Emission Factors for Priority Biofuels in Minnesota

FINAL REPORT

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EXECUTIVE SUMMARY

Biofuels are increasingly being considered for powering industrial, commercial, and institutional operations due to increased energy prices for fossil fuels, government incentives, and potential environmental benefits. Consequently, the Minnesota Pollution Control Agency (MPCA) and other state air permitting agencies are receiving permit applications requesting the use of biofuels in common combustion equipment, such as boilers, dryers, heaters, and internal combustion engines, found at industrial, commercial, and institutional sites.

State agencies must review permit applications and assess how combustion of biofuels will affect air quality. At this time, the U.S. Environmental Protection Agency does not have sufficient guidance on estimating emissions from combustion of biofuels, except for a few applications. The lack of information limits permitting authorities when evaluating biofuel application emission rates. To address this deficiency, MPCA has undertaken a project to collect emissions information on biofuels burned in stationary combustion devices and to develop emission factors. This report documents the results of this study.

The data collection efforts for this study were limited to a priority list of biofuels that were identified as most likely to be used in Minnesota. The prioritized list includes combustion of biodiesel, corn deriviatives, switchgrass, wheat straw, and gasification of logging (wood) residue and manure. Data were collected for all criteria and air toxic pollutants. Over 90 different potential sources of emission information were identified and reviewed, including research publications and academic journals, research organizations, professional societies, state and federal agencies, facilities combusting biofuels, and equipment manufacturers.

The study used over 200 emission data points to calculate average emission factors for the combinations of biofuels and pollutants. The results of the study provided emission factors for CO, NOx, PM, SO_2, and VOC for all the priority biofuels at stationary combustion sources. Most of the reported emission factors were for co-firing applications of the priority biofuel and fossil fuels. Emission factors for air toxics were limited to HCl from wheat straw and PAH's from biodiesel. However, the quality of 94 percent of the emission factors was determined to be poor due to insufficient documentation of emission test conditions or a limited number of data points for the emissions factors. Data gathered for gasification applications were comprised only of gas composition information and not emission factors. Gasification emission profiles were gathered for switchgrass and wheat straw.

The results of this study indicate that additional data gathering will be necessary to develop a higher quality compilation of emission factors, particularly for wheat straw and corn derivatives at stationary combustion sources, and all combustion applications of gasified biofuels. Some additional information may be obtained from test and study results unavailable at the time of this report. However, additional testing may also be warranted to gather the necessary amount of information. Consideration should also be made whether data gathering should be conducted for non-priority biofuels.

1.0 INTRODUCTION

Biofuels are increasingly being considered for powering industrial, commercial, and institutional operations due to increased energy prices for fossil fuels, government incentives, and potential environmental benefits. Consequently, the Minnesota Pollution Control Agency (MPCA) and other state air permitting agencies are receiving permit applications requesting the use of biofuels in common combustion equipment, such as boilers, dryers, heaters, and internal combustion engines, found at industrial, commercial, and institutional sites.

State agencies must review permit applications and assess how combustion of biofuels will affect air quality. At this time, the U.S. Environmental Protection Agency (U.S. EPA) does not have sufficient guidance on estimating emissions from combustion of biofuels, except for a few applications. The lack of information limits permitting authorities in comparing and evaluating biofuel application emission rates.

To address this deficiency, MPCA has undertaken a project to collect emissions information on biofuels burned in stationary combustion devices and to develop emission factors. This document presents the results of those efforts and is organized in the following manner:

- Section 2.0 discusses the data gathering criteria used in this study, including the selection of a priority list of biofuels to focus data collection efforts. The section also presents the methodology used to evaluate the quality of the emissions data.

- Section 3.0 presents all the data sources that were reviewed. The section also summarizes the information that was extracted from these sources.

- Section 4.0 presents the emission factors developed for the priority biofuels. The section also discusses the methodology used to develop average emission factors and to fill data gaps.

- Section 5.0 discusses potential next steps that may be taken to gather additional information, particularly for priority biofuels that have significant data gaps. The section also discusses the data gathered for the non-priority biofuels.

2.0 DATA COLLECTION REQUIREMENTS

This section presents the criteria used to gather information on biofuels, including the biofuels and pollutants that are the focus of this report, the data requirements that the literature sources met to be used in this report, and the methodology used to evaluate the data.

2.1 Prioritization of Biofuels for Data Collection

Initial literature reviews conducted for this study indicated that a wide variety of biofuels are used in stationary combustion sources. An emphasis on fuels that would most likely be used in Minnesota and time limitations for this study required that the list of potential biofuels be prioritized for data collection and emission factor development. The prioritization was based on the Minnesota Center for Energy and Environment (MNCEE) report "Identifying Effective Biofuel Strategies," as well as a general review of literature sources, to identify the available biofuels in Minnesota, and the biofuels that are projected to be more widely used in the near future. Based on these sources, the number of biofuels evaluated was narrowed to the following list of priority biofuels:

- Biodiesel,
- Corn derivatives (e.g., syrup, distillers wet grains, corn stover, and dried distillers grain and solubles),
- Hays and switchgrass,
- Logging (wood) residue,
- Wheat straw, and
- Manure (digester gas).

The biofuels in the priority list (except biodiesel) represent the top "categories of biomass that have the potential to serve as biomass power feedstocks" in Minnesota according to the MNCEE report. The MNCEE report inventoried all of the potential sources of biomass energy in Minnesota and then accounted for technical and economic limitations associated with using each biofuel to provide an accurate analysis of the biomass energy potential in Minnesota. While these five biofuel sources were not the most abundant in Minnesota, they represent the greatest potential sources of biomass power in Minnesota. Biodiesel was also discussed in the MNCEE report and was described as a "promising technology" for the production of electricity in biodiesel-powered generators. Information on biodiesel was also encountered frequently in other sources. Consequently, biodiesel was added to the list based on this abundant information and discussions with MPCA.

Data gathering was focused on obtaining emissions data for the priority biofuels used in stationary combustion sources (e.g., boilers, process heaters, internal combustion engines) and gasification applications. The gasification process generally produces a gas that has low calorific value. Typically this gas is co-fired with other gaseous fuels (e.g., natural gas) for energy production or steam generation, or used in gas turbines and engines for power generation. The data gathering activities were conducted for both combustion sources and gasification applications using corn derivatives, wheat straw, and other hays and switchgrass. Biodiesel emissions information was gathered only for stationary combustion sources because biodiesel is not expected to be used for gasification. Emission factors already exist for stationary combustion of logging (wood) residues. Digester gas from manure and waste lagoons was expected to be a rising source of residue fuel in Minnesota. Consequently, data gathering was only conducted for gasification application on manure and logging residue.

2.2 Data Gathering Criteria

The goal of this project is to develop emission factors for use in evaluating permit applications. The MPCA requested that emission factors be presented in standardized units of mass emitted per heat input of fuel burned, i.e., pounds of pollutant emitted per million British thermal units of heat input of fuel combusted (lb/MMBtu). Consequently, data gathering was conducted to obtain previously developed emission factors or inputs necessary to develop emission factors. The primary information necessary to develop emission factors in the standardized units include:

- Emission rates per pollutant (e.g., pounds per hour, tons per year), or concentration and flow rate data (e.g., parts per million and standard cubic feet per minute), and

- Fuel feed rates (e.g., tons per year) and fuel heat capacity or fuel heat input rates (e.g., MMBtu per hour).

Many combustion units co-fire biofuels with fossil fuels. Emissions measured from these units reflect the vent gas of the combined fuels. Consequently, the emissions cannot be apportioned to a specific fuel even when knowing the percent of biofuel and fossil fuel burned because the amount of emissions from the biofuel versus the fossil fuel cannot be determined. For example, it cannot be concluded that 20 percent of emissions are from biofuel if 20 percent of heat input is from biofuel. As a result, information is presented separately in this document for the various co-fired fuel combinations, unless the emission profiles indicate they are similar and can be reviewed together. For example, emissions information for a boiler firing 100 percent switchgrass is kept independent from emissions from a boiler firing 10 percent switchgrass and 90 percent coal.

Other information that was considered relevant to evaluating the validity of the emissions data included:

- Test method information, such as EPA Method used, problems encountered during testing, and any significant changes to test methodology, and

- Air pollution controls present on a combustion unit and whether the tests were conducted upstream or downstream of the control device.

Data gathered for gasification applications is comprised only of gas composition information. Emission factors could not be developed because the vent gas from the gasification process is a fuel used in another combustion device, which may or may not be co-firing another fuel type.

Consequently, any emission factors that could be developed would be for the vent gas exiting the combustion device and not the actual gasification process.

Data gathering was also conducted for all pollutants reported to be emitted from the priority biofuels. However, very little information is available for non-criteria pollutants. Therefore, while information on all air toxics are presented, the majority of the data is for carbon monoxide (CO), oxides of nitrogen (NOx), oxides of sulfur (SOx), particulate matter (PM), and volatile organic compounds (VOC).

2.3 Methodology for Data Evaluation

Data sources that did not already contain emission factors in the standardized units or information that could be used to calculate mass emission factors (i.e., concentration and associated vent gas flow information) were rejected from the data analysis. Similarly, sources that did not contain information on the fuel heat input rates or a means to calculate this value were also rejected.

The remaining sources were evaluated to determine whether the information in them was sufficient enough to be used for this analysis. Test reports contained the most detailed information and test conditions could be reviewed comprehensively. Test reports were evaluated to determine if the test methods used were valid and whether all the test method procedures were followed appropriately. Additionally, the reports were reviewed to identify if there were any unusual test conditions that occurred that would indicate the test might not be appropriate to develop a representative emission factor. Generally, each unique test was comprised of three test runs. An average emission factor for the entire test was calculated from the average of the three runs. If one of the test runs showed outlier tendencies (e.g., measured emissions were an order of magnitude different than the other test runs), then the test average would be calculated from the average of the remaining two test runs. None of the test reports reviewed contained a run that was eliminated due to outlier tendancies.

Non-test data sources (e.g., journal articles) could not be evaluated in such detail because the supporting information was not typically reported. If the test method, test conditions, and individual test run information were reported, a more detailed evaluation was undertaken. If these sources were rejected from the analysis because of the lack of validation information, a significant portion of the emissions information would be lost. Consequently, these data were included in the analysis. However, an attempt was made to evaluate the information in the reports by comparing the results to information for similar pollutant/fuel/control combinations. If emissions data from a particular report, when compared to other data sources, indicated it was an outlier (i.e, an order of magnitude different), the data point was documented in a note explaining the range of emission factors. Additionally, the lack of validation data was incorporated into a rating system developed for the emission factors to indicate that insufficient information was provided. The emission factor rating system is discussed in Section 3.2.

2.4 Development of Biofuels Emissions Database

A database in a Microsoft Access format was used to store the emissions information gathered. The stored information served as the basis for the development of the emission factors presented in this document. The database followed the structure established initially by MPCA in their

"Updated Minnesota Biomass Facilities Testing Database." The MPCA database included several tables and forms that allowed for the entry and storage of data are collected from three primary types of sources: biomass permits, biomass emission factors from published data, and biomass equipment manufacturers. In addition to the three types of data sources, the existing database format included several lists or "look-up" tables to provide standard naming conventions for data entry. These lists include options for selecting fuel type, fuel feed, capacity units, process type, emission limit units, pollutant type, and control equipment. The MPCA database was modified to incorporate information from the data collection sources documented in this report. A detailed discussion of the database is presented in a memorandum submitted to MPCA on April 3, 2007, "Draft Recommendation of Database Format for Minnesota Biofuel Emission Factor Development Project" (see Appendix A).

3.0 SUMMARY OF DATA COLLECTION

This section presents all of the data sources reviewed for this study and the information obtained from them. Over 90 different potential sources of information were identified and reviewed for this study. No specific beginning date for the literature search was set. If an article was identified that potentially contained relevant information, no matter how old, it was obtained and reviewed. The end date for the literature search was set to be April 2007.

3.1 Data Collection Sources

A wide variety of potential data sources were identified by using keyword searches over the Internet. The terms "biomass" and "biofuel" were used, as well as the name of each of the priority biofuels and selected nonpriority biofuels. Keyword searches also included various permutations of the following:

- Agricultural residue
- Biodiesel
- Bioenergy
- Biofuel
- Co-firing
- Combined heat and power
- Combustion
- Corn stover
- Dried distillers grains
- Emission factors
- Fuel analysis
- Gasification
- Oat hulls
- Power generation
- Switchgrass

The Internet keyword searches facilitated the identification of potential data sources, including research publications and academic journal articles, research organizations, professional societies, State and Federal agencies or research entities, and equipment manufacturers and vendors.

Four bibliographic databases were also used in the searches:

- Knovel Scientific and Engineering Databases - A collection of full-text databases in the following subject areas: adhesives, sealants, coatings & inks; biochemistry, biology & biotechnology; ceramics & ceramic engineering; chemistry & chemical engineering; environmental engineering; general engineering references; mechanics & mechanical engineering; metals & metallurgy; plastics & rubber, semiconductors & electronics.

- Applied Science & Technology Index - Coverage from October 1983 to present. Indexes international English-language periodicals in the applied sciences and technology. Areas covered include engineering, chemistry, mathematics, physics, computer technology, data processing and energy-related disciplines.

- Science Direct (http://www.sciencedirect.com) - Contains searchable, full-text and bibliographic scientific, medical, and technical information. Content from peer-reviewed journals, books, handbooks, and reference works include the physical sciences and engineering, life sciences, health sciences, the social sciences, and humanities.

- American Chemical Society (http://pubs.acs.org) - A publisher of peer-reviewed research journals in agriculture, biochemical research methods, biochemistry/molecular biology, biotechnology/applied microbiology, analytical chemistry, applied chemistry, inorganic and nuclear chemistry, medicinal chemistry, general chemistry, organic chemistry, physical chemistry, computer science, crystallography, energy and fuels, chemical engineering, environmental science and engineering, food science, materials science, nanoscience and nanotechnology, pharmacology, polymer science, and toxicology.

3.1.1 Research Publications and Academic Journals

As a result of the general Internet keyword searches performed, several academic journals were identified as possibly containing emissions data or related information for the various biofuels of interest. Journal articles and/or abstracts were searched generally via the Internet (e.g., Google and Google Scholar) and through selected academic journal clearinghouse sites, such as Science Direct. References within a journal article were also obtained. Table 3-1 lists the publications and journal titles identified that potentially contained biofuels emissions information.

Table 3-1. Publications and Academic Journal Sources

2nd World Conference on Biomass for Energy, Industry and Climate Protection, 10-14 May 2004, Rome, Italy
Agriculture, Ecosystems, and Environment[a]
Agronomy Journal[a]
American Society of Agricultural and Biological Engineers[a]
Applied Catalysis A[a]
Applied Energy[a]
Applied Engineering in Agriculture[a]
Applied Thermal Engineering[a]
Biodieselmagazine.com
Biomass and Bioenergy[a]
Bioresource Technology[a]
Chemosphere[a]
Crop Science[a]
Energy[a]
Energy & Fuels[a]
Energy Sources

Table 3-1. Publications and Academic Journal Sources

Environmental Chemistry Letters[a]
Environmental Science & Technology[a]
Ethanol Producer Magazine
Fuel[a]
Fuel Processing Technology[a]
Global Biogeochemical Cycles[a]
Heat Recovery Systems & CHP
IFRF Combustion Journal[a]
Journal of Agricultural Engineering Resources[a]
Journal of Industrial Ecology[a]
National Bioenergy Center, National Renewable Energy Laboratory
Nature[a]
Nutrient Cycling in Agroecosystems[a]
Progress in Energy and Combustion Science[a]
Reaction Kinetics and Catalysis Letters[a]

[a]Sources are academic journals.

3.1.2 State Agency Contacts

Several state air permitting agencies, energy offices, and economic development offices were contacted to identify facilities combusting or gasifying biomass fuels. Agencies from states in the Great Lakes States Biomass Partnership were contacted first because these states were expected to have facilities with biofuels most similar to the list of priority biofuels for Minnesota. Additional calls were made to other states with biomass programs or biomass initiatives. Table 3-2 shows a complete list of state agencies contacted. Appendix B lists the specific contacts made in these states.

Table 3-2. State Agencies Contacted

Alabama Department of Economic and Community Affairs. Energy, Weatherization and Technology Division
California ARB Air Toxic Emission Factors (CATEF) Database
Florida Department of Environmental Protection
Illinois Environmental Protection Agency
Iowa Department of Natural Resources
Iowa Municipal Utilities Authority
Kansas Department of Health and Environment
Kentucky Governor's Office of Energy Policy – Biofuels
Michigan Department of Environmental Quality
Michigan Department of Labor and Economic Growth
Minnesota Department of Agriculture

Table 3-2. State Agencies Contacted

Minnesota Senate
New York Power Authority
New York State Energy Research and Development Authority
North Carolina State Energy Office
North Dakota Department of Health, Division of Air Quality
Ohio Environmental Protection Agency
Oklahoma Department of Environmental Quality – Air Quality Division
Oregon Department of Environmental Quality
South Dakota Department of Environment and Natural Resources
Tennessee Department of Economic and Community Development Energy Division
Texas Commission of Environmental Quality
The Indiana State Department of Agriculture
Wisconsin Department of Natural Resources

Within the Great Lakes Biomass Partnership Region some state agencies maintained a formal electronic listing of all facilities permitted to combust biomass fuels, while other states required individual search of permit files.

- Illinois and Ohio provided a spreadsheet of all permitted facilities using biomass fuels. However, none of the facilities in these lists burned the priority biofuels at this time.

- The Iowa Department of Natural Resources did not have a formal list of biomass sources, but the state provided contacts at the Iowa Municipal Utilities Authority (IAMU). IAMU provided emissions test data for combustion of biodiesel blend B10 at two different units.

- Michigan had already provided a database of their listed biomass sources to the MPCA; however, none of the records in this database used fuels on the priority biofuels list.

- Indiana permitting contractors could not locate any emission test data for units permitted to burn any of the priority biofuels. Some permits in Indiana have been issued using wood emission factors for corn boilers or other biomass fuels, given the lack of available emission factors for the priority biofuels.

- Wisconsin required an individual permit-by-permit search to identify biomass combustion sources. However, the state contact summarized that there were no current permit applications for any of the priority biofuels.

Contacts were also made with state agencies from outside the Great Lakes region to increase the size of the emissions dataset.

- Alabama state contacts reported a switchgrass co-firing project, which matched findings from the U.S. Department of Energy (DOE).

- The California Air Resources Board maintained a database of HAP emissions from agricultural waste, urban wood waste, and blends of agricultural and urban wood waste, but these fuel categories were more generic than the list of priority biofuels, and were not included in the Minnesota database.

- Kentucky maintained an informal list of biomass facilities, but this list only contained woody biomass combustion sources.

- New York agencies had biodiesel emissions data in a powerpoint slide show because the final report had not been released by the conclusion of data collection efforts. The New York data was not included in the analysis since the data had not been finalized at the time of this report.

- South Dakota provided a stack test report from a boiler burning biodiesel.

- North Dakota provided permits for sunflower hulls combustion, which are not on the priority list.

- Contacts in North Carolina, North Dakota, Oklahoma, Oregon, South Carolina, and Texas reported that no facilities in the respective states were permitted to use any of the priority biofuels.

3.1.3 Federal and International Agency Contacts

A variety of energy, agriculture, and environmental agencies at the federal level were also contacted, based on guidance from the MPCA and prior experience in data gathering and emission factor development. Resources from federal agencies were used to identify biomass projects that received funding for biomass combustion and gasification research. Often, projects that are part of these government grant programs have detailed progress reports and summary reports to document the outcomes of their research. Table 3-3 shows the complete list of federal agencies contacted for information.

Table 3-3. Federal and International Agencies Contacted

Brookhaven National Laboratory
Energy Information Administration
National Defense Center for Environmental Excellence
National Renewable Energy Laboratory
Naval Facilities Engineering Service Center
U.S. Department of Agriculture, Agricultural Research Service
U.S. Environmental Protection Agency, AP-42, OTAQ, regulatory development
Ontario Ministry of Agriculture

The U.S. DOE's Office of Energy Efficiency and Renewable Energy provided a complete listing of DOE-sponsored utility co-fire projects. This listing noted the type of biomass fuels being used during co-fire tests. Research reports from facilities on the list that were co-firing any of the priority biomass fuels were obtained.

The U.S. EPA provided data from three different databases. The U.S. EPA Office of Transportation and Air Quality (OTAQ) developed a report and database of emissions from both road and non-road engine generators. The database provides emissions information on NOx, PM, VOC, and CO for various blends of biodiesel at these sources. The U.S. EPA's Compilation of Air Pollutant Emission Factors (referred to as AP-42) provided emissions data on several different biomass categories: wood residue combustion in boilers, bagasse combustion in sugar mills, and wildfire and prescribed burning. A review of this information indicated there was no overlap between the AP-42 emission factors and the list of priority biofuels. During the development of the National Emission Standard for Hazardous Air Pollutants (NESHAP) for boilers and process heaters at major sources (40 CFR Part 63 Subpart DDDDD), the EPA regulatory development group developed an emissions test database for boilers burning different fuel types. This database was reviewed for fuels in the agricultural residue category. This review resulted in 11 emission data points for bagasse and blends of urban wood, prunings, pits and shells. Since these biofuels did not overlap with the priority biofuels, they were not included in the Minnesota database.

Several defense-related organizations were contacted regarding the use of biofuels at military facilities. Although some biodiesel engines were identified at defense facilities during a literature search, follow-up contacts with several defense organizations did not result in any emissions data from these sources. Similarly, a review of the web site for the Ontario Ministry of Agriculture did not yield any emissions data.

3.1.4 Other Sources

Other sources contacted for data fell into one of four additional categories: research centers (both independent and university-affiliated), professional societies, end-users of biofuels, and equipment manufacturers. Tables 3-4 to 3-6 shows a complete listing of these other sources. Detailed contacts from these organizations are shown in Appendix B.

Of the independent research organizations contacted, only the Vermont Biofuels Association provided emissions data for any of the priority biofuels. Vermont Biofuels Association has conducted two separate projects to evaluate biodiesel blends in commercial and institutional boilers.

Table 3-4. Independent and University Research Organizations

Independent Research Organizations
Agricultural Utilization Research Institute
American Oil Chemists Society
Biomass Energy Foundation
Biotechnology Industry Organization
Council of Industrial Boiler Owners
Minnesota Soybean Growers Association
National Biodiesel Board.
The BioBusiness Alliance of Minnesota
Vermont Biofuels Association

Table 3-4. Independent and University Research Organizations

University Research Centers
Houston Advanced Research Center (HARC)
Iowa State University
Pennsylvania State University, Energy Institute
University of Iowa Utilities and Energy Management
University of Minnesota, Center for Biorefining
University of Minnesota, College of Biological Sciences
University of Minnesota, Department of Applied Economics, College of Agricultural, Food, and Environmental Sciences
University of Wisconsin-Madison
Washington Straw to Energy Project
Yale University Biofuels Program

Several universities across the country have departments devoted to researching biomass combustion, gasification, or co-firing. The Houston Advanced Research Center is researching emissions from biodiesel combustion, but the phase I research report was not completed in time for this study. Research at Iowa State is focused on characterizing the profiles of the gas from various biomass feedstocks for gasifiers, and not on measuring emission rates from the gas. Research at Penn State is focused on animal waste based-biomass, various oils, greases, switchgrass, and biodiesel. The emissions data for CO, NO_X, and SO_2 for the two priority biofuels were included in the final report. The University of Minnesota provided a report on modeled emissions data from corn derivatives. Washington University and Yale University had biomass research programs, but these did not produce any emissions data. In addition, some universities have sited biomass testing facilities on their own campus power plants. University of Wisconsin-Madison conducted a switchgrass co-firing test on their campus, and University of Iowa is currently co-firing oat hulls with coal; both of these sites provided emissions data.

End-users of biomass combustion were identified from Internet and literature research, or from listings with federal agencies such as the U.S. DOE. When journals or other state agencies did not supply data on other facilities suspected of combusting priority biofuels, these sources were contacted directly. Table 3-5 shows a complete list of facilities contacted directly.

Table 3-5. Facilities Contacted Utilizing Priority Biofuels

Company	Location
Badger State Ethanol	Monroe, WI
Griffin Industries	Butler, KY
Meister Cheese Co.	Muscoda, WI
Southern Flooring	Plant Gadsden, AL
Tandus Flooring	Dalton, GA

The Southern Flooring Company provided data on its plant Gadsden switchgrass co-firing project in Alabama, which matched data obtained from the U.S. DOE. None of the other facilities listed as combusting biomass had emissions data or test data available from biofuel combustion at their facility.

Given the limited installations of biomass gasification equipment in the United States, several manufacturers of biomass gasifiers were contacted. Contacts were made with each of the vendors, and then followed up with several e-mails. However, no data was obtained in time for this report. Table 3-6 shows a list of manufacturers contacted.

Table 3-6. Selected Gasification Equipment Manufacturers

Manufacturer	Location
PRM Energy	Hot Springs, AR
Frontline Bioenergy	Ames, IA
Prime Energy	Tulsa, OK
Emery Energy	Salt Lake City, UT
Energy Products of Idaho	Coeur d'Alene, ID

3.2 Description of Emission Data Obtained

Table 3-7 summarizes the distribution of emissions information gathered for the priority biofuels. In general, emissions data for criteria pollutants (PM, CO, NO_X, and SO_2) were available for the combustion of all of the priority biofuels. Limited data were available for emissions of HCl from wheat grass and corn derivative syrup only. Combustion of biodiesel and switchgrass had the most emissions data points, followed by corn deriviatives, and then wheat straw. There were no emission factors for gasification of any of the priority biofuels, however there were experimental data available on gas composition from gasified switchgrass and wheat straw, and modeled data were available on gasified corn derivative syrup. A summary of the data sources with emissions information is discussed below:

- A total of 30 journal articles and research reports were identified as potentially containing relevant emissions data,
- Nine emission test reports were obtained from State and Federal agencies,
- Two different facilities combusting biomass fuels provided raw emissions data,
- Two existing emission test databases, one for biodiesel and another for other plant-based biomass fuels were identified, and
- Existing emission factor data for wood residue, bagasse, and agriculture residue fuel categories were also reviewed.

Journal articles

Of the 30 journal articles:

- 12 publications did not contain any usable emissions data,

- 17 publications contained potentially usable emissions data from combusting priority and non-priority biofuels;

    - Seven of the 17 publications contained graphical emissions data. Only one of these seven publications contained data (for switchgrass co-fired with coal) used to develop emission factors,

    - Ten of the 17 publications contained non-graphical emissions data that were input to the database. Five of these ten publications had standardized emission data or sufficient information to convert the data into standardized emission factors for biodiesel, switchgrass fired alone and co-fired with coal, and wheat straw co-fired with coal. Emissions information from all five publications were used to develop emission factors. One of the five publications was modeled data, the other three contained experimental data.

- One publication was a research report that contained modeled data for the combustion of a priority biofuel. Emissions information from this publication was used to develop emission factors.

Test reports

All of the nine emissions test reports received from state and federal agencies or research organizations were used to create the standardized emission factors. The following data were obtained from the nine test reports:

- Three reports provided emissions data from switchgrass co-firing with coal,

- Two reports provided emissions data from corn derivatives co-fired with natural gas,

- One report provided modeled emissions data from 100% corn derivatives (stover, condensed distillers, solubles, dried distillers grains, and distillers wet grains), and

- The final three reports provided emissions data from various blends of biodiesel in boilers.

All of these reports contained emissions data for criteria pollutants, and two of the test reports also contained emissions data for HCl from corn derivatives. Of the nine test reports, four reports had emission rates in a standard lb/MMBtu format, and the emission rates from the other five reports were standardized using flowrates and fuel input data from the test report.

Raw emissions data

Raw emission data were received from two different facilities combusting biomass fuels. Neither of these data were used for the priority biofuel analysis. The first contained HCl, PM, and Hg emissions data from an oat hull and coal co-firing application. The second set of raw emissions data contained emissions for criteria pollutants from a biodiesel-fired engine; these data were received over the phone and in an e-mail without any documentation of test procedures or a description of the unit.

Table 3-7. Distribution of Emissions Information for Priority Biofuels

Biofuel Category[d]	CO	HCl	NOx	NO_x as NO	PAH[a]	PM	PM10	SO_2	VOC as THC	Total	Note
Biodiesel[b]	**13**	**-[c]**	**15**	**-[c]**	**18**	**13**	**1**	**4**	**8**	**72**	66 data points are measured experimental data reported numerically and 6 data points are measured experimental data reported graphically
Corn derivatives	**2**	**2**	**6**	**-[c]**	**-[c]**	**2**	**1**	**6**	**2**	**21**	
Syrup	2	2	3	-[c]	-[c]	2	1	3	2	15	13 data points are measured experimental data, 2 are modeled data
Dried Distillers Grains with Solubles	-[c]	-[c]	1	-[c]	-[c]	-[c]	-[c]	1	-[c]	2	Both data points are modeled
Stover	-[c]	-[c]	1	-[c]	-[c]	-[c]	-[c]	1	-[c]	2	Both data points are modeled
Distillers Wet Grains	-[c]	-[c]	1	-[c]	-[c]	-[c]	-[c]	1	-[c]	2	Both data points are modeled
Switchgrass	**6**	**-[c]**	**42**	**10**	**-[c]**	**1**	**1**	**51**	**-[c]**	**111**	103 data points are measured experimental data reported numerically, 3 are measured experimental data reported graphically, and 5 are modeled
Wheat straw		**1**	**1**		**-[c]**			**1**		**3**	3 data points are measured experimental data
Total	*23*	*5*	*70*	*10*	*18*	*18*	*4*	*68*	*12*	*228*	

[a]PAH represents the total of 21 different polycyclic aromatic hydrocarbons.
[b]Number of data points does not include data for 100% diesel tests used as baselines for comparing biodiesel emissions.
[c]Indicates no data was obtained for the priority biofuel.
[d]No emissions data for gasification of logging residue or manure (digester gas) were identified.

Emission test databases

Two emission databases were reviewed for emissions information. The U.S. EPA's OTAQ database contained biodiesel emissions from 826 road sources and 14 non-road engines. Biodiesel blends used in the non-road engines included B0 (100 percent fossil-based diesel), B30 (30% biodiesel and 70% fossil-based diesel), and B100 (100 percent biodiesel). Emissions data for PM, CO, NOx, and VOC as THC, from the 14 non-road sources were included in the emission factor analysis. These data were all converted from units of grams per horsepower-hour to lb/MMBtu. The boiler NESHAP database contained standardized emissions test data for speciated HAP. Information in this database was not included in this emission factor analysis because there was no overlap with the priority biofuels list. The only units in the NESHAP emissions test database fired bagasse or a blend of urban wood and prunings, pits, and hulls.

Existing emission factors

Existing emission factor data for wood residue combustion in boilers, and bagasse combustion in sugar mills are found in EPA's AP-42. Information is provided for PM, NOx, CO, SO_2, and speciated organic compounds. However, wood residue and bagasse were not included in this study because they are not in the priority biofuels list for combustion sources. Similarly, speciated HAP data from the California Air Resources Board Air Toxic Emission Factors (CATEF) Database for the agriculture residue fuel category were not included. Based on engineering judgment, these emission factors were excluded since their fuel categories, which included biomass/wood, blends of urban wood, prunings, pits, and shells, were too broad to assign to one of the priority biofuels.

4.0 EMISSION FACTOR DEVELOPMENT

This section presents the standardized emission factors developed using the information collected from the sources presented in section 3.0. This section also discusses the methodology used to fill in data gaps and describes an emission factor rating system developed to describe the quality of the emission factors developed.

4.1 Calculation of Average Emission Factors

As discussed in Section 2.0, emission factors for each biofuel and pollutant emitted were standardized for each unique test to units of lb/MMBtu. Where the literature already contained emission factors in the required units, that information was used directly in this study. Some literature sources provided emissions information as an emission rate (e.g., lb/hr) and also provided the fuel heat input rate (e.g., MMBtu/hour).

In general, three types of conversions were made to standardize the emission data: concentration data with associated flowrates, mass pollutant per energy (i.e, g/GWh electric), and mass pollutant per mass of fuel input. Concentrations were converted into a lb/MMBtu basis whenever associated flowrate data was available. For energy conversion, the articles were reviewed to determine if the energy was in units of energy input or output. In all cases, energy input was available and the emission factor was calculated based on the energy input. When pollutants were provided relative to the mass of the fuel input, the articles were reviewed to determine a higher heating value of the biofuel, and, in cases where the emissions were based on co-fired applications, the higher heating values and fuel input rates of both fuels were summed to provide a total fuel input heat rate.

For some biofuel/pollutant combinations, emissions information from multiple tests were obtained. For such cases, an average emission factor was calculated to represent the range of emission factors for the biofuel/pollutant combination. The average was calculated as both an arithmetic mean and median. In a normally distributed set of data, the average would be an appropriate value to represent the range of data. If data are not normally distributed, the median may be a better representation, or additional calculations may need to be performed. Comparable median and mean values indicate that an average emission factor calculated using the mean would be appropriate in characterizing the range of values. More rigorous statistical analyses were not considered appropriate because an insufficient number of data points were available for the biofuel/pollutant combinations.

After standardarized emission factors were developed for each biofuel/pollutant combination, they were reviewed to determine if some of the combinations could be generalized to create less specific combinations that would cover more biofuels and contain more data points. This procedure was followed for similar fuel mixes where the pollutant emissions were determined to be similar (e.g., within the same order of magnitude). Table 4-1 shows the biofuels where more generalized combinations were developed.

Table 4-1. Generalized Biofuels Developed by Combining Specific Fuel Mixes

General Biofuel Categories	Comprised of the following specific fuel mixes		
	Fuel blends	Biofuel feedstocks	Fossil fuel feedstock
# 6 Fuel oil with various % Biodiesel in a boiler	B5, B10, and B20	No variation	No variation
100 % biodiesel in engines	No variation	Palm oil, soya and rapeseed oil	No variation
Biodiesel at various blends in engines	B10, B20, B30, B50, and B75	Palm oil, soy and rapeseed oil	No variation
Coal with varying switchgrass inputs	Switchgrass heat input varies from 1 percent to 8.64 percent	Switchgrass was stored inside and outside, harvested before and after frosts, and used 1 year and 2 years after harvest	Powder river basis (PRB) and Pratt seam bituminous coal
Tub grinder switchgrass and coal with varying switchgrass inputs	Switchgrass heat input varies from 6.4% to 10.2%	No variation	No variation
Hammermill switchgrass and coal with varying switchgrass inputs	Switchgrass heat input varies from 5.1% to 7.9% heat input	No variation	No variation

4.2 Completing Data Gaps

After average emission factors were developed, the results were reviewed to identify remaining data gaps. To fill data gaps, the fuel compositions of biofuels were compared to identify similar fuels. Then, emission factors developed for similar biofuel/pollutant/control combinations were transferred to combinations where no information was obtained. Table 4-2 presents a summary of fuel composition information for each of the priority biofuels. The values in the table represent an average of all fuel composition data collected for this report. More detailed information for each fuel analysis citation is contained in Appendix C. Table 4-3 shows the biofuel/pollutant/control combinations where information was transferred from another combination. In all instances, the transfer was made because the fuels had similar compositions and physical properties. However, not all data gaps were filled using this methodology. Section 5.0 contains a discussion of the remaining data gaps and recommendations on additional testing and data gathering to fill in the gaps.

Another method considered to fill data gaps was to calculate worst-case emission factors using an ultimate analysis of the biofuel. However, emission factors calculated from the fuel analysis would potentially be inconsistent with emission factors that already exist because they would be based on worst-case scenarios. Additionally, the fuel analysis would not be able to provide adequate information to fill in data gaps for combustion based-pollutants (e.g., NOx, CO, or VOC).

Table 4-2. Average Fuel Composition Data for Priority Biofuels

Parameter	Pure Biodiesel (B100)	Biodiesel Blend (B5)	Biodiesel Blend (B10)	Biodiesel Blend (B20)	Corn Stover	Dried Distillers Grains with Solubles	Dried Distillers Grains without Solubles	Distillers Wet Grains	Syrup	Switchgrass (pellets)	Switchgrass (loose)	Wheat Straw
As received												
Moisture, %					16.76	9.70	13.35	64.46	67.29	9.30	9.07	11.97
Ash, %					5.46	3.79	1.96	0.97	2.31	2.90	4.63	7.71
Higher heating value, Btu/lb					6,305	8,414	8,473	3,349	2,765	7,381	7,323	6,668
Moisture Free												
Ash, %	0.06				7.90	4.01	2.24	2.58	7.02		5.43	10.15
Higher heating value, Btu/lb	19,020	18,259	18,353	18,223	8,130	9,386	9,848	9,438	8,482		8,293	7,636
Lower heating value, Btu/lb					7,192	8,703		8,819	7,819			
Proximate Analysis												
Volatile matter, %	99.60				64.58	82.50		83.18	81.71	72.30	79.05	51.05
Fixed Carbon, %	0.30				18.35	12.84		13.58	10.32	15.50	13.33	18.25
Chlorine, µg/g					984	1,757		1,673	3,459			
Chlorine, %											0.14	0.15
Chlorine, ppm	1,100									1,075.00	650.02	
Mercury, µg/g						<0.010		<0.10	<0.012			
Mercury, mg/kg											<0.1	
Ultimate Analysis												
Carbon, %	76.70	86.28	86.09	85.06	44.87	50.24		52.53	43.12	51.70	45.19	43.10
Hydrogen, %	0.10	10.50	10.31	10.64	5.41	6.89		6.60	7.07	7.00	5.47	5.56
Nitrogen, %	12.30				0.70	4.79		5.35	2.63	0.20	0.67	0.56
Oxygen, %	10.80	1.05	1.76	2.47	30.94	33.42		32.28	39.21	28.90	37.13	33.34
Sulfur, %	0.00	1.86	1.64	1.50	0.10	0.61	0.40	0.66	0.96	0.00	0.13	0.19
Metals, mg/kg												
Arsenic					2.50	<3.20		<3.10	<3.20		1.20	
Beryllium						<0.093		<0.093	<0.11			
Cadmium						<0.046		<0.50	<0.53			
Chromium						0.50		<0.79	0.75		58.00	
Lead					0.46	<0.046		<0.50	<0.53		40.00	

Table 4-2. Average Fuel Composition Data for Priority Biofuels

Parameter	Pure Biodiesel (B100)	Biodiesel Blend (B5)	Biodiesel Blend (B10)	Biodiesel Blend (B20)	Corn Stover	Dried Distillers Grains with Solubles	Dried Distillers Grains without Solubles	Distillers Wet Grains	Syrup	Switchgrass (pellets)	Switchgrass (loose)	Wheat Straw
Manganese					23.40	15.95		12.05	34.93			
Nickel						0.87		<1.20	1.97			
Potassium											0.81	
Selenium						1.80		<1.80	<1.60		4.00	
Silver											<10	
Reference (see below)												
	7, 10	12	12	12	2, 5, 8, 10, 14	2, 8	2	8	8	7	1, 2, 4, 7, 10, 14	2, 5, 6, 9, 13, 14

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14. US Department of Energy Biofuels Program. "Biomass Feedstock Composition and Property Database." http://www1.eere.energy.gov/biomass/feedstock_databases.html. For corn stover, all values are based on an average of 12 test results listed in the database. For wheat straw only a single test was in the database. For switchgrass the HHV, ash, volatile matter, and fixed carbon are based on the average of 12 test results listed in the database, oxygen and sulfur were based on 14 tests, while carbon and hydrogen are based on 30 tests, and nitrogen was based on 32 tests.

Table 4-3. Emission Factors Transferred from Other Biofuel/Pollutant Combinations

Emission factors for Fuel/pollutant	Transferred from the fuel mix…
100 % Dry distillers grains with solubles for HCl, CO, and VOC as THC	Corn syrup with 19% heat input natural gas
100 % Dried wet grains for HCl, CO, and VOC as THC	
100 % Corn syrup	
Coal with varying switchgrass inputs for HCl	Coal with 10% wheat straw by heat input
Tub grinder switchgrass and coal with varying switchgrass input for HCl	
Hammermill switchgrass and coal with varying switchgrass input for HCl	
PRB coal with 10% switchgrass by mass (co-milling and direct injection of switchgrass and no overfire air) for HCl	

4.3 Emission Factor Ratings

Each of the emission factors were assigned a quality rating based on the overall quality of the data and the representativeness of the data points that formed the basis of calculation for each emission factor. Data were classified as high-quality if sufficient information was provided to evaluate test conditions used to measure the data, such as information in test reports. Data were classified as low-quality if they were based on models or insufficient background information to assess the testing procedures and results. Table 4-4 describes the rating criteria.

Table 4-4. Qualitative Descriptions for Emission Factor Ratings

Emission Factor Rating	Data Criteria for Rating
A	High-quality data, significant number of data points from multiple sources.
B	High-quality data, limited number of data points from multiple or single sources.
C	Low-quality data, limited number of data points from a single source.
D	Low-quality data, and extremely limited number of data points from a single source, or a single data point.

A total of 56 average emission factors were calculated for the priority biofuels. Of these 56 factors, one "A" rating was assigned to NOx emissions from switchgrass. Two "B" ratings were assigned, one to SO_2 emissions from switchgrass, and another to emissions of PAH from biodiesel. These factors represented the highest quality emission factors calculated from the available raw data, relative to the entire collection of emission factors calculated for all priority biofuels. The overall distribution of the 56 emission factor ratings is presented in Table 4-5.

Table 4-5. Distribution of Emission Factor Ratings for the Calculated Emission Factors for the Priority Biofuels

Emission Factor Rating	Number of Ratings Assigned	Percentage of Emission Factors
A	1	1.8%
B	2	3.6%
C	19	33.9%
D	34	60.7%

4.4 Summary of Emission Factors

Table 4-6 through 4-9 present the emission factors developed for each pollutant and each priority biofuel combusted in stationary sources. The tables provide the range of emission factors as well as the mean and median average emission factor. The tables also contain a rating for each of the average emission factors developed based on the criteria in section 4.3, and identify the emission factors that were transferred from other biofuel/pollutant combinations. References for the emission factors are also presented in the table and correspond to references in section 6.0. Appendix D summarizes the arithmetic mean emission factor, and provides more specific detail on test conditions (e.g., Test ID, fuel mix burned, and controls), for each emission test. The information in Appendix D was extracted from the Microsoft Access database storing all the emissions information gathered for this study.

Table 4-6. Summary of Emission Factors for Biodiesel Combustion

Fuel	Note on Fuel Input Variation	Pollutant	Emission Factor (lb/MMBtu) Range	Mean	Median	Data Points	Note on Range of Emissions	Control	Emission Factor Rating	Reference
#6 Fuel oil with various % biodiesel in boiler	Biodiesel input varies from B5 to B20	CO	0.13-0.21	0.17	0.16	3	Min is w/B20. Max is w/B10.	None specified	**C**	**19**
		NO_X	0.27-0.31	0.30	0.31	3	Min is w/B20. Max is w/B5.		**C**	**19**
		SO_2	1.56-1.67	1.60	1.57	3	Min is w/B20. Max is w/B10.		**C**	**19**
100% biodiesel in boiler	NA[a]	CO	0.006-0.104	0.055	0.055	2	NA	None specified	**D**	**13,17**
	NA	NO_X	NA	0.109	NA	2	NA		**D**	**13, 17**
	NA	PM	NA	0.002	NA	1	NA		**D**	**17**
100% biodiesel in engines	NA	CO	0.12-0.71	0.43	0.42	6	Min is w/oxid. Catalyst. Max is w/o	None specified	**C**	**20**
	NA	NO_X	3.62-6.71	5.34	5.25	6	Min is w/rapeseed oil on John Deere model CD6068TL052. Max is w/soy methyl ester on Caterpillar model 3304PCNA	Oxidation catalyst or none	**C**	**20**
	NA	PM	0.07-0.23	0.11	0.08	6	Min is w/palm-based biodiesel on 4-stroke engine, model QC945. Max is w/rapeseed based biodiesel on 5 stroke John Deere model CD6068TL052	None specified	**C**	**11, 20**
	NA	Total PAH	2.66E-05 to 6.08E-05	4.82E-05	5.71E-05	3	All emissions from same engine and fuel		**C**	**11**
	NA	VOC as THC	0.02-0.16	0.07	0.06	6	Min has oxidation catalyst w/soy methyl ester based biodiesel on a Caterpillar model 3304PCNA. Max is w/o catalyst and w/rapeseed based biodiesel on John Deere model 6081T		**C**	**11, 20**

Table 4-6. Summary of Emission Factors for Biodiesel Combustion

Fuel	Note on Fuel Input Variation	Pollutant	Emission Factor (lb/MMBtu) Range	Mean	Median	Data Points	Note on Range of Emissions	Control	Emission Factor Rating	Reference
Biodiesel at various Blends in Engines	Biodiesel blend is B30	CO	0.19-0.7	0.45	0.45	2	Min is w/an oxid. Catalyst. Max is w/o	None specified	**D**	**20**
	Biodiesel blend ranges from B10 to B30	NOx	4.18-6.95	5.65	5.74	4	Min is w/B10 on a 1999 CAT engine. Max is w/B10 on a 1972 cooper Bessemer engine	Oxidation catalyst or none	**C**	**20**
	Biodiesel blend ranges from B10 to B75	PAH	1.19E-03 - 3.50E-03	2.36E-03	2.36E-03	15	Min is w/palm based biodiesel at B75. Max is w palm-based biodiesel at B10.	None specified	**B**	**11**
	Biodiesel blend ranges from B10 to B75	PM	0.03-013	6.01E-02	5.00E-02	7	Min is w/B10 palm based biodesel on 4-stroke. Max is w/cooper Bessemer diesel generator from 1972		**C**	**7, 11**
	Biodiesel blend is B30	VOC as THC	0.02-0.06	0.04	0.04	2	Min is w/oxid. Catalyst. Max is w/o		**D**	**20**

[a] NA – not applicable.

Table 4-7. Summary of Emission Factors for Corn Derivatives from Combustion

Fuel Mix	Pollutant	Mean / Median Emission Factor (lb/MMBtu)	Number of Data Points	Note on Emissions	Control	Emission Factor Rating	Reference
100% corn stover	NOx	0.56	1	Modeled data for a swirl stablized burner and furnace. The modeled burner is unstaged and does not adjust for any combustion optimization	none	**D**	**14**
	SOx	0.10	1			**D**	
100% distillers dried grains with solubles	NOx	1.09	1	Modeled data for a swirl stablized burner and furnace. The modeled burner is unstaged and does not adjust for any combustion optimization	none	**D**	**14**
	SOx	1.48	1			**D**	
	HCl	3.14E-03	1	EF transferred from EF for syrup co-fired with 19% natural gas by heat input	fabric filter	**D**	
	VOC as THC	4.41E-04	1			**D**	
	CO	2.82E-03	1			**D**	
100% distillers wet grains	NOx	3.02	1	Modeled data for a swirl stablized burner and furnace. The modeled burner is unstaged and does not adjust for any combustion optimization	none	**D**	**14**
	SOx	2.31	1			**D**	
	HCl	3.14E-03	1	EF transferred from EF for syrup co-fired with 19% natural gas by heat input	fabric filter	**D**	
	VOC as THC	4.41E-04	1			**D**	
	CO	2.82E-03	1			**D**	
100% syrup	NOx	0.94	1	Modeled data for a swirl stablized burner and furnace. The modeled burner is unstaged and does not adjust for any combustion optimization	none	**D**	**14**
	SOx	1.43	1			**D**	
	HCl	3.14E-03	1	EF transferred from EF for syrup co-fired with 19% natural gas by heat input	fabric filter	**D**	
	VOC as THC	4.41E-04	1			**D**	
	CO	2.82E-03	1			**D**	
syrup with 19% by heat input of natural gas	CO	2.82E-03	1	Measured data for an industrial circulating fludized bed boiler	fabric filter	**C**	**15**
	HCl	3.14E-03	1			**C**	
	NOx	2.90E-03	1			**C**	
	PM	2.71E-02	1			**C**	
	SO_2	1.99E-02	1			**C**	
	VOC as THC	4.41E-04	1			**C**	
syrup with 30% by heat input of natural gas	CO	2.00E-03	1		fabric filter	**C**	**16**
	HCl	2.26E-02	1			**C**	
	NOx	3.33E-02	1			**C**	
	PM	2.40E-02	1			**C**	
	PM10	1.52E-01	1			**C**	
	SO_2	1.17E-01	1			**C**	
	VOC as THC	9.40E-03	1			**C**	

Table 4-8. Summary of Emission Factors for Switchgrass from Combustion

Fuel Subcategory	Note on Fuel Input Varation	Pollutant	Emission Factor (lb/MMBtu)				Control	Note on Range of Emissions	Emission Factor Rating	Reference
			Range	Mean	Median	Data Points				
Coal with Varying Switchgrass Input	Switchgrass heat input varies from 1-34.1% by heat input	CO	4.30E-03 to 1.23	0.78	0.55	4	None specified	Min is at 1% switchgrass by heat input in a tangentially-fired utility boiler. Max is at 34% switchgrass by heat input in a bubbling fludizied bed boiler.	**D**	**2, 18**
	Switchgrass heat input varies from 1-34.1% by heat input	NO_X	0.39-0.8	0.60	0.61	38	None specified	Min is at 1% switchgrass by heat input in a tangentially-fired utility boiler. Max is at 4.63% switchgrass by heat input in a tangentially-fired utility boiler.	**A**	**2, 3, 4**
	Switchgrass input held at 1% by heat input	PM	NA	0.05	0.05	1	ESP	Emissions reflect a tangentially fired utility boiler	**D**	**2**
	Switchgrass input held at 1% by heat input	PM_{10}	NA	0.04	0.04	1	ESP		**D**	**2**
	NA[a]	HCl	NA	0.13	0.13	1	None	EF transferred from HCl EF for wheat straw	**D**	
	Switchgrass heat input varies from 1-34.1% by heat input	SO_2	0.53-4.9	2.72	2.65	39	None specified	Min is in a pilot-scale bubbling fluidized bed with 34.1% switchgrass. Max is modeled data for 5% switchgrass co-fired w/coal at the national average SOx emission rate for coal-fired electricity generation.	**B**	**3**
Tub Grinder Switchgrass and Coal with Varying Switchgrass Input	Switchgrass heat input varies from 6.2-10.2%	NO_X	0.36-0.49	0.41	0.41	7	None specified	Min is at 6.5% switchgrass by heat input. Max is at 6.4% switchgrass by heat input. Emissions reflect a wall-fired utility boiler.	**C**	**1**
	NA	HCl	NA	0.13	0.13	1	None	EF transferred from HCl EF for wheat straw	**D**	
	Switchgrass heat input varies from 6.2-10.2%	SO_2	1.84-3.03	2.30	2.28	7	None specified	Min is at 6.5% switchgrass by heat input. Max is at 10.2% switchgrass by heat input. Emissions reflect a wall-fired utility boiler.	**C**	**1**

Table 4-8. Summary of Emission Factors for Switchgrass from Combustion

Fuel Subcategory	Note on Fuel Input Varation	Pollutant	Emission Factor (lb/MMBtu)				Control	Note on Range of Emissions	Emission Factor Rating	Reference
			Range	Mean	Median	Data Points				
Hammermill Switchgrass and Coal with Varying Switchgrass Input	Switchgrass heat input varies from 5.1-7.9%	NO_X	0.41-0.46	0.43	0.42	3	None specified	Min is at 6.5% switchgrass by heat input. Max is at 6.4% switchgrass by heat input. Emissions reflect a wall-fired utility boiler.	**C**	**1**
	NA	HCl	NA	0.13	0.13	1	None	EF transferred from HCl EF for wheat straw	**D**	
	Switchgrass heat input varies from 5.1-7.9%	SO_2	2.29-2.42	2.35	2.33	3	None specified	Min is at 6.5% switchgrass by heat input. Max is at 10.2% switchgrass by heat input. Emissions reflect a wall-fired utility boiler.	**C**	**1**
PRB coal with 10% switchgrass by mass (no overfire air)	NA	HCl	NA	0.13	0.13	1	None	EF transferred from HCl EF for wheat straw	**D**	
PRB coal with 10% switchgrass by mass (no overfire air)	Switchgrass input held at 10% by mass	NO_X	0.63	0.64	0.64	2	None specified	Min is for direct injection. Max is for co-milling. Both reflect emissions from a pilot scale tangentially-fired boiler.	**D**	**4**
PRB coal with 10% switchgrass by mass (co-milling of switchgrass, 15% overfire air)			NA	0.44	0.44	1	None specified	Emissions reflect a pilot scale tangentially-fired boiler.	**D**	**4**
Switchgrass-fired alone	Switchgrass input held at 100% switchgrass	CO	0.60-0.77	0.69	0.69	2	None	Min is based on modeled data using loose switchgrass in a utility boiler. Max is based on test data from a bubbling fluidized bed boiler and pelletized switchgrass.	**D**	**13, 18**
		SO_X	0.02 – 0.24	0.13	0.13	2	None		**D**	**13, 18**
		NO_X	0.34 – 0.49	0.41	0.41	2	None	Min is based on test data from a bubbling fluidized bed boiler and pelletized switchgrass. Max is based on modeled data using loose switchgrass in a utility boiler.	**D**	**13, 18**

[a] NA – not applicable.

Table 4-9. Summary of Emission Factors for Wheat Straw from Combustion

Fuel Mix	Pollutant	Number of Emission Factors	Mean / Median Emission Factor (lb/MMBtu)	Control	Notes on Emissions	Emission Factor Rating	Reference
Coal with 10% Wheat Straw	SO_2	1	0.10	SO_2 and NO_X flue gas treatment (FGD and ammonia)	Measured data on a large utility boiler	**D**	**8**
	NO_X	1	0.30			**D**	
	HCl	1	0.13	None		**D**	

Table 4-10 compares the emission factors for each biofuel developed in this report to its corresponding replacement or blended conventional fuel. For example, in internal combustion engine applications, biodiesel serves as a substitute for, or is blended with, fossil-based diesel. In liquid fuel-fired boiler applications, biodiesel replaces or blends with a distillate or residual fuel oil. In solid fuel applications, boilers often co-fire one of the priority biofuels with a conventional fuel, such as coal. In a few instances solid biofuels have been combusted alone, without any co-firing. In the absence of other emission factor data, some state permitting agencies have used emission factors for wood to estimate the emissions from solid biofuel combustion.

Table 4-10. Comparison of Uncontrolled Emission Factors for Biofuels and Conventional Fuels

Fuel	Application	CO	NOx	SOx	PM	VOC	HCl	Note
Liquid Fuel Comparison								
100% Biodiesel (B100)	Engines	0.12-0.71	3.62-6.71	0.00	0.07-0.23	0.02-0.16	NA	A, B
Biodiesel blends (B10 to B75)		0.19-0.7	4.18-6.95	NA	0.03 - 0.13	0.02-0.06	NA	A, B
Diesel		0.95	4.41	0.29	0.31	0.35	NA	B, C
100% Biodiesel (B100)	Commercial/ Industrial Boilers (less than 100 mmBtu/hr)	0.006 - 0.104	0.109 - 0.119	0.00	0.002	NA	NA	
Biodiesel blends with #6 Fuel Oil (B5 to B20)		0.13-0.21	0.27-0.31	1.56-1.67	NA	NA	NA	
Residual Fuel Oil (#6)		0.03	0.37	1.92	0.07	1.07E-02	NA	B, D
Distillate Fuel Oil		0.04	0.14	1.01	0.01	3.97E-03	NA	B, E
Solid Fuel Comparison								
Corn Derivatives								
100% Stover	Modeled data for PC swirl-stabilized boiler	2.82E-03	0.56	0.10	NA	4.41E-04	3.14E-03	F, G
100% Distillers wet grains		2.82E-03	3.02	2.31	NA	4.41E-04	3.14E-03	F, G
100% Distillers dried grains with solubles		2.82E-03	1.09	1.48	NA	4.41E-04	3.14E-03	F, G
100% Syrup		2.82E-03	0.94	1.43	NA	4.41E-04	3.14E-03	F, G
Syrup and Natural Gas Blends	Circulating FBC Boiler	0.002 - 0.283	0.0029 - 0.033	0.0199 - 0.117	2.4 - 2.71	0.000441 - 0.00940	0.00314 - 0.0226	H
Switchgrass	Test data from Commercial watertube boiler and modeled data from utility boiler	0.60 - 0.77	0.34 - 0.49	0.02 - 0.24	NA	NA	NA	
Switchgrass and Coal Blend	Large utility PC wall-fired and tangentially-fired boilers (50 - 725 MW) and a pilot-scale bubbling fluidized bed boiler	0.004 - 1.23	0.36 - 0.8	0.53 - 4.9	2.5	NA	0.13	I, J
Wheat Straw and Coal Blend	Large utility boiler (unspecified design)	NA	0.30	0.97	NA	NA	0.13	K
Dry Wood	Stoker and fuel cell boilers	0.6	0.49	0.025	0.4	0.017	NA	L
	Circulating FBC Boiler	0.17						
Subituminous Coal	Circulating FBC Boiler	0.69	0.19	1.19	0.65	NA	0.05	M, N, P
	PC wall-fired Boiler	0.02	0.38	0.67	2.54	NA	0.05	O, P
	PC tangentially-fired Boiler		0.32					P, Q
Bituminous Coal	PC wall-fired Boiler	0.02	0.46	1.67 - 4.60	2.67 - 6.69	NA	0.05	R

Notes:

A. Some engines were listed as having a catalyst control to reduce Nox emissions. The removal efficiencies of these catalysts are not documented in the report, and engines with and without the catalyst are shown in these emission factor ranges.

B. Emissions are shown as THC as VOC for liquid fuels. VOC emissions are from exhaust only.

C. Source: US EPA AP-42. Chapter 3.3. Emission Factors for Uncontrolled Diesel Industrial Engines

D. Source: US EPA AP-42. Chapter 1.3. Criteria Pollutant Emission Factors for Fuel Oil Combustion in Boilers < 100 mmBtu/hr. **Assumes 1.83% Sulfur content of the fuel oil, based on the fuel oil used in the reference test report 19 (Southworth, T., 2006). A heat content of the fuel is assumed to be 150 mmBtu/1000 gallons. SOx is represented here as SO_2.

E. Source: US EPA AP-42. Chapter 1.3. Criteria Pollutant Emission Factors for Fuel Oil Combustion in Boilers < 100 mmBtu/hr. ***Assumes 1% sulfur content of the fuel oil and a heat content of 140 mmBtu/1000 gallons. SOx is represented here as SO_2.

F. The emission factor was tranferred from the emission factor for syrup co-fired with 19% natural gas by heat input.

G. The modeled data for NOx emissions are based on an un-staged burner and the effects of over-fire air on NOx are not included in the CFD modeling. In an actual test scenario, NOx emissions would be expected to be reduced from the predicted values shown here due to combustion optimizations in the boiler.

H. The emission factor for PM was adjusted assuming a control efficiency of (99%) based on the presence of a fabric filter.

I. The emission factor for PM was adjusted to uncontrolled assuming a control efficiency of 98% based on the presence of an ESP. Minimum emissions for CO are on a PC tangentially-fired large utility boiler combustor. Maximum CO emissions are in a pilot scale bubbling FBC boiler.

J. The emission factor was transferred from the HCl emission factor for wheat straw.

K. The emission factor for SOx was adjusted assuming a control efficiency of 90% based on the efficiencies of pollutant removal processes (FGD and ammonia), referenced in (Hartmann, D., 1999). The NOx emissions listed here are not uncontrolled, however, the removal efficiency of the NOx control were unknown and thus the emission factor could not be adjusted.

L. Source: US EPA AP-42. Chapter 1.6. Emission Factors from Wood Residue Combustion. Emissions from uncontrolled dry wood combustion were used in this summary.

M. Source: US EPA AP-42. Chaper 1.1. Emission Factors for from Bituminous and Subbituminous Coal. FBC, circulating bed boiler was used in this summary.

N. According to the note in AP-42, an emission factor for underfeed stokers was used for SO_2 since the presence of a calcium-based sorbent is unknown.

O. Source: US EPA AP-42. Chaper 1.1. Emission Factors for Bituminous and Subbituminous Coal. Emissions from a PC dry-bottom wall-fired boiler, pre-NSPS, were used for this summary.

P. Emissions reflect a low sulfur (0.5%) PRB coal with an estimate of 6.6% ash.

Q. US EPA AP-42. Chaper 1.1. Emission Factors for Bituminous and Subbituminous Coal. Emissions from PC dry-bottom tangentially-fired boiler, pre-NSPS, were used in this summary.

R. Emissions here reflect the coals used in co-firing applications range from an unspecified bitumionous (sulfur (1.14% dry), 10.7% ash) to a Pratt Seam coal (3.15 (% dry) sulfur, 6.95 (% dry ash).

NA = Not Applicable.

4.5 Summary of Gasification Data

The literature searches and information gathering activities obtained fuel speciation profiles from gasification processes. The data obtained included primarily experimental data contained in academic journal articles (five sources) and one source of computational modeling data. Of the six data sources obtained, gasification data for only three of the priority biofuels (wheatstraw, switchgrass, and dried distillers grains with solubles) were available, and of these, product gas compositions were available for only switchgrass and wheat straw (Table 4-11).

Table 4-11. Summary of Product Gas Compositions from the Gasification of Switchgrass and Wheat Straw

Fuel	**Switchgrass**	**Wheat Straw**	**Natural Gas**
Reference	Vriesman, P. et al.	Ergudenler A. and A.E. Ghaly	Union Gas
Gasification Unit Type	Fluidized Bed	Fluidized Bed	NA
Number of Samples	15	12	NA
Product Gas Component	*Average Composition*[a]		
CH_4	13.3 vol % (dry)	4.3 mol % (dry)	94.9 mol % (dry)
CO	35.7 vol % (dry)	20.4 mol % (dry)	NA
CO_2	24.0 vol % (dry)	14.7 mol % (dry)	0.7 mol % (dry)
C_2H_2	0.3 vol % (dry)	NA[b]	NA
C_2H_4	4.1 vol % (dry)	NA	NA
C_2H_6	0.2 vol % (dry)	NA	2.5 mol % (dry)
C_2H_n	NA	2.4 mol % (dry)	NA
C_3H_8	NA	NA	2.5 mol % (dry)
i-C_4H_{10}	NA	NA	0.03 mol % (dry)
n-C_4H_{10}	NA	NA	0.03 mol % (dry)
i-C_5H_{12}	NA	NA	0.01 mol % (dry)
n-C_5H_{12}	NA	NA	0.01 mol % (dry)
Hexanes	NA	NA	0.01 mol % (dry)
H_2	22.0 vol % (dry)	5.5 mol % (dry)	Trace
N_2	NA	51.5 mol % (dry)	1.6 mol % (dry)
O_2	NA	1.2 mol % (dry)	0.02 mol % (dry)

[a] Average product gas composition for switchgrass gasification is reported as volumetric percentages and does not include nitrogen or steam.
[b]Data not available/not applicable.

Sources:

Vriesman, P., E. Heginuz, and K. Sjöström. 2000. Biomass gasification in a laboratory-scale AFBG: influence of the location of the feeding point on the fuel-N conversion. Fuel 79: 1371-1378.

Ergudenler, A. and A.E. Ghaly. 1992. Quality of gas produced from wheat straw in a duel-distributor type fluidized bed gasifier. Biomass and Bioenergy 3(6): 419-430.

Union Gas. Chemical Composition of Natural Gas (inclusive of supplies from Western Canada, Ontario, and the United States). http://www.uniongas.com/aboutus/aboutng/composition.asp.

5.0 RECOMMENDATIONS

Section 4.2 discusses a rating system applied to the emission factors developed for this study. Table 4-5 shows that of the 56 emission factors developed, only three were considered to have been based on journals or test reports with sufficient background information on the test conditions. These were assigned a higher quality rating (A or B). However, two of the three sources were based on a limited number of data points from a single data source. The remaining 53 emission factors, or 95 percent of the factors, were assigned an emission factor rating of C or D, indicating that they were based on either a single data point, or limited data from lower quality information from sources without sufficient documentation.

Table 5-1 shows the significant data gaps in emission factors for pollutants that are the most common ones measured for the priority biofuels. SO_2 and PAH emissions were not included in this table. If MPCA were to prioritize emissions testing or further data gathering, SO_2 emissions are not expected to increase when a facility switches to any of the priority biofuels, and CO could be used as a surrogate for emissions of PAH. The table indicates that biodiesel is the only fuel where emission factors were developed for the majority of pollutants.

Table 5-1. Priority Biofuel and Pollutant Combinations With the Most Limited Data
(An X indicates where additional data gathering and/or testing is suggested)

Application	Biofuel Category	CO	HCl	Nox	PM	PM_{10}	THC as VOC
combustion	**biodiesel**		X			X	
	corn derivatives						
	syrup					X	
	dried distillers grains with solubles	X	X	X	X	X	X
	stover	X	X	X	X	X	X
	distillers wet grains	X	X	X	X	X	X
	switchgrass		X		X	X	X
	wheat straw	X	X	X	X	X	X
gasification	manure (digester gas)	X	X	X	X	X	X
	logging (wood) residue	X	X	X	X	X	X

These results are not surprising considering biofuels have not previously been widely used in combustion sources or tested. Additional data gathering will be necessary to develop a higher quality compilation of emission factors. The following recommendations are next steps to fill in the remaining data gaps and develop higher confidence in the emission factors.

5.1 Collect data from outstanding data sources

The end date for gathering data to be included in this study was April 2007. During the data collection, several sources that had been contacted and may have potential data did not provide information in time to be used in this study. Table 5-2 lists the additional data sources, the type of information that may be obtained, and when the information may be available. The majority of the additional information is for sources combusting biodiesel blends. One of the sources also are burning switchgrass. This information will not fill in data gaps for the other priority biofuels, but it may increase the quality of the emission factors developed for biodiesel and switchgrass.

Table 5-2. Potential Emissions Data Sources From Ongoing and Planned Tests for Priority Biofuels

Facility/ Data Source	State	Biofuel	Status
Meister Cheese Company	WI	switchgrass co-fired with wood	Testing in late 2008
New York Power Authority: Poletti Power Project	NY	biodiesel in boilers blended with #6 fuel oil, blends will vary from B5 to B20	Final report due summer 2007
Iowa Municipal Utilities: Winterset and Story City	IA	biodiesel in engines, blends will be B10 and B20	Testing in early summer 2007
Houston Advanced Research Center	TX	biodiesel in engines	Ongoing research, milestone report due early summer 2007
Agricultural Utilization Research Institute	MN	Glycerin (non-priority biofuel)	Tests completed, data analysis ongoing

5.2 Conduct additional data gathering

Permitted Facilities

Due to time restraints in this study, not all states were contacted for potential sources of facilities combusting the priority biofuels. Other states may have data on permitted facilities or experimental tests using the priority biofuels. Alternately, these other states may have “state biomass initiatives” in place to manage and track the recent growth in biomass and biofuels. In addition, some of the states reviewed during this study did not have a consolidated list of facilities within the state permitted to combust biomass, or more specifically, the priority biofuels. If a consolidated list did not exist, and only a permit-by-permit search was available, this information was not gathered due to time restraints. Individual permits could be reviewed when the permits are available on the Internet.

Additional Journal Publications

Although an extensive literature search was performed for combustion and gasification applications on all the priority biofuels, some articles did not contain emissions data, but the reference section of the article may have included articles with relevant emissions data. A complete list of the articles reviewed has been maintained, and as time allows a thorough review of each article’s reference section could be performed to identify additional articles with emissions data for priority biofuels.

Manufacturer Data

Several manufacturers of biomass gasifiers were contacted via telephone and e-mail during this study. However, none of these companies provided gas composition data or emissions data from boilers or engines using gasified biomass fuels. Given the interest from these manufacturers to get facilities permitted to install and use biomass gasifiers, a direct request from a state permitting authority such as the MPCA, or other permitting authorities from the surrounding Great Lakes Regional Biomass Partnership states may encourage more emissions data for biomass gasifiers and applications using gasified biomass fuels.

Test data

Corn derivatives are expected to be more widely used as biofuels, particularly in the Great Lakes Region, because corn is a significant agricultural crop in the region, and its use as a feedstock for ethanol has spurred the development of several ethanol production facilities in the area. It is likely that combustion tests will be conducted at some of these facilities. However, it is unknown the number of tests planned or the scheduling and availability of testing information. Because of the anticipated use of corn derivatives, it may be necessary for the State of Minnesota to conduct its own initial tests to develop emission factors in a more timely manner.

Although wheat straw may not be as widely used as corn derivatives, it is still expected to be a priority biofuel for Minnesota in the longer-term. However, wheat straw has significant data gaps and no additional data sources have been identified combusting this fuel in the United States. Therefore, if it is to remain on the priority biofuels list, testing will be needed to develop emission factors.

The manufacturers of gasifiers are expected to be a significant data source for emissions from gasified biomass fuels. Given the limited data on gasifier installations in the United States, the MPCA or surrounding pollution control agencies may work with manufacturers of gasifiers to sponsor emissions testing for these applications.

Even with additional information collected from outstanding sources and new sources of information, it still likely that testing may need to be conducted to obtain data on air toxics emitted from the priority biofuels. The only air toxics that data had been collected for were HCl (for corn derivatives and wheat straw) and PAH’s (for biodiesel blends).

5.3 Identification of non-priority biofuels for further study

During the data gathering process, MPCA had a specific request for HCl emissions from oat hull combustion to meet the needs of a current permit application. Given that a proposed facility will co-fire oat hulls this fuel may be moved to priority status.

Additionally, data for other biofuels were gathered during this study. Table 5-3 shows data sources containing emission information or permit limit data for 19 other biofuels. None of these data were targeted as priority biofuels for this study, but these data may be useful in the event that a permit application for any of these fuels is submitted to MPCA.

Table 5-3. Available Emission Data for Non-Priority Biofuels

	Source					
Biofuel	Cargill Oilseeds, North Dakota (Title V Permit)	Northern Sun, North Dakota (Title V Permit)	Penn State Energy Institute, PEDA Report	Results of Boiler MACT Testing - University of Iowa	A Demonstration of Fat and Grease as an Industrial Boiler Fuel, University of Georgia	Stack Emissions Evaluation: Combustion of Crude Glycerin and Yellow Grease in an Industrial Fire Tube Boiler, AURI
Cull-Cow Carcasses / Coal			X			
Cull-Cow SRMs / Coal			X			
Feather Meal / Coal			X			
Fed Cattle SRMs / Coal			X			
Glycerin						X
Hatgrow / Coal			X			
Meat & Bone Meal / Coal			X			
Meat & Bone Meal / Nat Gas			X			
Meat & Bone Meal / Pulverized Coal			X			
Oat Hulls / Coal				X		
Pork Meal / Coal			X			
Poultry Fat			X		X	
Poultry Meal / Coal			X			
Poultry Meal / Nat Gas			X			
Poultry Meal / Pulverized Coal			X			
Soybean Oil			X			
Sunflower Seed Hulls	X	X				
Tallow			X		X	
White Grease			X		X	
Yellow Grease			X		X	X

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Appendix A

MEMORANDUM ON THE RECOMMENDATION OF DATABASE FORMAT FOR MPCA BIOFUEL EMISSION FACTOR DEVELOPMENT PROJECT

MEMORANDUM

TO: Heather Magee-Hill, MPCA

FROM: John Carter and Amanda Singleton, ERG

DATE: April 3, 2007

SUBJECT: Recommendation of Database Format for Minnesota Biofuel Emission Factor Development Project

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1.0 Introduction

This memorandum presents Eastern Research Group, Inc. (ERG) review of existing database formats and presents ERG's recommendation for the database format for the Minnesota Biofuel Emission Factor Development Project. Based on this review, ERG suggests Minnesota Pollution Control Agency (MPCA) existing "Updated Minnesota Biomass Facilities Testing Database" be retained for this project. Section 2.0 of this memorandum discusses the format options ERG considered and Section 3.0 outlines the existing contents of the MPCA database. As a result of preliminary data research, ERG has identified some additional data fields and categories that may be added as data collection and entry progresses. Section 4.0 of this memorandum outlines ERG's suggested additions as well as some minor modifications to the existing links between the data tables to improve the structure of the database.

2.0 Database Format Considerations

MPCA provided two existing Access databases for ERG to consider as the format for use in this project. ERG was also given the option of developing a new format of our own design. The first existing Access database, MPCA's "Updated Minnesota Biomass Facilities Testing Database," is pre-populated with quality-checked permit data from 37 facilities permitted to use biomass energy. Although the emissions test data for these permits were incomplete at the time it was submitted to ERG, these data will be made available to ERG as this project proceeds. The MPCA database was also designed to house emissions data from sources other than permits including published sources and equipment manufacturers.

The second Access database provided by MPCA is the "Biomass Published Emission Factor Summary Database" developed by the state of Michigan. This database arrived with only one example record and was designed primarily as a storehouse for data from published sources.

After significant screening-level research into biofuel use in Minnesota and a review of sources with potentially available emissions data for biofuels, ERG recommends using MPCA's "Updated Minnesota Biomass Facilities Testing Database" as the basis for the format to develop biofuels emission factors for MPCA. ERG believes an Access database is the appropriate software for this project given the complex and interrelated nature of the data we expect to collect. ERG also believes the MPCA provides a more robust and flexible format than the Michigan database and also represents a significant amount of time and resources spent not only in its development, but in entering and checking the Minnesota biomass permit data. Where necessary, it can be easily modified to fit the specific needs of the data we will collect for this project and using it will save the time and money required to build a new database from scratch and re-enter the permit data it already contains.

3.0 Database Characterization

The existing database format includes several tables and forms that allow for the entry and storage of data collected from three primary types of sources:

1. ***Biomass Permits***: Associated tables contain permit information for facilities with units combusting biofuels, the permitted emission limits, and any available test data for various pollutants.

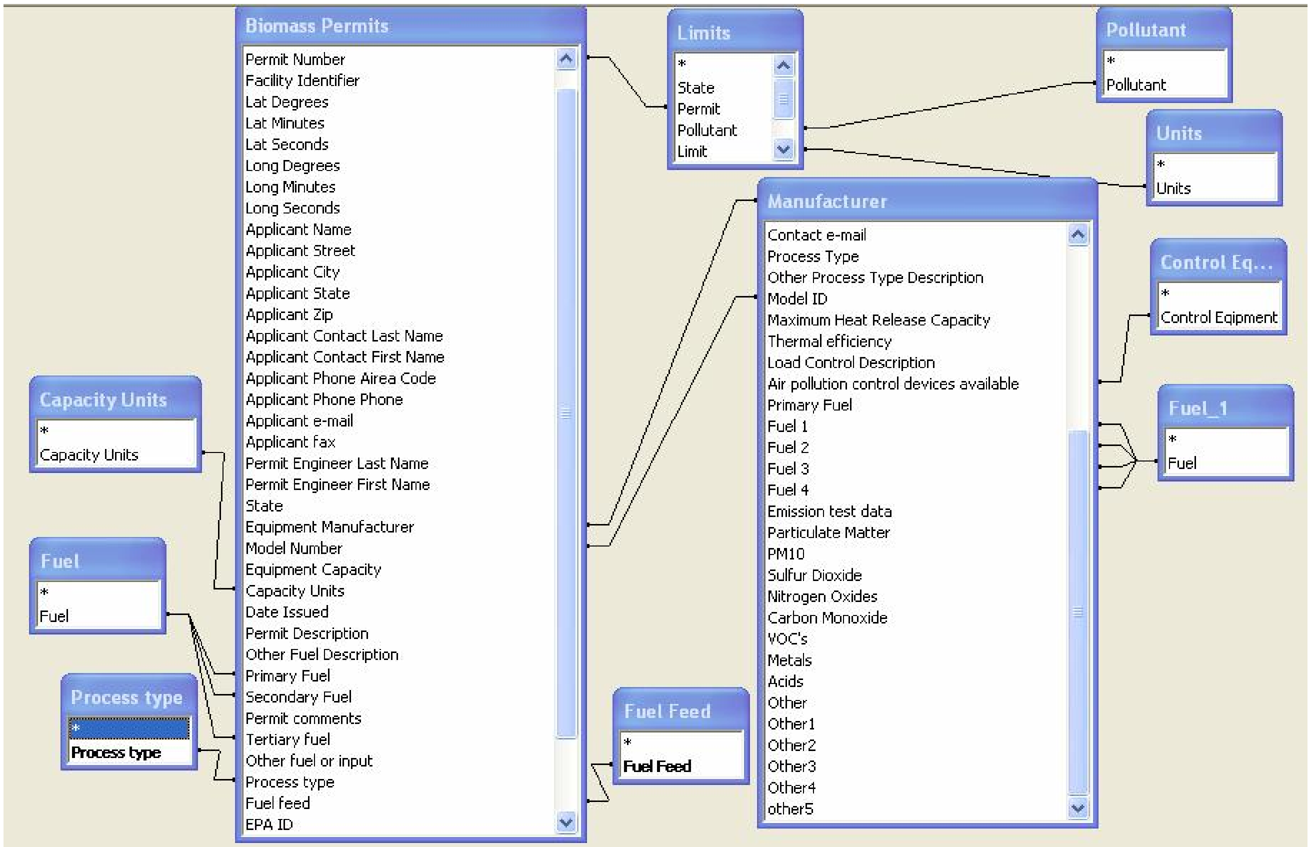
2. ***Biomass Emission Factor Published Data***: Associated tables contain publicly available emission information such as journals, web-sites, or research centers, and trade associations.

3. ***Biomass Equipment Manufacturers***: Associated tables contain a list of manufacturers, their associated equipment models, and a brief characterization of the end-use application (pyrolysis, combustion, gasification, boiler, dryer, digester, fermentation, transesterification, hydrolysis, and other). Also contains performance data and emissions test data from equipment manufacturers.

In addition to the three types of data sources, the existing database format includes several lists or "look-up" tables to provide standard naming conventions for data entry. These lists include options for selecting fuel type, fuel feed, capacity units, process type, emission limit units, pollutant type, and control equipment. Attachment A presents a list of the existing contents of these list tables. Attachment B presents a list of data fields in the primary tables for data collected from permits, published data, and equipment manufacturers.

Figure 1 presents the relationship between the Biomass Permit data table and the data lists, or look-up tables. The Biomass Emission Factor Published Data and Biomass Equipment Manufacturers Data tables will have similar relationships.

Figure 1. Example Database Relationships



4.0 Suggested Database Modifications

The seven data lists or "look-up" tables provide a starting point for data collection and a method for standardizing the data formats. However, as a result of initial research, we have identified some changes to the database that will enhance its flexibility and performance in storing and manipulating the data for this project. Listed below are preliminary suggested additions and modifications to the existing database format. This list is not necessarily complete and further modifications are likely to be recommended as data collection and entry progress.

Fuel Types: The fuel listing does not include diesel or heating oil. Since these are both common fuels for blending with biodiesel, these fuels may be added to the fuel list. Additionally, there are various sub-types of coal fuel (e.g., low sulfur coal, powder river basin coal, anthracite coal, etc...). These coal sub-types have unique emission factors in *AP-42*, and blends of biofuels with various subcategories of coal may also have unique emission factors.

Applications: Preliminary research has resulted in emissions data for reciprocating engines burning biodiesel or biodiesel blends. "Reciprocating engine" is currently not on the list of process types, and may be added in the future.

Data Relationships: A primary key or set of primary keys represents the unique identification of a record. Since permit data, emission test data, publicly available information, and equipment manufacturer data can all be at the unit-specific level, we recommend adding a unit ID data field in addition to the permit number and facility identifier.

We also recommend the testing database have more than one primary key identifier in order to have a unique testing record for each unit at a facility. In addition, emission test data could be available for units without a corresponding permit number (e.g., testing data from journal articles or equipment manufacturers). For the testing table, the primary keys should include a link to the facility ID, unit ID, and test run ID, and these IDs should be related to the permit data table, manufacturer table, and publicly-available data table.

Text Data Fields: Several of the text description fields are not long enough (i.e., permit description field), and the text is cutoff in the middle of the description. The text is correctly stored in a "memo" data field type, which allows for long descriptions. However, a truncation of the text occurred when importing the data into this field in Access. If complete descriptions are available, we would like to include them in the revised database format.

NAICS Codes: The newer industry classification system is the North American Industrial Classification System (NAICS), which has replaced the SIC code system. We recommend adding a NAICS field to the following data tables: biomass permits, testing, and publicly available information.

Attachment A. Currently Available Categories for Database Lists or "Look-up" Tables

Fuel	Fuel Feed	Process type	Units	Capacity Units	Control Equipment Choices	Pollutant		
Alfalfa	Atomized burner	Boiler	lb/1,000 lbs of exhaust gases	HP (boiler)	Centrifugal collector	1,1,1-Trichloroethane	Dibenzo(a,h) anthracene	Pentachlorodibenzo-p-dioxins, total
Animal foils and fats	Fluidized bed	Digester	lb/day	HP (brake)	Multiple cyclone without fly ask re-injection	1,2-Ethylene dibromide	Dichlorobiphenyl	Pentachlorophenol (PCP)
Animal oils and fats	Gas burner	Dryer	lb/hour	Kilowatts	Wet cyclone separator	2,3,7,8-Tetrachlorodibenzofuran	Dichloromethane	Perchloroethylene
Biodiesel w/ additives	Hand fired	Fermentation	lb/MMBtu	lbs/day	Electrostatic precipitators	2,3,7,8-Tetrachlorodibenzo-p-dioxin	Dioctyl phthalate	Perylene
Biodiesel w/ additives	Overfeed stoker	Gasifier	lb/month	lbs/hour	Fabric filter	2,4,4'-Trichlorobiphenyl	Dioxin	Phenanthrene
Biodiesel w/out additives	Pulverized	Generator	lb/ton of feed	lbs/month	Spray tower	2,4,6-Trichlorophenol	Dysprosium	Phenol
Biodiesel w/out additives	Screw conveyor, top feed	Hydrolysis	percent by weight	lbs/year	Venturi scrubber	2,4-Dinitrophenol	Ethylbenzene	Phosphorus (yellow or white)
Biogas	Screw conveyor, underfeed	Pyrolysis	ppm	Megawatts	Impingement plate scrubber	2-Chloronaphthalene	Ethylene dichloride	PM
Cherry pits	Slurry	Transesterifcation	ppmv	MMBtu's/hr (input)	HEPA and other wall filters	2-Chlorophenol	Fluoranthene	PM10
Cherry pits	Spread stoker		ppmw	thousand pounds steam/hr	Afterburners	2-Methyl Naphthalene	Fluorene	PM2.5
Coal			tons/day	tons/day	Flaring	2-Monochlorobiphenyl	Formaldehyde	Polychlorinated dibenzofurans, total
Coffee grounds			tons/hour	tons/hour	Baghouse/spray dryer	2-Nitrophenol	Germanium	Polychlorinated dibenzo-p-dioxins, total
Coke			tons/month	tons/month		4-Nitrophenol	Heptachlorobiphenyls, total	Potassium
Corn cob			tons/year	tons/year		Acenaphthene	Heptachlorodibenzofurans, total	Praseodymium
Corn gluten			ug/cubic meter			Acetaldehyde	Heptachlorodibenzo-p-dioxins, total	Propionaldehyde
Corn oil						Acetone	Hexachlorobiphenyls, total	Propylene dichloride
Corn seed						Acetophenone	Hexachlorodibenzofurans, total	p-Tolualdehyde
Corn shell						Acrolein	Hexachlorodibenzo-p-dioxins, total	Pyrene
Corn stover/stalks						Ammonia	Hexanal	Rubidium
Cow manure						Anthracene	Hydrogen chloride	Samarium
Distillers syrup						Antimony	Indeno(1,2,3-cd)pyrene	Selenium
Dried distillers grain						Arsenic	Iodine	Silver
Fuel oil						Barium	Iron	Sodium
Glycerin						Benzaldehyde	Isobutyraldehyde	Solicyaldehyde

Attachment A. Currently Available Categories for Database Lists or "Look-up" Tables

Fuel	Fuel Feed	Process type	Units	Capacity Units	Control Equipment Choices	Pollutant		
Miscanthus						Benzene	Lead	Strontium
Multiple petroleum						Benzo (a) anthracene	Lead	Styrene
Natural gas						Benzo (a) pyrene	Lithium	Sulfur dioxide
Nut shells						Benzo (b) fluoranthene	Manganese	Sulfuric acid
Oat straw						Benzo (e) pyrene	Mercury	Tetrachlorobiphenyls, total
Oats hulls						Benzo (g,h,i) perylene	Methane	Tetrachlorodibenzofurans, total
Paper processing sludges						Benzo (k) fluoranthene	Methyl bromide	Tetrachlorodibenzo-p-dioxins, total
Pig manure						Benzo(b+k)fluoranthene	Methyl chloride	Thorium
Propane						Benzofluoranthenes	Methyl ethyl ketone	Tin
RDF/pelletized waste fuels						Benzoic acid	Methylanthracene, mixed isomers	Titanium
Rice straw						Beryllium	Molybdenum	Toluene
Solid waste						Boron	Naphthalene	Total organic compounds (TOC)
Soybeans (hulls)						Bromine	Neodymium	Trichloroethylene
Sugar beets						Cadmium	Nickel	Trichlorofluoromethane
Switchgrass						Carbazole	Niobium	Trichlorotrifluoroethane
Tire derived fuel						Carbon dioxide	Nitrogen dioxide	Tungsten
Turkey manure						Carbon monoxide	Nitrogen oxides	Vanadium
Wheat middlings						Carbon tetrachloride	Octachlorodibenzofurans, total	Vinyl chloride
Wheat straw						Chlorine	Octachlorodibenzo-p-dioxins, total	Visible Emissions
Wood bark						Chlorobenzene	*o*-Tolualdehyde	Volatile organic compound (VOCs)
Wood chips						Chloroform	*o*-Xylene	Yttrium
Wood pallets						Chromium	Pentachlorobiphenyls, total	Zinc
Wood saw dust						Chromium (VI)	Pentachlorodibenzofurans, total	Zirconium
Wood sludge						Chrysene		
Yellow grease						Cobalt		
						Copper		
						Crotonaldehyde		
						Decachlorobiphenyl		

Testing Table	Biomass Permits Table	Permit Limits Table	Manufacturers	Biomass Equipment Manufacturers	Publicly Available Information
State	Permit Number	State	Manufacturer Name	Manufacturer Name	Publication Title
Permit Number	Facility Identifier	Permit	Manufacturer ID	Applicant Street	Primary Author Last Name
Pollutant	Lat Degrees	Pollutant	Manufacturer Street	Manufacturer City	Primary Author First Name
Arithmetic mean emission rate	Lat Minutes	Limit	Manufacturer City	Manufacturer State	Publication Date
Emission unit	Lat Seconds	Units	Manufacturer State	Manufacturer Zip	Boiler
Standard deviation	Long Degrees	Unit ID	Manufacturer Zip Code	Manufacturer Contact Last Name	Gasifier
Min test value	Long Minutes		Manufacturer Area Code	Manufacturer Contact First Name	Transesterification
Max test value	Long Seconds		Manufacturer Phone Number	Manufacturer Area Code	Other
Number of tests	Applicant Name		Manufacturer Phone Extension	Manufacturer Phone Phone	Digester
Test method	Applicant Street		Manufacturer Fax Number	Manufacturer e-mail	Pyroloysis
Test date	Applicant City		Contact Last Name	Manufacturer fax	Dryer
Duration of test in hrs	Applicant State		Contact First Name	Model Number	Fermentation
Primary control equipment	Applicant Zip		Contact Title	Date Issued	Hydrolysis
Secondary control equipment	Applicant Contact Last Name		Contact e-mail	Boiler	Document Title
Fuel throughput rate	Applicant Contact First Name		Process Type	Digester	Other Description
Units fuel throughput	Applicant Phone Area Code		Other Process Type Description	Dryer	Equipment Capacity
Heat input MMBtu per hr	Applicant Phone Phone		Model ID	Gasifier	Capacity Unit
Product throughput rate	Applicant e-mail		Maximum Heat Release Capacity	Other	
Units product throughput	Applicant fax		Thermal efficiency	Other Description	
Moisture content Bw %v	Permit Engineer Last Name		Load Control Description	Pyrolysis	
Molecular weight dry gas	Permit Engineer First Name		Air pollution control devices available	Fermentation	
Air flow	State		Primary Fuel	Transesterifcation	
Stack pressure	Equipment Manufacturer		Fuel 1	Hydrolysis	
% O2 dry	Model Number		Fuel 2		
% CO2 dry	Equipment Capacity		Fuel 3		
%CO and N dry	Capacity Units		Fuel 4		
Test quality rating	Date Issued		Emission test data		
Completeness of QA and QC	Permit Description		Particulate Matter		
Test method deviations	Other Fuel Description		PM10		
Upsets during test	Primary Fuel		Sulfur Dioxide		
Burner temp Deg F	Secondary Fuel		Nitrogen Oxides		
Primary control equipment installation date	Permit comments		Carbon Monoxide		
Primary control equipment maintenance	Tertiary fuel		VOC's		
Primary control equipment date of last maintenance	Other fuel or input		Metals		
Equipment ID	Process type		Acids		
Fuel Tested	Fuel feed		Other		
Run #	EPA ID		Other1		
	Facility start up date		Other2		
	Secondary Process		Other3		
	Tertiary Process		Other4		
	SIC Code		Other5		

Appendix B

TELEPHONE CONTACT LIST

Appendix B
Telephone Contact List

BIOFUELS SOURCES

Contacts

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Ahern, Mike. Ohio Environmental Protection Agency. Contacted April 20, 2007.

Allen, Rasha. Kansas Department of Health and Environment. Contacted April 3, 2007.

Anex, Robert. Iowa State University. Contacted March 23, 2007.

Bachman, Tom. North Dakota Department of Health, Division of Air Quality. Contacted April 3, 2007.

Baileys, Ron. PRM Energy (manufacturer of gasifiers). Contacted April 6, 2007.

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Mann, Clarence. Alabama Department of Economic and Community Affairs. Energy, Weatherization and Technology Division. Contacted April 24, 2007.

McQuigg, K. Prim Energy (manufacturer of gasifiers). Contacted April 6, 2007.

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Miller, Bruce. Penn State Energy Institute. Contacted April 20, 2007.

Milster, Ferman. University of Iowa Utilities and Energy Management. Contacted April 19, 2007.

Moyer, Heather. National Defense Center for Environmental Excellence. Contacted April 11, 2007.

Namovicz, Chris. U.S. Energy Information Administration. Contacted March 24, 2007.

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Phillips, B. Emery Energy (manufacturer of gasifiers). Contacted April 6, 2007.

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Poley, Leslie. National Renewal Energy Laboratory. Contacted May 7, 2007.

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Rich, Ben. North Carolina State Energy Office. Contacted March 23, 2007.

Saltzman, Michael. New York Power Authority, Polletti Power Project. Contacted April 10, 2007.

Smeenk, Jerod. Frontline Bioenergy (manufacturer of gasifers). Contacted March 26, 2007.

Tonsor, Shauna. Michigan Department of Labor and Economic Growth - Energy Office. Contacted April 25, 2007.

Urbanksi, Ann and Don Faith, III. Wisconsin Department of Natural Resources. Contacted April 3, 2007.

Appendix C

DETAILED LISTING OF FUEL ANALYSIS CITATIONS

Appendix C. Detailed Listing of Fuel Analysis Citations

	Dried Distillers Grains with Solubles		**Dried Distillers Grains without Solubles**	**Distillers Wet Grains**	**Syrup**	**Corn Stover**				
Fuel Note										
As received										
Moisture, %	10.12	9.27	13.35	64.46	67.29	6.15	35.00	9.14		
Ash, %	3.41	4.16	1.96	0.97	2.31	6.31	3.25	6.81		
Higher heating value, Btu/lb	8,368	8,459	8,473	3,349	2,765	7,235	4,623	7,057		
Moisture Free										
Ash, %	3.89	4.13	2.24	2.58	7.02	6.73		7.64	5.60	11.63
Higher heating value, Btu/lb	9,349	9,422	9,848	9,438	8,482	7,709		7,768	9,175	7,867
Lower heating value, Btu/lb	8,703			8,819	7,819	7,192				
Proximate										
Volatile matter, %	82.50			83.18	81.71	66.58	54.60			72.57
Fixed Carbon, %	12.84			13.58	10.32	26.65	7.15			21.26
Chlorine, µg/g	1,757			1,673	3,459	984				
Chlorine, %										
Chlorine, ppm										
Mercury, µg/g	<0.010			<0.10	<0.012	<0.010				
Mercury, mg/kg										
Ultimate										
Carbon, %	50.24			52.53	43.12	45.48	42.50			46.64
Hydrogen, %	6.89			6.60	7.07	5.52	5.04			5.66
Nitrogen, %	4.79			5.35	2.63	0.69	0.75			0.67
Oxygen, %	33.42			32.28	39.21	41.52	42.60	0.04		39.59
Sulfur, %	0.77	0.45	0.40	0.66	0.96	0.04	0.18			0.08
Metals, mg/kg										
Arsenic	<3.20			<3.10	<3.20	2.50				
Barium										
Beryllium	<0.093			<0.093	<0.11	<0.089				
Cadmium	<0.046			<0.50	<0.53	<0.45				
Chromium	0.50			<0.79	0.75	<0.45				
Lead	<0.046			<0.50	<0.53	0.46				
Manganese	15.95			12.05	34.93	23.40				
Nickel	0.87			<1.20	1.97	<0.45				
Phosphorus	-			-	-	-				
Potassium	-			-	-	-				
Selenium	1.80			<1.80	<1.60	<1.30				
Silver										
Reference	8	2	2	8	8	8	5	2	10	14

Appendix C. Detailed Listing of Fuel Analysis Citations

Parameter	Wheat Straw						Switchgrass (pellets)
Fuel Note							
As received							9.30
Moisture, %	8.26		8-23		8.63		2.90
Ash, %	10.40		2-6		12.45		7,381
Higher heating value, Btu/lb	6,839		6,032		7,134		
Moisture Free							
Ash, %	11.33	8.90				10.22	
Higher heating value, Btu/lb	7,375	7,544		8,143		7,481	
Lower heating value, Btu/lb							
Proximate							
Volatile matter, %		19.80	70-80		63.96	69.38	72.30
Fixed Carbon, %					14.96	21.54	15.50
Chlorine, µg/g							
Chlorine, %				0.15			
Chlorine, ppm							1,075
Mercury, µg/g							
Mercury, mg/kg							
Ultimate							
Carbon, %		41.80	40.10	46.20	42.11	43.88	51.70
Hydrogen, %		5.50	5.20	5.80	6.53	5.26	7.00
Nitrogen, %		0.70	0.40	0.59	0.58	0.63	0.20
Oxygen, %	0.08	35.50	40.00	41.30	40.51	38.75	28.90
Sulfur, %		-	0.1-0.3	0.08	0.32	0.16	0.00
Metals, mg/kg							
Arsenic							
Barium							
Beryllium							
Cadmium							
Chromium							
Lead							
Manganese							
Nickel							
Phosphorus							
Potassium							
Selenium							
Silver							
Reference	2	5	13	9	6	14	7

Appendix C. Detailed Listing of Fuel Analysis Citations

Parameter	Switchgrass (loose)						
Fuel Note	loose	loose (hammermilled)	loose	loose	mechanically harvested	manually harvested	loose
As received							
Moisture, %		9.60	6.34	11.00	9.53	8.89	
Ash, %		3.10	5.35	4.80	5.95	3.93	
Higher heating value, Btu/lb		7,322	7,458	7,082	7,333	7,421	
Moisture Free							
Ash, %	4.5 - 5.8		5.70	5.30	6.58	4.31	5.84
Higher heating value, Btu/lb	9,540		7,965	7,962	8,105	8,145	8,040
Lower heating value, Btu/lb							
Proximate							
Volatile matter, %		76.20	73.84	84.00	76.30	89.77	74.21
Fixed Carbon, %		11.10	14.48	10.70	17.12	5.92	20.64
Chlorine, µg/g							
Chlorine, %			0.14	0.03			
Chlorine, ppm		1,300					
Mercury, µg/g							
Mercury, mg/kg			<0.1				
Ultimate							
Carbon, %		49.60	48.41	42.31	40.54	43.55	46.74
Hydrogen, %		6.50	5.06	5.12	5.28	5.13	5.76
Nitrogen, %		0.30	0.56	0.71	0.92	0.79	0.76
Oxygen, %		30.80	40.16	35.97	37.57	37.61	40.70
Sulfur, %	0.12	0.10	0.12	0.16	0.20	0.10	0.09
Metals, mg/kg							
Arsenic			1.20				
Barium							
Beryllium							
Cadmium			<5				
Chromium			58.00				
Lead			40.00				
Manganese							
Nickel							
Phosphorus							
Potassium			0.81				
Selenium			4.00				
Silver			<10				
Reference	10	7	3	1	4	4	14

Appendix C. Detailed Listing of Fuel Analysis Citations

Parameter	Pure Biodiesel (B100)		Biodiesel Blend (B5)	Biodiesel Blend (B10)	Biodiesel Blend (B20)
Fuel Note					
As received					
Moisture, %					
Ash, %					
Higher heating value, Btu/lb					
Moisture Free					
Ash, %	<0.02	0.10			
Higher heating value, Btu/lb	20,852	17,189	18,259	18,353	18,223
Lower heating value, Btu/lb					
Proximate					
Volatile matter, %		99.60			
Fixed Carbon, %		0.30			
Chlorine, µg/g					
Chlorine, %					
Chlorine, ppm		1,100			
Mercury, µg/g					
Mercury, mg/kg					
Ultimate					
Carbon, %		76.70	86.28	86.09	85.06
Hydrogen, %		0.10	10.50	10.31	10.64
Nitrogen, %		12.30			
Oxygen, %		10.80	1.05	1.76	2.47
Sulfur, %	<0.05	0.00	1.86	1.64	1.50
Metals, mg/kg					
Arsenic					
Barium					
Beryllium					
Cadmium					
Chromium					
Lead					
Manganese					
Nickel					
Phosphorus					
Potassium	<0.0001				
Selenium					
Silver					
Reference	10	7	12	12	12

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Appendix D

SUMMARY OF EMISSION FACTORS FOR INDIVIDUAL TESTS AND JOURNAL ARTICLES

Appendix D. Summary of Emission Factors for Individual Tests

Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
19	T000005	NA[a]	NA	biodiesel	NA	#6 fuel oil with 10% biodiesel	CO	2.12E-01	Measured data	None specified
19	T000005	NA	NA	biodiesel	NA	#6 fuel oil with 10% biodiesel	NOx	3.13E-01	Measured data	None specified
19	T000005	NA	NA	biodiesel	NA	#6 fuel oil with 10% biodiesel	SO_2	1.67E+00	Measured data	None specified
19	T000005	NA	NA	biodiesel	NA	#6 fuel oil with 20% biodiesel	CO	1.32E-01	Measured data	None specified
19	T000005	NA	NA	biodiesel	NA	#6 fuel oil with 20% biodiesel	NOx	2.74E-01	Measured data	None specified
19	T000005	NA	NA	biodiesel	NA	#6 fuel oil with 20% biodiesel	SO_2	1.56E+00	Measured data	None specified
19	T000005	NA	NA	biodiesel	NA	#6 fuel oil with 5% biodiesel	CO	1.63E-01	Measured data	None specified
19	T000005	NA	NA	biodiesel	NA	#6 fuel oil with 5% biodiesel	NOx	3.14E-01	Measured data	None specified
19	T000005	NA	NA	biodiesel	NA	#6 fuel oil with 5% biodiesel	SO_2	1.57E+00	Measured data	None specified
20	2000-01-1969	2000-01-1969-A	2000-01-1969-45	biodiesel	NA	100% biodiesel	CO	6.11E-01	Measured data	None
20	2000-01-1969	2000-01-1969-B	2000-01-1969-48	biodiesel	NA	100% biodiesel	CO	7.06E-01	Measured data	None
20	2000-01-1969	2000-01-1969-AC	2000-01-1969-43	biodiesel	NA	100% biodiesel	CO	2.19E-01	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-BC	2000-01-1969-47	biodiesel	NA	100% biodiesel	CO	1.24E-01	Measured data	Oxidation catalyst
20	950400	950400A	950400-225	biodiesel	NA	100% biodiesel	CO	6.64E-01	Measured data	None
20	950400	950400ADOC	950400-228	biodiesel	NA	100% biodiesel	CO	2.26E-01	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-A	2000-01-1969-45	biodiesel	NA	100% biodiesel	NOx	5.16E+00	Measured data	None
20	2000-01-1969	2000-01-1969-B	2000-01-1969-48	biodiesel	NA	100% biodiesel	NOx	5.33E+00	Measured data	None
20	950400	950400A	950400-225	biodiesel	NA	100% biodiesel	NOx	6.32E+00	Measured data	None
20	2000-01-1969	2000-01-1969-AC	2000-01-1969-43	biodiesel	NA	100% biodiesel	NOx	3.62E+00	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-BC	2000-01-1969-47	biodiesel	NA	100% biodiesel	NOx	4.88E+00	Measured data	Oxidation catalyst

Appendix D. Summary of Emission Factors for Individual Tests

Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
20	950400	950400ADOC	950400-228	biodiesel	NA	100% biodiesel	NOx	6.71E+00	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-A	2000-01-1969-45	biodiesel	NA	100% biodiesel	PM	1.47E-01	Measured data	None
20	2000-01-1969	2000-01-1969-B	2000-01-1969-48	biodiesel	NA	100% biodiesel	PM	2.26E-01	Measured data	None
20	2000-01-1969	2000-01-1969-AC	2000-01-1969-43	biodiesel	NA	100% biodiesel	PM	6.90E-02	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-BC	2000-01-1969-47	biodiesel	NA	100% biodiesel	PM	1.01E-01	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-A	2000-01-1969-45	biodiesel	NA	100% biodiesel	VOC as THC	2.95E-02	Measured data	None
20	2000-01-1969	2000-01-1969-B	2000-01-1969-48	biodiesel	NA	100% biodiesel	VOC as THC	1.57E-01	Measured data	None
20	950400	950400A	950400-225	biodiesel	NA	100% biodiesel	VOC as THC	6.45E-02	Measured data	None
20	2000-01-1969	2000-01-1969-AC	2000-01-1969-43	biodiesel	NA	100% biodiesel	VOC as THC	5.52E-02	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-BC	2000-01-1969-47	biodiesel	NA	100% biodiesel	VOC as THC	7.67E-02	Measured data	Oxidation catalyst
20	950400	950400ADOC	950400-228	biodiesel	NA	100% biodiesel	VOC as THC	1.94E-02	Measured data	Oxidation catalyst
13	J012	NA	05/31/06	biodiesel	NA	100% biodiesel from soya	CO	0.104	Measured data	None specified
13	J012	NA	05/31/06	biodiesel	NA	100% biodiesel from soya	NOx	0.104	Measured data	None specified
13	J012	NA	05/31/06	biodiesel	NA	100% biodiesel from soya	SO_2	0.00	Measured data	None specified
17	T000009	NA	NA	biodiesel	NA	100% biodiesel from soya	CO	5.71E-03	Measured data	None specified
17	T000009	NA	NA	biodiesel	NA	100% biodiesel from soya	NOx	1.09E-01	Measured data	None specified
17	T000009	NA	NA	biodiesel	NA	100% biodiesel from soya	PM	2.11E-03	Measured data	None specified
11	J004	NA	NA	biodiesel	NA	100% palm biodiesel	PAH	6.08E-05	Measured data	None
11	J004	NA	NA	biodiesel	NA	100% palm biodiesel	PAH	5.71E-05	Measured data	None
11	J004	NA	NA	biodiesel	NA	100% palm biodiesel	PAH	2.66E-05	Measured data	None
11	J004	NA	NA	biodiesel	NA	100% palm biodiesel	PM	6.72E-02	Measured data from graph	None
7	T000006	NA	NA	biodiesel	NA	diesel with 10% biodiesel	NOx	6.95E+00	Measured data	None specified

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Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
7	T000006	NA	NA	biodiesel	NA	diesel with 10% biodiesel	NOx	4.18E+00	Measured data	None specified
7	T000006	NA	NA	biodiesel	NA	diesel with 10% biodiesel	PM	1.30E-01	Measured data	None specified
7	T000006	NA	NA	biodiesel	NA	diesel with 10% biodiesel	PM	5.00E-02	Measured data	None specified
20	950400	950400A	950400-226	biodiesel	NA	diesel with 30% biodiesel	CO	7.03E-01	Measured data	None
20	950400	950400ADOC	950400-229	biodiesel	NA	diesel with 30% biodiesel	CO	1.87E-01	Measured data	Oxidation catalyst
20	950400	950400A	950400-226	biodiesel	NA	diesel with 30% biodiesel	NOx	5.42E+00	Measured data	None
20	950400	950400ADOC	950400-229	biodiesel	NA	diesel with 30% biodiesel	NOx	6.06E+00	Measured data	Oxidation catalyst
20	950400	950400A	950400-226	biodiesel	NA	diesel with 30% biodiesel	VOC as THC	5.80E-02	Measured data	None
20	950400	950400ADOC	950400-229	biodiesel	NA	diesel with 30% biodiesel	VOC as THC	1.94E-02	Measured data	Oxidation catalyst
11	J004	NA	NA	biodiesel	NA	premium diesel	PAH	3.91E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel	PAH	3.82E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel	PAH	3.82E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel	PM	5.21E-02	Measured data from graph	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 10% palm biodiesel	PAH	3.50E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 10% palm biodiesel	PAH	3.29E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 10% palm biodiesel	PAH	3.21E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 10% palm biodiesel	PM	2.56E-02	Measured data from graph	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 20% palm biodiesel	PAH	2.84E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 20% palm biodiesel	PAH	2.81E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 20% palm biodiesel	PAH	2.73E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 20% palm biodiesel	PM	4.17E-02	Measured data from graph	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 30% palm biodiesel	PAH	2.58E-03	Measured data	None

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Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
11	J004	NA	NA	biodiesel	NA	premium diesel with 30% palm biodiesel	PAH	2.36E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 30% palm biodiesel	PAH	2.10E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 30% palm biodiesel	PM	4.98E-02	Measured data from graph	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 50% palm biodiesel	PAH	1.96E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 50% palm biodiesel	PAH	1.83E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 50% palm biodiesel	PAH	1.64E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 50% palm biodiesel	PM	5.79E-02	Measured data from graph	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 75% palm biodiesel	PAH	1.94E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 75% palm biodiesel	PAH	1.52E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 75% palm biodiesel	PAH	1.19E-03	Measured data	None
11	J004	NA	NA	biodiesel	NA	premium diesel with 75% palm biodiesel	PM	6.59E-02	Measured data from graph	None
20	2000-01-1969	2000-01-1969-A	2000-01-1969-46	biodiesel	NA	pure diesel	CO	6.42E-01	Measured data	None
20	2000-01-1969	2000-01-1969-B	2000-01-1969-50	biodiesel	NA	pure diesel	CO	1.13E+00	Measured data	None
20	950400	950400A	950400-224	biodiesel	NA	pure diesel	CO	7.10E-01	Measured data	None
20	2000-01-1969	2000-01-1969-AC	2000-01-1969-44	biodiesel	NA	pure diesel	CO	2.22E-01	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-BC	2000-01-1969-49	biodiesel	NA	pure diesel	CO	1.85E-01	Measured data	Oxidation catalyst
20	950400	950400ADOC	950400-227	biodiesel	NA	pure diesel	CO	2.26E-01	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-A	2000-01-1969-46	biodiesel	NA	pure diesel	NOx	5.15E+00	Measured data	None
20	2000-01-1969	2000-01-1969-B	2000-01-1969-50	biodiesel	NA	pure diesel	NOx	5.00E+00	Measured data	None
20	950400	950400A	950400-224	biodiesel	NA	pure diesel	NOx	6.19E+00	Measured data	None

Appendix D. Summary of Emission Factors for Individual Tests

Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
20	2000-01-1969	2000-01-1969-AC	2000-01-1969-44	biodiesel	NA	pure diesel	NOx	4.10E+00	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-BC	2000-01-1969-49	biodiesel	NA	pure diesel	NOx	4.71E+00	Measured data	Oxidation catalyst
20	950400	950400ADOC	950400-227	biodiesel	NA	pure diesel	NOx	6.52E+00	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-B	2000-01-1969-50	biodiesel	NA	pure diesel	PM	2.08E-01	Measured data	None
20	2000-01-1969	2000-01-1969-AC	2000-01-1969-44	biodiesel	NA	pure diesel	PM	1.11E-01	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-BC	2000-01-1969-49	biodiesel	NA	pure diesel	PM	2.69E-01	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-A	2000-01-1969-46	biodiesel	NA	pure diesel	VOC as THC	2.07E-01	Measured data	None
20	2000-01-1969	2000-01-1969-B	2000-01-1969-50	biodiesel	NA	pure diesel	VOC as THC	4.66E-01	Measured data	None
20	950400	950400A	950400-224	biodiesel	NA	pure diesel	VOC as THC	7.74E-02	Measured data	None
20	2000-01-1969	2000-01-1969-AC	2000-01-1969-44	biodiesel	NA	pure diesel	VOC as THC	1.30E-01	Measured data	Oxidation catalyst
20	2000-01-1969	2000-01-1969-BC	2000-01-1969-49	biodiesel	NA	pure diesel	VOC as THC	1.62E-01	Measured data	Oxidation catalyst
20	950400	950400ADOC	950400-227	biodiesel	NA	pure diesel	VOC as THC	1.94E-02	Measured data	Oxidation catalyst
20	10500053-005	NA	NA	biodiesel	NA	not specified	PM10	3.90E-03	None specified	None specified
14	T000008	NA	NA	corn derivatives	corn stover	100% biomass	NOx	5.60E-01	Modeled	None
14	T000008	NA	NA	corn derivatives	distillers dried grains with solubles	100% biomass	NOx	1.09E+00	Modeled	None
14	T000008	NA	NA	corn derivatives	distillers wet grains	100% biomass	NOx	3.02E+00	Modeled	None
14	T000008	NA	NA	corn derivatives	syrup	100% biomass	NOx	9.40E-01	Modeled	None
14	T000008	NA	NA	corn derivatives	corn stover	100% biomass	SOx	1.00E-01	Modeled	None
14	T000008	NA	NA	corn derivatives	distillers dried grains with solubles	100% biomass	SOx	1.48E+00	Modeled	None

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Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
14	T000008	NA	NA	corn derivatives	distillers wet grains	100% biomass	SOx	2.31E+00	Modeled	None
14	T000008	NA	NA	corn derivatives	syrup	100% biomass	SOx	1.43E+00	Modeled	None
15	04300041-008	NA	09/15/2005	corn derivatives	syrup	syrup with 19% by heat input of natural gas	HCl	3.14E-03	Measured data	Fabric filter
15	04300041-008	NA	09/15/2005	corn derivatives	syrup	syrup with 19% by heat input of natural gas	NOx	2.90E-03	Measured data	Fabric filter
15	04300041-008	NA	09/15/2005	corn derivatives	syrup	syrup with 19% by heat input of natural gas	PM	2.71E-02	Measured data	Fabric filter
15	04300041-008	NA	09/15/2005	corn derivatives	syrup	syrup with 19% by heat input of natural gas	SO_2	1.99E-02	Measured data	Fabric filter
15	04300041-008	NA	09/15/2005	corn derivatives	syrup	syrup with 19% by heat input of natural gas	THC as VOC	4.41E-04	Measured data	Fabric filter
15	04300041-008	NA	09/15/2005	corn derivatives	syrup	syrup with 30% by heat input of natural gas	CO	2.82E-03	Measured data	Fabric filter
16	04300041-008	NA	07/06/2006	corn derivatives	Syrup	syrup with 30% by heat input of natural gas	CO	2.00E-03	Measured data	Fabric filter
16	04300041-008	NA	07/06/2006	corn derivatives	syrup	syrup with 30% by heat input of natural gas	HCl	2.26E-02	Measured data	Fabric filter
16	04300041-008	NA	07/06/2006	corn derivatives	syrup	syrup with 30% by heat input of natural gas	NOx	3.33E-02	Measured data	Fabric filter
16	04300041-008	NA	07/06/2006	corn derivatives	syrup	syrup with 30% by heat input of natural gas	PM	2.40E-02	Measured data	Fabric filter
16	04300041-008	NA	07/06/2006	corn derivatives	syrup	syrup with 30% by heat input of natural gas	PM10	1.52E-01	Measured data	Fabric filter
16	04300041-008	NA	07/06/2006	corn derivatives	syrup	syrup with 30% by heat input of natural gas	SO_2	1.17E-01	Measured data	Fabric filter
16	04300041-008	NA	07/06/2006	corn derivatives	syrup	syrup with 30% by heat input of natural gas	THC as VOC	9.40E-03	Measured data	Fabric filter
2	T000003	NA	NA	switchgrass	NA	coal with 1% switchgrass by heat	CO	4.30E-03	Measured data	ESP
2	T000003	NA	NA	switchgrass	NA	coal with 1% switchgrass by heat	NOx	3.94E-01	Measured data	ESP
2	T000003	NA	NA	switchgrass	NA	coal with 1% switchgrass by heat	PM	4.60E-02	Measured data	ESP
2	T000003	NA	NA	switchgrass	NA	coal with 1% switchgrass by heat	PM10	4.00E-02	Measured data	ESP
2	T000003	NA	NA	switchgrass	NA	coal with 1% switchgrass by heat	SO_2	6.56E-01	Measured data	ESP

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Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
1	T000004	NA	NA	switchgrass	NA	coal with 10.3% switchgrass (hammermill) by wt	NOx as NO	3.70E-01	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.3% switchgrass (hammermill) by wt	SO_2	2.28E+00	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.4% switchgrass (tub grinder) by wt	NOx as NO	4.93E-01	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.4% switchgrass (tub grinder) by wt	NOx as NO	3.63E-01	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.4% switchgrass (tub grinder) by wt	NOx as NO	3.63E-01	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.4% switchgrass (tub grinder) by wt	SO_2	2.37E+00	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.4% switchgrass (tub grinder) by wt	SO_2	1.99E+00	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.4% switchgrass (tub grinder) by wt	SO_2	1.84E+00	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.5% switchgrass (tub grinder) by wt	NOx as NO	4.30E-01	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.5% switchgrass (tub grinder) by wt	SO_2	2.28E+00	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.6% switchgrass (tub grinder) by wt	NOx as NO	4.09E-01	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 10.6% switchgrass (tub grinder) by wt	SO_2	2.30E+00	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 11.6% switchgrass (hammermill) by wt	NOx as NO	4.21E-01	Measured data	ESP

Appendix D. Summary of Emission Factors for Individual Tests

Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
1	T000004	NA	NA	switchgrass	NA	coal with 11.6% switchgrass (hammermill) by wt	SO_2	2.29E+00	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 15.3% switchgrass (hammermill) by wt	SO_2	3.03E+00	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 15.3% switchgrass (tub grinder) by wt	NOx as NO	4.70E-01	Measured data	ESP
3	T000002	PW-5	NA	switchgrass	NA	coal with 2.2% switchgrass	NOx	5.50E-01	Measured data	ESP
3	T000002	PW-5	NA	switchgrass	NA	coal with 2.2% switchgrass	SO_2	3.43E+00	Measured data	ESP
3	T000002	PW-1	NA	switchgrass	NA	coal with 2.68% switchgrass	NOx	6.50E-01	Measured data	ESP
3	T000002	PW-1	NA	switchgrass	NA	coal with 2.68% switchgrass	SO_2	2.30E+00	Measured data	ESP
3	T000002	PW-1	NA	switchgrass	NA	coal with 3.32% switchgrass	NOx	6.10E-01	Measured data	ESP
3	T000002	PW-1	NA	switchgrass	NA	coal with 3.32% switchgrass	SO_2	2.32E+00	Measured data	ESP
3	T000002	PW-2	NA	switchgrass	NA	coal with 3.37% switchgrass	NOx	7.20E-01	Measured data	ESP
3	T000002	PW-2	NA	switchgrass	NA	coal with 3.37% switchgrass	SO_2	2.36E+00	Measured data	ESP
3	T000002	Black-2	NA	switchgrass	NA	coal with 3.52% switchgrass	NOx	6.60E-01	Measured data	ESP
3	T000002	Black-2	NA	switchgrass	NA	coal with 3.52% switchgrass	SO_2	2.59E+00	Measured data	ESP
3	T000002	Black-1	NA	switchgrass	NA	coal with 3.65% switchgrass	NOx	5.80E-01	Measured data	ESP
3	T000002	Black-1	NA	switchgrass	NA	coal with 3.65% switchgrass	SO_2	2.74E+00	Measured data	ESP
3	T000002	Red-1	NA	switchgrass	NA	coal with 3.73% switchgrass	NOx	6.60E-01	Measured data	ESP
3	T000002	Red-1	NA	switchgrass	NA	coal with 3.73% switchgrass	SO_2	2.33E+00	Measured data	ESP
3	T000002	Blue out -2	NA	switchgrass	NA	coal with 3.96% switchgrass	NOx	6.10E-01	Measured data	ESP
3	T000002	Blue out -1	NA	switchgrass	NA	coal with 3.96% switchgrass	NOx	5.60E-01	Measured data	ESP

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Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
3	T000002	Blue out -2	NA	switchgrass	NA	coal with 3.96% switchgrass	SO_2	2.65E+00	Measured data	ESP
3	T000002	Blue out -1	NA	switchgrass	NA	coal with 3.96% switchgrass	SO_2	2.64E+00	Measured data	ESP
3	T000002	Blue out -1	NA	switchgrass	NA	coal with 3.98% switchgrass	NOx	7.00E-01	Measured data	ESP
3	T000002	Blue out -1	NA	switchgrass	NA	coal with 3.98% switchgrass	SO_2	2.64E+00	Measured data	ESP
3	T000002	PW-2	NA	switchgrass	NA	coal with 3.99% switchgrass	NOx	6.40E-01	Measured data	ESP
3	T000002	PW-2	NA	switchgrass	NA	coal with 3.99% switchgrass	SO_2	2.30E+00	Measured data	ESP
3	T000002	Blue in - 1	NA	switchgrass	NA	coal with 4.09% switchgrass	NOx	6.90E-01	Measured data	ESP
3	T000002	Blue in - 1	NA	switchgrass	NA	coal with 4.09% switchgrass	SO_2	2.52E+00	Measured data	ESP
3	T000002	Blue in - 2	NA	switchgrass	NA	coal with 4.17% switchgrass	NOx	5.90E-01	Measured data	ESP
3	T000002	Blue in - 2	NA	switchgrass	NA	coal with 4.17% switchgrass	SO_2	2.61E+00	Measured data	ESP
3	T000002	PW-4	NA	switchgrass	NA	coal with 4.49% switchgrass	NOx	5.30E-01	Measured data	ESP
3	T000002	PW-4	NA	switchgrass	NA	coal with 4.49% switchgrass	SO_2	3.37E+00	Measured data	ESP
3	T000002	Red-2	NA	switchgrass	NA	coal with 4.63% switchgrass	NOx	8.00E-01	Measured data	ESP
3	T000002	Red-2	NA	switchgrass	NA	coal with 4.63% switchgrass	SO_2	2.28E+00	Measured data	ESP
3	T000002	Red-3	NA	switchgrass	NA	coal with 4.66% switchgrass	NOx	6.90E-01	Measured data	ESP
3	T000002	Red-3	NA	switchgrass	NA	coal with 4.66% switchgrass	SO_2	2.35E+00	Measured data	ESP
3	T000002	Red-1	NA	switchgrass	NA	coal with 4.75% switchgrass	NOx	5.90E-01	Measured data	ESP
3	T000002	Red-1	NA	switchgrass	NA	coal with 4.75% switchgrass	SO_2	2.31E+00	Measured data	ESP
18	J009	NA	NA	switchgrass	NA	coal with 5% switchgrass	CO	7.75E-02	Modeled	None
18	J009	NA	NA	switchgrass	NA	coal with 5% switchgrass	SOx	4.90E+00	Modeled	None
3	T000002	Yellow-1	NA	switchgrass	NA	coal with 5.31% switchgrass	NOx	5.80E-01	Measured data	ESP

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Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
3	T000002	Yellow-1	NA	switchgrass	NA	coal with 5.31% switchgrass	SO_2	2.65E+00	Measured data	ESP
3	T000002	PW-3	NA	switchgrass	NA	coal with 5.34% switchgrass	NOx	6.40E-01	Measured data	ESP
3	T000002	PW-3	NA	switchgrass	NA	coal with 5.34% switchgrass	SO_2	2.25E+00	Measured data	ESP
3	T000002	Red-2	NA	switchgrass	NA	coal with 5.54% switchgrass	NOx	6.60E-01	Measured data	ESP
3	T000002	Red-2	NA	switchgrass	NA	coal with 5.54% switchgrass	SO_2	2.36E+00	Measured data	ESP
3	T000002	PW-2	NA	switchgrass	NA	coal with 5.57% switchgrass	NOx	5.20E-01	Measured data	ESP
3	T000002	PW-2	NA	switchgrass	NA	coal with 5.57% switchgrass	SO_2	3.32E+00	Measured data	ESP
3	T000002	PW-1	NA	switchgrass	NA	coal with 5.76% switchgrass	NOx	6.50E-01	Measured data	ESP
3	T000002	PW-1	NA	switchgrass	NA	coal with 5.76% switchgrass	SO_2	3.21E+00	Measured data	ESP
3	T000002	Black-1	NA	switchgrass	NA	coal with 5.93% switchgrass	NOx	5.00E-01	Measured data	ESP
3	T000002	Black-1	NA	switchgrass	NA	coal with 5.93% switchgrass	SO_2	3.34E+00	Measured data	ESP
3	T000002	Black-3	NA	switchgrass	NA	coal with 5.94% switchgrass	NOx	6.30E-01	Measured data	ESP
3	T000002	Black-3	NA	switchgrass	NA	coal with 5.94% switchgrass	SO_2	3.30E+00	Measured data	ESP
3	T000002	Blue in - 1	NA	switchgrass	NA	coal with 6.51% switchgrass	NOx	5.00E-01	Measured data	ESP
3	T000002	Blue in - 1	NA	switchgrass	NA	coal with 6.51% switchgrass	SO_2	3.08E+00	Measured data	ESP
3	T000002	Blue out - 2	NA	switchgrass	NA	coal with 6.54% switchgrass	SO_2	3.07E+00	Measured data	ESP
3	T000002	PW-3	NA	switchgrass	NA	coal with 6.57% switchgrass	NOx	5.30E-01	Measured data	ESP
3	T000002	PW-3	NA	switchgrass	NA	coal with 6.57% switchgrass	SO_2	3.29E+00	Measured data	ESP
3	T000002	Blue out - 1	NA	switchgrass	NA	coal with 6.63% switchgrass	NOx	6.10E-01	Measured data	ESP
3	T000002	Blue out - 1	NA	switchgrass	NA	coal with 6.63% switchgrass	SO_2	2.93E+00	Measured data	ESP

Appendix D. Summary of Emission Factors for Individual Tests

Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
3	T000002	Blue in - 2	NA	switchgrass	NA	coal with 6.76% switchgrass	NOx	6.00E-01	Measured data	ESP
3	T000002	Blue in - 2	NA	switchgrass	NA	coal with 6.76% switchgrass	SO_2	2.96E+00	Measured data	ESP
3	T000002	Black-2	NA	switchgrass	NA	coal with 6.84% switchgrass	NOx	5.10E-01	Measured data	ESP
3	T000002	Black-2	NA	switchgrass	NA	coal with 6.84% switchgrass	SO_2	3.40E+00	Measured data	ESP
3	T000002	Black-4	NA	switchgrass	NA	coal with 7.06% switchgrass	NOx	6.20E-01	Measured data	ESP
3	T000002	Black-4	NA	switchgrass	NA	coal with 7.06% switchgrass	SO_2	3.38E+00	Measured data	ESP
3	T000002	Red-1	NA	switchgrass	NA	coal with 7.25% switchgrass	NOx	4.80E-01	Measured data	ESP
3	T000002	Red-1	NA	switchgrass	NA	coal with 7.25% switchgrass	SO_2	3.53E+00	Measured data	ESP
13	J012	NA	05/11/06	switchgrass	NA	coal with 26% switchgrass	CO	1.02	Measured data	None
13	J012	NA	05/11/06	switchgrass	NA	coal with 26% switchgrass	NOx	0.68	Measured data	None
13	J012	NA	05/11/06	switchgrass	NA	coal with 26% switchgrass	SO_2	0.62	Measured data	None
1	T000004	NA	NA	switchgrass	NA	coal with 7.8% switchgrass (hammermill) by wt	NOx as NO	4.61E-01	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 7.8% switchgrass (hammermill) by wt	SO_2	2.42E+00	Measured data	ESP
3	T000002	Red-2	NA	switchgrass	NA	coal with 7.83% switchgrass	NOx	6.10E-01	Measured data	ESP
3	T000002	Red-2	NA	switchgrass	NA	coal with 7.83% switchgrass	SO_2	3.37E+00	Measured data	ESP
3	T000002	Yellow-1	NA	switchgrass	NA	coal with 8.60% switchgrass	NOx	4.90E-01	Measured data	ESP
3	T000002	Yellow-1	NA	switchgrass	NA	coal with 8.60% switchgrass	SO_2	3.17E+00	Measured data	ESP
3	T000002	Yellow-2	NA	switchgrass	NA	coal with 8.64% switchgrass	NOx	6.30E-01	Measured data	ESP
3	T000002	Yellow-2	NA	switchgrass	NA	coal with 8.64% switchgrass	SO_2	3.15E+00	Measured data	ESP

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Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
1	T000004	NA	NA	switchgrass	NA	coal with 9.2% switchgrass (hammermill) by wt	NOx as NO	4.09E-01	Measured data	ESP
1	T000004	NA	NA	switchgrass	NA	coal with 9.2% switchgrass (hammermill) by wt	SO_2	2.33E+00	Measured data	ESP
4	J011	NA	2	switchgrass	co-milling of switchgrass, 15% overfire air	PRB coal with 10% switchgrass by mass	NOx	4.40E-01	Measured data from graph	None specified
4	J011	NA	1	switchgrass	co-milling of switchgrass, no overfire air	PRB coal with 10% switchgrass by mass	NOx	6.40E-01	Measured data from graph	None specified
4	J011	NA	3	switchgrass	direct injection of switchgrass, no overfire air	PRB coal with 10% switchgrass by mass	NOx	6.30E-01	Measured data from graph	None specified
18	J009	NA	NA	switchgrass	NA	switchgrass-fired alone	CO	5.98E-01	Modeled	None
18	J009	NA	NA	switchgrass	NA	switchgrass-fired alone	NOx	4.89E-01	Modeled	None
18	J009	NA	NA	switchgrass	NA	switchgrass-fired alone	SOx	2.50E-02	Modeled	None
13	J012	NA	04/27/06	switchgrass	pellets	switchgrass-fired alone	CO	0.77	Measured data	None
13	J012	NA	04/27/06	switchgrass	pellets	switchgrass-fired alone	NOx	0.34	Measured data	None
13	J012	NA	04/27/06	switchgrass	pellets	switchgrass-fired alone	SO_2	0.24	Measured data	None
13	J012	NA	04/27/06	switchgrass	pellets	coal with 34% switchgrass	CO	1.23	Measured data	None
13	J012	NA	04/27/06	switchgrass	pellets	coal with 34% switchgrass	NOx	0.52	Measured data	None
13	J012	NA	04/27/06	switchgrass	pellets	coal with 34% switchgrass	SO_2	0.53	Measured data	None
8	J003	NA	NA	wheat straw	NA	coal with 10% wheat straw	HCl	1.30E-01	Measured data	SO_2 and NOx flue gas treatment (FGD and ammonia

Appendix D. Summary of Emission Factors for Individual Tests

Report Reference	Facility ID	Unit ID	Test ID	Biofuel Category	Biofuel Subcategory	Fuel Mix Description	Pollutant	Mean EF (lb/MMBtu)	Data Type	Control Information
8	J003	NA	NA	wheat straw	NA	coal with 10% wheat straw	NOx	3.05E-01	Measured data	SO_2 and NOx flue gas treatment (FGD and ammonia
8	J003	NA	NA	wheat straw	NA	coal with 10% wheat straw	SO_2	9.70E-02	Measured data	SO_2 and NOx flue gas treatment (FGD and ammonia
8	J003	NA	NA	wood residue	NA	coal with 10% residual wood	HCl	3.22E-03	Measured data	SO_2 and NOx flue gas treatment (FGD and ammonia
8	J003	NA	NA	wood residue	NA	coal with 10% residual wood	NOx	1.94E-01	Measured data	SO_2 and NOx flue gas treatment (FGD and ammonia
8	J003	NA	NA	wood residue	NA	coal with 10% residual wood	SO_2	2.40E-02	Measured data	SO_2 and NOx flue gas treatment (FGD and ammonia
Minnesota Database	03700280-004	NA	NA	wood residue	NA	none provided	PM	3.10E-01	Not specified	Not specified
	06100001-008	NA	NA	wood residue	NA	none provided	PM	7.00E-02	Not specified	Not specified
	06100001-008	NA	NA	wood residue	NA	none provided	PM	6.60E-02	Not specified	Not specified