CO_2 SOURCE CHARACTERIZATION OF THE PCOR PARTNERSHIP REGION

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EXECUTIVE SUMMARY

The Plains CO_2 Reduction (PCOR) Partnership region is expansive, covering the states of Iowa, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Wisconsin, the Powder River Basin portion of Wyoming, the portion of Montana containing both the Williston and Powder River Basins, and the Canadian provinces of Alberta, Saskatchewan, and Manitoba. The upper Mississippi River Valley and the western shores of the Great Lakes are home to large coal-fired electrical generation plants that power the manufacturing plants and breweries of St. Louis, Minneapolis–St. Paul, and Milwaukee. Coal-fired power plants, natural gas-processing plants, ethanol plants, and refineries located in the prairies and badlands of the north-central United States and central and Western Canada further fuel the industrial and domestic needs of cities throughout North America. The PCOR Partnership region is also home to much of North America's most fertile agricultural lands.

The geographic and socioeconomic diversity of the region is reflected in the variable nature of the carbon dioxide (CO_2) sources found there. Nearly 1400 significant point sources were identified for the PCOR Partnership region using U.S. Environmental Protection Agency and Environment Canada databases (EPA, 2000; Environment Canada, 2000 a-c, 2004) (all references cited in the Executive Summary are found in the reference section of the report). The CO_2 is emitted during electricity generation; energy exploration and production activities; agriculture; fuel, chemicals, and ethanol production; and various manufacturing and industrial activities. The majority of the region's emissions from stationary sources come from just a few source types. About two-thirds of the CO_2 is emitted during electricity generation, followed by the manufacture of paper and wood products, petroleum and natural gas processing, chemicals and fuels production, ethanol production, petroleum refining, and cement/clinker production.

In 2000, the PCOR Partnership region contributed approximately 13% of the total CO_2 emissions from the United States and Canada. The U.S. PCOR Partnership region contributed about 10% of the U.S. CO_2 emissions, while the Canadian portion of the PCOR Partnership region produced almost 40% of Canada's total (EPA, 2000; Environment Canada, 2000 a-c, 2004). The emissions profile (i.e., percentage of CO_2 emissions from various source types) for the Canadian portion of the PCOR Partnership is virtually identical to that of Canada as a whole. On the other hand, when compared to the total U.S. CO_2 emissions, the states in the PCOR Partnership region emit relatively more CO_2 from electric utilities and less from industries and transportation. This is undoubtedly because the region is made up largely of agricultural, energy-producing areas with relatively fewer

industrial facilities located primarily in the far eastern portion of the region.

The effects of the differences in geography and socioeconomics across the U.S. portion of the PCOR Partnership region were explored by comparing the CO_2 emissions profiles of each state. Electric utilities were found to generally contribute a greater share of the emissions than the other point sources (industrial, commercial, and residential sectors). Emissions from mobile sources (i.e., the transportation sector) averaged slightly less than one-fourth of the total for the entire region. Three pairs of states were seen to have very similar emissions profiles: North Dakota and Wyoming, Iowa and Nebraska, and Minnesota and Wisconsin. The states in these pairs are geographically close and have similar major industries, probably explaining the similarities in CO_2 emissions.

Trends in CO_2 emissions over time were also evaluated. Annual total CO_2 emissions for the U.S. portion of the PCOR Partnership region increased at a slower rate from 1990 through 2000 than did the total emissions for the United States. Trends similar to the total U.S. CO_2 emissions were found for the PCOR Partnership region for the industrial, commercial, residential, and transportation sectors. Emissions from the utility sector appear to have increased more quickly in the PCOR Partnership region than for the United States as a whole.

While the CO_2 emissions from the individual PCOR Partnership point sources are no different from similar sources located around the United States, the wide range of source types within the PCOR Partnership region offers the opportunity to evaluate the capture, separation, and transportation of CO_2 in many different scenarios. The fact that the PCOR Partnership region's emissions trends are generally similar to those of the United States indicates that the region's sources are similar to those of the entire United States and that the work performed during Phase II of the PCOR Partnership will be readily transferable to the rest of the country.

ACKNOWLEDGMENTS

The PCOR Partnership is a collaborative effort of public and private sector stakeholders working toward a better understanding of the technical and economic feasibility of capturing and storing (sequestering) anthropogenic carbon dioxide (CO_2) emissions from stationary sources in the central interior of North America. It is one of seven regional partnerships funded by the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) Regional Carbon Sequestration Partnership (RCSP) Program. The Energy & Environmental Research Center (EERC) would like to thank the following partners who provided funding, data, guidance, and/or experience to support the PCOR Partnership:

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- Minnesota Power
- Minnkota Power Cooperative, Inc.
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- Montana Department of Environmental Quality
- Montana Public Service Commission
- Murex Petroleum Corporation
- Nexant, Inc.
- North Dakota Department of Health
- North Dakota Geological Survey
- North Dakota Industrial Commission Lignite Research, Development and Marketing Program
- North Dakota Industrial Commission Oil and Gas Division
- North Dakota Natural Resources Trust
- North Dakota Petroleum Council
- North Dakota State University
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- Petroleum Technology Transfer Council
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INTRODUCTION

The Plains CO_2 Reduction (PCOR) Partnership region consists of the states of Iowa, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Wisconsin, the Powder River Basin portion of the Wyoming, the portion of Montana containing both the Williston and Powder River Basins, and the Canadian provinces of Alberta, Saskatchewan, and Manitoba. Figure 1 shows the PCOR Partnership region. The upper Mississippi River Valley and the western shores of the Great Lakes are home to large coal-fired electrical generation plants that power the manufacturing plants and breweries of St. Louis, Minneapolis–St. Paul, and Milwaukee. Coal-fired power plants, natural gas-processing plants, ethanol plants, and refineries located in the prairies and badlands of the north-central United States and central and western Canada further fuel the industrial and domestic needs of cities throughout North America. The PCOR Partnership region is also home too much of North America's most fertile agricultural lands.

The geographic and socioeconomic diversity of the region is reflected in the variable nature of the carbon dioxide (CO_2) sources found there. Point source types ranging from electric utilities to animal processing to cement/clinker production all contribute to the region's CO_2 emissions.

CO_2 SOURCES IN THE PCOR PARTNERSHIP REGION

Identification and Summary of Major CO_2 Point Sources

Considerable effort has gone into identifying and defining the CO_2 point

Figure 1. The PCOR Partnership geographic region.

sources within the region. The majority of the data were obtained from the U.S. Environmental Protection Agency (EPA) Technology Transfer Network and Environment Canada Web sites (EPA, 1996; EPA, 2002; North American Commission for Environmental Cooperation, 2002; Environment Canada, 2004). Data were gathered for 1395 point sources. Table 1 summarizes these major stationary sources and their contributions to the region's CO_2 emissions. The majority of CO_2 emissions come from just a few source types. About two-thirds of the CO_2

Table 1. Summary of Major CO_2 Point Sources in the PCOR Partnership Region[a]

Source Type	Quantity	% of All Sources	CO_2 Emissions, tons/yr	% of CO_2 Emissions
Agricultural Processing	137	9.8	3,647,014	0.6
Ammonia Production	5	0.4	2,250,600	0.4
Animal Processing	9	0.6	6203	0.0
Asphalt Production	23	1.6	1,485,825	0.3
Cement/Clinker Production	16	1.1	13,935,570	2.4
Chemical and Fuel Production	43	3.1	24,162,087	4.1
Cogeneration	2	0.1	588,559	0.1
Electricity Generation	170	12.2	395,248,410	67.1
Ethanol Production	63	4.5	16,433,289	2.8
Fertilizer Production	7	0.5	40,898	0.0
Foundries	4	0.3	2,063,867	0.4
Industrial/Institutional Heat and Power	118	8.5	3,142,973	0.5
Iron Ore Processing	6	0.4	2,930,200	0.5
Lime Production	13	0.9	4,521,484	0.8
Manufacturing	229	16.4	10,500,266	1.8
Metals Processing	27	1.9	788,309	0.1
Minerals Processing	30	2.2	4,926,676	0.8
Mining	15	1.1	386,032	0.1
Miscellaneous	14	1.0	102,966	0.0
Municipal Heat and Power	10	0.7	680,882	0.1
Natural Gas Liquids	13	0.9	231,826	0.0
Natural Gas Processing	73	5.2	9,610,525	1.6
Natural Gas Transmission	141	10.1	3,889,880	0.7
Paper and Wood Products	141	10.1	35,398,181	6.0
Petroleum and Natural Gas Processing	32	2.3	28,941,451	4.9
Petroleum Refining	21	1.5	16,008,485	2.7
Sugar Production	13	0.9	4,585,173	0.8
Waste Processing	20	1.4	2,336,808	0.4
Total	**1395**	**100.0**	**588,844,441**	**100.0**

[a] These data include only the major stationary sources in the PCOR Partnership region as obtained from EPA's Technology Transfer Network and provincial data sets. Smaller stationary sources and transportation are not included. Table 2, which comprises data from EPA's Energy CO_2 Inventories and Environment Canada, does include this information. The total CO_2 emissions listed in this table do not match the total CO_2 emissions for the PCOR Partnership in Table 2 because of differences between the data sets and the inclusion of additional sectors in Table 2.

is emitted during electricity generation, followed by the manufacture of paper and wood products, petroleum and natural gas processing, production of chemicals and fuel, ethanol production, petroleum refining, and cement/clinker production.

As shown in Figure 2, more than 97% of the CO_2 emissions from electricity generation in the U.S. portion of the PCOR Partnership region are from coal-fired utilities and only 2.7% are from natural gas-fired plants. A minimal amount of CO_2 is emitted from oil- or wood-fired facilities.

PCOR Partnership Region Total CO_2 Emissions

In addition to the point source data collected for the region, data were gathered from the EPA Energy CO_2 Inventories and Environment Canada Web sites (EPA, 2000; Environment Canada, 2000a–c, 2004) regarding all CO_2 emissions in the PCOR Partnership region, including mobile (i.e., transportation) sources. In 2000 (the only year for which both U.S. and Canadian data were available), the PCOR Partnership region generated 910.86 million tons of anthropogenic CO_2, about 13% of the U.S. and Canadian total (EPA, 2000; Environment Canada, 2000a–c, 2004). Table 2 summarizes the region's CO_2 emissions at that time and shows that the U.S. portion of the PCOR Partnership contributed about 10% of the U.S. CO_2 emissions, while the Canadian portion of the PCOR Partnership produced almost 40% of Canada's total.

The contributions from the PCOR Partnership region to the total CO_2 emissions for the United States and Canada in 2000 can be examined in greater detail with the information given in Table 3. Considering the large area included in the PCOR Partnership region (16% of the total area of the United States) the PCOR Partnership states contributed a relatively small percentage of the U.S. CO_2 emissions for each source type, ranging from about 8% of industrial emissions to roughly 15% of electric utility emissions

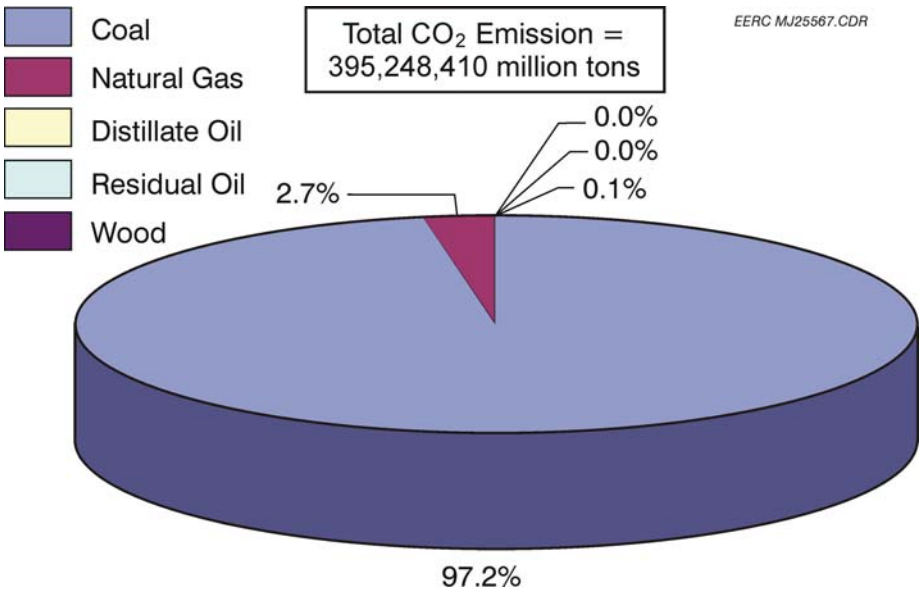

Figure 2. Breakdown of electricity generation emissions in the U.S. portion of the PCOR Partnership region.

Table 2. CO_2 Emissions in Millions of Tons of CO_2 for the PCOR Partnership Region During 2000

State/Province	Electric Utilities	Other Stationary	Transportation	Total
Iowa[a]	38.47	27.59	20.60	86.66
Minnesota[a]	35.13	32.28	38.33	105.74
Missouri[a]	69.26	24.60	43.39	137.25
Montana[a]	0.4[b]	26.09[b]	8.30	34.79
Nebraska[a]	20.62	10.97	13.38	44.97
North Dakota[a]	35.11	10.76	6.11	51.98
South Dakota[a]	4.16	4.99	6.40	15.55
Wisconsin[a]	47.15	38.20	32.68	118.03
Wyoming[a]	47.53	12.75	8.70	68.98
Alberta[c]	55.89	106.59	29.32	191.80
Manitoba[d]	1.08	5.71	6.88	13.67
Saskatchewan[e]	15.87	16.37	9.20	41.44
U.S. PCOR	297.83	188.23	177.89	663.95
Canada PCOR	72.84	128.67	45.40	246.91
PCOR Total	**370.67**	**316.90**	**223.29**	**910.86**
Canada Total[f]				**631.62**
U.S. Total[a]				**6305.85**

[a] EPA,2000.
[b] Based on 1990–1999 data, it appears that the majority of the electric utility emissions during 2000 in Montana were considered to have emanated from the industrial sector, which is a subset of "Other Stationary" on this table. It is not possible to determine the fraction of the industrial sector that comprises electric utilities.
[c] Environment Canada, 2000a.
[d] Environment Canada, 2000b.
[e] Environment Canada, 2000c.
[f] Environment Canada, 2004.

Table 3. Contributions of the PCOR Partnership Region to CO_2 Emissions from the United States and Canada During 2000

Source Type	United States (million tons CO_2)	U.S. PCOR States (million tons CO_2)	% of U.S. Emissions	Canada (million tons CO_2)	Canada PCOR Provinces (million tons CO_2)	% of Canadian Emissions
Commercial	260.42	27.35	10.5			
Industrial	1535.33	117.33	7.6	348.33[a]	128.67[a]	36.9[a]
Residential	412.80	43.55	10.6			
Transportation	2074.66	177.89	8.6	138.89	45.40	32.7
Electric Utilities	2022.62	297.83	14.7	144.40	72.84	50.4
Total	6305.85	663.95	10.5	631.62	246.92	39.1

[a] Canadian data do not subdivide emissions from "Other Stationary" sources.

The Canadian provinces in the PCOR Partnership region, on the other hand, contributed much larger fractions to the CO_2 emissions. Nearly 37% of the CO_2 emitted by nonutility point sources, about 33% of the transportation emissions, and 50% of the electric utility emissions came from sources in the PCOR Partnership provinces in 2000 while comprising only 21% of the Canadian land mass.

The same data also can be used to compare the emissions split between source types for the PCOR Partnership states/provinces, the United States, and Canada. As the pie charts of Figure 3 show, there is a significant difference between the apportionment of emissions between the United States and Canada. In Canada, stationary sources other than electric utilities emit a larger fraction of the CO_2 than is the case in the United States. The division of emissions between source types for the PCOR Partnership provinces mirrors that of the whole of Canada, while the division between source types for the PCOR Partnership states differs from that of the United States as a whole. Relatively speaking, the PCOR Partnership region emits more CO_2 from electric utilities and less from industries and transportation than the United States, undoubtedly because the region is made up largely of agricultural, energy-producing areas, with the majority of the industries located primarily in the far eastern portion of the region. This distribution of sources (i.e., denser in the east, larger but further apart in the west) can be seen in the map of Figure 4 showing the largest point sources in the region.

State CO_2 Emissions Profiles

The effects of these differences in geography and socioeconomics across the region were explored by comparing the CO_2 emissions profiles of each state, shown in Figures 5–13. The data used for this comparison came from EPA's Energy CO_2 Inventories (because these data do not show the location of emission sources within a state, the charts for both Montana and Wyoming include emissions from the entire state, rather than just the portion of the state included in the PCOR Partnership region. In addition, emissions profiles for the Canadian provinces were not charted as the historical data required to do so were not readily available). The states' total emissions were averaged over the period from 1990 through 2000 and their source-type distributions plotted as pie charts. The values shown on the charts are the percentages of emissions for each source type.

These charts show that electric utilities generally contributed a greater share of the emissions than the other point sources (industrial, commercial, and residential sectors). Emissions from mobile sources (i.e., the transportation sector) average slightly more than one-fourth of the total for the entire region.

Three pairs of states have very similar emissions profiles: North Dakota and Wyoming, Iowa and Nebraska, and Minnesota and Wisconsin. The states in these pairs are geographically close and share similar industrial profiles, probably explaining the similarities in CO_2 emissions.

Trends in CO_2 Emissions in the United States

Trends in CO_2 emissions were evaluated using the same data that were used to determine the emissions profiles. Annual total CO_2 emissions for the PCOR Partnership region are increasing at a slower rate than the total emissions for the United States. This is shown in Figure 14. When the various sectors are plotted, differences between the states can be seen. Emissions from the utilities sector (shown in Figure 15) appear to have increased at a faster rate in the PCOR Partnership region than in the United States as a whole. A

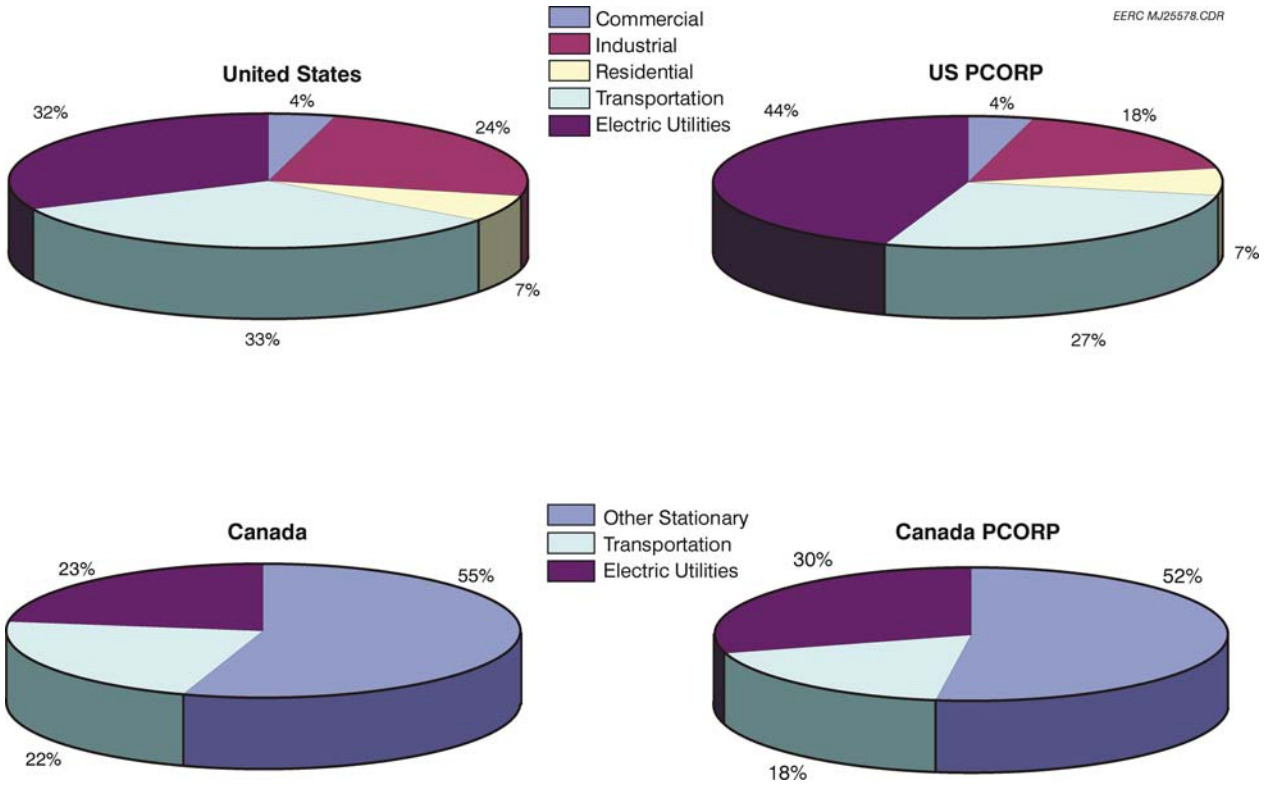

Figure 3. Comparison of CO_2 emissions apportionment between source types for the United States, Canada, and the PCOR Partnership region.

particularly large increase can be seen in Missouri's utilities emissions after 1994,while a more modest increase is noted for Wisconsin. Montana shows a sharp decrease in 2000. This corresponds with a sharp increase in industrial sector emissions that same year. Based on EPA's 1990–1999 data, it appears that the method of allocating emissions to categories was changed when Montana's 2000 data were tabulated. The majority of the electric utility emissions for 2000 in Montana seem to have been assigned to the industrial sector.

Figure 16 shows the trends exhibited by the industrial sector emissions. The PCOR Partnership trend is similar to that of the United States, although only Wisconsin, the Dakotas, and Minnesota exhibited an increase between 1998 and 2000 such as that which occurred in the U.S. as a whole. The spike in the Montana data is explained in the previous paragraph.

Trends in both the commercial- and residential-sector CO_2 emissions (Figures 17 and 18, respectively) are more volatile for the states but followed the general trend exhibited by the U.S. data. The states with the wider variations in emissions are Minnesota, Wisconsin, Missouri, and Iowa, undoubtedly because they are also the most populous states in the region.

Transportation sector emissions (shown in Figure 19) increased gradually through time for both the United States and the PCOR Partnership region. More rapid increases can be seen in the Minnesota and Wisconsin data, while the Missouri emissions associated with transportation decreased after 1998.

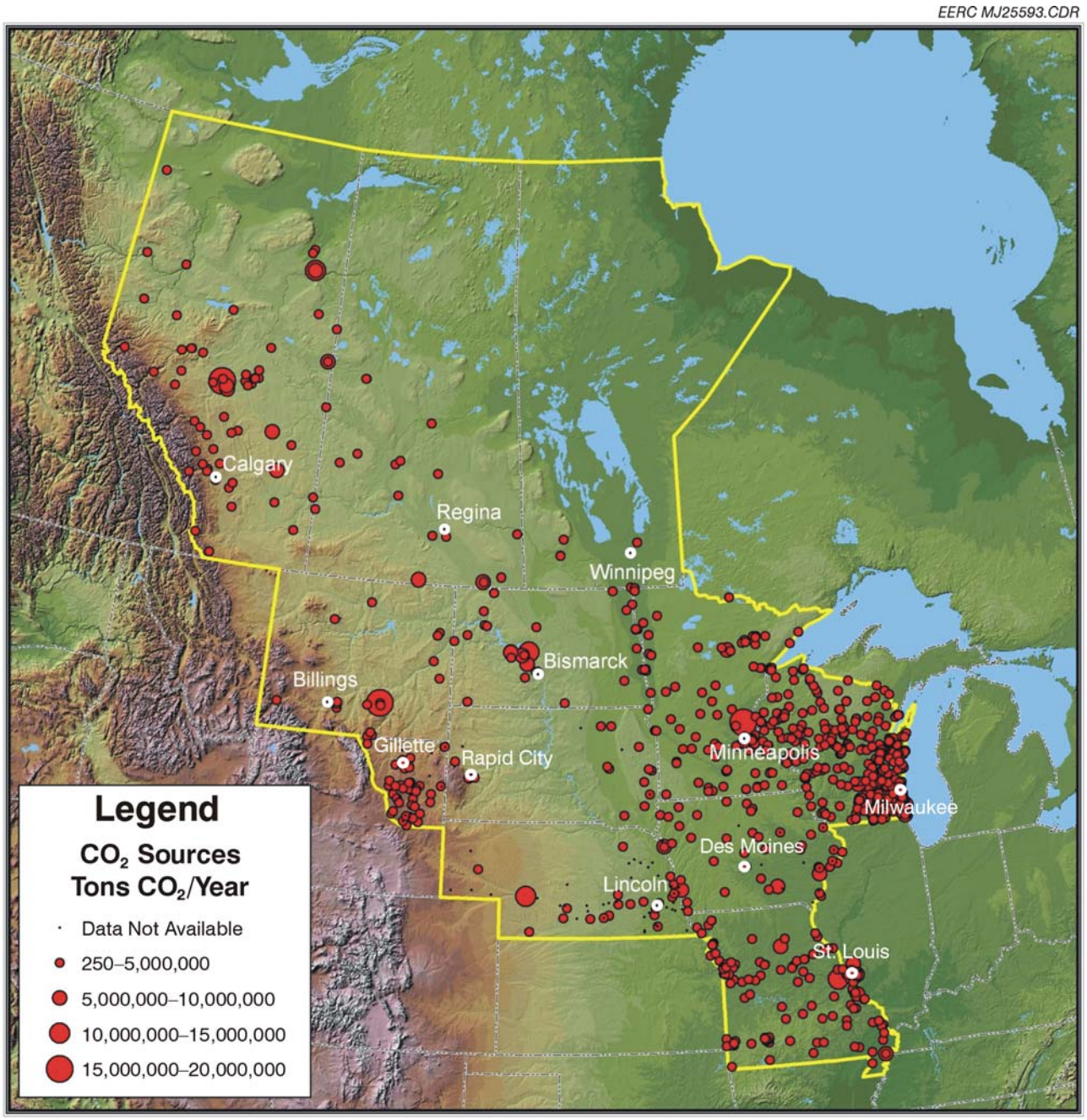

Figure 4. Location and relative output for the PCOR Partnership region's major CO_2 sources.

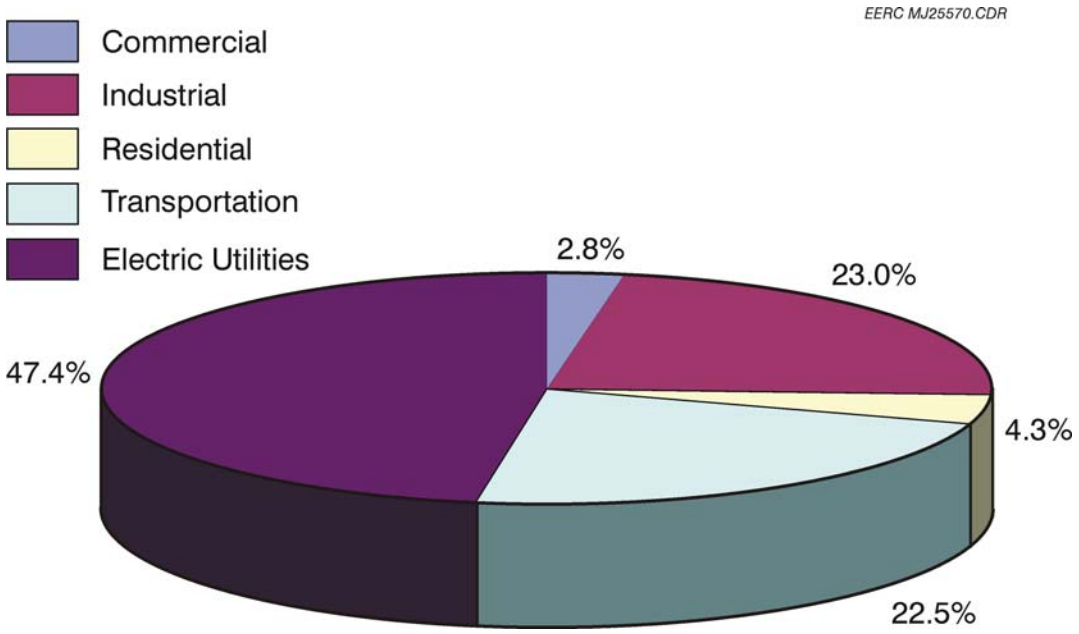

Figure 5. Average Distribution by sector of Montana's CO_2 emissions for the period 1990 through 2000.

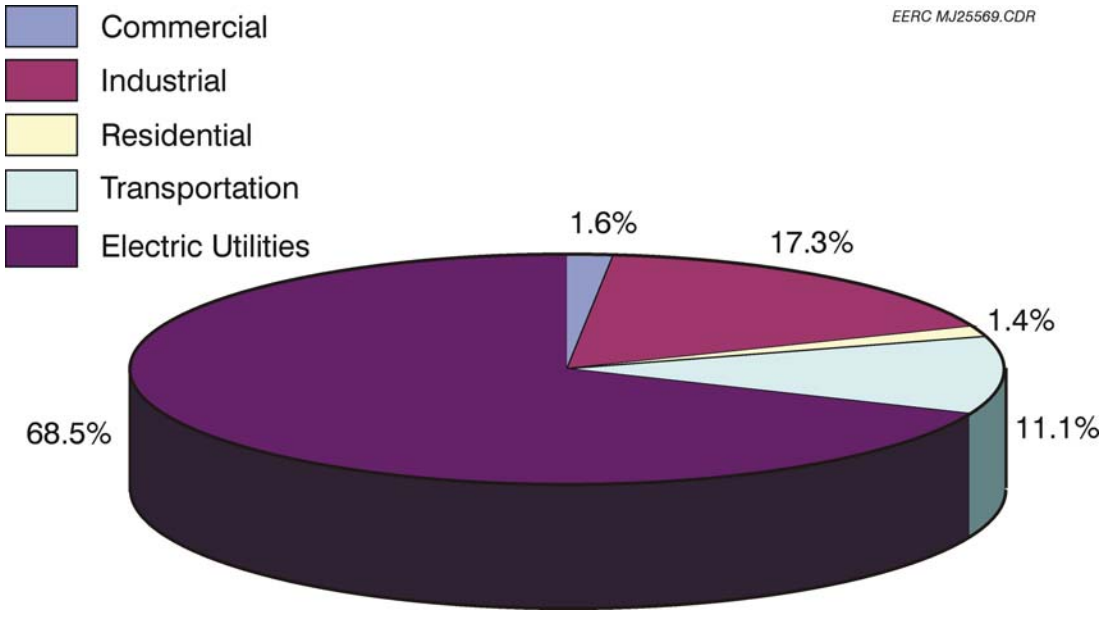

Figure 6. Average Distribution by sector of Wyoming's CO_2 emissions for the period 1990 through 2000.

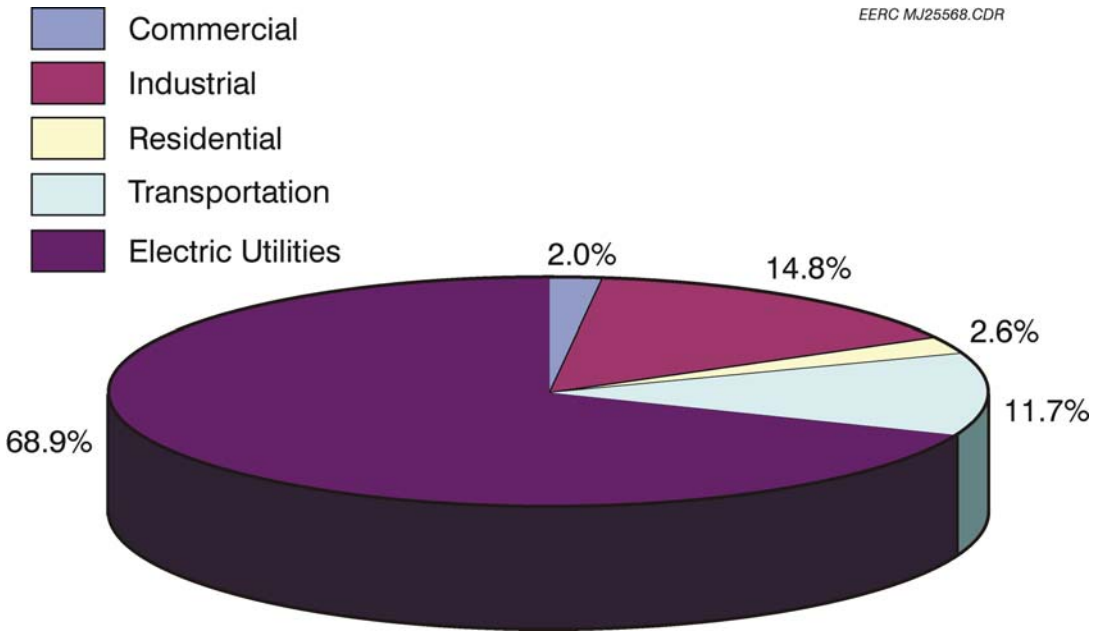

Figure 7. Average Distribution by sector of North Dakota's CO_2 emissions for the period 1990 through 2000.

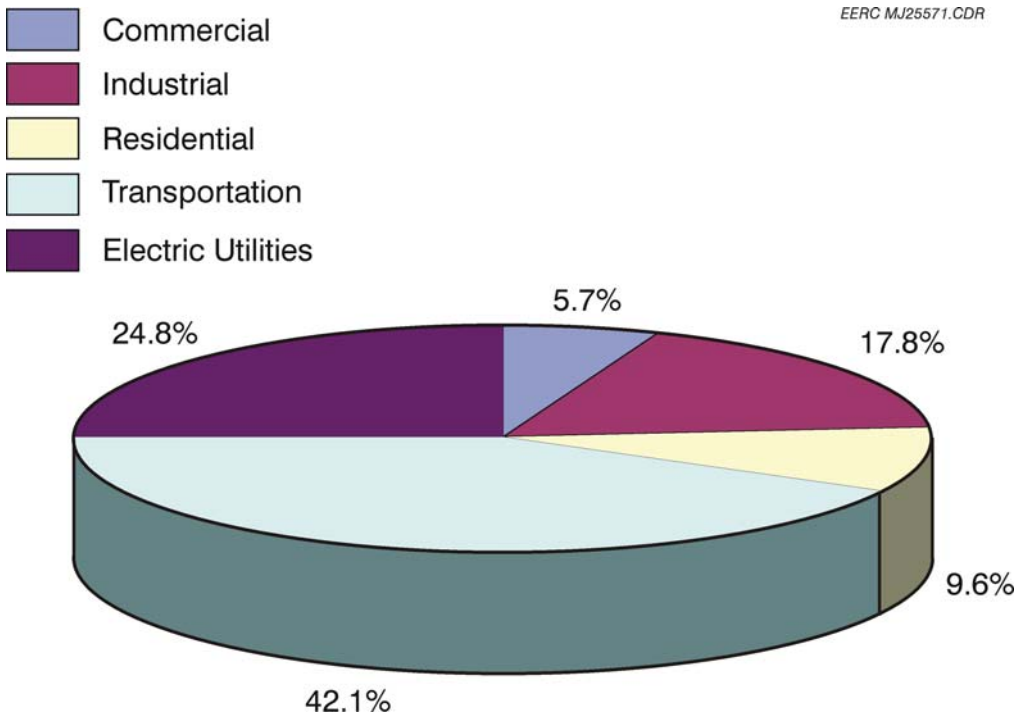

Figure 8. Average Distribution by sector of South Dakota's CO_2 emissions for the period 1990 through 2000.

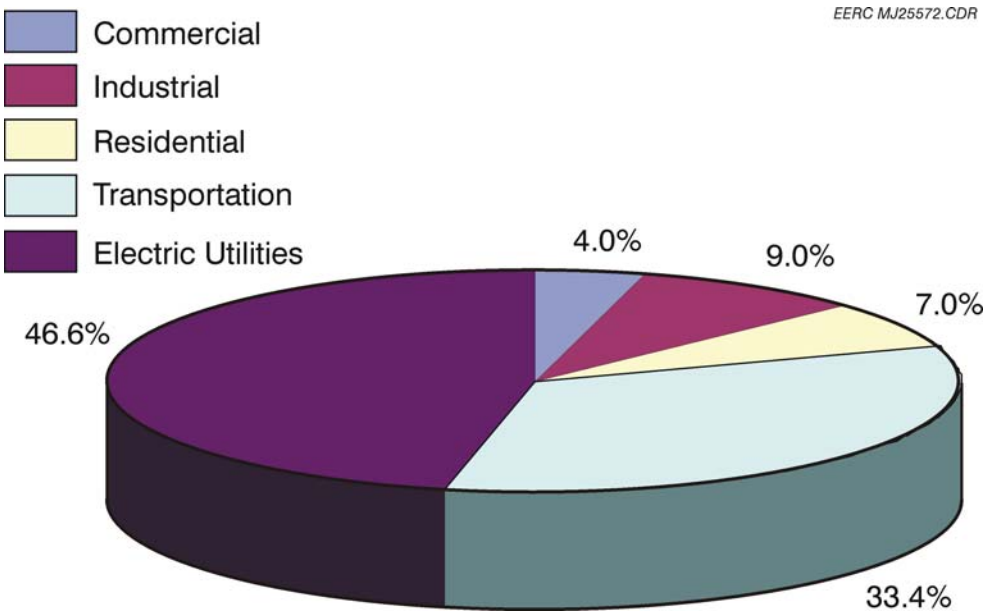

Figure 9. Average Distribution by sector of Missouri's CO_2 emissions for the period 1990 through 2000.

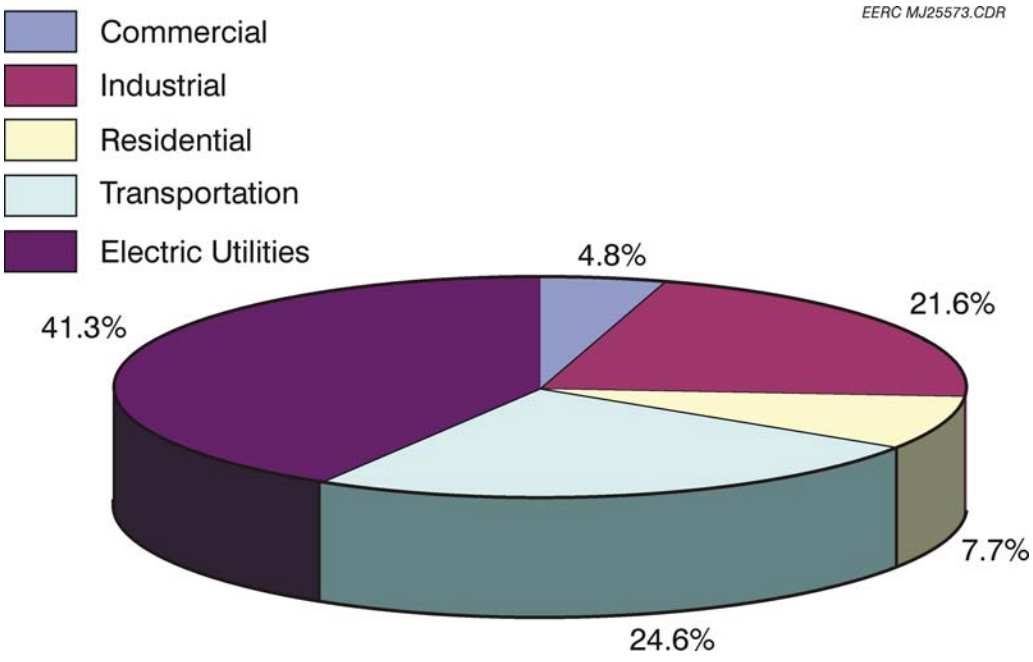

Figure 10. Average Distribution by sector of Iowa's CO_2 emissions for the period 1990 through 2000.

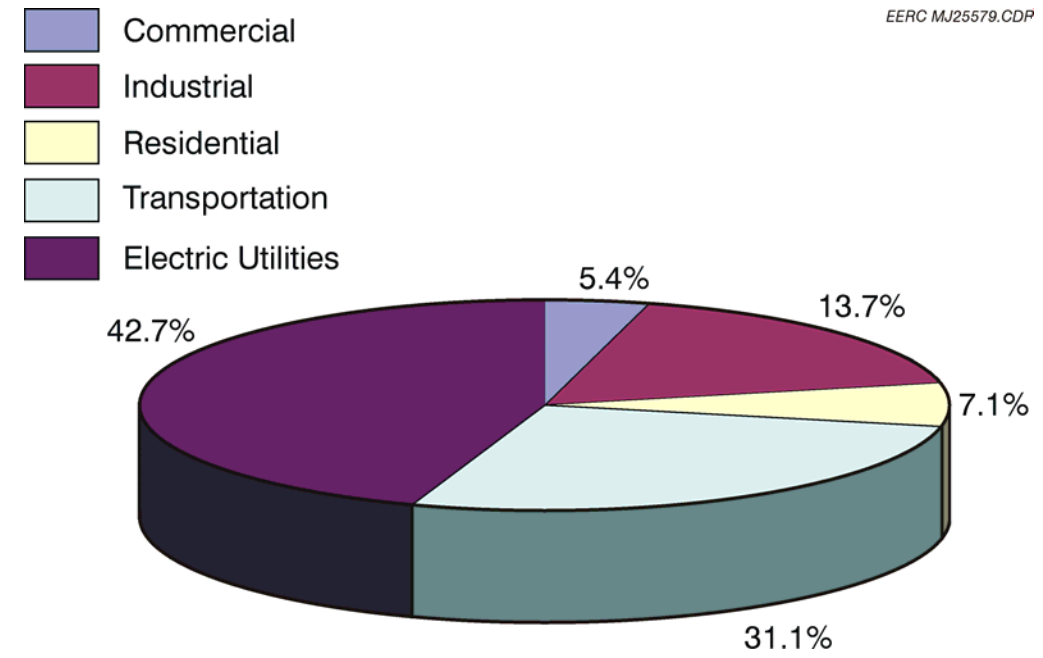

Figure 11. Average Distribution by sector of Nebraska's CO_2 emissions for the period 1990 through 2000.

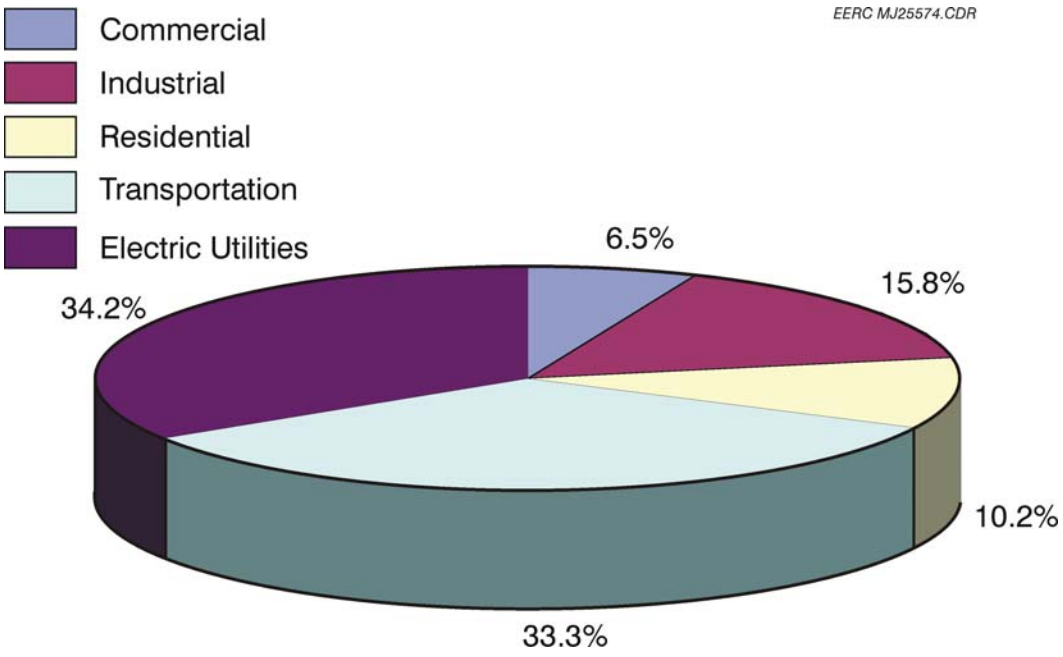

Figure 12. Average Distribution by sector of Minnesota's CO_2 emissions for the period 1990 through 2000.

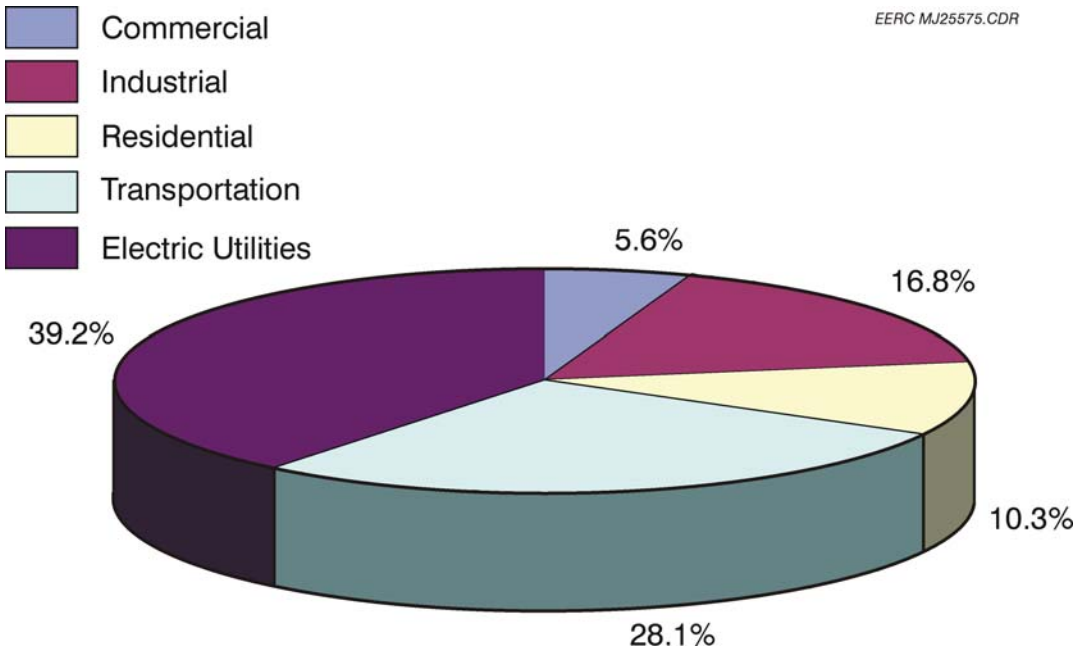

Figure 13. Average Distribution by sector of Wisconsin's average CO_2 emissions for the period 1990 through 2000.

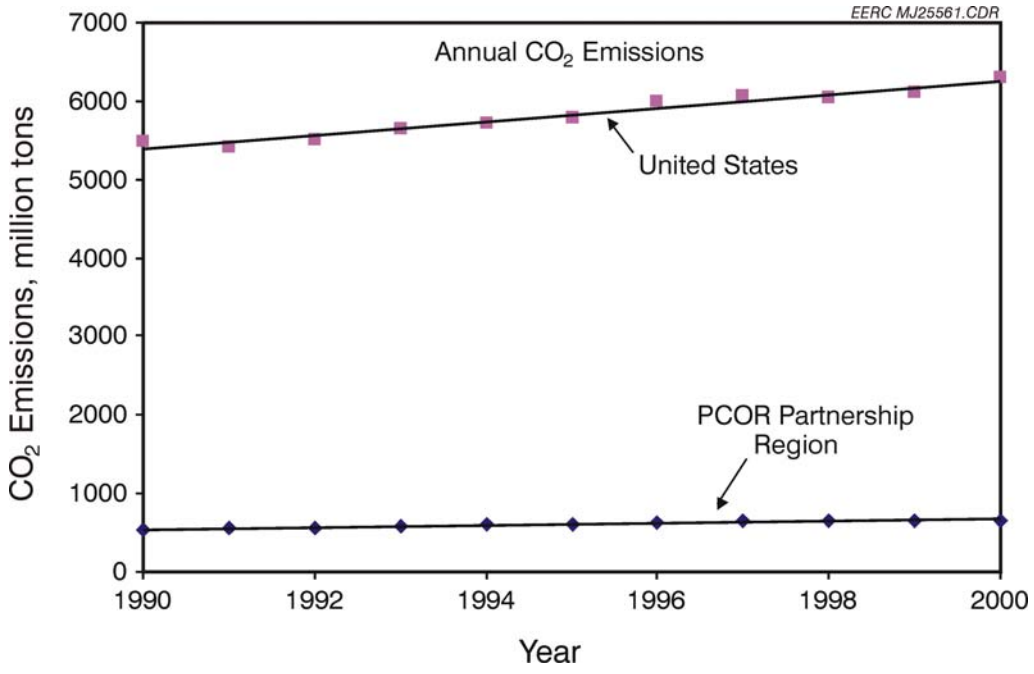

Figure 14. Annual CO_2 emissions, 1990–2000.

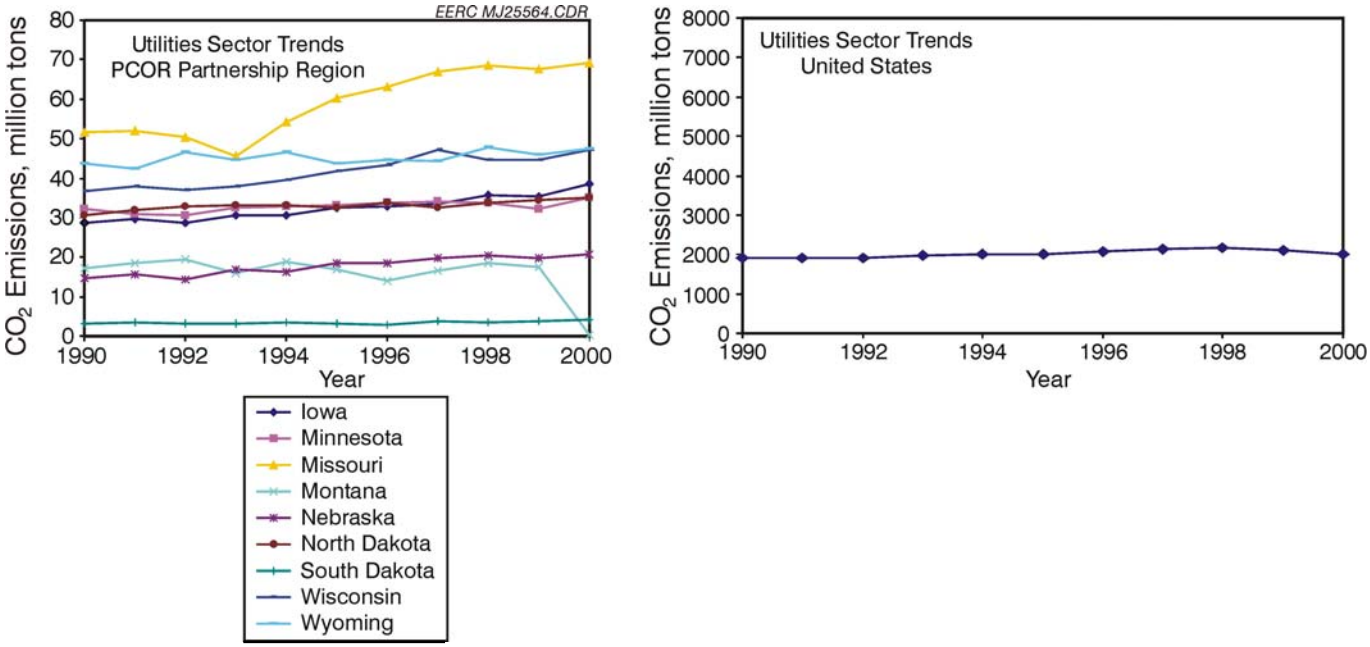

Figure 15. Trends in utility sector emissions.

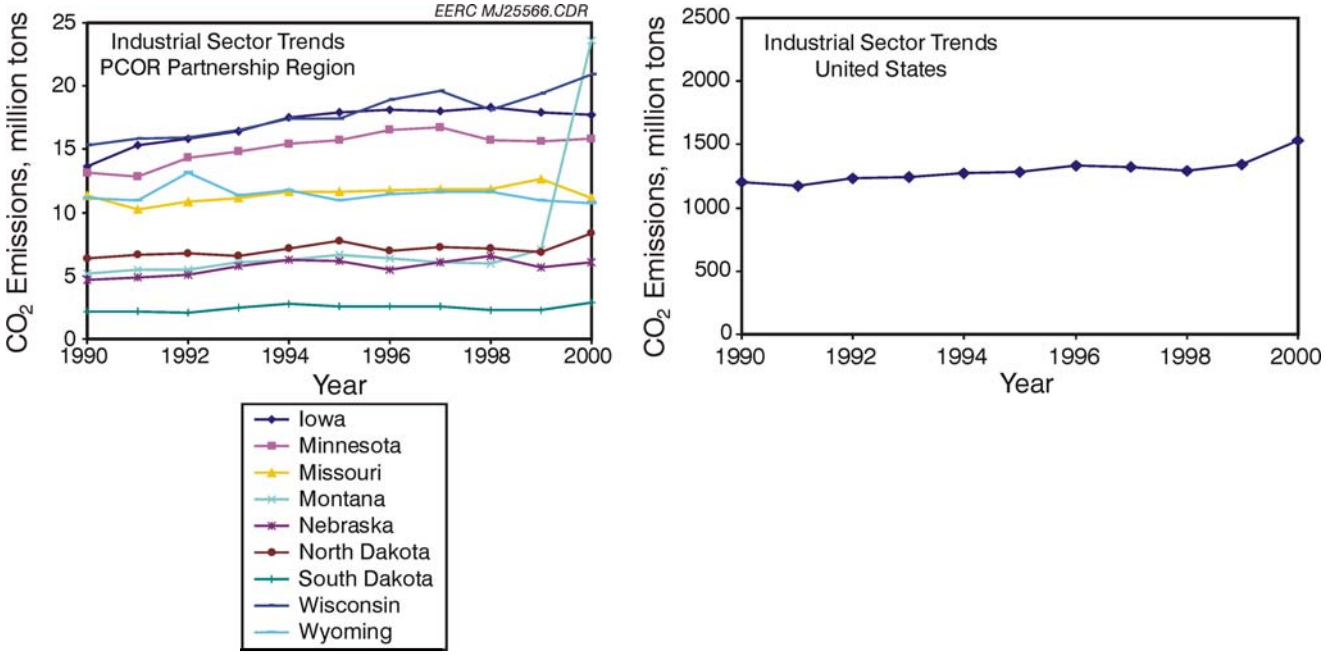

Figure 16. Trends in industrial sector emissions.

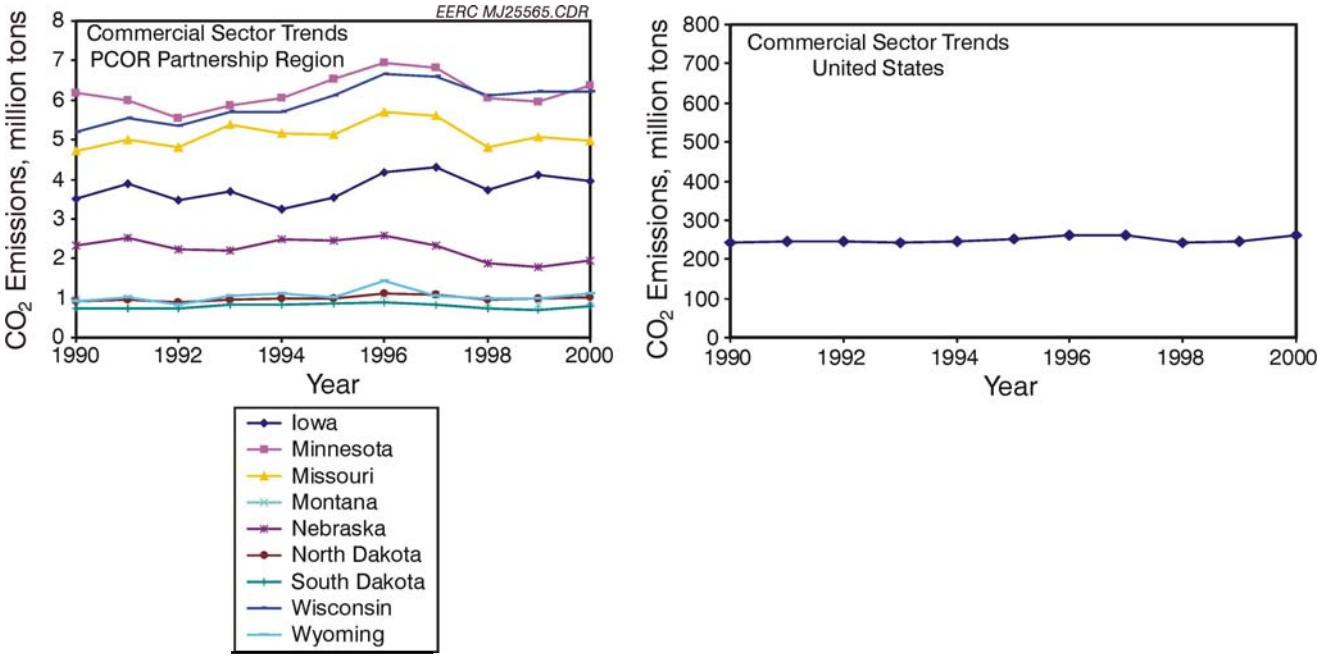

Figure 17. Trends in commercial sector emissions.

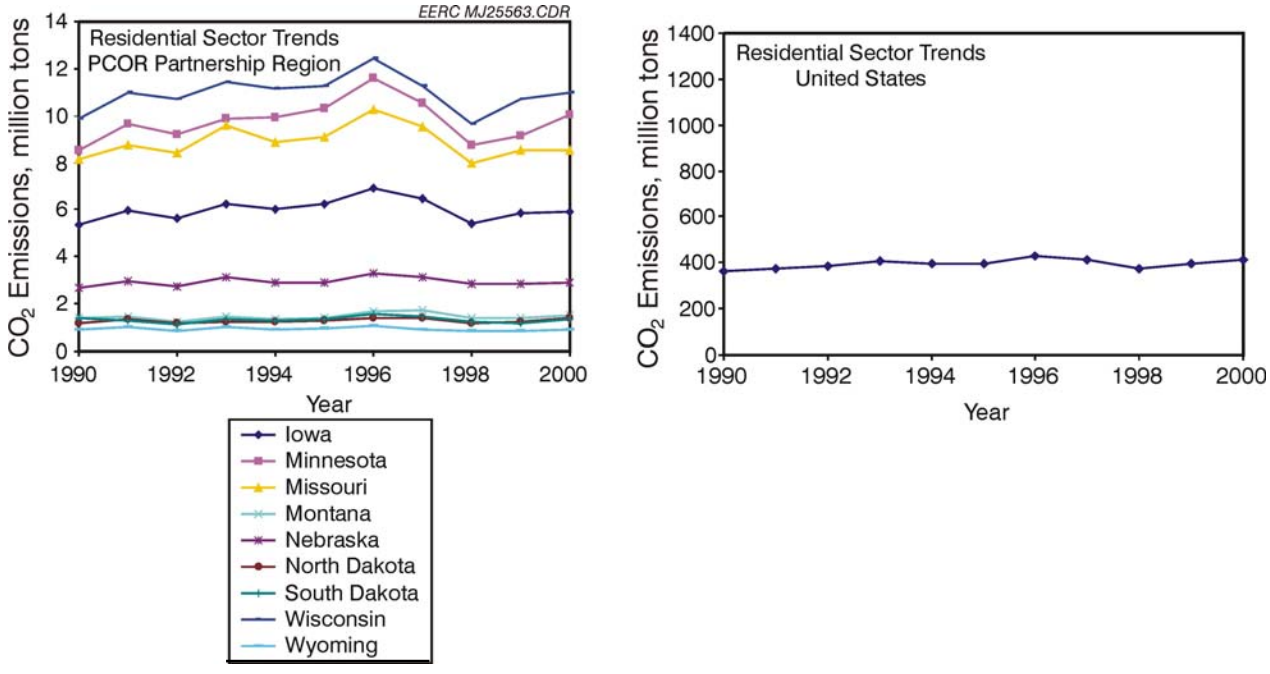

Figure 18. Trends in residential sector emissions.

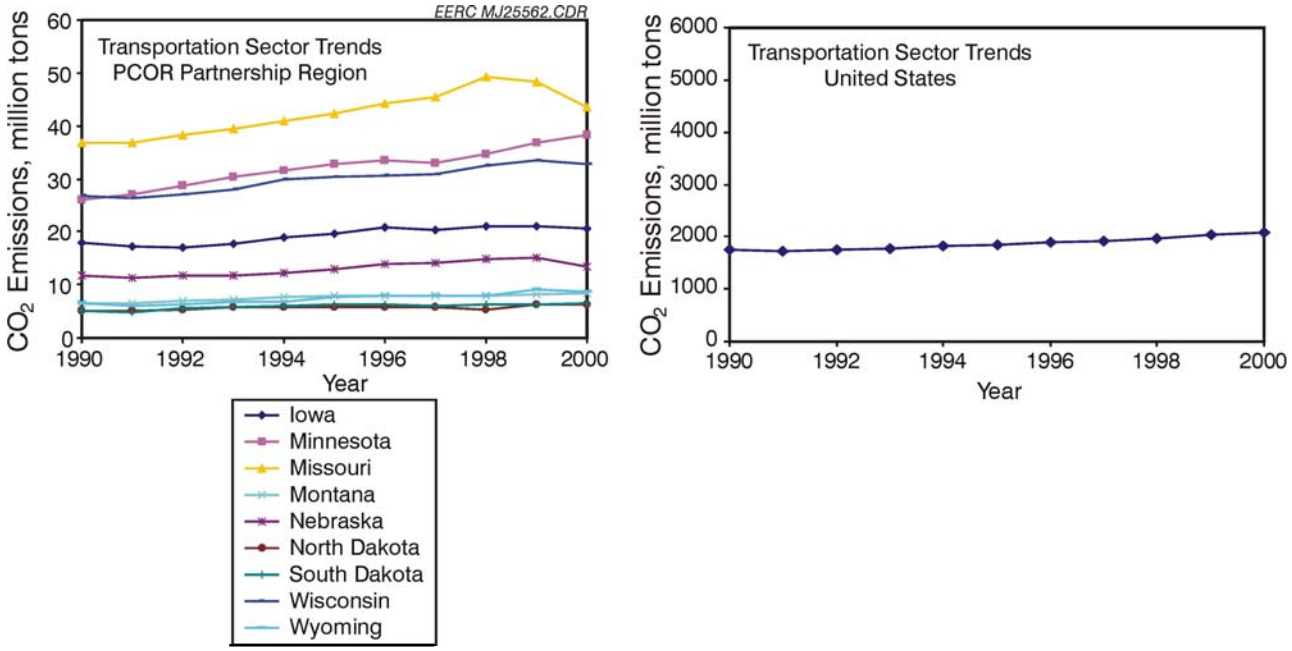

Figure 19. Trends in transportation sector emissions.

CONCLUSION

The PCOR Partnership region's varied geographic features and socioeconomic diversity are reflected in the variability of its CO_2 sources. CO_2 from stationary sources is emitted during electricity generation; energy exploration and production activities; agriculture; fuel, chemicals, and ethanol production; and various manufacturing and industrial activities.

While the emissions from the individual sources are no different from similar sources located around the United States, the wide range of point source types within the PCOR Partnership region offers the opportunity to evaluate the capture, separation, and transportation of CO_2 in many different scenarios. The emissions data in this report were used to develop field technology validation projects for Phase II of the PCOR Partnership program. The fact that the PCOR Partnership region's emissions trends are similar to those of the United States suggests that the region's sources are similar to those of the entire United States and that the work performed during Phase II will be readily transferable to the rest of the country.

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