210	0	0	0	0	210
Crude oil (air)	tons	0	0	0	9	0	9
Diesel (air)	tons	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	0	0	0	0
Ethanol-95 (air)	tons	0	0	0	0	0	0
Gasoline (air)	tons	0	45	0	0	0	45
Hydrocarbons	tons	0	0	9	0	0	9
Acetaldehyde (air)	tons	0.14	0	0	0	0	0.14
Acetone (air)	tons	0	0	0	0	0.02	0.02
Benzene (air)	tons	0.8	0	0	0	0.02	0.82
Butadiene (air)	tons	0.1	0	0	0	0	0.1
Butane (iso) (air)	tons	0	0	0	0	0.06	0.06
Butane (n) (air)	tons	0	0	0	0	1.16	1.16
Cycloparaffins (C-7)	tons	0	0	0	0	0.25	0.25
Cycloparaffins (C-8)	tons	0	0	0	0	0.95	0.95
Ethane (air)	tons	0	0	0	0	1	1
Formaldehyde (air)	tons	0.22	0	0	0	0.23	0.45
Heptane (air)	tons	0	0	0	0	1.81	1.81
Hexane (air)	tons	0	0	0	0	1.37	1.37
Isoprene (air)	tons	0	0	0	0	0	0
Methane (air)	tons	0	0	0	0	5.6	5.6
Monoprene (air)	tons	0	0	0	0	0	0
Octane (air)	tons	0	0	0	0	1.2	1.2
Pentane (air)	tons	0	0	0	0	0.87	0.87
Propane (air)	tons	0	0	0	0	1.58	1.58
Water Releases							
Arsenic (water)	tons	0	0	0	0	0	0
Benzene (water)	tons	0	0	0	0	0.06	0.06

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table B. Fuel Cycle Inventory: Reformulated Gasoline, 2000 continued

Input or Output	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Water Releases							
Boron (water)	tons	0	0	0	0	1.33	1.33
Chloride (water)	tons	0	0	0	0	980	980
Cr (water)	tons	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0	0
Insecticides (water)	tons	0	0	0	0	0	0
Mobile ions (water)	tons	0	0	0	0	3090	3090
NO3N (water)	tons	0	0	0.03	0	0	0.03
N-Fertilizer (water)	tons	0	0	0	0	0	0
Oil & Grease (water)	tons	0	0	0.09	0	7	7.09
P2O5-Fertilizer (water)	tons	0	0	0	0	0	0
Phenols (water)	tons	0	0	0	0	0	0
Sodium (water)	tons	0	0	0	0	1300	1300
Soil (water)	tons	0	0	0	0	0	0
Sulfides (water)	tons	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	1.1	0	0	1.1
Thermal (water)		0	0	0	0	0	0
BOD (water)	tons	0	0	0.2	0	0	0.2
COD (water)	tons	0	0	2.1	0	0	2.1
K2O-Fertilizer (water)	tons	0	0	0	0	0	0
TOC (water)	tons	0	0	1.7	0	0	1.7
Groundwater Releases							
Herbicides (gw)	tons	0	0	0	0	0	0
Insecticides (gw)	tons	0	0	0	0	0	0
K2O-Fertilizer (gw)	tons	0	0	0	0	0	0
N-Fertilizer (gw)	tons	0	0	0	0	0	0
P2O5-Fertilizer (gw)	tons	0	0	0	0	0	0
Soil (gw)	tons	0	0	0	0	0	0
Land Concerns							
Herbicides (land)	tons	0	0	0	0	0	0
Insecticides (land)	tons	0	0	0	0	0	0
K2O-Fertilizer (land)	tons	0	0	0	0	0	0
N-Fertilizer (land)	tons	0	0	0	0	0	0
P2O5-Fertilizer (land)	tons	0	0	0	0	0	0
Formation Water	gallons	0	0	0	0	3.24E+07	3.24E+07
Sludge	tons	0	0	0	0	0	0
Soil (land)	tons	0	0	0	0	0	0
Solid Waste	tons	0	0	400	0	0	400
Solid Waste (Haz)	tons	0	0	300	0	100	400
Wastewater (Treated)	gallons	0	0	1.38E+07	0	0	1.38E+07

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table C. Fuel Cycle Inventory: E95, Tifton GA

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Inputs										
Crude oil	bbls	0	0	46294	0	0	0	0	0	46294
Diesel	gallons	0	99000	67720.6	253150	498000	244020	224100	30710	917871
Diesel (No. 6)	gallons	0	0	27966	0	0	0	0	0	27966
Ethanol-10	gallons	0	0	0	0	0	0	0	0	0
Ethanol-95	gallons	35400000	0	0	0	0	0	0	0	35400000
Gasoline	gallons	0	0	1973000	0	0	0	0	0	1973000
Insecticides	tons	0	0	0	0	0.415	0.249	0.083	0.083	0.415
MTBE	gallons	0	0	0	0	0	0	0	0	0
Natural gas	mmscf	0	0	11.85	0	0	0	0	0	11.85
Refinery Products	gallons	0	0	0	0	0	0	0	0	0
Water	gallons	0	0	226191827	0	0	0	0	0	226191827
Electricity	kWh	0	13311000	-49081990	0	0	0	0	0	-35770990
Herbicides	tons	0	0	0	0	3.569	1.328	1.992	0.166	3.569
K2O-Fertilizer	tons	0	0	0	0	1070.7	838.3	124.5	107.9	1070.7
N-Fertilizer	tons	0	0	0	0	1361.2	755.3	415	182.6	1361.2
P2O5-Fertilizer	tons	0	0	0	0	747	556.1	124.5	66.4	747
Antifoam	tons	0	0	15.77	0	0	0	0	0	15.77
CS Liquor	tons	0	0	265.6	0	0	0	0	0	265.6
Glucose	tons	0	0	506.3	0	0	0	0	0	506.3
H2SO4	tons	0	0	4233	0	0	0	0	0	4233
Lime	tons	0	0	3145.7	0	0	0	0	0	3145.7
Limestone	tons	0	0	514.6	0	0	0	0	0	514.6
NH3	tons	0	0	646	0	0	0	0	0	646
Nutrients	tons	0	0	76.36	0	0	0	0	0	76.36
BFW Chemicals										
Amine	tons	0	0	0.6225	0	0	0	0	0	0.6225
Hydrazine	tons	0	0	2.075	0	0	0	0	0	2.075
Na2PO4	tons	0	0	0.2075	0	0	0	0	0	0.2075
CW Chemicals										
Orthophosphate	tons	0	0	1.5189	0	0	0	0	0	1.5189
Phosphonate	tons	0	0	0.4565	0	0	0	0	0	0.4565
Polyphosphate	tons	0	0	1.5189	0	0	0	0	0	1.5189
Silicate	tons	0	0	1.2118	0	0	0	0	0	1.2118
Zinc	tons	0	0	0.747	0	0	0	0	0	0.747
WWT Chemicals										
Phosphate	tons	0	0	183	0	0	0	0	0	183
Polymer	tons	0	0	0	0	0	0	0	0	0
Urea	tons	0	0	469.5	0	0	0	0	0	469.5
Air Releases										
CO	tons	1867	2	104.895	9.13	42.33	20.75	19.09	2.49	2025.355
NOx	tons	220	8	70.504	9.13	42.33	20.75	19.09	2.49	349.964
PM (total)	tons	0	0	4.89206	0	4.15	1.66	1.66	0	9.04206
SOx	tons	4	0	19.72	0.83	1.66	0.83	0.83	0	26.21
CO_2 Fossil	tons	16672	1100	3981.6	2822	5644	2739	2573	332	30219.6
CO_2 Organic	tons	213928	0	276058	99849	-557594	-238874	-268422	-49883	32241

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table C. Fuel Cycle Inventory: E95, Tifton GA continued

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Air Releases										
NH3 (air)	tons	0	0	9.794	0	0	0	0	0	9.794
Cd (air)	tons	0	0	0	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0	0	0	0
HCl	tons	0	0	0	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0.4648	0.2075	0.2075	0.0415	0.4648
K2O-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	136.12	75.53	41.5	18.26	136.12
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	1826	913	830	166	1826
Herbicides (air)	tons	0	0	0	0	2.6726	0.9794	1.5272	0.1577	2.6726
VOC (total)	tons	176	19	19.879	2.49	1251.64	4.98	1244.17	2.49	1469.009
VOC-exhaust	tons	99	1	0.395	2.49	9.96	4.98	4.15	0.83	112.845
VOC-engine evap	tons	77	0	0	0	0	0	0	0	77
Crude oil (air)	tons	0	0	0.632	0	0	0	0	0	0.632
Diesel (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	3.32	0	0	0	0	0	3.32
Ethanol-95 (air)	tons	0	18	0	0	0	0	0	0	18
Gasoline (air)	tons	0	0	0	0	0	0	0	0	0
Hydrocarbons	tons	0	0	0.316	0	0	0	0	0	0.316
Acetaldehyde (air)	tons	0.56	0	0.2158	0	0	0	0	0	0.7758
Acetone (air)	tons	0	0	0.00237	0	0	0	0	0	0.00237
Benzene	tons	0.19	0	0.00079	0	0	0	0	0	0.19079
Butadiene (air)	tons	0.02	0	0	0	0	0	0	0	0.02
Butane (iso) (air)	tons	0	0	0.00474	0	0	0	0	0	0.00474
Butane (n) air	tons	0	0	0.08137	0	0	0	0	0	0.08137
Cycloparaffins (C-7)	tons	0	0	0.01738	0	0	0	0	0	0.01738
Cycloparaffins (C-8)	tons	0	0	0.00632	0	0	0	0	0	0.00632
Ethane (air)	tons	0	0	0.06952	0	0	0	0	0	0.06952
Formaldehyde (air)	tons	0.19	0	0.1652	0	0	0	0	0	0.3552
Heptane (air)	tons	0	0	0.12719	0	0	0	0	0	0.12719
Hexane (air)	tons	0	0	0.09796	0	0	0	0	0	0.09796
Isoprene (air)	tons	0	0	0	0	1152.04	0	1152.04	0	1152.04
Methane (air)	tons	0	0	0.40132	0	0	0	0	0	0.40132
Monoprene (air)	tons	0	0	0	0	89.4906	0	87.4239	2.0169	89.4906
Octane (air)	tons	0	0	0.08532	0	0	0	0	0	0.08532
Pentane (air)	tons	0	0	0.06162	0	0	0	0	0	0.06162
Propane (air)	tons	0	0	0.10981	0	0	0	0	0	0.10981
Water Releases										
Arsenic (water)	tons	0	0	0	0	0	0	0	0	0
Benzene (water)	tons	0	0	0.00395	0	0	0	0	0	0.00395

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table C. Fuel Cycle Inventory: E95, Tifton GA continued

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Water Releases										
Boron (water)	tons	0	0	0.08888	0	0	0	0	0	0.08888
Chloride (water)	tons	0	0	58.6343	0	0	0	0	0	58.6343
Cr (water)	tons	0	0	0	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0.3569	0.1328	0.1992	0.0166	0.3569
Insecticides (water)	tons	0	0	0	0	0.0581	0.0249	0.0249	0.0083	0.0581
Mobile ions (water)	tons	0	0	187.1885	0	0	0	0	0	187.1885
NO3N (water)	tons	0	0	0.00237	0	0	0	0	0	0.00237
N-Fertilizer (water)	tons	0	0	0	0	68.06	38.18	20.75	9.13	68.06
Oil & Grease (water)	tons	0	0	0.48032	0	0	0	0	0	0.48032
P2O5-Fertilizer (water)	tons	0	0	0	0	37.35	28.22	5.81	3.32	37.35
Phenols (water)	tons	0	0	0	0	0	0	0	0	0
Sodium (water)	tons	0	0	78.9004	0	0	0	0	0	78.9004
Soil (water)	tons	0	0	0	0	1909	913	830	166	1909
Sulfides (water)	tons	0	0	0	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	258.0351	0	0	0	0	0	258.0351
Thermal (water)		0	0	0	0	0	0	0	0	0
BOD (water)	tons	0	0	0.0158	0	0	0	0	0	0.0158
COD (water)	tons	0	0	308.9694	0	0	0	0	0	308.9694
K2O-Fertilizer (water)	tons	0	0	0	0	53.12	42.33	5.81	5.81	53.12
TOC (water)	tons	0	0	0.1185	0	0	0	0	0	0.1185
Groundwater Releases										
Herbicides (gw)	tons	0	0	0	0	0.2822	0.0996	0.166	0.0166	0.2822
Insecticides (gw)	tons	0	0	0	0	0.0498	0.0249	0.0249	0	0.0498
K2O-Fertilizer (gw)	tons	0	0	0	0	53.12	42.33	5.81	5.81	53.12
N-Fertilizer (gw)	tons	0	0	0	0	68.06	38.18	20.75	9.13	68.06
P2O5-Fertilizer (gw)	tons	0	0	0	0	37.35	28.22	5.81	3.32	37.35
Soil (gw)	tons	0	0	0	0	0	0	0	0	0
Land Concerns										
Herbicides (land)	tons	0	0	0	0	0.1826	0.0664	0.0996	0.0083	0.1826
Insecticides (land)	tons	0	0	0	0	0.0332	0.0166	0.0166	0	0.0332
K2O-Fertilizer (land)	tons	0	0	0	0	53.12	42.33	5.81	5.81	53.12
N-Fertilizer (land)	tons	0	0	0	0	68.06	38.18	20.75	9.13	68.06
P2O5-Fertilizer (land)	tons	0	0	0	0	74.7	55.61	12.45	6.64	74.7
Formation Water	gallons	0	0	1910062	0	0	0	0	0	1910062
Sludge	tons	0	0	830	0	0	0	0	0	830
Soil (land)	tons	0	0	0	0	15023	7470	6474	1079	15023
Solid Waste	tons	0	0	14971.6	0	0	0	0	0	14971.6
Solid Waste (Haz.)	tons	0	0	23.7	0	0	0	0	0	23.7
Wastewater (Treated)	gallons	0	0	124527351	0	0	0	0	0	124527351

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table D. Fuel Cycle Inventory: E95, Peoria, IL

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Inputs										
Crude oil	bbls	0	0	46294	0	0	0	0	0	46294
Diesel	gallons	0	104000	77546.62	162360	552680	294380	191880	66420	896587
Diesel (No. 6)	gallons	0	0	27966	0	0	0	0	0	27966
Ethanol-10	gallons	0	0	0	0	0	0	0	0	0
Ethanol-95	gallons	35400000	0	0	0	0	0	0	0	35400000
Gasoline	gallons	0	0	1973000	0	0	0	0	0	1973000
Insecticides	tons	0	0	0	0	1.148	0.246	0.082	0.738	1.148
MTBE	gallons	0	0	0	0	0	0	0	0	0
Natural gas	mmscf	0	0	11.85	0	0	0	0	0	11.85
Refinery Products	gallons	0	0	0	0	0	0	0	0	0
Water	gallons	0	0	237246927	0	0	0	0	0	237246927
Electricity	kWh	0	13284000	-54584990	0	0	0	0	0	-41300990
Herbicides	tons	0	0	0	0	5.494	1.23	1.23	2.952	5.494
K2O-Fertilizer	tons	0	0	0	0	1123.4	877.4	73.8	172.2	1123.4
N-Fertilizer	tons	0	0	0	0	1402.2	902	254.2	246	1402.2
P2O5-Fertilizer	tons	0	0	0	0	795.4	590.4	73.8	131.2	795.4
Antifoam	tons	0	0	18.04	0	0	0	0	0	18.04
CS Liquor	tons	0	0	282.9	0	0	0	0	0	282.9
Glucose	tons	0	0	533	0	0	0	0	0	533
H2SO4	tons	0	0	4346	0	0	0	0	0	4346
Lime	tons	0	0	3214.4	0	0	0	0	0	3214.4
Limestone	tons	0	0	803.6	0	0	0	0	0	803.6
NH3	tons	0	0	645	0	0	0	0	0	645
Nutrients	tons	0	0	81.18	0	0	0	0	0	81.18
BFW Chemicals										
Amine	tons	0	0	0.615	0	0	0	0	0	0.615
Hydrazine	tons	0	0	2.05	0	0	0	0	0	2.05
Na2PO4	tons	0	0	0.205	0	0	0	0	0	0.205
CW Chemicals										
Orthophosphate	tons	0	0	1.599	0	0	0	0	0	1.599
Phosphonate	tons	0	0	0.4756	0	0	0	0	0	0.4756
Polyphosphate	tons	0	0	1.599	0	0	0	0	0	1.599
Silicate	tons	0	0	1.271	0	0	0	0	0	1.271
Zinc	tons	0	0	0.82	0	0	0	0	0	0.82
WWT Chemicals										
Phosphate	tons	0	0	178	0	0	0	0	0	178
Polymer	tons	0	0	0	0	0	0	0	0	0
Urea	tons	0	0	465	0	0	0	0	0	465
Air Releases										
CO	tons	1871	3	105.295	5.74	46.74	24.6	16.4	5.74	2031.775
NOx	tons	220	9	72.244	5.74	46.74	24.6	16.4	5.74	353.724
PM (total)	tons	0	0	4.91906	0	4.92	2.46	1.64	0.82	9.83906
SOx	tons	4	0	29.37	0.82	2.46	0.82	0.82	0	36.65
CO_2 Fossil	tons	16672	1200	3981.6	1804	6232	3362	2214	738	29889.6
CO_2 Organic	tons	214028	0	289214	101926	-569244	-288804	-194996	-85772	35924

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table D. Fuel Cycle Inventory: E95, Peoria, IL continued

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Air Releases										
NH3 (air)	tons	0	0	10.25	0	0	0	0	0	10.25
Cd (air)	tons	0	0	0	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0	0	0	0
HCl	tons	0	0	0	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0.8282	0.2214	0.041	0.5658	0.8282
K2O-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	152.52	90.2	25.42	36.9	152.52
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	16154	6642	4346	5084	16154
Herbicides (air)	tons	0	0	0	0	4.1246	0.9512	0.9184	2.255	4.1246
VOC (total)	tons	176	19	20.489	1.64	2121.34	5.74	2113.14	2.46	2338.469
VOC-exhaust	tons	99	1	0.395	1.64	10.66	5.74	4.1	1.64	112.695
VOC-engine evap	tons	77	0	0	0	0	0	0	0	77
Crude oil (air)	tons	0	0	0.632	0	0	0	0	0	0.632
Diesel (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	3.28	0	0	0	0	0	3.28
Ethanol-95 (air)	tons	0	18	0	0	0	0	0	0	18
Gasoline (air)	tons	0	0	0	0	0	0	0	0	0
Hydrocarbons	tons	0	0	0.316	0	0	0	0	0	0.316
Acetaldehyde (air)	tons	0.56	0	0.246	0	0	0	0	0	0.806
Acetone (air)	tons	0	0	0.00237	0	0	0	0	0	0.00237
Benzene	tons	0.19	0	0.00079	0	0	0	0	0	0.19079
Butadiene (air)	tons	0.02	0	0	0	0	0	0	0	0.02
Butane (iso) (air)	tons	0	0	0.00474	0	0	0	0	0	0.00474
Butane (n) air	tons	0	0	0.08137	0	0	0	0	0	0.08137
Cycloparaffins (C-7)	tons	0	0	0.01738	0	0	0	0	0	0.01738
Cycloparaffins (C-8)	tons	0	0	0.00632	0	0	0	0	0	0.00632
Ethane (air)	tons	0	0	0.06952	0	0	0	0	0	0.06952
Formaldehyde (air)	tons	0.19	0	0.1798	0	0	0	0	0	0.3698
Heptane (air)	tons	0	0	0.12719	0	0	0	0	0	0.12719
Hexane (air)	tons	0	0	0.09796	0	0	0	0	0	0.09796
Isoprene (air)	tons	0	0	0	0	2109.04	0	2109.04	0	2109.04
Methane (air)	tons	0	0	0.40132	0	0	0	0	0	0.40132
Monoprene (air)	tons	0	0	0	0	1.681	0	0	1.681	1.681
Octane (air)	tons	0	0	0.08532	0	0	0	0	0	0.08532
Pentane (air)	tons	0	0	0.06162	0	0	0	0	0	0.06162
Propane (air)	tons	0	0	0.10981	0	0	0	0	0	0.10981
Water Releases										
Arsenic (water)	tons	0	0	0	0	0	0	0	0	0
Benzene (water)	tons	0	0	0.00395	0	0	0	0	0	0.00395

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table D. Fuel Cycle Inventory: E95, Peoria, IL continued

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Water Releases										
Boron (water)	tons	0	0	0.08058	0	0	0	0	0	0.08058
Chloride (water)	tons	0	0	58.4682	0	0	0	0	0	58.4682
Cr (water)	tons	0	0	0	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0.5494	0.123	0.123	0.2952	0.5494
Insecticides (water)	tons	0	0	0	0	0.1148	0.0246	0.0082	0.0738	0.1148
Mobile ions (water)	tons	0	0	186.902	0	0	0	0	0	186.902
NO3N (water)	tons	0	0	0.00237	0	0	0	0	0	0.00237
N-Fertilizer (water)	tons	0	0	0	0	82.82	45.1	13.12	24.6	82.82
Oil & Grease (water)	tons	0	0	0.48032	0	0	0	0	0	0.48032
P2O5-Fertilizer (water)	tons	0	0	0	0	39.36	29.52	4.1	6.56	39.36
Phenols (water)	tons	0	0	0	0	0	0	0	0	0
Sodium (water)	tons	0	0	79.3608	0	0	0	0	0	79.3608
Soil (water)	tons	0	0	0	0	8118	3362	2214	2542	8118
Sulfides (water)	tons	0	0	0	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	265.7511	0	0	0	0	0	265.7511
Thermal (water)										
BOD (water)	tons	0	0	0.0158	0	0	0	0	0	0.0158
COD (water)	tons	0	0	319.1064	0	0	0	0	0	319.1064
K2O-Fertilizer (water)	tons	0	0	0	0	56.58	44.28	4.1	8.2	56.58
TOC (water)	tons	0	0	0.1185	0	0	0	0	0	0.1185
Groundwater Releases										
Herbicides (gw)	tons	0	0	0	0	0.4428	0.0984	0.0984	0.246	0.4428
Insecticides (gw)	tons	0	0	0	0	0.0902	0.0246	0	0.0574	0.0902
K2O-Fertilizer (gw)	tons	0	0	0	0	56.58	44.28	4.1	8.2	56.58
N-Fertilizer (gw)	tons	0	0	0	0	94.3	45.1	13.12	36.9	94.3
P2O5-Fertilizer (gw)	tons	0	0	0	0	39.36	29.52	4.1	6.56	39.36
Soil (gw)	tons	0	0	0	0	0	0	0	0	0
Land Concerns										
Herbicides (land)	tons	0	0	0	0	0.2788	0.0656	0.0656	0.1476	0.2788
Insecticides (land)	tons	0	0	0	0	0.0492	0.0082	0	0.041	0.0492
K2O-Fertilizer (land)	tons	0	0	0	0	56.58	44.28	4.1	8.2	56.58
N-Fertilizer (land)	tons	0	0	0	0	82.82	45.1	13.12	24.6	82.82
P2O5-Fertilizer (land)	tons	0	0	0	0	79.54	59.04	7.38	13.12	79.54
Formation Water	gallons	0	0	1910062	0	0	0	0	0	1910062
Sludge	tons	0	0	820	0	0	0	0	0	820
Soil (land)	tons	0	0	0	0	56580	23370	15334	17876	56580
Solid Waste	tons	0	0	16677.6	0	0	0	0	0	16677.6
Solid Waste (Haz.)	tons	0	0	23.7	0	0	0	0	0	23.7
Wastewater (Treated)	gallons	0	0	128568195	0	0	0	0	0	128568195

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table E. Fuel Cycle Inventory: E95 Rochester, NY

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Inputs										
Crude oil	bbls	0	0	46294	0	0	0	0	0	46294
Diesel	gallons	0	65000	84114	284540	597780	396060	201720	0	1031434
Diesel (No. 6)	gallons	0	0	27966	0	0	0	0	0	27966
Ethanol-10	gallons	0	0	0	0	0	0	0	0	0
Ethanol-95	gallons	34500000	0	0	0	0	0	0	0	34500000
Gasoline	gallons	0	0	1973000	0	0	0	0	0	1973000
Insecticides	tons	0	0	0	0	0.656	0.574	0.082	0	0.656
MTBE	gallons	0	0	0	0	0	0	0	0	0
Natural gas	mmscf	0	0	11.85	0	0	0	0	0	11.85
Refinery Products	gallons	0	0	0	0	0	0	0	0	0
Water	gallons	0	0	241685587	0	0	0	0	0	241685587
Electricity	kWh	0	13472000	-53795990	0	0	0	0	0	-40323990
Herbicides	tons	0	0	0	0	4.182	2.46	1.722	0	4.182
K2O-Fertilizer	tons	0	0	0	0	1869.6	1763	106.6	0	1869.6
N-Fertilizer	tons	0	0	0	0	2386.2	2025.4	360.8	0	2386.2
P2O5-Fertilizer	tons	0	0	0	0	1279.2	1172.6	106.6	0	1279.2
Antifoam	tons	0	0	16.4	0	0	0	0	0	16.4
CS Liquor	tons	0	0	269.78	0	0	0	0	0	269.78
Glucose	tons	0	0	508.4	0	0	0	0	0	508.4
H2SO4	tons	0	0	4346	0	0	0	0	0	4346
Lime	tons	0	0	3206.2	0	0	0	0	0	3206.2
Limestone	tons	0	0	717.5	0	0	0	0	0	717.5
NH3	tons	0	0	650	0	0	0	0	0	650
Nutrients	tons	0	0	77.08	0	0	0	0	0	77.08
BFW Chemicals										
Amine	tons	0	0	0.615	0	0	0	0	0	0.615
Hydrazine	tons	0	0	2.05	0	0	0	0	0	2.05
Na2PO4	tons	0	0	0.205	0	0	0	0	0	0.205
CW Chemicals										
Orthophosphate	tons	0	0	1.5416	0	0	0	0	0	1.5416
Phosphonate	tons	0	0	0.4674	0	0	0	0	0	0.4674
Polyphosphate	tons	0	0	1.5416	0	0	0	0	0	1.5416
Silicate	tons	0	0	1.2382	0	0	0	0	0	1.2382
Zinc	tons	0	0	0.738	0	0	0	0	0	0.738
WWT Chemicals										
Phosphate	tons	0	0	194	0	0	0	0	0	194
Polymer	tons	0	0	0	0	0	0	0	0	0
Urea	tons	0	0	504	0	0	0	0	0	504
Air Releases										
CO	tons	1871	2	106.935	9.02	50.84	33.62	17.22	0	2039.795
NOx	tons	220	5	73.064	14.76	50.84	33.62	17.22	0	363.664
PM (total)	tons	0	0.1	4.91906	0	4.92	3.28	1.64	0	9.93906
SOx	tons	4.8	0.2	26.09	0.82	2.46	1.64	0.82	0	34.37
CO_2 Fossil	tons	16672	700	3981.6	3198	6724	4428	2296	0	31275.6
CO_2 Organic	tons	214028	0	288804	119638	-584004	-379988	-202294	0	38466

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table E. Fuel Cycle Inventory: E95 Rochester, NY continued

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Air Releases										
NH3 (air)	tons	0	0	10.25	0	0	0	0	0	10.25
Cd (air)	tons	0	0	0	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0	0	0	0
HCl	tons	0	0	0	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0.5002	0.4428	0.0574	0	0.5002
K2O-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	238.62	202.54	36.08	0	238.62
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	4838	4100	738	0	4838
Herbicides (air)	tons	0	0	0	0	3.0832	1.7712	1.312	0	3.0832
VOC (total)	tons	176	19	19.669	2.46	2739.62	7.38	2731.42	0	2956.749
VOC-exhaust	tons	99	0	0.395	2.46	11.48	7.38	4.1	0	113.335
VOC-engine evap	tons	77	0	0	0	0	0	0	0	77
Crude oil (air)	tons	0	0	0.632	0	0	0	0	0	0.632
Diesel (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	3.28	0	0	0	0	0	3.28
Ethanol-95 (air)	tons	0	18	0	0	0	0	0	0	18
Gasoline (air)	tons	0	0	0	0	0	0	0	0	0
Hydrocarbons	tons	0	0	0.316	0	0	0	0	0	0.316
Acetaldehyde (air)	tons	0.56	0	0.2378	0	0	0	0	0	0.7978
Acetone (air)	tons	0	0	0.00237	0	0	0	0	0	0.00237
Benzene	tons	0.19	0	0.00079	0	0	0	0	0	0.19079
Butadiene (air)	tons	0.02	0	0	0	0	0	0	0	0.02
Butane (iso) (air)	tons	0	0	0.00474	0	0	0	0	0	0.00474
Butane (n) air	tons	0	0	0.08137	0	0	0	0	0	0.08137
Cycloparaffins (C-7)	tons	0	0	0.01738	0	0	0	0	0	0.01738
Cycloparaffins (C-8)	tons	0	0	0.00632	0	0	0	0	0	0.00632
Ethane (air)	tons	0	0	0.06952	0	0	0	0	0	0.06952
Formaldehyde (air)	tons	0.2	0	0.1798	0	0	0	0	0	0.3798
Heptane (air)	tons	0	0	0.12719	0	0	0	0	0	0.12719
Hexane (air)	tons	0	0	0.09796	0	0	0	0	0	0.09796
Isoprene (air)	tons	0	0	0	0	2727.32	0	2727.32	0	2727.32
Methane (air)	tons	0	0	0.40132	0	0	0	0	0	0.40132
Monoprene (air)	tons	0	0	0	0	0	0	0	0	0
Octane (air)	tons	0	0	0.08532	0	0	0	0	0	0.08532
Pentane (air)	tons	0	0	0.06162	0	0	0	0	0	0.06162
Propane (air)	tons	0	0	0.10981	0	0	0	0	0	0.10981
Water Releases										
Arsenic (water)	tons	0	0	0	0	0	0	0	0	0
Benzene (water)	tons	0	0	0.00395	0	0	0	0	0	0.00395

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table E. Fuel Cycle Inventory: E95 Rochester, NY continued

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Water Releases										
Boron (water)	tons	0	0	0.08058	0	0	0	0	0	0.08058
Chloride (water)	tons	0	0	58.624	0	0	0	0	0	58.624
Cr (water)	tons	0	0	0	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0.41	0.2378	0.1722	0	0.41
Insecticides (water)	tons	0	0	0	0	0.0656	0.0574	0.0082	0	0.0656
Mobile ions (water)	tons	0	0	187.189	0	0	0	0	0	187.189
NO3N (water)	tons	0	0	0.00237	0	0	0	0	0	0.00237
N-Fertilizer (water)	tons	0	0	0	0	118.9	101.68	18.04	0	118.9
Oil & Grease (water)	tons	0	0	0.48032	0	0	0	0	0	0.48032
P2O5-Fertilizer (water)	tons	0	0	0	0	63.96	59.04	4.92	0	63.96
Phenols (water)	tons	0	0	0	0	0	0	0	0	0
Sodium (water)	tons	0	0	78.8934	0	0	0	0	0	78.8934
Soil (water)	tons	0	0	0	0	4838	4100	738	0	4838
Sulfides (water)	tons	0	0	0	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	255.9111	0	0	0	0	0	255.9111
Thermal (water)		0	0	0	0	0	0	0	0	0
BOD (water)	tons	0	0	0.0076	0	0	0	0	0	0.0076
COD (water)	tons	0	0	306.8064	0	0	0	0	0	306.8064
K2O-Fertilizer (water)	tons	0	0	0	0	93.48	88.56	4.92	0	93.48
TOC (water)	tons	0	0	0.0365	0	0	0	0	0	0.0365
Groundwater Releases										
Herbicides (gw)	tons	0	0	0	0	0.328	0.1968	0.1394	0	0.328
Insecticides (gw)	tons	0	0	0	0	0.0492	0.0492	0.0082	0	0.0492
K2O-Fertilizer (gw)	tons	0	0	0	0	93.48	88.56	4.92	0	93.48
N-Fertilizer (gw)	tons	0	0	0	0	118.9	101.68	18.04	0	118.9
P2O5-Fertilizer (gw)	tons	0	0	0	0	63.96	59.04	4.92	0	63.96
Soil (gw)	tons	0	0	0	0	0	0	0	0	0
Land Concerns										
Herbicides (land)	tons	0	0	0	0	0.205	0.1148	0.0902	0	0.205
Insecticides (land)	tons	0	0	0	0	0.0246	0.0246	0	0	0.0246
K2O-Fertilizer (land)	tons	0	0	0	0	93.48	88.56	4.92	0	93.48
N-Fertilizer (land)	tons	0	0	0	0	118.9	101.68	18.04	0	118.9
P2O5-Fertilizer (land)	tons	0	0	0	0	127.92	117.26	10.66	0	127.92
Formation Water	gallons	0	0	1910062	0	0	0	0	0	1910062
Sludge	tons	0	0	820	0	0	0	0	0	820
Soil (land)	tons	0	0	0	0	38704	32636	6068	0	38704
Solid Waste	tons	0	0	16677.6	0	0	0	0	0	16677.6
Solid Waste (Haz.)	tons	0	0	23.7	0	0	0	0	0	23.7
Wastewater (Treated)	gallons	0	0	123408427	0	0	0	0	0	123408427

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table F. Fuel Cycle Inventory: E95, Portland, OR

Inputs and Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Inputs										
Crude oil	bbls	0	0	46294	0	0	0	0	0	46294
Diesel	gallons	0	81000	35491.91	350740	536050	0	536050	0	1003282
Diesel (No. 6)	gallons	0	0	27966	0	0	0	0	0	27966
Ethanol-10	gallons	0	0	0	0	0	0	0	0	0
Ethanol-95	gallons	35400000	0	0	0	0	0	0	0	35400000
Gasoline	gallons	0	0	1973000	0	0	0	0	0	1973000
Insecticides	tons	0	0	0	0	0.213	0	0.213	0	0.213
MTBE	gallons	0	0	0	0	0	0	0	0	0
Natural gas	mmscf	0	0	11.85	0	0	0	0	0	11.85
Refinery Products	gallons	0	0	0	0	0	0	0	0	0
Water	gallons	0	0	293956117	0	0	0	0	0	293956117
Electricity	kWh	0	13545000	-1.00E+08	0	0	0	0	0	-86876990
Herbicides	tons	0	0	0	0	4.118	0	4.118	0	4.118
K2O-Fertilizer	tons	0	0	0	0	248.5	0	248.5	0	248.5
N-Fertilizer	tons	0	0	0	0	852	0	852	0	852
P2O5-Fertilizer	tons	0	0	0	0	248.5	0	248.5	0	248.5
Antifoam	tons	0	0	20.59	0	0	0	0	0	20.59
CS Liquor	tons	0	0	338.67	0	0	0	0	0	338.67
Glucose	tons	0	0	596.4	0	0	0	0	0	596.4
H2SO4	tons	0	0	3976	0	0	0	0	0	3976
Lime	tons	0	0	2903.9	0	0	0	0	0	2903.9
Limestone	tons	0	0	262.7	0	0	0	0	0	262.7
NH3	tons	0	0	733	0	0	0	0	0	733
Nutrients	tons	0	0	97.27	0	0	0	0	0	97.27
BFW Chemicals										
Amine	tons	0	0	0.7952	0	0	0	0	0	0.7952
Hydrazine	tons	0	0	2.627	0	0	0	0	0	2.627
Na2PO4	tons	0	0	0.2627	0	0	0	0	0	0.2627
CW Chemicals										
Orthophosphate	tons	0	0	2.0448	0	0	0	0	0	2.0448
Phosphonate	tons	0	0	0.6106	0	0	0	0	0	0.6106
Polyphosphate	tons	0	0	2.0448	0	0	0	0	0	2.0448
Silicate	tons	0	0	1.633	0	0	0	0	0	1.633
Zinc	tons	0	0	0.994	0	0	0	0	0	0.994
WWT Chemicals										
Phosphate	tons	0	0	99.4	0	0	0	0	0	99.4
Polymer	tons	0	0	0	0	0	0	0	0	0
Urea	tons	0	0	261	0	0	0	0	0	261
Air Releases										
CO	tons	1867	2	129.065	9.94	45.44	0	45.44	0	2053.445
NOx	tons	219	6	81.034	25.56	45.44	0	45.44	0	377.034
PM (total)	tons	0	0.1	5.22606	0.71	4.97	0	4.97	0	11.00606
SOx	tons	3.8	0.3	11.76	1.42	2.13	0	2.13	0	19.41
CO_2 Fossil	tons	16672	900	3981.6	3976	6035	0	6035	0	31564.6
CO_2 Organic	tons	213928	0	286911	92939	-544996	0	-544996	0	48782

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table F. Fuel Cycle Inventory: E95, Portland, OR continued

Inputs and Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Air Releases										
NH3 (air)	tons	0	0	11.502	0	0	0	0	0	11.502
Cd (air)	tons	0	0	0	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0	0	0	0
HCl	tons	0	0	0	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0.142	0	0.142	0	0.142
K2O-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	85.2	0	85.2	0	85.2
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	852	0	852	0	852
Herbicides (air)	tons	0	0	0	0	3.1098	0	3.1098	0	3.1098
VOC (total)	tons	176	19	23.749	2.84	2854.2	0	2854.2	0	3075.789
VOC-exhaust	tons	99	0	0.395	2.84	10.65	0	10.65	0	112.885
VOC-engine evap	tons	77	0	0	0	0	0	0	0	77
Crude oil (air)	tons	0	0	0.632	0	0	0	0	0	0.632
Diesel (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	3.55	0	0	0	0	0	3.55
Ethanol-95 (air)	tons	0	19	0	0	0	0	0	0	19
Gasoline (air)	tons	0	0	0	0	0	0	0	0	0
Hydrocarbons	tons	0	0	0.316	0	0	0	0	0	0.316
Acetaldehyde (air)	tons	0.56	0	0.2698	0	0	0	0	0	0.8298
Acetone (air)	tons	0	0	0.00237	0	0	0	0	0	0.00237
Benzene	tons	0.19	0	0.00079	0	0	0	0	0	0.19079
Butadiene (air)	tons	0.02	0	0	0	0	0	0	0	0.02
Butane (iso) (air)	tons	0	0	0.00474	0	0	0	0	0	0.00474
Butane (n) air	tons	0	0	0.08137	0	0	0	0	0	0.08137
Cycloparaffins (C-7)	tons	0	0	0.01738	0	0	0	0	0	0.01738
Cycloparaffins (C-8)	tons	0	0	0.00632	0	0	0	0	0	0.00632
Ethane (air)	tons	0	0	0.06952	0	0	0	0	0	0.06952
Formaldehyde (air)	tons	0.19	0	0.2004	0	0	0	0	0	0.3904
Heptane (air)	tons	0	0	0.12719	0	0	0	0	0	0.12719
Hexane (air)	tons	0	0	0.09796	0	0	0	0	0	0.09796
Isoprene (air)	tons	0	0	0	0	2843.55	0	2843.55	0	2843.55
Methane (air)	tons	0	0	0.40132	0	0	0	0	0	0.40132
Monoprene (air)	tons	0	0	0	0	0	0	0	0	0
Octane (air)	tons	0	0	0.08532	0	0	0	0	0	0.08532
Pentane (air)	tons	0	0	0.06162	0	0	0	0	0	0.06162
Propane (air)	tons	0	0	0.10981	0	0	0	0	0	0.10981
Water Releases										
Arsenic (water)	tons	0	0	0	0	0	0	0	0	0
Benzene (water)	tons	0	0	0.00395	0	0	0	0	0	0.00395

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table F. Fuel Cycle Inventory: E95, Portland, OR continued

Inputs and Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Water Releases										
Boron (water)	tons	0	0	0.08768	0	0	0	0	0	0.08768
Chloride (water)	tons	0	0	58.6091	0	0	0	0	0	58.6091
Cr (water)	tons	0	0	0	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0.426	0	0.426	0	0.426
Insecticides (water)	tons	0	0	0	0	0.0213	0	0.0213	0	0.0213
Mobile ions (water)	tons	0	0	187.1945	0	0	0	0	0	187.1945
NO3N (water)	tons	0	0	0.00237	0	0	0	0	0	0.00237
N-Fertilizer (water)	tons	0	0	0	0	42.6	0	42.6	0	42.6
Oil & Grease (water)	tons	0	0	0.48032	0	0	0	0	0	0.48032
P2O5-Fertilizer (water)	tons	0	0	0	0	12.78	0	12.78	0	12.78
Phenols (water)	tons	0	0	0	0	0	0	0	0	0
Sodium (water)	tons	0	0	78.9148	0	0	0	0	0	78.9148
Soil (water)	tons	0	0	0	0	852	0	852	0	852
Sulfides (water)	tons	0	0	0	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	304.0221	0	0	0	0	0	304.0221
Thermal (water)		0	0	0	0	0	0	0	0	0
BOD (water)	tons	0	0	0.0158	0	0	0	0	0	0.0158
COD (water)	tons	0	0	364.4984	0	0	0	0	0	364.4984
K2O-Fertilizer (water)	tons	0	0	0	0	12.78	0	12.78	0	12.78
TOC (water)	tons	0	0	0.1185	0	0	0	0	0	0.1185
Groundwater Releases										
Herbicides (gw)	tons	0	0	0	0	0.3337	0	0.3337	0	0.3337
Insecticides (gw)	tons	0	0	0	0	0.0142	0	0.0142	0	0.0142
K2O-Fertilizer (gw)	tons	0	0	0	0	12.78	0	12.78	0	12.78
N-Fertilizer (gw)	tons	0	0	0	0	42.6	0	42.6	0	42.6
P2O5-Fertilizer (gw)	tons	0	0	0	0	12.78	0	12.78	0	12.78
Soil (gw)	tons	0	0	0	0	0	0	0	0	0
Land Concerns										
Herbicides (land)	tons	0	0	0	0	0.2059	0	0.2059	0	0.2059
Insecticides (land)	tons	0	0	0	0	0.0071	0	0.0071	0	0.0071
K2O-Fertilizer (land)	tons	0	0	0	0	12.78	0	12.78	0	12.78
N-Fertilizer (land)	tons	0	0	0	0	42.6	0	42.6	0	42.6
P2O5-Fertilizer (land)	tons	0	0	0	0	24.85	0	24.85	0	24.85
Formation Water	gallons	0	0	1910062	0	0	0	0	0	1910062
Sludge	tons	0	0	1207	0	0	0	0	0	1207
Soil (land)	tons	0	0	0	0	6532	0	6532	0	6532
Solid Waste	tons	0	0	11675.6	0	0	0	0	0	11675.6
Solid Waste (Haz.)	tons	0	0	23.7	0	0	0	0	0	23.7
Wastewater (Treated)	gallons	0	0	147071966	0	0	0	0	0	147071966

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table G. Fuel Cycle Inventory: E95 Lincoln, NE

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Inputs										
Crude oil	bbls	0	0	46294	0	0	0	0	0	46294
Diesel	gallons	0	92000	195876.75	166000	650720	650720	0	0	1104596.7
Diesel (No. 6)	gallons	0	0	27966	0	0	0	0	0	27966
Ethanol-10	gallons	0	0	0	0	0	0	0	0	0
Ethanol-95	gallons	35400000	0	0	0	0	0	0	0	35400000
Gasoline	gallons	0	0	1973000	0	0	0	0	0	1973000
Insecticides	tons	0	0	0	0	0.747	0.747	0	0	0.747
MTBE	gallons	0	0	0	0	0	0	0	0	0
Natural gas	mmscf	0	0	11.85	0	0	0	0	0	11.85
Refinery Products	gallons	0	0	0	0	0	0	0	0	0
Water	gallons	0	0	226708087	0	0	0	0	0	226708087
Electricity	kWh	0	13375000	-50484990	0	0	0	0	0	-37109990
Herbicides	tons	0	0	0	0	3.652	3.652	0	0	3.652
K2O-Fertilizer	tons	0	0	0	0	2365.5	2365.5	0	0	2365.5
N-Fertilizer	tons	0	0	0	0	2124.8	2124.8	0	0	2124.8
P2O5-Fertilizer	tons	0	0	0	0	1577	1577	0	0	1577
Antifoam	tons	0	0	14.94	0	0	0	0	0	14.94
CS Liquor	tons	0	0	239.04	0	0	0	0	0	239.04
Glucose	tons	0	0	473.1	0	0	0	0	0	473.1
H2SO4	tons	0	0	4399	0	0	0	0	0	4399
Lime	tons	0	0	3245.3	0	0	0	0	0	3245.3
Limestone	tons	0	0	813.4	0	0	0	0	0	813.4
NH3	tons	0	0	601.00	0	0	0	0	0	601
Nutrients	tons	0	0	68.89	0	0	0	0	0	68.89
BFW Chemicals										
Amine	tons	0	0	0.5395	0	0	0	0	0	0.5395
Hydrazine	tons	0	0	1.826	0	0	0	0	0	1.826
Na2PO4	tons	0	0	0.1826	0	0	0	0	0	0.1826
CW Chemicals										
Orthophosphate	tons	0	0	1.4525	0	0	0	0	0	1.4525
Phosphonate	tons	0	0	0.4316	0	0	0	0	0	0.4316
Polyphosphate	tons	0	0	1.4525	0	0	0	0	0	1.4525
Silicate	tons	0	0	1.162	0	0	0	0	0	1.162
Zinc	tons	0	0	0.747	0	0	0	0	0	0.747
WWT Chemicals										
Phosphate	tons	0	0	214.00	0	0	0	0	0	214
Polymer	tons	0	0	0	0	0	0	0	0	0
Urea	tons	0	0	544.00	0	0	0	0	0	544
Air Releases										
CO	tons	1871	3	101.575	5.81	55.61	55.61	0	0	2036.995
NOx	tons	220	8	79.634	5.81	55.61	55.61	0	0	369.054
PM (total)	tons	0	0.2	4.89206	0	5.81	5.81	0	0	10.90206
SOx	tons	3.9	0.3	29.68	0.83	2.49	2.49	0	0	37.2
CO_2 Fossil	tons	16672	1000	3981.6	1826	7387	7387	0	0	30866.6
CO_2 Organic	tons	214028	0	280955	174881	-631796	-631796	0	0	38068

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table G. Fuel Cycle Inventory: E95 Lincoln, NE continued

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Air Releases										
NH3 (air)	tons	0	0	9.462	0	0	0	0	0	9.462
Cd (air)	tons	0	0	0	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0	0	0	0
HCl	tons	0	0	0	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0.581	0.581	0	0	0.581
K2O-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	212.48	212.48	0	0	212.48
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	42828	42828	0	0	42828
Herbicides (air)	tons	0	0	0	0	2.6477	2.6477	0	0	2.6477
VOC (total)	tons	176	19	19.879	1.66	12.45	12.45	0	0	228.989
VOC-exhaust	tons	99	1	0.395	1.66	12.45	12.45	0	0	114.505
VOC-engine evap	tons	77	0	0	0	0	0	0	0	77
Crude oil (air)	tons	0	0	0.632	0	0	0	0	0	0.632
Diesel (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	3.32	0	0	0	0	0	3.32
Ethanol-95 (air)	tons	0	18	0	0	0	0	0	0	18
Gasoline (air)	tons	0	0	0	0	0	0	0	0	0
Hydrocarbons	tons	0	0	0.316	0	0	0	0	0	0.316
Acetaldehyde (air)	tons	0.56	0	0.2324	0	0	0	0	0	0.7924
Acetone (air)	tons	0	0	0.00237	0	0	0	0	0	0.00237
Benzene	tons	0.19	0	0.00079	0	0	0	0	0	0.19079
Butadiene (air)	tons	0.02	0	0	0	0	0	0	0	0.02
Butane (iso) (air)	tons	0	0	0.00474	0	0	0	0	0	0.00474
Butane (n) air	tons	0	0	0.08137	0	0	0	0	0	0.08137
Cycloparaffins (C-7)	tons	0	0	0.01738	0	0	0	0	0	0.01738
Cycloparaffins (C-8)	tons	0	0	0.00632	0	0	0	0	0	0.00632
Ethane (air)	tons	0	0	0.06952	0	0	0	0	0	0.06952
Formaldehyde (air)	tons	0.19	0	0.1735	0	0	0	0	0	0.3635
Heptane (air)	tons	0	0	0.12719	0	0	0	0	0	0.12719
Hexane (air)	tons	0	0	0.09796	0	0	0	0	0	0.09796
Isoprene (air)	tons	0	0	0	0	0	0	0	0	0
Methane (air)	tons	0	0	0.40132	0	0	0	0	0	0.40132
Monoprene (air)	tons	0	0	0	0	0	0	0	0	0
Octane (air)	tons	0	0	0.08532	0	0	0	0	0	0.08532
Pentane (air)	tons	0	0	0.06162	0	0	0	0	0	0.06162
Propane (air)	tons	0	0	0.10981	0	0	0	0	0	0.10981
Water Releases										
Arsenic (water)	tons	0	0	0	0	0	0	0	0	0
Benzene (water)	tons	0	0	0.00395	0	0	0	0	0	0.00395

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table G. Fuel Cycle Inventory: E95 Lincoln, NE continued

Inputs or Outputs	Units	End-Use	E95 Dist.	E95 Prodtn.	Fdstk S&T	Aggregate Fdstk	Grass Fdstk	Tree Fdstk	Cane Fdstk	Grand Total
Water Releases										
Boron (water)	tons	0	0	0.08058	0	0	0	0	0	0.08058
Chloride (water)	tons	0	0	58.6343	0	0	0	0	0	58.6343
Cr (water)	tons	0	0	0	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0.3735	0.3735	0	0	0.3735
Insecticides (water)	tons	0	0	0	0	0.0747	0.0747	0	0	0.0747
Mobile ions (water)	tons	0	0	187.1968	0	0	0	0	0	187.1968
NO3N (water)	tons	0	0	0.00237	0	0	0	0	0	0.00237
N-Fertilizer (water)	tons	0	0	0	0	106.24	106.24	0	0	106.24
Oil & Grease (water)	tons	0	0	0.48032	0	0	0	0	0	0.48032
P2O5-Fertilizer (water)	tons	0	0	0	0	78.85	78.85	0	0	78.85
Phenols (water)	tons	0	0	0	0	0	0	0	0	0
Sodium (water)	tons	0	0	78.9004	0	0	0	0	0	78.9004
Soil (water)	tons	0	0	0	0	10707	10707	0	0	10707
Sulfides (water)	tons	0	0	0	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	235.6251	0	0	0	0	0	235.6251
Thermal (water)										
BOD (water)	tons	0	0	0.0158	0	0	0	0	0	0.0158
COD (water)	tons	0	0	283.5714	0	0	0	0	0	283.5714
K2O-Fertilizer (water)	tons	0	0	0	0	117.86	117.86	0	0	117.86
TOC (water)	tons	0	0	0.1185	0	0	0	0	0	0.1185
Groundwater Releases										
Herbicides (gw)	tons	0	0	0	0	0.2905	0.2905	0	0	0.2905
Insecticides (gw)	tons	0	0	0	0	0.0664	0.0664	0	0	0.0664
K2O-Fertilizer (gw)	tons	0	0	0	0	117.86	117.86	0	0	117.86
N-Fertilizer (gw)	tons	0	0	0	0	106.24	106.24	0	0	106.24
P2O5-Fertilizer (gw)	tons	0	0	0	0	78.85	78.85	0	0	78.85
Soil (gw)	tons	0	0	0	0	0	0	0	0	0
Land Concerns										
Herbicides (land)	tons	0	0	0	0	0.1826	0.1826	0	0	0.1826
Insecticides (land)	tons	0	0	0	0	0.0415	0.0415	0	0	0.0415
K2O-Fertilizer (land)	tons	0	0	0	0	117.86	117.86	0	0	117.86
N-Fertilizer (land)	tons	0	0	0	0	106.24	106.24	0	0	106.24
P2O5-Fertilizer (land)	tons	0	0	0	0	157.7	157.7	0	0	157.7
Formation Water	gallons	0	0	1910062	0	0	0	0	0	1910062
Sludge	tons	0	0	747	0	0	0	0	0	747
Soil (land)	tons	0	0	0	0	53535	53535	0	0	53535
Solid Waste	tons	0	0	23686.6	0	0	0	0	0	23686.6
Solid Waste (Haz.)	tons	0	0	23.7	0	0	0	0	0	23.7
Wastewater (Treated)	gallons	0	0	114228462	0	0	0	0	0	114228462

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table H. Fuel Cycle Inventory: Reformulated Gasoline, 2010

Inputs and Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Inputs							
Crude oil	bbls	0	0	0	0	586000	586000
Diesel	gallons	0	41000	0	6000	0	47000
Diesel (No. 6)	gallons	0	48000	0	354000	0	402000
Ethanol-10	gallons	0	0	0	0	0	0
Ethanol-95	gallons	0	0	0	0	0	0
Gasoline	gallons	24980000	0	0	0	0	0
Insecticides	tons	0	0	0	0	0	0
MTBE	gallons	3120000	0	3.12E+06	0	0	3.12E+06
Natural gas	mmscf	0	0	150	0	0	150
Refinery Products	gallons	0	0	0	0	0	0
Water	gallons	0	0	0	0	213000	213000
Electricity	kWh	0	1.76E+07	3.91E+06	6.93E+06	3.35E+06	3.18E+07
Herbicides	tons	0	0	0	0	0	0
K2O-Fertilizer	tons	0	0	0	0	0	0
N-Fertilizer	tons	0	0	0	0	0	0
P2O5-Fertilizer	tons	0	0	0	0	0	0
Antifoam	tons	0	0	0	0	0	0
CS Liquor	tons	0	0	0	0	0	0
Glucose	tons	0	0	0	0	0	0
H2SO4	tons	0	0	0	0	0	0
Lime	tons	0	0	0	0	0	0
Limestone	tons	0	0	0	0	0	0
NH3	tons	0	0	0	0	0	0
Nutrients	tons	0	0	0	0	0	0
BFW Chemicals							
Amine	tons	0	0	0	0	0	0
Hydrazine	tons	0	0	0	0	0	0
Na2PO4	tons	0	0	0	0	0	0
CW Chemicals							0
Orthophosphate	tons	0	0	0	0	0	0
Phosphonate	tons	0	0	0	0	0	0
Polyphosphate	tons	0	0	0	0	0	0
Silicate	tons	0	0	0	0	0	0
Zinc	tons	0	0	0	0	0	0
WWT Chemicals							
Phosphate	tons	0	0	0	0	0	0
Polymer	tons	0	0	0	0	0	0
Urea	tons	0	0	0	0	0	0
Air Releases							
CO	tons	1874	3	8	10	7	1902
NOx	tons	220	5	72	23	41	361
PM (total)	tons	0	0.2	2.3	1.06	0.78	4.34
SOx	tons	44.1	0.32	44	1	5	94.42
CO_2 Fossil	tons	267900	1100	29700	4500	16200	319400
CO_2 Organic	tons	0	0	0	0	0	0

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table H. Fuel Cycle Inventory: Reformulated Gasoline, 2010 continued

Inputs and Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Air Releases							
NH3 (air)	tons	0	0	0	0	0	0
Cd (air)	tons	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0
HCl (air)	tons	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0	0
K2O-Fertilizer (air)	tons	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	0	0
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	0	0
Herbicides (air)	tons	0	0	0	0	0	0
VOC (total)	tons	198	39	4	13	14	268
VOC-exhaust	tons	99	1	0	5	0	105
VOC-engine evap	tons	99	0	0	0	0	99
Crude oil (air)	tons	0	0	0	8	0	8
Diesel (air)	tons	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	0	0	0	0
Ethanol-95 (air)	tons	0	0	0	0	0	0
Gasoline (air)	tons	0	38	0	0	0	38
Hydrocarbons	tons	0	0	4	0	0	4
Acetaldehyde (air)	tons	0.07	0	0	0	0	0.07
Acetone (air)	tons	0	0	0	0	0.03	0.03
Benzene (air)	tons	0.41	0	0	0	0.01	0.42
Butadiene (air)	tons	0.06	0	0	0	0	0.06
Butane (iso) (air)	tons	0	0	0	0	0.06	0.06
Butane (n) (air)	tons	0	0	0	0	1.03	1.03
Cycloparaffins (C-7)	tons	0	0	0	0	0.22	0.22
Cycloparaffins (C-8)	tons	0	0	0	0	0.08	0.08
Ethane (air)	tons	0	0	0	0	0.88	0.88
Formaldehyde (air)	tons	0.1	0	0	0	0.2	0.3
Heptane (air)	tons	0	0	0	0	1.61	1.61
Hexane (air)	tons	0	0	0	0	1.24	1.24
Isoprene (air)	tons	0	0	0	0	0	0
Methane (air)	tons	0	0	0	0	5.08	5.08
Monoprene (air)	tons	0	0	0	0	0	0
Octane (air)	tons	0	0	0	0	1.08	1.08
Pentane (air)	tons	0	0	0	0	0.78	0.78
Propane (air)	tons	0	0	0	0	1.39	1.39
Water Releases							
Arsenic (water)	tons	0	0	0	0	0	0
Benzene (water)	tons	0	0	0	0	0.05	0.05

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table H. Fuel Cycle Inventory: Reformulated Gasoline, 2010 continued

Inputs and Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Water Releases							
Boron (water)	tons	0	0	0	0	1.02	1.02
Chloride (water)	tons	0	0	0	0	740	740
Cr (water)	tons	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0	0
Insecticides (water)	tons	0	0	0	0	0	0
Mobile ions (water)	tons	0	0	0	0	2370	2370
NO3N (water)	tons	0	0	0.03	0	0	0.03
N-Fertilizer (water)	tons	0	0	0	0	0	0
Oil & Grease (water)	tons	0	0	0.08	0	6	6.08
P2O5-Fertilizer (water)	tons	0	0	0	0	0	0
Phenols (water)	tons	0	0	0	0	0	0
Sodium (water)	tons	0	0	0	0	1000	1000
Soil (water)	tons	0	0	0	0	0	0
Sulfides (water)	tons	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	0.9	0	0	0.9
Thermal (water)		0	0	0	0	0	0
BOD (water)	tons	0	0	0.2	0	0	0.2
COD (water)	tons	0	0	1.6	0	0	1.6
K2O-Fertilizer (water)	tons	0	0	0	0	0	0
TOC (water)	tons	0	0	1.5	0	0	1.5
Groundwater Releases							
Herbicides (gw)	tons	0	0	0	0	0	0
Insecticides (gw)	tons	0	0	0	0	0	0
K2O-Fertilizer (gw)	tons	0	0	0	0	0	0
N-Fertilizer (gw)	tons	0	0	0	0	0	0
P2O5-Fertilizer (gw)	tons	0	0	0	0	0	0
Soil (gw)	tons	0	0	0	0	0	0
Land Concerns							
Herbicides (land)	tons	0	0	0	0	0	0
Insecticides (land)	tons	0	0	0	0	0	0
K2O-Fertilizer (land)	tons	0	0	0	0	0	0
N-Fertilizer (land)	tons	0	0	0	0	0	0
P2O5-Fertilizer (land)	tons	0	0	0	0	0	0
Formation Water	gallons	0	0	0	0	2.42E+07	2.42E+07
Sludge	tons	0	0	0	0	0	0
Soil (land)	tons	0	0	0	0	0	0
Solid Waste	tons	0	0	400	0	0	400
Solid Waste (Haz)	tons	0	0	200	0	100	300
Wastewater (Treated)	gallons	0	0	1.49E+07	0	0	1.49E+07

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table I. Fuel Cycle Inventory for the 5% Gasoline in E95 Fuels

Inputs or Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Inputs							
Crude oil	bbls	0	0	46,294	0	0	46294
Diesel	gallons	0	0	474	0	0	474
Diesel (No. 6)	gallons	0	0	27,966	0	0	27,966
Ethanol-10	gallons	0	0	0	0	0	0
Ethanol-95	gallons	0	0	0	0	0	0
Gasoline	gallons	0	0	1,973,000	0	0	1973000
Insecticides	tons	0	0	0	0	0	0
MTBE	gallons	0	0	0	0	0	0
Natural gas	mmscf	0	0	12	0	0	11.85
Refinery Products	gallons	0	0	0	0	0	0
Water	gallons	0	0	16,827	0	0	16,827
Electricity	kWh	0	0	1,121,010	0	0	1,121,010
Herbicides	tons	0	0	0	0	0	0
K2O-Fertilizer	tons	0	0	0	0	0	0
N-Fertilizer	tons	0	0	0	0	0	0
P2O5-Fertilizer	tons	0	0	0	0	0	0
Antifoam	tons	0	0	0	0	0	0
CS Liquor	tons	0	0	0	0	0	0
Glucose	tons	0	0	0	0	0	0
H2SO4	tons	0	0	0	0	0	0
Lime	tons	0	0	0	0	0	0
Limestone	tons	0	0	0	0	0	0
NH3	tons	0	0	0	0	0	0
Nutrients	tons	0	0	0	0	0	0
BFW Chemicals							
Amine	tons	0	0	0	0	0	0
Hydrazine	tons	0	0	0	0	0	0
Na2PO4	tons	0	0	0	0	0	0
CW Chemicals							
Orthophosphate	tons	0	0	0	0	0	0
Phosphonate	tons	0	0	0	0	0	0
Polyphosphate	tons	0	0	0	0	0	0
Silicate	tons	0	0	0	0	0	0
Zinc	tons	0	0	0	0	0	0
WWT Chemicals							
Phosphate	tons	0	0	0	0	0	0
Polymer	tons	0	0	0	0	0	0
Urea	tons	0	0	0	0	0	0
Air Releases							
CO	tons	0	0	1.975	0	0	1.98
NOx	tons	0	0	10.744	0	0	10.74
PM (total)	tons	0	0	0.327	0	0	0.33
SOx	tons	0	0	3.950	0	0	3.95
CO_2 Fossil	tons	0	0	3,982	0	0	3,982
CO_2 Organic	tons	0	0	0	0	0	0

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table I. Fuel Cycle Inventory for the 5% Gasoline in E95 Fuels continued

Inputs or Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Air Emissions							
NH3 (air)	tons	0	0	0	0	0	0
Cd (air)	tons	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0
HCl (air)	tons	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0	0
K2O-Fertilizer (air)	tons	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	0	0
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	0	0
Herbicides (air)	tons	0	0	0	0	0	0
VOC (total)	tons	0	0	2.45	0	0	2.45
VOC-exhaust	tons	0	0	0.40	0	0	0.40
VOC-engine evap	tons	0	0	0	0	0	0
Crude oil (air)	tons	0	0	0.63	0	0	0.63
Diesel (air)	tons	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	0	0	0	0
Ethanol-95 (air)	tons	0	0	0	0	0	0
Gasoline (air)	tons	0	0	0	0	0	0
Hydrocarbons	tons	0	0	0.32	0	0	0.32
Acetaldehyde (air)	tons	0	0	0	0	0	0
Acetone (air)	tons	0	0	0	0	0	0.002
Benzene (air)	tons	0	0	0	0	0	0.001
Butadiene (air)	tons	0	0	0	0	0	0
Butane (iso) (air)	tons	0	0	0	0	0	0.005
Butane (n) (air)	tons	0	0	0.08	0	0	0.081
Cycloparaffins (C-7)	tons	0	0	0.02	0	0	0.017
Cycloparaffins (C-8)	tons	0	0	0.01	0	0	0.006
Ethane (air)	tons	0	0	0.07	0	0	0.070
Formaldehyde (air)	tons	0	0	0.02	0	0	0.016
Heptane (air)	tons	0	0	0.13	0	0	0.127
Hexane (air)	tons	0	0	0.10	0	0	0.098
Isoprene (air)	tons	0	0	0	0	0	0
Methane (air)	tons	0	0	0.40	0	0	0.40
Monoprene (air)	tons	0	0	0	0	0	0
Octane (air)	tons	0	0	0.09	0	0	0.09
Pentane (air)	tons	0	0	0.06	0	0	0.06
Propane (air)	tons	0	0	0.11	0	0	0.11
Water Releases							
Arsenic (water)	tons	0	0	0	0	0	0
Benzene (water)	tons	0	0	0	0	0	0.004

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table I. Fuel Cycle Inventory for the 5% Gasoline in E95 Fuels continued

Inputs or Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Water Releases							
Boron (water)	tons	0	0	0.08	0	0	0.08
Chloride (water)	tons	0	0	58	0	0	58.46
Cr (water)	tons	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0	0
Insecticides (water)	tons	0	0	0	0	0	0
Mobile ions (water)	tons	0	0	187.23	0	0	187.23
NO3N (water)	tons	0	0	0	0	0	0.002
N-Fertilizer (water)	tons	0	0	0	0	0	0
Oil & Grease (water)	tons	0	0	0.48	0	0	0.48
P2O5-Fertilizer (water)	tons	0	0	0	0	0	0
Phenols (water)	tons	0	0	0	0	0	0
Sodium (water)	tons	0	0	79.00	0	0	79
Soil (water)	tons	0	0	0	0	0	0
Sulfides (water)	tons	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	0.07	0	0	0.07
Thermal (water)		0	0	0	0	0	0
BOD (water)	tons	0	0	0.02	0	0	0.02
COD (water)	tons	0	0	0.13	0	0	0.13
K2O-Fertilizer (water)	tons	0	0	0	0	0	0
TOC (water)	tons	0	0	0.12	0	0	0.12
Groundwater Releases							
Herbicides (gw)	tons	0	0	0	0	0	0
Insecticides (gw)	tons	0	0	0	0	0	0
K2O-Fertilizer (gw)	tons	0	0	0	0	0	0
N-Fertilizer (gw)	tons	0	0	0	0	0	0
P2O5-Fertilizer (gw)	tons	0	0	0	0	0	0
Soil (gw)	tons	0	0	0	0	0	0
Land Concerns							
Herbicides (land)	tons	0	0	0	0	0	0
Insecticides (land)	tons	0	0	0	0	0	0
K2O-Fertilizer (land)	tons	0	0	0	0	0	0
N-Fertilizer (land)	tons	0	0	0	0	0	0
P2O5-Fertilizer (land)	tons	0	0	0	0	0	0
Formation Water	gallons	0	0	1,910,062	0	0	1,910,062
Sludge	tons	0	0	0	0	0	0
Soil (land)	tons	0	0	0	0	0	0
Solid Waste	tons	0	0	31.60	0	0	31.6
Solid Waste (Haz)	tons	0	0	23.70	0	0	23.7
Wastewater (Treated)	gallons	0	0	1,179,391	0	0	1,179,391

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table J. Fuel Cycle Inventory: E10 without Gasoline Fuel Cycle Emissions

Inputs or Outputs	Units	End-Use	E10/ E95 Dist.	E95 Prodtn.	MSW Trans	MSW Sort	MSW Collctn	Grand Total
Inputs								
Crude oil	bbls	0	0	0	0	0	0	0
Diesel	gallons	0	37000	4350	16530	6090	18270	82240
Diesel (No. 6)	gallons	0	0	0	0	0	0	0
Ethanol-10	gallons	33100000	0	0	0	0	0	33100000
Ethanol-95	gallons	0	3484210	0	0	0	0	3484210
Gasoline	gallons	0	29615790	174210	0	0	0	29790000
Insecticides	tons	0	0	0	0	0	0	0
MTBE	gallons	0	0	0	0	0	0	0
Natural gas	mmscf	0	0	0	0	0	0	0
Refinery Products	gallons	0	0	0	0	0	0	0
Water	gallons	0	0	30828450	0	0	0	30828450
Electricity	kWh	0	9579000	-3498000	214890	1295430	0	7591320
Herbicides	tons	0	0	0	0	0	0	0
K2O-Fertilizer	tons	0	0	0	0	0	0	0
N-Fertilizer	tons	0	0	0	0	0	0	0
P2O5-Fertilizer	tons	0	0	0	0	0	0	0
Antifoam	tons	0	0	3.48	0	0	0	3.48
CS Liquor	tons	0	0	57.42	0	0	0	57.42
Glucose	tons	0	0	69.6	0	0	0	69.6
H2SO4	tons	0	0	522	0	0	0	522
Lime	tons	0	0	382.8	0	0	0	382.8
Limestone	tons	0	0	78.3	0	0	0	78.3
NH3	tons	0	0	84	0	0	0	84
Nutrients	tons	0	0	16.53	0	0	0	16.53
BFW Chemicals		0	0	0	0	0	0	0
Amine	tons	0	0	0.0609	0	0	0	0.0609
Hydrazine	tons	0	0	0.174	0	0	0	0.174
Na2PO4	tons	0	0	0.0174	0	0	0	0.0174
CW Chemicals		0	0	0	0	0	0	0
Orthophosphate	tons	0	0	0.2001	0	0	0	0.2001
Phosphonate	tons	0	0	0.0609	0	0	0	0.0609
Polyphosphate	tons	0	0	0.2001	0	0	0	0.2001
Silicate	tons	0	0	0.1653	0	0	0	0.1653
Zinc	tons	0	0	0.087	0	0	0	0.087
WWT Chemicals		0	0	0	0	0	0	0
Phosphate	tons	0	0	10.8	0	0	0	10.8
Polymer	tons	0	0	0	0	0	0	0
Urea	tons	0	0	28	0	0	0	28
		0	0	0	0	0	0	
Air Releases		0	0	0	0	0	0	
CO	tons	2311	4	10.44	0.87	0	0.87	2327.18
NOx	tons	440	15	6.09	2.61	0.87	0.87	465.44
PM (total)	tons	0	0	0.522	0	0	0	0.522
SOx	tons	45	0	2.61	0	0	0	47.61
CO_2 Fossil	tons	289368	1300	0	174	87	174	291103
CO_2 Organic	tons	17432	0	30798	0	0	0	48230

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table J. Fuel Cycle Inventory: E10 without Gasoline Fuel Cycle Emissions continued

Inputs or Outputs	Units	End-Use	E10/ E95 Dist.	E95 Prodtn.	MSW Trans	MSW Sort	MSW Collctn	Grand Total
Air Emissions								
NH3 (air)	tons	0	0	1.044	0	0	0	1.044
Cd (air)	tons	0	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0	0
HCl	tons	0	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0	0	0
K2O-Fertilizer (air)	tons	0	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	0	0	0
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	0	0	0
Herbicides (air)	tons	0	0	0	0	0	0	0
VOC (total)	tons	419	48	1.74	0	0	0	468.74
VOC-exhaust	tons	209	12	0	0	0	0	221
VOC-engine evap	tons	209	0	0	0	0	0	209
Crude oil (air)	tons	0	0	0	0	0	0	0
Diesel (air)	tons	0	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	34	0	0	0	0	34
Ethanol-100 (air)	tons	0	0	0	0	0	0	0
Ethanol-95 (air)	tons	0	2	0	0	0	0	2
Gasoline (air)	tons	0	0	0	0	0	0	0
Hydrocarbons	tons	0	0	0	0	0	0	0
Acetaldehyde (air)	tons	0.46	0	0.0261	0	0	0	0.4861
Acetone (air)	tons	0	0	0	0	0	0	0
Benzene	tons	0.94	0	0	0	0	0	0.94
Butadiene (air)	tons	0.12	0	0	0	0	0	0.12
Butane (iso) (air)	tons	0	0	0	0	0	0	0
Butane (n) air	tons	0	0	0	0	0	0	0
Cycloparaffins (C-7)	tons	0	0	0	0	0	0	0
Cycloparaffins (C-8)	tons	0	0	0	0	0	0	0
Ethane (air)	tons	0	0	0	0	0	0	0
Formaldehyde (air)	tons	0.53	0	0.0174	0	0	0	0.5474
Heptane (air)	tons	0	0	0	0	0	0	0
Hexane (air)	tons	0	0	0	0	0	0	0
Isoprene (air)	tons	0	0	0	0	0	0	0
Methane (air)	tons	0	0	0	0	0	0	0
Monoprene (air)	tons	0	0	0	0	0	0	0
Octane (air)	tons	0	0	0	0	0	0	0
Pentane (air)	tons	0	0	0	0	0	0	0
Propane (air)	tons	0	0	0	0	0	0	0
		0	0	0	0	0	0	0
Water Releases		0	0	0	0	0	0	0
Arsenic (water)	tons	0	0	0	0	0	0	0
Benzene (water)	tons	0	0	0	0	0	0	0

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table J. Fuel Cycle Inventory: E10 without Gasoline Fuel Cycle Emissions continued

Inputs or Outputs	Units	End-Use	E10/ E95 Dist.	E95 Prodtn.	MSW Trans	MSW Sort	MSW Collctn	Grand Total
Water Releases								
Boron (water)	tons	0	0	0	0	0	0	0
Chloride (water)	tons	0	0	0	0	0	0	0
Cr (water)	tons	0	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0	0	0
Insecticides (water)	tons	0	0	0	0	0	0	0
Mobile ions (water)	tons	0	0	0	0	0	0	0
NO3N (water)	tons	0	0	0	0	0	0	0
N-Fertilizer (water)	tons	0	0	0	0	0	0	0
Oil & Grease (water)	tons	0	0	0	0	0	0	0
P2O5-Fertilizer (water)	tons	0	0	0	0	0	0	0
Phenols (water)	tons	0	0	0	0	0	0	0
Sodium (water)	tons	0	0	0	0	0	0	0
Soil (water)	tons	0	0	0	0	0	0	0
Sulfides (water)	tons	0	0	0	0	0	0	0
Susp. Solids (water)	tons	0	0	33.321	0	0	0	33.321
Thermal (water)		0	0	0	0	0	0	0
BOD (water)	tons	0	0	0	0	0	0	0
COD (water)	tons	0	0	39.672	0	0	0	39.672
K2O-Fertilizer (water)	tons	0	0	0	0	0	0	0
TOC (water)	tons	0	0	0	0	0	0	0
		0	0	0	0	0	0	0
Groundwater Releases		0	0	0	0	0	0	0
Herbicides (gw)	tons	0	0	0	0	0	0	0
Insecticides (gw)	tons	0	0	0	0	0	0	0
K2O-Fertilizer (gw)	tons	0	0	0	0	0	0	0
N-Fertilizer (gw)	tons	0	0	0	0	0	0	0
P2O5-Fertilizer (gw)	tons	0	0	0	0	0	0	0
Soil (gw)	tons	0	0	0	0	0	0	0
		0	0	0	0	0	0	0
Land Concerns		0	0	0	0	0	0	0
Herbicides (land)	tons	0	0	0	0	0	0	0
Insecticides (land)	tons	0	0	0	0	0	0	0
K2O-Fertilizer (land)	tons	0	0	0	0	0	0	0
N-Fertilizer (land)	tons	0	0	0	0	0	0	0
P2O5-Fertilizer (land)	tons	0	0	0	0	0	0	0
Formation Water	gallons	0	0	0	0	0	0	0
Sludge	tons	0	0	0	0	0	0	0
Soil (land)	tons	0	0	0	0	0	0	0
Solid Waste	tons	0	0	5568	0	-30450	0	-24882
Solid Waste (Haz.)	tons	0	0	0	0	0	0	0
Wastewater (Treated)	gallons	0	0	15913170	0	3630423	0	19543593

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table K. Fuel Cycle Inventory: Gasoline Fuel Cycle Inventory added to the E10 Fuel Cycle Inventory

Inputs or Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Inputs							
Crude oil	bbls	0	681360	4008	0	0	685368
Diesel	gallons	0	57120	36	0	0	57156
Diesel (No. 6)	gallons	0	442680	2268	0	0	444948
Ethanol-10	gallons	0	0	0	0	0	0
Ethanol-95	gallons	0	0	0	0	0	0
Gasoline	gallons	0	0	0	0	0	0
Insecticides	tons	0	0	0	0	0	0
MTBE	gallons	0	0	21678	0	0	21678
Natural gas	mmscf	0	163.2	0.96	0	0	164.16
Refinery Products	gallons	0	0	0	0	0	0
Water	gallons	0	143820	846	0	0	144666
Electricity	kWh	0	36383400	91800	0	0	36475200
Herbicides	tons	0	0	0	0	0	0
K2O-Fertilizer	tons	0	0	0	0	0	0
N-Fertilizer	tons	0	0	0	0	0	0
P2O5-Fertilizer	tons	0	0	0	0	0	0
Antifoam	tons	0	0	0	0	0	0
CS Liquor	tons	0	0	0	0	0	0
Glucose	tons	0	0	0	0	0	0
H2SO4	tons	0	0	0	0	0	0
Lime	tons	0	0	0	0	0	0
Limestone	tons	0	0	0	0	0	0
NH3	tons	0	0	0	0	0	0
Nutrients	tons	0	0	0	0	0	0
BFW Chemicals		0	0	0	0	0	0
Amine	tons	0	0	0	0	0	0
Hydrazine	tons	0	0	0	0	0	0
Na2PO4	tons	0	0	0	0	0	0
CW Chemicals		0	0	0	0	0	0
Orthophosphate	tons	0	0	0	0	0	0
Phosphonate	tons	0	0	0	0	0	0
Polyphosphate	tons	0	0	0	0	0	0
Silicate	tons	0	0	0	0	0	0
Zinc	tons	0	0	0	0	0	0
WWT Chemicals		0	0	0	0	0	0
Phosphate	tons	0	0	0	0	0	0
Polymer	tons	0	0	0	0	0	0
Urea	tons	0	0	0	0	0	0
		0	0	0	0	0	0
Air Releases		0	0	0	0	0	0
CO	tons	0	37.74	0.192	0	0	37.932
NOx	tons	0	164.22	0.912	0	0	165.132
PM (total)	tons	0	4.998	0.02748	0	0	5.02548
SOx	tons	0	49.3476	0.288	0	0	49.6356
CO_2 Fossil	tons	0	49674	284.4	0	0	49958.4
CO_2 Organic	tons	0	0	0	0	0	0

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table K. Fuel Cycle Inventory: Gasoline Fuel Cycle Inventory added to the E10 Fuel Cycle Inventory continued

Inputs or Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Air Releases							
NH3 (air)	tons	0	0	0	0	0	0
Cd (air)	tons	0	0	0	0	0	0
Cr (air)	tons	0	0	0	0	0	0
Hg (air)	tons	0	0	0	0	0	0
Ni (air)	tons	0	0	0	0	0	0
Pb (air)	tons	0	0	0	0	0	0
HCl (air)	tons	0	0	0	0	0	0
Insecticides (air)	tons	0	0	0	0	0	0
K2O-Fertilizer (air)	tons	0	0	0	0	0	0
N-Fertilizer (air)	tons	0	0	0	0	0	0
P2O5-Fertilizer (air)	tons	0	0	0	0	0	0
Soil (air)	tons	0	0	0	0	0	0
Herbicides (air)	tons	0	0	0	0	0	0
VOC (total)	tons	0	79.56	0.186	0	0	79.746
VOC-exhaust	tons	0	9.18	0.042	0	0	9.222
VOC-engine evap	tons	0	0	0	0	0	0
Crude oil (air)	tons	0	9.18	0.054	0	0	9.234
Diesel (air)	tons	0	0	0	0	0	0
Ethanol-10 (air)	tons	0	0	0	0	0	0
Ethanol-100 (air)	tons	0	0	0	0	0	0
Ethanol-95 (air)	tons	0	0	0	0	0	0
Gasoline (air)	tons	0	45.9	0	0	0	45.9
Hydrocarbons	tons	0	9.18	0.054	0	0	9.234
Acetaldehyde (air)	tons	0	0	0	0	0	0
Acetone (air)	tons	0	0.0204	0.00012	0	0	0.02052
Benzene (air)	tons	0	0.0204	0.00012	0	0	0.02052
Butadiene (air)	tons	0	0	0	0	0	0
Butane (iso) (air)	tons	0	0.0612	0.00036	0	0	0.06156
Butane (n) (air)	tons	0	1.1832	0.00696	0	0	1.19016
Cycloparaffins (C-7)	tons	0	0.255	0.0015	0	0	0.2565
Cycloparaffins (C-8)	tons	0	0.969	0.0057	0	0	0.9747
Ethane (air)	tons	0	1.02	0.006	0	0	1.026
Formaldehyde (air)	tons	0	0.2346	0.00138	0	0	0.23598
Heptane (air)	tons	0	1.8462	0.01086	0	0	1.85706
Hexane (air)	tons	0	1.3974	0.00822	0	0	1.40562
Isoprene (air)	tons	0	0	0	0	0	0
Methane (air)	tons	0	5.712	0.0336	0	0	5.7456
Monoprene (air)	tons	0	0	0	0	0	0
Octane (air)	tons	0	1.224	0.0072	0	0	1.2312
Pentane (air)	tons	0	0.8874	0.00522	0	0	0.89262
Propane (air)	tons	0	1.6116	0.00948	0	0	1.62108
		0	0	0	0	0	0
Water Releases		0	0	0	0	0	0
Arsenic (water)	tons	0	0	0	0	0	0
Benzene (water)	tons	0	0.0612	0.00036	0	0	0.06156

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table K. Fuel Cycle Inventory: Gasoline Fuel Cycle Inventory added to the E10 Fuel Cycle Inventory continued

Inputs or Outputs	Units	End-Use	Gas Dist.	Crude Refining	Crude Trans	Crude Prod.	Grand Total
Water Releases							
Boron (water)	tons	0	1.3566	0.00798	0	0	1.36458
Chloride (water)	tons	0	999.6	5.88	0	0	1005.48
Cr (water)	tons	0	0	0	0	0	0
Herbicides (water)	tons	0	0	0	0	0	0
Insecticides (water)	tons	0	0	0	0	0	0
Mobile ions (water)	tons	0	3151.8	18.54	0	0	3170.34
NO3N (water)	tons	0	0.0306	0.00018	0	0	0.03078
N-Fertilizer (water)	tons	0	0	0	0	0	0
Oil & Grease (water)	tons	0	7.2318	0.04254	0	0	7.27434
P2O5-Fertilizer (water)	tons	0	0	0	0	0	0
Phenols (water)	tons	0	0	0	0	0	0
Sodium (water)	tons	0	1326	7.8	0	0	1333.8
Soil (water)	tons	0	0	0	0	0	0
Sulfides (water)	tons	0	0	0	0	0	0
Susp. Solids (water)	tons	0	1.122	0.0066	0	0	1.1286
Thermal (water)		0	0	0	0	0	0
BOD (water)	tons	0	0.204	0.0012	0	0	0.2052
COD (water)	tons	0	2.142	0.0126	0	0	2.1546
K2O-Fertilizer (water)	tons	0	0	0	0	0	0
TOC (water)	tons	0	1.734	0.0102	0	0	1.7442
		0	0	0	0	0	0
Groundwater Releases		0	0	0	0	0	0
Herbicides (gw)	tons	0	0	0	0	0	0
Insecticides (gw)	tons	0	0	0	0	0	0
K2O-Fertilizer (gw)	tons	0	0	0	0	0	0
N-Fertilizer (gw)	tons	0	0	0	0	0	0
P2O5-Fertilizer (gw)	tons	0	0	0	0	0	0
Soil (gw)	tons	0	0	0	0	0	0
		0	0	0	0	0	0
Land Concerns		0	0	0	0	0	0
Herbicides (land)	tons	0	0	0	0	0	0
Insecticides (land)	tons	0	0	0	0	0	0
K2O-Fertilizer (land)	tons	0	0	0	0	0	0
N-Fertilizer (land)	tons	0	0	0	0	0	0
P2O5-Fertilizer (land)	tons	0	0	0	0	0	0
Formation Water	gallons	0	33061260	194478	0	0	33255738
Sludge	tons	0	0	0	0	0	0
Soil (land)	tons	0	0	0	0	0	0
Solid Waste	tons	0	408	2.4	0	0	410.4
Solid Waste (Haz)	tons	0	408	2.4	0	0	410.4
Wastewater (Treated)	gallons	0	14040300	82590	0	0	14122890

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table L. Energy Balances Base Cases

		E95		MSW		REFORM		REFORM.	
		Averages				GASOLINE		GASOLINE	
INPUTS AND OUTPUTS				PEORIA		2000		2010	
	UNITS	UNITS/ 10^9VMT	MMBTU/ 10^9VMT	UNITS/ 10^9VMT	MMBTU/ 10^9VMT	UNITS/ 10^9VMT	MMBTU/ 10^9VMT	UNITS/ 10^9VMT	MMBTU/ 10^9VMT
FEEDSTOCK PRODUCTION									
DIESEL #2	GAL	567046	72978.820	24,360	3,135	0	0	0	0
DIESEL #6	GAL	0	0	0	0	0	0	0	0
ELECTRICITY	KWHR	0	0	1,295,430	13,472	3.710E+06	38,584	3.350E+06	34,840
NATURAL GAS	MMSCF	0	0	0	0	0	0	0	0
N-FERTILIZER	TONS	1,625	81264	0	0		0	0	0
K2O FERTILIZER	TONS	1,336	8014.2	0	0		0	0	0
P2O5 FERTILIZER	TONS	929	5576.52	0	0		0	0	0
SUBTOTAL			167833.54		16,608		38,584		34,840
FEEDSTOCK TRANSPORT									
DIESEL #2	GAL	243358	31320.174	16,530	2,127	6,000	772	6,000	772
DIESEL #6	GAL	0	0	0	0	378,000	51,975	354,000	48,675
ELECTRICITY	KWHR	0	0	214,890	2,235	7.080E+06	73,632	6.930E+06	72,072
NATURAL GAS	MMSCF	0	0	0	0	0	0	0	0
SUBTOTAL			31320.174		4,362		126,379		121,519
FUEL PRODUCTION									
DIESEL #2	GAL	92,150	11,860	4,386	564	0	0	0	0
DIESEL #6	GAL	27,966	3,845	2,268	312	0	0	0	0
ELECTRICITY	KWHR	1,121,010	11,659	91,800	955	4.520E+06	47,008	3.910E+06	40,664
NATURAL GAS	MMSCF	11.85	11850	1.0	960	160	160,000	150	150,000
MTBE	GAL	0	0	0	0	3610000	339,600	3120000	293,505
AMMONIA	TONS	655	26,971	84	3,459	0	0	0	0
UREA	TONS	448	13,801	28	862	0	0	0	0
PHOSPHATE	TONS	174	1,042	10.8	65	0	0	0	0
SUBTOTAL		0	81,028		7,177		546,608		484,169
FUEL DISTRIBUTION									
DIESEL #2	GAL	88,200	11,351	94,120	12,113	50,000	6,435	41,000	5,277
DIESEL #6	GAL	0	0	442,680	60,869	56,000	7,700	48,000	6,600
ELECTRICITY	KWHR	13,402,400	139,385	4.596E+07	478,009	2.040E+07	212,160	1.760E+07	183,040
NATURAL GAS	MMSCF	0	0	163.2	163,200	0	0	0	0
SUBTOTAL			150,736		714,191		226,295		194,917
TOTAL CYCLE									
DIESEL #2	GAL	990,754	127,510	139,396	17,940	56,000	7,207	47,000	6,049
DIESEL #6	GAL	27,966	3,845	444,948	61,180	434,000	59,675	402,000	55,275
ELECTRICITY	KWHR	14,523,410	151,043	47,564,520	494,671	35,710,000	371,384	31,790,000	330,616
NATURAL GAS	MMSCF	12	11,850	164.2	164,160	160.0	160,000	150.0	150,000
MTBE	GAL	0	0	0.0	0	3610000	339,600	3120000	293,505
N-FERTILIZER	TONS	1,625	81,264	0	0	0	0	0	0
K2O FERTILIZER	TONS	1,336	8,014	0	0	0	0	0	0
P2O5 FERTILIZER	TONS	929	5,577	0	0	0	0	0	0
AMMONIA	TONS	655	26,971	84	3,459	0	0	0	0
UREA	TONS	448	13,801	28	862	0	0	0	0
PHOSPHATE	TONS	174	1,042	11	65	0	0	0	0

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table L. Energy Balances Base Cases continued

TOTAL ENERGY INPUTS(MMBTU)			430,918		742,338		937,866		835,445
Crude oil inputs	BBLS	46,294	245,358	685,368	3,632,450	668,000	3,540,400	586,000	3,105,800
Biomass inputs	TONS	310638	4,659,570	24,850	372,750	0	0	0	0
FUEL PRODUCTION		35,400,000	2,751,642	33,100,000	3,546,334	32,500,000	3,594,500	28,100,000	3,107,860
COPRODUCT PRODUCTION		62,994,800	655,146	3,498,000	36,379		6,675,500		7,251,673
		(KWHR)		(KWHR)		ALL OTHER REFINERY PRODUCTS, Btu Equivalents			
Ratio of inputs/outputs			In/Out		In/Out		In/Out		In/Out
Process efficiency			0.16		0.21		0.26		0.27
Fossil fuel efficiency			0.25		1.23		1.25		1.27
Total Efficiency			1.94		1.34		1.25		1.27

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table M. Energy Balances, Unallocated Fuel Cycles

INPUTS AND OUTPUTS	UNITS	E95 Averages		MSW PEORIA		REFORM GASOLINE 2000		REFORM. GASOLINE 2010	
		UNITS/ 10^9VMT	MMBTU/ 10^9VMT	UNITS/ 10^9VMT	MMBTU/ 10^9VMT	UNITS/ 10^9VMT	MMBTU/ 10^9VMT	UNITS/ 10^9VMT	MMBTU/ 10^9VMT
FEEDSTOCK PRODUCTION									
DIESEL #2	GAL	698614.278	89911.657	28,000	3,604	0	0	0	0
DIESEL #6	GAL	0	0	0	0	0	0	0	0
ELECTRICITY	KWHR	0	0	1,489,000	15,486	1.060E+07	110,240	1.117E+07	116,133
NATURAL GAS	MMSCF	0	0	0	0	0	0	0	0
N-FERTILIZER	TONS	1,972	98610.474	0	0		0	0	0
K2O FERTILIZER	TONS	1,601	9607.0499	0	0		0	0	0
P2O5 FERTILIZER	TONS	1,117	6704.8498	0	0		0	0	0
SUBTOTAL			204834.03		19,089		110,240		116,133
FEEDSTOCK TRANSPORT									
DIESEL #2	GAL	304759.026	39222.486	19,000	2,445	17,143	2,206	20,000	2,574
DIESEL #6	GAL	0	0	0	0	1,080,000	148,500	1,180,000	162,250
ELECTRICITY	KWHR	0	0	247,000	2,569	2.023E+07	210,377	2.310E+07	240,240
NATURAL GAS	MMSCF	0	0	0	0	0	0	0	0
SUBTOTAL			39222.486		5,014		361,083		405,064
FUEL PRODUCTION									
DIESEL #2	GAL	110,698	14,247	5,005	644	0	0	0	0
DIESEL #6	GAL	27,966	3,845	2,268	312	0	0	0	0
ELECTRICITY	KWHR	1,121,010	11,659	91,800	955	1.291E+07	134,309	1.303E+07	135,547
NATURAL GAS	MMSCF	11.85	11850	1.1	1,070	457	457,143	500	500,000
MTBE	GAL	0	0	0	0	3610000	339,600	3120000	293,505
AMMONIA	TONS	812	33,425	97	3,976	0	0	0	0
UREA	TONS	552	17,004	32.18	991	0	0	0	0
PHOSPHATE	TONS	211	1,267	12.41	74	0	0	0	0
SUBTOTAL		0	93,296		8,022		931,051		929,051
FUEL DISTRIBUTION									
DIESEL #2	GAL	88,200	11,351	94,120	12,113	50,000	6,435	41,000	5,277
DIESEL #6	GAL	0	0	442,680	60,869	56,000	7,700	48,000	6,600
ELECTRICITY	KWHR	13,402,400	139,385	4.596E+07	478,009	2.040E+07	212,160	1.760E+07	183,040
NATURAL GAS	MMSCF	0	0	163.2	163,200	0	0	0	0
SUBTOTAL			150,736		714,191		226,295		194,917
TOTAL CYCLE									
DIESEL #2	GAL	1,202,271	154,732	146,125	18,806	67,143	8,641	61,000	7,851
DIESEL #6	GAL	27,966	3,845	444,948	61,180	1,136,000	156,200	1,228,000	168,850
ELECTRICITY	KWHR	14,523,410	151,043	47,790,200	497,018	64,142,857	667,086	64,900,000	674,960
NATURAL GAS	MMSCF	12	11,850	164.3	164,270	457.1	457,143	500.0	500,000
MTBE	GAL	0	0	0.0	0	3610000	339,600	3120000	293,505
N-FERTILIZER	TONS	1,972	98,610	0	0	0	0	0	0
K2O FERTILIZER	TONS	1,601	9,607	0	0	0	0	0	0
P2O5 FERTILIZER	TONS	1,117	6,705	0	0	0	0	0	0
AMMONIA	TONS	812	33,425	97	3,976	0	0	0	0
UREA	TONS	552	17,004	32	991	0	0	0	0
PHOSPHATE	TONS	211	1,267	12	74	0	0	0	0

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Table M. Energy Balances, Unallocated Fuel Cycles continued

TOTAL ENERGY INPUTS(MMBTU)			488,089		746,316		1,628,670		1,645,165
Crude oil inputs	BBLS	46,294	245,358	685,368	3,632,450	1,908,571	10,115,429	1,953,333	10,352,667
Biomass inputs	TONS	387400	5,811,000	35,000	525,000	0	0	0	0
FUEL PRODUCTION		35,400,000	2,751,642	33,100,000	3,546,334	32,500,000	3,594,500	28,100,000	3,107,860
COPRODUCT PRODUCTION		62,994,800	655,146	3,498,000	36,379		6,675,500		7,251,673
		(KWHR)		(KWHR)		ALL OTHER REFINERY PRODUCTS, Btu Equivalents			
Ratio of inputs/outputs			In/Out		In/Out		In/Out		In/Out
Process efficiency			0.14		0.21		0.16		0.16
Fossil fuel efficiency			0.22		1.22		1.14		1.16
Total Efficiency			1.92		1.37		1.14		1.16

Note: These numbers are subject to change as revisions or refinements proceed. These numbers are derived from calcuations shown in the appendices and modified as described in the author's notes and the main body of the report. These values do not necessarily reflect the degree of signficance implied by the number of digits. These numbers are reported as derived in order to enable the interested person to recalculate and thus verify calculations made.

Document Control Page	**1. NREL Report No.** TP-463-4950	**2. NTIS Accession No.** DE94000227	**3. Recipient's Accession No.**

4. Title and Subtitle
Fuel Cycle Evaluations of Biomass-Ethanol and Reformulated Gasoline

5. Publication Date
November 1993

6.

7. Author(s)
D. K. Shaine Tyson

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401

10. Project/Task/Work Unit No.
BF320470

11. Contract (C) or Grant (G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

13. Type of Report & Period Covered
Technical report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This study was undertaken for the U.S. Department of Energy, which is using the total fuel cycle analysis (TFCA) methodology to evaluate energy choices. The TFCA allows new fuels and energy technologies to be consistently evaluated and compared, providing a sound basis for ranking policy options that expand the fuel choices available to consumers. This study is limited to creating an inventory of inputs and outputs for three transportation fuels: (1) reformulated gasoline that meets the standards of the Clean Air Act Amendments of 1990; (2) E10, a mixture of 10% ethanol made from municipal solid waste and 90% gasoline; and (3) E95, a mixture of 5% gasoline and 95% ethanol made from biomass.

17. Document Analysis
a. Descriptors
ethanol, reformulated gasoline, fuel cycle analyses, alternative fuels

b. Identifiers/Open-Ended Terms

c. UC Categories 334

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
147

20. Price
A07

Form No. 0069E (6-30-87)