U.S. CARBON DIOXIDE EMISSIONS AND INTENSITIES OVER TIME: A DETAILED ACCOUNTING FOR INDUSTRIES, GOVERNMENT AND HOUSEHOLDS

Technical Appendix*

Prepared by
U.S. Department of Commerce
Economics and Statistics Administration

April 2010

*This is the Technical Appendix to the report, titled "U.S. Carbon Dioxide Emissions and Intensities Over Time: A Detailed Accounting of Industries, Government and Households" released on April 21, 2010 (available at http://www.esa.doc.gov/CO2). This Technical Appendix describes the data and methods used to estimate the CO_2 emissions data discussed in the above summary report and provides the results for 349 detailed industry sectors, Government and Households.

Table of Contents

List of Tables

The following is a list of tables that was used to develop the estimates of CO_2 emissions for 349 industries, Government and Households. The ones marked with a "*" are inserted into the text of this Appendix. The ones without a "*" follow the references.

List of Tables (continued)

List of Tables (continued)

U.S. CARBON DIOXIDE EMISSIONS AND INTENSITIES OVER TIME: A DETAILED ACCOUNTING OF INDUSTRIES, GOVERNMENT AND HOUSEHOLDS

TECHNICAL APPENDIX

I. SUMMARY

This analysis provides quantitative measures of carbon dioxide gas emissions (CO_2) for 349 detailed industries, Government (Federal, state and local), and Households. Emissions estimates by industry in million metric tons (Mmt) are provided for 1998, 2002 and 2006. [1]

Almost all (99 percent) of the CO_2 emissions in this report are associated with energy use—the use of all types of fuels for both heat and power and for fuels used in an industry's production process, known as fuel feedstocks. A relatively small portion of CO_2 emissions result from production processes in industries that are not associated with energy consumption, but are simply released during the production process (called non-energy related process emissions). These are also included in this analysis and while total process emissions is small compared to overall energy-related emissions, it is significant for a handful of industries, such as Cement and Lime.

In addition, this report provides CO_2 emissions per unit of output across industries and Government. This measure of direct carbon intensity is measured in Mmt per billion dollars of output in 2000 prices. The output denominator of intensity in this study is the real gross output of industries, which is a specific measure of production volume. Real gross output for industries and Government is the value of total production deflated (adjusted for price changes year to year) by an industry specific price index. (U.S. Bureau of Economic Analysis (a) and (b)) Gross output is the total value of a product in producers' prices, so it includes the cost of intermediate materials and services, as well as wages, capital income and net indirect taxes.

CO_2 intensities for Households are measured by emissions (in Mmt) per thousand households. The number of households used in the denominator of the Household emissions intensity coefficients is from the Bureau of the Census (U.S. Bureau of the Census 1996, 2002 and 2006).

The summary paper, released on April 21, 2010 and available at http://www.esa.doc.gov/CO2 includes a section (Section III) summarizing the data and methods used in our analysis. It also briefly describes the input-output (I-O) economic methodology that was used to estimate the indirect as well as the direct emissions produced by the 349 industries (Section V). Indirect emissions are those embodied in the intermediate goods and services used in the production process. For example, in the Construction sector, the direct emissions described above account

[1] In 2007, CO_2 emissions were responsible for about 81% of all greenhouse gases and practically all of these were energy-related. A small amount, just over 1 percentage point of the CO_2 total, was non-energy related. The remaining greenhouse gases are methane (about 10%), nitrous oxides (5%) and manmade gases (the remaining 4%) (U.S. Energy Information Administration 2010 (a)).

for only a small portion of the total emissions associated with Construction. Because purchased construction materials—steel, cement and asphalt—are associated with substantial levels of CO_2 emissions, it is useful to account for these indirect emissions for Construction.

The total of the direct and indirect emissions represent an industry's "total carbon footprint." Moreover, since many production inputs are purchased from our foreign trading partners, some emissions associated with indirect inputs occur abroad. We describe in the summary paper how we compute emissions related to indirect purchases from domestic versus foreign sources.

The intent of this Appendix is to expand on our summary paper so that the results can be replicated as well as understood more completely. The following sections of this Appendix will refer to a number of working tables that will allow the reader to do this.

II. PURPOSE

The sector-level CO_2 measures developed in this report show how different economic sectors contribute to economy-wide CO_2 emissions. They identify sectors that emit large volumes of direct CO_2 emissions both in absolute terms and relative to the volume of industry production. Moreover, since we have information on emissions and output for 349 sectors over three separate years, it is possible to decompose aggregate changes in emissions over time into those due to variations in emissions intensity by industry and those due to changes in industrial composition.

In addition to direct CO_2 emissions and intensities, the report also estimates indirect CO_2 emissions and related intensities for each of the 349 industries using a detailed I-O framework for 1998, 2002 and 2006. The sum of direct and indirect production for each industry is called an industry's "total requirements" or "carbon footprint." This I-O analysis also provides estimates of imports associated with indirect requirements so that the CO_2 emissions associated with indirect requirements so that the CO_2 emissions associated with indirect requirements can be partitioned into emissions produced domestically and emissions produced outside the U.S.

The detailed CO_2 direct, indirect and total intensities over time will be helpful for the analysis of climate change mitigation or associated international trade policies. For example, one can use the total CO_2 carbon footprint as an estimate of the maximum total supply chain cost of any carbon price. The data also provides a starting point for the examination of trade and competitiveness issues in pricing the carbon content of tradable goods at a detailed level.

The remaining sections of this Technical Appendix describe in detail how estimates of emissions for the 349 industries, the Government sector and Households were made. In Section III, we provide (1) a comparison of how the detailed ESA estimates in detail compare with aggregate estimates from the U.S. Energy Information Administration (EIA) and the U.S. Environmental Protection Agency (EPA), (2) how ESA decomposition of the EIA aggregate emissions estimates were treated, i.e., how ESA took EIA emissions sectors and allocated them to industries; (3) industry classifications used in the study; and (4) detailed examples of how emission estimates were made using sample worksheets for relevant industries. Finally, all ESA worksheets for each of the EIA sectors are referred to in Section III and either displayed in the text or referred to in the text and displayed at the end of this document.

Section IV of this appendix provides (1) a description the I-O algebra used to estimate CO_2 emissions associated with an industry's indirect requirements for 1998, 2002 and 2006 and (2) how the indirect CO_2 emissions were partitioned between emissions produced domestically and abroad.

III. DIRECT EMISSIONS ESTIMATES

The primary sources of data used to measure the direct energy-related CO_2 emissions of each industry, the Government and Households come from EIA and EPA. The data are publically available.

The emissions estimates developed in this report for each year are consistent with EIA's published totals. Table A-1, below, lists EIA's published estimates of energy-related CO_2 emissions for 1998, 2002, and 2006 for what EIA terms the Industrial, Transportation, Commercial and Residential sectors. (U.S. Energy Information Administration 2010 (b)) According to EIA, energy use for the industrial sector is for establishments engaged in Manufacturing; Agriculture, Forestry and Fisheries; Mining and Construction. Energy use in the EIA Transportation sector is primarily for passenger travel and freight movement, including land, air, water and pipeline. Energy use for the commercial sector, according to EIA, consists of all activities, other than Transportation, associated with maintaining the building environment for a diverse set of functions not easily identified. Energy consumption (and thus CO_2 emissions) for EIA's residential sector includes fuels consumed to cool and heat homes, heat water and

Appendix Table A-1. Total Energy-Related Carbon Dioxide Emissions by End-Use Sector
(Million Metric Tons of Carbon Dioxide)

Year	Industrial	Transportation	Commercial	Residential	Total
Published EIA Emissions by End-Use Sector					
1998	1,794.9	1,779.5	943.6	1,097.0	5,615.0
2002	1,715.5	1,890.9	1,017.9	1,196.3	5,820.6
2006	1,652.4	2,013.4	1,043.0	1,197.9	5,906.7
ESA Summary Comparison					
1998	1,794.9	1,766.9	940.8	1,097.0	5,599.6
2002	1,715.5	1,882.6	1,017.5	1,196.3	5,811.9
2006	1,652.4	2,035.3	1,042.2	1,197.9	5,927.8
ESA Compared to EIA (% difference)					
1998	0.0%	-0.7%	-0.3%	0.0%	-0.3%
2002	0.0%	-0.4%	0.0%	0.0%	-0.1%
2006	0.0%	1.1%	-0.1%	0.0%	0.4%

Source: ESA

operate appliances.

Table A-1 shows the comparison of the ESA estimates by industries, Government and Households to the EIA data. The difference in total energy-related emissions between EIA and

ESA ranges from -0.3 percent in 1998 to 0.4 percent in 2006. Finally, ESA estimates of energy-related CO_2 emissions are consistent with the EIA notion that emissions associated with utilities—electricity and natural gas—were not estimated directly, but were accounted for when consumed. That is, the emissions associated with electricity consumption of an industry, a building or a home were accounted for at the site of consumption—the industry, building, or home—not at the site of production such as a coal-fired electric utility.

The goal of this analysis was to decompose the emissions within the broad EIA sectors, as shown in Table A-1, and allocate them to detailed industries defined by the 2002 North American Industry Classification System (NAICS). The purpose of the decomposition was to align emissions by industry sectors, Government and Households so that they could be utilized in climate change and international trade policy analysis. The re-allocation of EIA emissions estimates to industries, Government and Households resulted in no discrepancies in emissions in what EIA calls the residential and industrial sector, only minor discrepancies in overall CO_2 emissions in what EIA calls the commercial sector and up to a 1.1% difference in what EIA calls the Transportation sector.

III-A. Summary Tables: Direct Estimates

Table A-2, below, is presented here as a visual guide to explain, how the EIA sector emissions are allocated to industries. Tables A-3 through A-5 show the actual summary emissions estimates for 1998, 2002 and 2006. *Tables presented in the text portion of this Technical Appendix are compact enough to be presented within the text. Because of the number and size of most tables, however, they are referred to in the text, but presented separately as files. These files can be found on the same ESA web page as this Technical Appendix and the Summary Report.*

Appendix Table A-2. CO_2 Emissions Summary Table (Sample Table)

Appendix Table A-2. Translating EIA Emission Sectors to Industries, Government and Households (Sample Table)

(Million metric tons of CO_2)

		EIA Sector									
			Transportation			Commercial					
INDUSTRY TITLE	NAICS Code	Industrial	Trans Less LDV's	LDVs	Total	Com. Less Off. & Com.	Offices & Com. Sp.	Total	Residential	Non-Energy Emissions*	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Agriculture, forestry, fisheries, and hunting	11										
Mining	21										
Utilities (Emissions passed on to end users)	22										
Construction	23										
Manufacturing	31-33										
Wholesale trade	42										
Retail trade	44-45										
Transportation and warehousing	48-49										
Information	51										
Finance and insurance	52										
Real estate and rental and leasing	53										
Professional, scientific, and technical services	54										
Management of companies and enterprises	55										
Administrative and waste management services	56										
Educational services	61										
Health care and social assistance	62										
Arts, entertainment, and recreation	71										
Accommodation and food services	72										
Other services, except government	81										
Government	92										
Households	n.a.										
	Totals										

* Non-energy emissions are non-energy related process emissions.

Source: ESA

Table A-2 shows the basic decomposition of the emissions presented in EIA's industrial, transportation, commercial and residential sectors into NAICS-coded industries (codes shown in column 2 and described in column 1). The EIA sectors of industrial, transportation, commercial and residential are shown in columns 3 through 10. Non-energy process emissions are provided in column 11. The NAICS industry estimates are calculated as the sum of any entries for columns 3, 6, 9, 10 and 11. We can see in this example table that emissions from LDVs (for light duty vehicles) are made separate (column 5) from all other forms of emissions associated with transportation (column 4). In the actual tables, A-3, A-4 and A-5, we can see the emissions estimates associated with LDVs distributed to all industries, including Manufacturing and Service industries, and for Government and Households. We can also see from Table A-2 that emissions associated with office and commercial space (column 8) are separated from other commercial activities (column 7). In this case, the owning and/or leasing of office and commercial space by industries and Government are distributed separately to industries. The criteria for this distribution are described in the sections on decomposing EIA's Transportation and Commercial sector, respectively.

III-B. Industry Classification

Allocation of EIA direct emissions into NAICS industries was essentially completed in three steps. The first step started with 66 industry sectors from 3-digit to 6-digit NAICS in the Manufacturing sector based on EIA's Manufacturing Energy Consumption Survey (MECS) industry data. (U.S. Energy Information Administration 2010 (c)) Table A-6, *Industry Selection for ESA Emissions Study: Step 1*, shows the 66 industry sectors, for which energy consumption data are available. The table also shows the energy consumption coverage in each of the MECS survey years. There are 15 separate industry sectors for which energy consumption data are available in 2002 and 2006 survey years, but not available in the 1998 survey year.[2] The next MECS survey will gather data for 2010.

Step 2 expanded the coverage beyond the 66 industry sectors included in Step 1. Table A-7, *Industry Selection for ESA Emissions Study: Step 2,* lists the 114 industries for which direct emissions were estimated in Step 2, and Government and Households. These 114 industries encompass the entire economy and include the 66 Manufacturing sectors, described above, in addition to Agriculture, Forestry and Fisheries; Mining; Construction and 45 service sector industries. These industry sectors and the Government sector were chosen since they mirror the output data by industry published from BEA. (U.S. Bureau of Economic Analysis 2010 (a)) In addition, BEA also provides data on the value of fixed assets, equipment and structures, for the

[2] An industry sector was chosen for analysis in step 1 if that sector had coverage for at least two of the three survey years. For example, the 1998 MECS had estimates of energy consumption for the Wood Preservation industry (NAICS 321114). However, the 2002 and 2006 survey did not, presumably lumping the energy consumption of Wood Preservation into the total Wood Products (NAICS 321) sector. Likewise, the 2006 MECS provided energy consumption data on Fruit and Vegetable Preserving and Specialty Foods (NAICS 3114). However, the 1998 and 2002 MECS surveys had no energy consumption data for this sector, presumably lumping the energy consumption of this sector into the total Food (NAICS 311) sector. Unless the sector had coverage for two out of the three surveys, the emission estimates were not performed separately until Step 3—the final industry expansion.

same number and composition of industries. (U.S. Bureau of Economic Analysis 2010 (c)) These detailed fixed asset data were used to allocate emissions from LDVs and office and commercial space.

Finally, step 3 of the study expands the emissions estimates of CO_2 emissions for the 116 industries in step 2 to the 349 industries consistent with the industry classification scheme in Inforum's Inter-industry Large-scale Integrated and Dynamic (Iliad) model. (See University of Maryland 2010) This allocation is done using energy use data in Iliad, an inter-industry input-output (I-O) model, which provides a consistent underlying database for gross output, imports and exports by industry through time. Step 3 industries are listed in Appendix Table A-8, *Industry Selection for ESA Emissions Study: Step 3*. A detailed description of how energy use data in the Iliad model can be used to expand the industry sector coverage in step 1 and step 2 is described in Section III-K at the end of this section.

III-C. Decomposing Emissions in EIA's Industrial Sector

The EIA energy-related emissions associated with what it calls its industrial sector include emissions from Manufacturing, Mining, Construction, and Agriculture, Forestry and Fisheries. Table A-9 provides an ESA decomposition of the industrial sector into component parts.

Appendix Table A-9. Allocation of CO_2 Emissions in EIA's Industrial Sector

	1998	2002	2006
	(Million Metric Tons)		
Total Industrial	1,794.9	1,715.5	1,652.4
Allocation to			
Mining	158.1	157.0	176.5
Construction	107.9	131.0	133.9
Manufacturing	1,486.2	1,392.3	1,314.8
Subtotal: Mining, Construction and Manufacturing	1,752.2	1,680.3	1,625.2
Total Industrial less subtotal of Mining, Construction and Manufacturing	42.7	35.2	27.2
Agriculture, Forestry and Fisheries	42.7	35.2	27.2

Source: Total industrial emissions, EIA; all other emission estimates, ESA.

The total industrial emissions in Table A-9 are consistent with published totals from EIA (See U.S. Energy Information Administration 2010 (b)). The components of Mining, Construction and Manufacturing are from ESA decomposition estimates. The energy-related CO_2 emissions for Agriculture, Forestry and Fisheries were calculated as the residual. Energy-related consumption in the Agriculture, Forestry and Fisheries sector was made consistent with EIA's definition of the Industrial sector and there was no separate analysis to determine the energy-related CO_2 emissions of this sector. The reader should also note that these estimates are energy-related only and does not include non-energy related process emissions which, although small, have a significant impact on some Manufacturing sectors such as Lime and Cement manufacturing.

The following is a description, along with some examples, of how we determined the CO_2 emissions in the Manufacturing sector from the EIA Industrial sector emissions. Next, we describe how emissions data for Mining and Construction, based primarily on EPA estimates of emissions, were determined and made consistent with our benchmark years (U.S. Environmental Protection Agency 2008).

Table A-10 provides the components of Manufacturing for which we were able to obtain specific emissions estimates for 1998 from either the EPA or EIA, or both. The EIA published a paper on emissions for the Manufacturing sectors called "*Energy-Related Carbon Dioxide Emissions in U.S. Manufacturing*" (Schipper 2006). The EPA published a working draft called "*Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States*" (U.S. Environmental Protection Agency 2008) which provided estimates of emissions for Manufacturing sectors as well as for Construction and Mining. We provide both the EIA and EPA estimates of emissions by sectors in Tables A-10 for 1998 and A-19 for 2002. The EIA and EPA have not yet made separate estimates of emissions for these sectors for 2006.

As an example, according to Table A-10, the EPA made an estimate of 93.7 Mmt of CO_2 emissions for the Food industry in 1998. (U.S. Environmental Protection Agency 2008) Since EIA had no similar estimate for Food, the EPA emission estimate for 1998 was taken as a given and its level was distributed among more detailed sectors (Wet Corn Milling and Beverages and Tobacco) using the energy-use data indicated in Table A-11, which is the MECS Table 1.2, *First Use of Energy for All Purposes (Fuel and Nonfuel), 1998.* (U.S. Energy Information Administration 2010 (c)) It shows fuel consumption in trillion British thermal units (tBtus) by fuel types (including electricity, residual fuel oil, distillate fuel oil, natural gas, LPG and NGL, coal, coke and breeze and other) by industry sectors. The EPA used EIA's MECS data in their estimates.

The following provides two examples of how we used these published EIA and EPA emissions estimates by sector which are primarily within Manufacturing. Our first example is a continuation of the discussion of the Food sector in 1998. As stated above, we start with the EPA published estimate of emissions for the Food sector and the decomposition of its fuel consumption by primary fuels from the MECS in order to obtain CO_2 emission estimates for individual Food sectors within the aggregate industry. Table A-12, below, provides this breakdown.

Appendix Table A-12. Emissions from the Food Products Sector, 1998

From the EIA Industrial Sector

NAICS	Industry	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG and NGL	Coal	Coke and Breeze	Other
		Fuel Consumption (trillion Btus)								
311, 312	Food and beverages	1,152.0	237.0	16.0	18.0	613.0	6.0	158.0	2.0	101.0
311	Food	1,044.0	213.0	14.0	16.0	568.0	5.0	129.0	2.0	97.0
311221	Wet Corn Milling	173.0	24.0	0.0	0.0	77.0	0.0	65.0	0.0	6.0
31131	Sugar Manufacturing	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
312	Beverage and Tobacco Products	108.0	24.0	2.0	2.0	45.0	1.0	29.0	0.0	4.0
3121	Beverages	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3122	Tobacco	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Emissions Conversion Factors			182.21	78.80	73.15	53.06	62.68	93.98	93.71	
		CO2 Emissions (Million metric tons CO2)								
311, 312	Food & beverages	93.7	43.2	1.3	1.3	32.5	0.4	14.8	0.2	0.0
311	Food	84.9	39.9	1.1	1.2	30.1	0.3	12.1	0.2	0.0
311221	Wet Corn Milling	14.1	3.9	0.0	0.0	4.1	0.0	6.1	0.0	0.0
31131	Sugar Manufacturing	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
312	Beverage and Tobacco Products	8.8	3.3	0.2	0.1	2.4	0.1	2.7	0.0	0.0
3121	Beverages	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3122	Tobacco	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Note: Used EPA estimate for Food and beverages for 1998 of 93.7 and EIA conversion factors for 1998; then backed into the total for net electricity to calculate its conversion factor. Used same approach to calculate the totals for food and beverage and tobacco products (proportionality of the total and residual for net electricity).

Note: Sugar mfg., beverage and tobacco data from MECS were not available in 1998.

The bottom half of Table A-12 shows that the EPA total emissions estimate for 1998 of 93.7 Mmt of CO_2 was used as the total CO_2 emissions for NAICS 311 and 312 for Food and Beverages. The top half of Table A-12 shows that a total of 1,044 tBtus of fuel was consumed by NAICS 311 for Food and 108 tBtus for NAICS 312, Beverages and Tobacco products. Total energy consumption across the primary fuels was 1,152 tBtus, the sum of NAICS 311 and 312. The top half of Table A-12, then, includes the energy consumption from survey data for these two sectors by primary fuel type from the 1998 MECS, as shown in Appendix Table A-11. (U.S. Energy Information Administration 2010, (c))

Emission conversion factors are published by the U.S. EIA and provide conversion factors for 40 fuel types. (U.S. Energy Information Administration 2010 (c)) The conversion factor for each primary fuel type is in Mmt of CO_2 per quadrillion Btus of energy consumed. However, there is no conversion factor listed for electricity since the Mmt of CO_2 is dependent on how the electricity was generated, i.e., from coal, natural gas, hydro or nuclear power. We estimate the emissions conversion factor for electricity by utilizing the available information. For example, the EPA estimates a total of 93.7 Mmt of emissions result from the Food and Beverage industry. In addition, we know the conversion factors for residual and distillate fuel oil, LPG and NGL, Coal, Coke and Breeze. This enables us to estimate emissions from all the primary fuels. (In this example, we assume that the fuel consumption in the Other category, the last column of Table A-12, is included in "Electricity.") In order to compute the emissions associated with electricity consumption, we subtract the emissions from all the primary fuels, except for electricity, from the total, 93.7 Mmt, for Food and Beverages in 1998. This gives us 43.2 Mmt of CO_2 emissions in the Food and Beverage industry that originates from the consumption of electricity. We then use this to calculate a conversion factor for electricity.

Note that this conversion factor is a national average which accounts for the national mix of fuels and their relative carbon intensity during the year of generation. Since industries tend to be clustered regionally and since electricity–consuming regions have different fuel mixes, the actual carbon emissions computed for any given industry may not reflect the actual emissions taking into account regional differentials in fuel mix. However, from a national point of view, it is probably best to assume that electricity is fungible and to allocate CO_2 emissions from electrical generation across industries, Government and Households by its relative consumption.

We can see from Table A-12 that the MECS survey estimate for fuel consumption for electricity in this sector is 237.0 tBtus. We also calculated that emissions associated with electricity for this sector (the residual) as 43.2 Mmt, so the conversion factor for electricity for this industry is 182.17 (43.2 Mmt of $C0_2$ per (237.0/1,000)) Mmt $C0_2$ per quadrillion Btu.

The question is, if we already have total emissions number for Food and Beverages, why do we need a conversion factor for electricity for this sector? The answer is that we need an electricity conversion factor, which is averaged for the whole industry, in order to consistently estimate the emissions due to electricity for the sub-sectors of this industry. For the Food and Beverage industry, we have the Food industry sector (NAICS 311) and the Beverage and Tobacco industry (NAICS 312). Also, within the Food industry, we have a separate breakout for Wet Corn Milling (NAICS 311221). These breakouts are included in the 1998 MECS. Note that Table A-12 has separate breakouts for Sugar Manufacturing (NAICS 31131) and Beverages (NAICS 3121) and Tobacco (NAICS 3122), but the 1998 data are not available for these sectors. Place markers were provided in this table, however, since the detailed fuel consumption and, thus, emissions estimates are available from the expansion of industry coverage in the 2002 and 2006 MECS.

To finish this example of Food and Beverages, we estimated the Food "share" and the Beverage "share" of total emissions by calculating the proportion of the total emissions in the MECS that resulted from Food and from Beverages. This leaves us with a slightly different conversion factor for these two sub-sectors. Instead of a 182.17 conversion factor as calculated for the aggregate Food and Beverage sector, we have a very specific conversion factor for electricity for Food of 187.18 and Beverages and Tobacco of 137.68.

We employed this method so that the sum of all of the parts would equal the total 93.7 Mmt of CO_2 for Food and Beverages published by the EPA. If we had used a constant conversion factor for electricity, the sum of the parts would not have equaled the total. We are reassured that the conversion factor for the largest share of Food and Beverages is similar and just slightly greater than the aggregate. On the other hand, we do not have enough information as to why the electricity conversion factor for Beverages and Tobacco was calculated to be significantly smaller.

The second example, however, shows the desirability of creating an electricity conversion factor for a slightly different type of industry worksheet. Table A-14 shows the energy consumption of primary fuels from the 1998 MECS survey and estimates of CO_2 emissions by fuel type for the Forest Products industry.

Appendix Table A-14. Emissions from the Forest Product Sector, 1998
From the EIA Industrial Sector

NAICS	Industry	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG and NGL	Coal	Coke and Breeze	Other
						(trillion Btus)				
321, 322	Forest products	3,256.0	312.0	152.0	22.0	659.0	9.0	279.0	0.0	1,821.0
321.0	Wood products	509.0	72.0	1.0	13.0	73.0	4.0	2.0	0.0	343.0
321113	Sawmills	166.0	20.0	1.0	6.0	9.0	0.0	0.0	0.0	130.0
3212	Veneer, Plywood, and Engineered W	223.0	36.0	0.0	2.0	48.0	2.0	2.0	0.0	132.0
3219	Other Wood Products	106.0	15.0	0.0	2.0	12.0	1.0	0.0	0.0	75.0
322	Paper	2,747.0	240.0	151.0	9.0	586.0	5.0	277.0	0.0	1,478.0
322110	Pulp Mills	198.0	5.0	9.0	2.0	24.0	0.0	4.0	0.0	154.0
322121	Paper Mills, except Newsprint	1,154.0	87.0	85.0	4.0	231.0	2.0	131.0	0.0	614.0
322122	Newsprint Mills	175.0	50.0	11.0	0.0	23.0	1.0	31.0	0.0	59.0
322130	Paperboard Mills	984.0	51.0	40.0	2.0	227.0	1.0	98.0	0.0	564.0
	Emissions Conversion Factors		190.00	80.00	90.00	53.06	62.68	100.00	93.71	0.65
					(Million metric tons CO2)					
321, 322	Forest Products	134.6	55.8	12.2	2.0	35.0	0.6	27.9	0.0	1.2
321.0	Wood products	19.5	13.7	0.1	1.2	3.9	0.3	0.2	0.0	0.2
321113	Sawmills	5.0	3.8	0.1	0.5	0.5	0.0	0.0	0.0	0.1
3212	Veneer, Plywood, and Engineered W	10.0	6.8	0.0	0.2	2.5	0.1	0.2	0.0	0.1
3219	Other Wood Products	3.8	2.9	0.0	0.2	0.6	0.1	0.0	0.0	0.0
322	Paper	118.6	45.6	12.1	0.8	31.1	0.3	27.7	0.0	1.0
322110	Pulp Mills	3.6	1.0	0.7	0.2	1.3	0.0	0.4	0.0	0.1
322121	Paper Mills, except Newsprint	49.6	16.5	6.8	0.4	12.3	0.1	13.1	0.0	0.4
322122	Newsprint Mills	14.8	9.5	0.9	0.0	1.2	0.1	3.1	0.0	0.0
322130	Paperboard Mills	35.3	9.7	3.2	0.2	12.0	0.1	9.8	0.0	0.4

Note: Controlled 1998 paper industry emissions to EIA (Shipper) by fuel type and calculated revised emissions conversion factors to match. Then, used EPA total for forest products.

In this table, we already have a total of 134.6 Mmt from EPA for the Forest Products industry and a total of 118.6 Mmt from EIA for the Paper industry (Schipper 2006). We calculate an electricity conversion factor based on these totals and based on other primary fuels. In this rather simplistic approach, we discount emissions from the primary fuel column labeled "Other" since (1) the label is generic and a significant conversion factor would mean that the sum of the parts would be much greater than the whole and (2) we suspect that the "Other" primary fuel is used from the chemical process of making paper and the extraction of its cell wall glue, called lignin. Burning lignin, then, as a bio-fuel supplement was about half of the Btus generated for energy by the Paper industry. Another data point to note in the table is the emissions conversion factor of 90 Mmt per quadrillion Btu for distillate fuel oil. But we know that the conversion factor for this primary fuel is 73, not 90. We used 90 for this conversion factor for two reasons—the first is to make the pieces fit together and the second is because the contribution of distillate fuels for this industry's energy requirements is relatively small.

We discounted the contribution of Other to total emissions and we determined the amount of emissions from the primary fuels of natural gas and coal. Next, the electricity conversion factor needs to be computed. To do this, we need to subtract the primary fuel emissions from the total and we have 55.8 Mmt of emissions for electricity. We calculate an electricity conversion factor of 190.0 from Btus of electricity consumed and calculated Mmt of emissions for the Paper industry and apply this as the conversion factor for Wood Products and Paper subsectors for which we don't have a published total.

The remaining appendix tables list industry sectors with energy consumption data by primary fuel type published in the 1998, 2002 and 2006 MECS. They employ approximately the same methodology to estimate emissions by industry with one exception. The EIA and EPA did not produce estimates of CO_2 emissions for aggregate sectors for 2006. In other words, we did not have total CO_2 emissions by sector for 2006 as we did for 1998 and 2002 so we could not compute an electricity conversion factor. For 2006, then, we used the same conversion factors for electricity as in 2002. Conversion factors for the other primary fuels are available from the EIA website (U.S. Energy Information Administration 2010 (d)).

Appendix Tables for the industry sectors using the MECS primary fuel consumption data as a basis of estimating emissions are as follows:

- Summary with Comparisons to EIA and EPA, A-10, 1998; A-20, 2002;
- Summary with no Comparisons, A-29, 2006.
- MECS Table 1.2, Fuel and Non-Fuel, A-11, 1998; A-21, 2002 and A-30, 2006.
- Food Products; A-12, 1998; A-22, 2002 and A31, 2006.
- Textiles; A-13, 1998;
- Textiles and all other industries, A-23, 2002 and A-32, 2006.
- Forest Products; A-14, 1998; A-24, 2002 and A-33, 2006.
- Petroleum Products; A-15, 1998; A-25, 2002 and A-34, 2006.
- Chemicals; A-16, 1998; A-26, 2002 and A-35, 2006.
- Non Metallic Mineral Products; A-17, 1998; A-27, 2002 and A-36, 2006.
- Primary Metals; A-18, 1998; A-28, 2002 and A-37, 2006.
- All other Manufacturing sectors; A-19, 1998.

On another note, Table A-15 provides an example of some apparent discrepancy between EPA's and EIA's published estimates of emissions for the Petroleum Products industry. EPA estimated that the Petroleum and Coal Products industry had CO_2 emissions of 363.0 Mmt while the EIA estimated 320.4 Mmt. After a review, we discovered that the EPA emissions estimate included the energy-related CO_2 emissions from the Oil and Natural Gas Exploration industry in the Petroleum Products industry. Since our goal is to be consistent with the 2002 NAICS definitions of industries, we decided to (1) use the EIA published total which did not include the emissions from Oil and Natural Gas Exploration, a part of the Mining industry, and (2) add the emissions from Oil and Natural Gas Exploration to EPA's estimated emissions from Mining. This is described below in Section III-D.

Note that these emission estimates for Manufacturing industries based on MECS were the first step in completing our final emission estimates for Manufacturing. As mentioned previously and shown in the Table A-2, total emissions from Manufacturing industries were adjusted to include estimates of emissions for vehicle use of businesses that owned or leased light-duty vehicles, and commercial and office space. A detailed description of the methodology for LDV distribution is shown in Section III-G and for commercial and office space distribution, Section III-H.

III-D. Emissions from the Mining Sector

The EPA published estimates for CO_2 emissions for Mining for 1997 and 2002, based on Census data for fuel and electricity purchases (U.S. Environmental Protection Agency 2008). EPA's estimates for emissions from the Mining sector, however, did not include emissions from Oil and Natural Gas Exploration, a mining industry as defined by the 2002 NAICS. EPA included these emissions as part of the Petroleum Products sector. In order to be consistent with the 2002 NAICS, however, we moved the emissions associated with Oil and Natural Gas Exploration from Petroleum Products to Mining.

Table A-38 shows the EPA estimates of emissions for Mining, not including Oil and Natural Gas exploration, and emissions associated with Oil and Natural Gas Exploration separately (U.S. Environmental Protection Agency 2008). These emissions are energy-related CO_2 emissions only. The Table also shows the real output for this industry for 1997, 1998, 2002 and 2006. (U.S. Bureau of Economic Analysis 2010, (a) and (b)) The emissions for 1998 were estimated based on the percent change of real output between 1997 and 1998, and for 2006 based on the percent change between 2002 and 2006.

Appendix Table A-38. Mining Industry Emissions

For the EIA Industrial Sector

	Emissions (Mmt)			
Mining	**1997**	**1998**	**2002**	**2006**
Not including oil and gas exploration				
Fossil Fuel Combustion	20.0		15.0	
Purchased electricity	32.9		27.0	
Oil and gas exploration				
Fossil fuel combustion	80.9		77.0	
Non-combustion	7.0		7.0	
Purchased electricity	21.0		31.0	
Total	161.8		157.0	
Real Output, billions (2000$)	217.6	212.6	205.7	231.3
Change in Output		-2.3%		12.4%
Emissions estimates based on outputs		158.1	157.0	176.5

Sources: ESA calculation based on emissions for 1997 and 2002 from EPA and real outputs from BEA.

This method makes an implicit assumption regarding energy intensity change, i.e., the energy intensity for 1998 is held at the 1997 level. Intensity for 2006 is held constant at the 2002 level. The assumption for 1998 may be less of a problem than the assumption for 2006. In 1998, there is only one year difference between a data supported year and an extrapolated year. For 2006, however, there is a four year difference.

III-E. Emissions from Construction

Emissions from Construction for 1998, 2002 and 2006 were constructed in a manner similar to that for Mining. Construction emission estimates for 1997 and 2002 were available from the EPA (U.S. Environmental Protection Agency 2008). The BEA provided inflation-adjusted output data for Construction for 1997, 1998, 2002 and 2006 (U.S. Bureau of Economic Analysis 2010 (a) and (b)). Table A-39 provides output and emissions data for Construction.

Appendix Table A-39. Construction Industry Emissions
For the EIA Industrial Sector

Construction	Emissions (Mmt) 1997	1998	2002	2006
EPA emissions estimates	103.1		131.0	
Output, $billions, 2000$	757.4	792.4	848.2	897.8
Output change, 1997 to 1998		4.6%		5.8%
Output change, 2002 to 2006				
Emissions for				
1998 based on change in real output		107.8		
2006 based on change in real output				138.6
Final emissions estimates		107.8	131.0	138.6

Sources: ESA calculation based on emissions for 1997 and 2002 from EPA and real outputs from BEA.

Emissions for 1998 were estimated as the increase in output between 1997 and 1998 multiplied by emissions in 1997. The same calculation was made for 2006, i.e., multiplying the increase in real output between 2002 and 2006 by emissions in 2002. As stated previously, these calculations assume that the emissions intensity in 1998 was the same as it was in 1997. The one year difference supports that assumption. However, for 2006, the four year difference between 2002 and 2006 may invalidate the assumption that intensity remained constant during that period.

III-F. Emissions from the Agriculture, Forestry and Fisheries Sector

As stated earlier in this paper, the energy-related CO_2 emissions for Agriculture, Forestry and Fisheries were calculated simply as the residual, i.e., as emissions for the EIA industrial sector total less Mining and Construction. This calculation was done to conform to EIA's definition of the industrial sector. See Table A-9 in Section III-C.

III-G. Decomposing the EIA Transportation Sector

Calculation of emissions from the EIA Transportation sector was performed in three steps. Step 1 included a special run of the EIA National Energy Modeling System (NEMS) to backcast (1998, 2002 and 2006) the consumption of fuels by fuel type by mode of transportation[3] (U.S. Energy Information Administration 2010 (e)) Table A-40 shows the NEMS results for the transportation sector for energy use in trillion Btus (tBtus) by fuel type within a transportation mode for those three years. For instance, LDVs (for light-duty vehicles including cars and light trucks) in 2006 used primarily motor gasoline, 16,154 tBtus, and some distillate fuel or diesel (250 tBtus) resulting in a total consumption of 16,404 tBtus for 2006. There is also a separate

[3] NEMS is used normally to make forecasts.

breakout of ethanol, compressed natural gas, liquefied petroleum gases, electricity and hydrogen. For those three years, these fuels played a relatively minor role.

Table A-40 shows major transportation modes of Freight Trucks, Freight Rail, Water Transportation of Domestic and International Shipping; Air Transportation; military use of fuels for transportation; Transit, Intercity and School Bus; Intercity and Commuter Rail Transportation; Recreation Boats; Pipelines and Miscellaneous.

Step 2 of decomposing the EIA Transportation sector was to take the detailed breakout of energy use by fuel type by mode of transportation shown in Table A-40 and (1) assign the mode of transportation, if possible, to a NAICS defined Transportation service sector industry and (2) using the EIA conversion factors of emissions to energy use by fuel type, calculate the CO_2 emissions. Tables A-41 shows this assignment to NAICS industries and the calculation of emissions by mode and fuel type.

Step 3 of decomposing the EIA transportation sector was the assignment of LDVs to industries, Government and Households.[4] The distribution was made using the Inforum LIFT model's estimates of sales of LDVs to business investment, Government and personal consumption for 1998, 2002 and 2006. See Table A-44.

Appendix Table 44. LDV Emission Distribution to Industries, Government and Households

	1998		2002		2006	
	Sales of LDVs (%)	LDV Emissions (Mmt)	Sales of LDVs (%)	Total LDV Emissions (Mmt)	Sales of LDVs (%)	Total LDV Emissions (Mmt)
Domestic Production Sales to Industries, Government and Households						
Business investment (industries)	46.1	468.2	37.6	412.4	42.7	491.3
Government	4.8	48.7	5.4	58.7	6.1	70.2
Personal consumption (households)	49.1	498.7	57.0	625.2	51.2	589.2
Total	100.0	1,015.6	100.0	1,096.9	100.0	1,150.7

Sources: Sales of LDVs from the LIFT distribution of autos and light trucks, by year; total LDV emissions estimated by ESA.

Table A-44 shows that in 2006, 51 percent of the value of LDVs was attributable to personal consumption, 43 percent to business investment and 6 percent to Government. These shares were used as a proxy for the distribution of the total capital stock of LDVs in the U.S. and their likely consumption of fuel. LDV emissions in 2006 were estimated at 1,150.7 Mmt and applying the shares of sales suggests that LDV emissions resulting from personal use were 589 Mmt of CO_2, from business investment 491 Mmt and from Government were 70 Mmt. The 491 Mmt for business investment was in addition to the estimated 43 Mmt of CO_2 estimated from commercial light trucks.

The 43 Mmt for commercial light trucks was assigned to the Truck Transportation industry. However, the 491 Mmt assigned to business investment was not. It was assigned to industries based on the distribution of the cost of capital stock of autos and light-duty trucks (LDVs) as an

[4] Note that in tables A-41, A-42 and A-43 a portion of light-duty trucks were designated for commercial use already. These were assigned to the Truck transportation industry (NAICS 484).

asset for private industries as published by the BEA. (U.S. Bureau of Economic Analysis 2010 (c) and (d)) These files contain detailed estimates for private nonresidential fixed assets by detailed industry sector and by detailed asset type for net stocks and their chain-type quantity indexes.

According to BEA, “chain-type quantity indexes are provided as part of the detailed data for fixed assets and can be used to measure the real growth rate of the component, but should not be used to analyze shares.” BEA goes on to say that current-cost and/or historical-cost tables should be used to analyze shares and/or the magnitude of these components. (U.S. Bureau of Economic Analysis 2010 (e))

We wanted to see, however, if there were much growth in the capital stock of autos and light trucks by industry from between 1998 to 2002 and 2002 to 2006. To do this, we needed to compute an inflation-adjusted dollar estimate of autos and light-duty trucks by industry for each of the years. See Tables A-45, A-46 and A-47. In these Tables, we took the cost of autos and light trucks from BEA’s detailed fixed asset tables and used quantity indexes to get a real (2000$) estimate by industry.

We summarized the total value of real costs of owning or leasing autos and light trucks in 2000$ in Table A-48. We also computed real shares despite the warning by BEA not to do so. There were two reasons to do this. First, the quantity indexes were based on 2000$ and two of the three years being evaluated, 1998 and 2002, were only two years away from the index years so the distortions of chain-weighting would be minimal. This led to the conclusion that the current-dollar shares would not be significantly different from the real shares. Second, the shares were computed for all three years, 1998, 2002 and 2006, in order to check if there was any significant change in the shares over the period being investigated. The data show no considerable change. Table A-48 shows that there was a difference of only 0.1 percentage points in “real” shares for all industries between either 1998 and 2002 or 2002 and 2006. The conclusion, after all this, was that the capital stock of autos and light-duty trucks did not move much over the eight year period. This led to the further conclusion that we could distribute emissions across industries based on the real share estimates for each of the years because of the proximity of the base year and the stability of the shares

Finally, the emission estimates by year for LDVs were assigned to industry sectors according to the NAICS listing in Table A-48. Summary Tables A-3, A-4 and A-5 provide these emissions estimates. For example, the Agriculture, Forestry and Fisheries sector had 35.2 Mmt of CO_2 in 2006 as determined in the industrial sector, described in the previous decomposition. Now, we add another 12.9 Mmt of CO_2 for consumption of fuels in autos and light-duty trucks. This comes to a total, so far, of 48.1 Mmt in 2006.

Finally, notice that the emissions for many or all of the Manufacturing industries were for 3-digit NAICS industries. These emissions estimates were further distributed within a 3-digit NAICS sector by the output of the more detailed industries within that sector.

III-H. Decomposing the EIA Commercial Sector

Another primary data source to estimate emissions by industry was EIA's Commercial Building Energy Consumption Survey (U.S. Energy Information Administration 2010 (f)). The CBECS was last published for 1999 and 2003. See Tables A-49 for 1999 survey data from CBECS Table C1 for "Total Energy Consumption by Major Fuels for All Buildings" and Table A-50 for 2003 survey data from CBECS C1A. A compilation of 2007 survey data is underway. Data from the 1999 and 2003 CBECS surveys used in this report were re-benchmarked to 1998 and 2002, respectively. The commercial building energy consumption estimates used in this analysis were estimated from ESA's 2002 CBECS re-benchmark and 2006 totals for energy use for the commercial sector.

The primary focus of Tables A-49 and A-50 is energy consumption by primary fuel type for all buildings by the principal building activity such as education, food sales, health care and retail. For example, in 1999, total energy consumption for all buildings was 5.7 quadrillion Btus with breakdowns into electricity, natural gas, fuel oil and what EIA calls district heat. District heat refers to steam or hot water produced outside of a building in a central plant and piped into the building as an energy source for space heating or other end use. (U.S. Energy Information Administration 2010 (j)) Tables A-49 and A-50 show that electricity consumption is broken into two categories: primary and site. Site electricity refers to the amount of electricity in tBtus that is delivered to commercial buildings while primary electricity includes the delivered and site electricity and conversion losses in its generation, transmission and distribution. (U.S. Energy Information Administration 2010 (k))

Our task, once again, was to assign the building consumption of primary fuel types to NAICS industries. While we could make educated guesses on some of the EIA categories based on the principal building activity of education, food sales, health care and retail, there were some categories such as offices, services and other where we could not make educated guesses. Finally, such building activity as public assembly, public order and safety, and religious were assigned to the Government and Household sectors. To assist us in assigning these building activities, the EIA provided us with a CBECS building activity breakdown with likely and the most likely industries using these facilities. Table A-51 presents this information. For example, Table A-51 shows us that the building activity of food sales, most likely takes place in the Food and Beverage Store industry (NAICS 445). However, the Table also shows that food sales is represented through Nondurable Wholesalers (NAICS 424), Gasoline Stations (NAICS 447), Educational Services (NAICS 611), Museums (712) and Amusement, Gambling and Recreation Facilities (NAICS 713). We used these categories to assign primary fuel consumption.

Tables A-52 and A-53 are our assignments of primary fuel consumption by NAICS industries using the CBECS data from Tables A-51 and A-52. The industry and NAICS assignments are shown in the first two columns. The fuel types and their energy consumption are shown in the next six columns while the building activity and notes on their energy consumption distribution are shown in the last column. For example, Food Service sales is split between wholesale and retail based on revenue information from the Census on data for NAICS 4224, Grocery and Related Product Wholesalers, and NAICS 445, Retail Food Stores (U.S. Bureau of the Census 2010 (c) and (d)).

Another category was assigned in the Industry Assignment column to be split based on the BEA detailed fixed asset data. These included the EIA categories in the CBECS primary building activities as offices, services and other.

Finally, energy consumption was summed across all the categories and all the primary fuels so that conversion coefficients for all the primary fuels could be calculated. We were able to do this because the EIA publishes the total emissions for the commercial sector by fuel type. (U.S. Energy Information Administration 2010 (b)) For instance, EIA estimates that in 1999, the total emissions were 955.5 Mmt of which electricity as the primary fuel for heat and power was 732 Mmt, natural gas 166 Mmt, petroleum 48 Mmt and coal 10 Mmt. Once again we have control totals for which to generate conversion factors for electricity, and for this sector, the remainder of the primary fuels. We need these conversion factors so that we can make separate estimates of emissions for each of the industry, Household and Government pieces that make up the EIA commercial sector. The last rows of Tables A-52 and A-53 are calculated conversion factors that we can use so that the sum of the parts does not exceed the total emissions estimates by fuel type published by EIA.[5]

Table A-54 uses the 1999 CBECS breakdown from Table A-52 to make estimates for the benchmark year of this study for 1998 using the shares of industry emissions in 1999 to distribute across the total commercial sector emissions for 1998. Table A-54 shows us that in 1999, EIA estimated that the Commercial Sector was responsible for 996.1 Mmt of CO_2. In 1998, however, the Commercial Sector was responsible for 943.6 Mmt. We then use the shares of emissions by industry in 1999 to distribute the total commercial Sector emissions in 1998. Table A-55 is used in the same way except that the shares of emissions by industry for 2003 were used to distribute the total emissions for 2002 and 2006.

Finally, we have only one more task to complete the emissions distribution of the Commercial Sector, i.e., to distribute the CBECS categories of offices, services and other to industries. We do this by employing the same methodology that we used to distribute the fuel consumption of LDVs in EIA's transportation sector. That is, we employ the detailed fixed assets data by industry for commercial space and offices in the construction categories of fixed assets just as we distributed the autos and light trucks capital stock in the equipment portion of the BEA data. (U.S. Bureau of Economic Analysis 2010 (c) and (d))

We wanted to see, however, if there were much growth in the capital stock of office and commercial buildings by industry between 1998 and 2002 and between 2002 and 2006. To do this, we needed to compute a real dollar estimate of office and commercial structures by industry for each of the years. See Tables A-45, A-46 and A-47. In these tables we took the cost of

[5] Note that the conversion factors for electricity are not close to our earlier estimates for energy consumption to emissions. First, it really does not matter since our goal is only decompose the published EIA emission estimate and second, we overstated in Tables A-52 and A-53 the electricity Btus consumed since we added Primary to Site electricity. Really, Site electricity is really part of Primary and we should have used Primary only to account for the use and the losses. Again, the only reason to care would be if the ratio of site to primary consumption changes from one industry category to another based on the ESA assignment of building activities to industries. It does not and remains steady at one-third Site to two-thirds Primary across categories.

office and commercial structures by industry in the BEA detailed fixed asset tables and used quantity indexes to get a real (2000$) estimate by industry.

We summarized the total value of real costs of owning or leasing office and commercial structures in 2000$. See Tables A-56, A-57 and A-58. We again computed real shares despite BEA's warning. Our reasoning was the same for office and commercial space as it was for autos and light trucks. First, the quantity indexes were based on 2000$ and two of the three years being evaluated, 1998 and 2002, were only two years away from the index years, so the distortions of chain-weighting were likely to be minimal. This led to the conclusion that the current dollar shares would not be significantly different from the real shares. Second, the shares were computed for all three years, 1998, 2002 and 2006 in order to see if there were any significant changes in the shares over the period being investigated.

Table A-59 shows that there were only a few sectors where the real shares were greater than 0.1 percentage point, but the majority had no or little movement in their shares of the value of their stock, when adjusted for inflation. The conclusion, after all this, was that the capital stock of office and commercial structures by industry did not move much over the eight year period. This led to the further conclusion that we could distribute emissions across industries based on the real share estimates for each of the years because of the proximity of the base year and the stability of the shares. The emission results by industry for these categories are shown in Table A-59.

III-I. Using the EIA Residential Sector

Published emissions data from the EIA residential sector were used in EIA's totality for households (U.S. Energy Information Administration 2010 (b)). EIA's emission estimates for the residential sector cover energy consumption for heat and power in residential structures and are based on the EIA Residential Energy Consumption Survey (RECS) (U.S. Energy Information Administration 2010 (l)). The emissions data are published annually. In addition to EIA residential sector emissions, we used the emissions associated with fuel use for LDVs and recreational boats. This was explained in Section III-G on *Decomposing the EIA Transportation Sector* and the *Summary Tables: Direct Estimates* in Section III-A. The estimates for Households by category are found in Tables A-3 (1998), A-4 (2002) and A-5 (2006).

III-J. Non-Energy Related Industrial Process Emissions

Non-energy related CO_2 industrial process emissions estimates by industry were also developed from estimates published by EPA in their 2007 Greenhouse Gas Inventory Report and in an interagency report and published by EPA called "The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade-Exposed Industries" (U.S. Environmental Protection Agency 2009 (b) and 2007 (c)). See Table A-60. While the sum of non-energy related industrial process emissions are small compared to the total, 121 Mmt or about 2 percent) of 5,933 Mmt total in 2006, they are a significant part of emissions for a number of industries. These include Nitrogenous Fertilizers (NAICS 325311) with 73 percent of its total emissions coming from non-energy related process emissions in 2006; Cement (NAICS 327310) at 51 percent and Lime (NAICS 327410) at 58 percent.

Appendix Table A-60. Non-Energy Related Industrial Process Emissions

INDUSTRY TITLE	NAICS	1998	2002	2006
			Mmt of CO_2	
Chemicals	325	61.7	54.0	50.6
Petrochemicals	325110	0.7	0.8	0.7
Industrial Gases	325120	1.0	1.0	1.2
Alkalies and Chlorine	325181	5.2	4.1	4.2
Carbon Black	325182	3.8	3.0	3.0
Other Basic Inorganic Chemicals	325188	6.5	5.1	5.1
Other Basic Organic Chemicals	325199	5.3	5.0	5.9
Nitrogenous Fertilizers	325311	39.2	34.9	30.5
Nonmetallic Mineral Products	327	60.4	56.6	61.7
Cement	327310	41.8	42.9	46.6
Lime	327410	18.6	13.7	15.1
Primary Metals	331	12.4	10.2	9.0
Electrometallurgical Ferroalloy Products	331112	1.7	1.3	1.5
Alumina and Aluminum	3313	9.3	7.7	6.7
Nonferrous Metals, except Aluminum	3314	1.5	1.2	0.8

Sources: EPA Inventory of U.S. Greenhouse Gases and Sinks, 1990-2005; and Interagency report called "The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade Exposed Industries."

While the 2002 and 2006 process emissions were based on the sources shown in Table A-60, the estimates for 1998 were interpolated based on the change in real output between 1998 and 2002 and benchmarked to 2002 non-energy related process emissions by industry.

III-K. Expanding Industry Coverage: Step 2 to Step 3 Industries.

In the previous section called “Industry Classification,” we explained the three step process of determining direct emissions estimates. In Step 1, we looked at 66 Manufacturing sectors that were covered by MECS data. In Step 2, we expanded the coverage to 116 sectors (114 industries, the Government sector and Households) to cover the whole economy. The methodology and tables discussed so far in Section II of this report relates to what we call Step 2 industries. For these industries, we found specific historical energy use and/or emissions data that allows the estimation of carbon emissions by industry. It includes emissions estimates for all the NAICS two digit sectors (11, 21, 22, etc.) and most three digit sectors across Manufacturing, Transportation and Services. In addition, there was some distribution of more detailed NAICS industries, at the six-digit level, in Manufacturing.

But the Step 2 industries are about as granular as any energy use or emissions data goes. There is no similar information for more detailed industries, and, therefore, the direct CO_2 estimates for 114 “Step 2” industries detail are uneven.

For example, while Step 2 industry data contains the emissions for the entire Food Products sector (101.7 Mmt in 2006), it includes data for only two 6-digit subsectors: Wet Corn Milling (16.7 Mmt) and Sugar Manufacturing (5.7 Mmt). For the Food industry, it would be useful to allocate the remaining Food Products emissions (101.7 – 16.7 – 5.7 = 79.3 Mmt) across all the other Food Products subsectors including Dog and Cat Food, Other Animal Food, Flour and Rice Milling, Soybean Processing and the remaining Food Products sub-sectors. The goal of the expansion is to include the more detailed sectors where direct energy consumption by type of fuel is unknown. In order to allocate these emissions, however, we need another source of data on energy use.

The U.S. Bureau of Economic Analysis publishes a detailed I-O table which contains energy use, in dollar terms, across 490 industries. This information can be leveraged to provide estimates for carbon emissions at a more detailed level, i.e. Step 2 industries to Step 3. In this case we chose the Inforum Iliad model industry classification scheme which contains 349 sectors.[6] The method for the allocation follows.

The historical I-O tables developed for and used in the Iliad model provide the necessary information for the allocation across sectors. These I-O tables have industry details at the five and six digit NAICS levels that are expressed in real terms (i.e., the flows in the tables have been inflation-adjusted) and they are available for each of the benchmark emission years—1998, 2002, and 2006.[7] Specifically, we derived CO_2 emissions for the sectors without direct emissions estimates (the residual of the total less the pieces for which we do have direct emission estimates) based on a weighted average emissions function derived from the intermediate fuel demand flows for these unknown sectors from the I-O table for coal, natural gas, petroleum products, and electricity.

The first factor computed is a measure of the direct CO_2 emissions implied by multiplying the I-O table flow from each fuel sector to each productive sector by a coefficient for physical emission per unit of 2000 dollar (00$) output for the respective fuel types.[8] That is:

$eio_j = \Sigma_i \, amf_{ij} \times eit_i$ where

eio_j = CO_2 emissions in Mmt implied from the I-O table for sector j, j = 1,…349;

---

[6] The Iliad model was well suited for this study because its data base contains annual real dollar gross outputs, imports and exports by industry in addition to annual I-O matrices for 1998, 2002 and 2006. The unique data set not only allows us to allocate the direct emissions of "Step 2" across to the "Step 3" industries. It also is used to determine total direct and indirect emissions by industry, i.e, its total carbon footprint. The existence of real trade data also allows an estimation of what portion of the indirect emissions come from imported inputs, such as from imported inputs of steel and chemicals.

[7] The 350 ILIAD subsectors are a selected aggregation of the BEA 1997 benchmark input-output table.

[8] Note that for a variety of reasons, the emissions computed in this fashion will not actually correspond to the actual emissions observed by using the MECS data, but they are reasonable proxies for determining relative intensity. For the current work, they provide a good approximation of the CO_2 intensity of each sector *relative to the other subsectors* for which totals from the direct emissions in Tables A-3, A-4 and A-5 will be spread.

amf_{ij} = input of fuel i (coal, natural gas, petroleum products and electricity) into the production of commodity j in 2000$, as estimated in the Iliad real historical I-O accounts; and
eit_j = CO_2 emissions intensity in Mmt per unit of gross *consumption* in 2000$ for each type of fuel j.

The per unit of gross output emissions for each of the direct fossil fuels – coal, natural gas, and petroleum fuel (eit_i) is determined using data on emissions per Btu and absolute 2000 price data in dollars per Btu reported by EIA. For example, EIA reports that the average CO_2 of petroleum-based fuels is 74 Mmt per quadrillion Btus. They also report that the average price of petroleum products was $9.97 per billion Btu in 2000. Therefore, the implied emissions from using petroleum products is 7.4 Mmt per billion dollars of petroleum products used (74 Mmt/$9.97 billion).

Computing a similar coefficient for electricity is complicated because we do not have a good average figure for carbon emissions per Btu or a suitable average price figure. Instead, for each year we use the total CO_2 emissions from the Electric Utility industry (NAICS 2211) divided by the real gross output of this industry. We compute this for each year because the carbon intensity can vary year to year based on the electricity fuel mix.

We now turn to estimating the total direct emissions per productive sector, or emp_{ij} where j = 1, 349. Where available, emp_j is equal to the emissions identified in A-3, A-4 and A-5 (Step 2 industries). For instance, in the Food Products example mentioned above, emissions for Iliad sector 41 (Wet Corn Milling) and 45 (Sugar Manufacturing) are 16.7 Mmt and 5.7 Mmt, respectively.

Where these numbers are not available, we can begin to allocate aggregated "unused" CO_2 emissions among subsectors using the general procedure:

$emp_j = (emtot \times eio_j / \Sigma_j eio_j)$ where

emp_j is the direct CO_2 emissions from production from each industry not currently allocated emissions (Step 3 industries less Step 2 industries) and
eio_j is as computed above and emtot is the total unused emissions.

In the Food sector, industries to be allocated emissions are Iliad sector 49 through 54, excluding 41 and 45 where we already know the emissions. The total unused emissions are the 79.3 Mmt that we computed above. (Food Product emissions not accounted for in sectors 41 and 45, or 101.7 – 16.7 – 5.7)

IV. CALCULATING EMISSIONS: FROM INDIRECT INPUTS and the IMPORT SHARE of INDIRECT INPUTS.

The emissions and emissions intensity measurements discussed so far are the *direct* CO_2 emission requirements per unit of output. Though they include electricity and other energy produced outside the direct production process, they can still be thought of as energy directly used for producing the products of each industry. However, these figures do not account for the potentially substantial energy embodied within the non-energy intermediate inputs to the industries.

For example, Tables R-1998, R-2002 and R-2006 show that direct emissions intensities within the Construction sectors are relatively low. These emissions are due to direct energy use on construction sites and in incidental transport. They do not include the emissions from energy consumed in the production of the concrete, wood, metal and other products integral to construction activity. It would be useful to have an accounting for such indirect CO_2 emissions. Among other advantages, a measure of the total (i.e., direct and indirect) CO_2 emissions per unit of output for each sector will enable a convenient computation of the sectoral price impacts of any given carbon price.

To obtain indirect emissions requirements, we first use input-output algebra to compute the total CO_2 emissions requirements. In input-output terminology the intermediate flow matrix (AF) shows, for any consuming industry represented by a column of the matrix, the inputs needed to produce the particular product pertaining to that column. For example, if the column industry is Construction, the column would show the value of petroleum fuels, wood products, concrete products, metal products, and equipment replacement parts consumed in erecting structures. Furthermore, we can divide these flows among domestically produced and imported goods and services, the domestic flow matrix (AD) and imported flow matrix (AM). Note that AF = AD + AM.

Dividing each of the intermediate flows in AF down the column, expressed in dollar terms, by the total dollar output of the consuming (column) industry yields the coefficient for the direct cost per unit of output. This is the "A" coefficient matrix of input-output algebra.

Above we have computed the direct carbon emissions intensity for the supply of each input. Dividing each emissions level with the real gross output in 2000 dollars provides the carbon intensity coefficient, $c_{i,}$, for each sector. Furthermore, we assume that the carbon intensities of imported goods and services are the same as domestically produced ones. Therefore, we can compute and estimate of the indirect emission requirements for each of the j column consuming industries by multiplying the sum of the domestic and the imported intermediate input flows by the respective direct carbon intensity coefficient and adding across inputs:

$$emi_j = \Sigma_i c_i \text{ x } (AD_{ij} + AM_{ij}) \quad \text{for } i,j = 1,\ldots.349.$$

However, the indirect emissions computed in this way account for only the first round of intermediate demand. For instance, while the indirect figure for Construction includes the energy embodied in concrete products use in Construction, it does not yet include the energy embodied in the cement used to produce the concrete products.

In order to produce this more comprehensive picture, we will need a more sophisticated version of the I-O algebra which allows the computation of indirect emissions across the several levels of the supply chain. To accomplish this task, we will use a version of I-O price accounting. The first step is to divide each of the total intermediate inputs, expressed in dollar terms, in the flow table (AF) by the total dollar output of the consuming (the column in the I-O matrix) industry. This transformation yields the "A" coefficient matrix which shows, for each column industry, the input cost by row sector per unit of output. This is the "A" coefficient matrix of I-O algebra.

In order to estimate the total cost per unit of output (including wages and capital income), we use the I-O price equation, which assumes no imports:

$$p_v = p_v A + v'$$

In this equation, the row vector of sectoral unit prices p is determined as the weighted average of all of the prices of the intermediate inputs, where the weights are the proportion of the inputs in final production (the input-output coefficients found in A), plus the vector v which is unit value added (wages, capital income and indirect taxes) per sector. To solve this equation for the vector "p" we use the price input-output solution:

$$p_v = v\,(I - A)^{-1}$$

where $(I - A)^{-1}$ is the Leontief Input-Output inverse.

For the current problem, we are interested in finding the total CO_2 emissions intensity for each sector. Total carbon intensity means the total direct emissions intensity plus the weighted average of the total emissions intensities for the intermediate inputs. For example, for the Construction sector we want to measure not only the emissions from making ready-mix concrete directly, but also the energy and process emissions coming from the manufacture of the cement used to make the ready-mix concrete.

The total emissions requirement coefficient is found using a mark-up equation very similar to the prices equation:

$$tc = tc\,A + c$$ where

tc is the row vector of total intensity coefficients for each sector;
A is the I-O coefficient matrix; and
c is the row vector of direct intensity coefficients (Mmt of CO_2 per unit of output).

The equation is solved similarly to the price equation:

$$tc = c\,(I-A)^{-1}$$

The intermediate intensity is therefore:

$$ic = tc - c$$

To find the indirect carbon intensity from domestic intermediate goods and services we have:

$$dc = dc\,A_d + c$$

$$dc = c\,(I-A_d)^{-1}$$

The total intermediate imported emissions intensity is thus:

$$mc = ic - dc$$

To convert each emissions intensity to emissions volume, the respective vectors are simply multiplied element-by-element (*):

$$emp = q * c$$

where q is the vector of gross output, c is the vector of the emissions direct coefficient, and emp is the vector of direct emissions attributed to domestic production (already known from the previous sector). Then:

$$emt = tc * q$$

where emt is vector of total emissions, that is the direct plus all indirect emissions, then

$$emd = q * dc$$

where emd is the vector of indirect emissions from domestically produced intermediate goods and services, then

$$emm = q * mc$$

where emm is the vector of indirect emissions from imported intermediate goods and services.

In summary, the total CO_2 emissions requirements per sector is the sum of emissions attributable to direct production in the sector and the total emission requirements needed to produce the intermediate goods and services used in production. In addition, the intermediate requirements can be split among domestic emissions and emissions abroad embodied in imports.

V. RESULTS

Tables A-61 (1998), A-62 (2002) and A-63 (2006) present the detailed results that were used to prepare the charts and tables as presented in the report. The rows in Tables A-61, A-62 and A-63 show an aggregate sector, and its industry title, and its corresponding NAICS code followed by disaggregated sectors within the aggregate with their Iliad sector number and industry title. For example, the first row shows the results for the aggregate sector of Agriculture, Forestry and Fisheries (NAICS) followed by Iliad sectors 1, Oilseed Farming, through 15, Agriculture and Forestry support activities. Note that the Utility sectors are shown in the table, but their results are "0" for direct emissions intensity and direct emissions. We have already discussed in this Appendix, that the emissions and, thereby its emission intensities, are passed on to the end users.

The data columns in these results tables (A-61, A-62 and A-63) per year are:

- Column 1, Direct emissions intensity (Mmt CO_2 per Output in $Billions, 2000$)
- Column 2, Indirect emissions intensity, domestically produced inputs (Mmt CO_2 per Output in $Billions, 2000$)
- Column 3, Indirect emissions intensity, foreign produced inputs (Mmt CO_2 per Output in $Billions, 2000$)
- Column 4, Direct and indirect emissions intensity, (Mmt CO_2 per Output in $Billions, 2000$)
- Column 5, Direct emissions (Mmt CO_2)
- Column 6, Indirect emissions from domestically produced inputs (Mmt CO_2)
- Column 7, Indirect emissions from foreign produced inputs (Mmt CO_2)
- Column 8, Direct and indirect emissions (Mmt CO_2)
- Column 9, Real Output (billions of 2000$)

The results for the direct and indirect emissions coefficients by industry are in A-61, A-62 and A-63. It shows, for example, that in 2006, New Residential Construction (Iliad sector 30) emitted 42.6 Mmt directly. However, through its intermediate use of domestically produced goods and services it was responsible for another 207.1 Mmt in additional domestic emissions. Moreover, assuming that global production of inputs is roughly the same intensity as domestic production, the production of imported inputs emitted an additional 61.0 Mmt of CO_2. Therefore, in 2006, the total global emissions attributable to New residential Construction in the United States were 424.3 Mmt.

VI. NEXT STEPS

So, after all this, what's next? The summary report (available at http://www.esa.doc.gov/CO2), presents a brief summary of our findings. However, as is evident from the detailed results tables presented in this appendix, a lot of in-depth analysis could be performed for groups of other industries, say for Construction, or even individual industries, such as Cement and Primary Ferrous Metal Products (Steel). Each row in the results tables provides a description of how each of these industries or group of industries has performed in terms of its CO_2 intensity over time, its carbon footprint (its direct and indirect emissions), and the import share of its indirect emissions. For instance, the Agriculture, Forestry and Fisheries industries show improved emissions efficiency based on their consumption of energy-related products between 1998 and 2006, but their total carbon footprint remains relatively high. For example, for every Mmt of CO_2 produced from energy-related consumption in the Grain Farming industry, the indirect emissions associated with production of indirect goods (such as Fertilizer) and indirect services (such as Truck Transportation) needed by the Grain Farming industry to produce its output is over five times the original 1 Mmt of CO_2 produced. This is just one example of a story that could, and probably should, be told.

Next, our goal was to present a baseline over a time period. We chose 1998, 2002 and 2006 since we had ample data and previous estimates to make our distributions of energy consumption and emissions to industries, something that had not been done at this level of detail. We are, however, presenting findings that are already four years behind our current year. We can only hope that when new data begin to appear, such as a new EIA 2010 MECS or a new EPA 2010 Greenhouse Gas Inventory Report, that a reasonable update could be made and that it could be completed expeditiously.

Finally, we believe that the results presented here could be useful to determine CO_2 emissions levels of programs and policies that may affect the growth of not only the U.S. economy, but the world economy in general. These might include climate change policies, international trade policies or agreements or even incentives to stimulate job growth. The possibilities are endless. After all, the energy/climate debate is not going to end any time soon. These CO_2 estimates by industries, Government and Households will, at least, provide us with a means to quantify how we might be affecting our future.

References

Schipper, Mark. "Energy-Related Carbon Dioxide Emissions in U.S. Manufacturing." U.S. Energy Information Administration. November 2006. http://www.eia.doe.gov/oiaf/1605/ggrpt/pdf/industry_mecs.pdf

U.S. Bureau of the Census. Current Population Survey. "Table A. Households by Type and Selected Characteristics: 1998". December 11, 1998. http://www.census.gov/population/socdemo/hh-fam/98ppla.txt

U.S. Bureau of the Census. American Community Survey. "Table: General Demographic Characteristics: 2002." Accessed February 18, 2010 (a). http://factfinder.census.gov/servlet/ADPTable?_bm=y&-geo_id=01000US&-ds_name=ACS_2002_EST_G00_&-_lang=en&-_caller=geoselect&-redoLog=true&-format=

U.S. Bureau of the Census. American Community Survey. "Table: Selected Social Characteristics in the United States: 2006." Accessed February 18, 2010 (b). http://factfinder.census.gov/servlet/ADPTable?_bm=y&-geo_id=01000US&-parsed=true&-ds_name=ACS_2006_EST_G00_&-_lang=en&-_caller=geoselect&-format=

U.S. Bureau of the Census. Economic Census, 2007, Table: Sector 42: Wholesale Trade: Industry Series: Preliminary Summary Statistics for the United States: 2007, Accessed April 14, 2010 (c). http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=&-ds_name=EC0742I1&-_lang=en

U.S. Bureau of the Census. Economic Census, 2007, Table: Sector 44: Retail Trade: Industry Series: Preliminary Summary Statistics for the United States: 2007, Accessed April 14, 2010 (d) http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=&-ds_name=EC0742I1&-_lang=en

U.S. Bureau of Economic Analysis. "Table: Gross Output by Industry (Billions of Dollars)."Accessed February 18, 2010 (a). http://www.bea.gov/industry/gpotables/gpo_action.cfm?anon=481302&table_id=24759&format_type=0

U.S. Bureau of Economic Analysis. "Table: Chain-Type Price Indexes for Gross Output by Industry [2000=100]." Accessed February 18, 2010 (b). http://www.bea.gov/industry/gpotables/gpo_action.cfm?anon=481281&table_id=24762&format_type=0

U.S. Bureau of Economic Analysis. "Table: Current-Cost Net Capital Stock of Private Nonresidential Fixed Assets." Accessed April 14, 2010 (c). http://www.bea.gov/national/FA2004/Details/xls/detailnonres_stk1.xls

U.S. Bureau of Economic Analysis. “Table: Quantity Indexes for Net Capital Stock of Private Nonresidential Fixed Assets.” Accessed April 14, 2010 (d). http://www.bea.gov/national/FA2004/Details/xls/detailnonres_stk2.xls

U.S. Bureau of Economic Analysis. “Note: Detailed Data for Fixed Assets and Consumer Durable Goods” Accessed April 14, 2010 (e). http://www.bea.gov/national/FA2004/Details/Index.html

U.S. Energy Information Administration. “Energy and Environment Explained.” Accessed February 7, 2010(a). http://tonto.eia.doe.gov/energyexplained/

U.S. Energy Information Administration. “Table: Historical Data Series: Total Energy -Related Carbon Dioxide by End-Use Sector, and the Electric Power Sector, by Fuel Type, 1949-2007.” Accessed February 17, 2010(b). http://www.eia.doe.gov/oiaf/1605/ggrpt/excel/historical_co2.xls

U.S. Energy Information Administration. “National Energy Modeling System (NEMS).” Accessed February 18, 2010(c). http://www.eia.doe.gov/oiaf/aeo/overview/

U.S. Energy Information Administration. “Table: Carbon Dioxide Emission Factors (1980-2006).” Accessed February 17, 2010(d). http://www.eia.doe.gov/oiaf/1605/ggrpt/excel/CO2_coeff.xls

U.S. Energy Information Administration. “Manufacturing Energy Consumption Survey (MECS).” Accessed February 18, 2010(e). http://www.eia.doe.gov/emeu/mecs/

U.S. Energy Information Administration. “Commercial Building Energy Consumption Survey (CBECS).” Accessed February 18, 2010(f). http://www.eia.doe.gov/emeu/cbecs/

U.S. Energy Information Administration. “Table 1.3: Primary Energy Consumption by Source: 1949-2008.” Accessed February 24, 2010(g). http://www.eia.doe.gov/emeu/aer/txt/stb0103.xls

U.S. Energy Information Administration. “Table 4. Residential Sector Key Indicators and Consumption.” Annual Energy Outlook 2010 Early Release Overview. Accessed March 5, 2010(h). http://www.eia.doe.gov/oiaf/aeo/excel/aeotab_4.xls

U.S. Energy Information Administration. “Table 7. Transportation Sector Key Indicators and Delivered Energy Consumption.” Annual Energy Outlook 2010 Early Release Overview. Accessed March 5, 2010(i). http://www.eia.doe.gov/oiaf/aeo/excel/aeotab_4.xls

U.S. Energy Information Administration. “Glossary: District Heat,” Accessed April 14, 2010(j) http://www.eia.doe.gov/glossary/glossary_d.htm

U.S. Energy Information Administration. “Glossary: Site Electricity,” Accessed April 14, 2010(k) http://www.eia.doe.gov/glossary/glossary_s.htm

U.S. Energy Information Administration. “Residential Energy Consumption Survey, home uses and costs” Accessed April 14, 2010(l) http://www.eia.doe.gov/emeu/recs/contents.html

U.S. Environmental Protection Agency (EPA). “Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States.” Working Draft: May 2008 (a). http://www.epa.gov/ispd/pdf/greenhouse-report.pdf

U.S. Environmental Protection Agency. “The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade-Exposed Industries.” December 2009(b) http://www.epa.gov/climatechange/economics/pdfs/InteragencyReport_Competitiveness&EmissionLeakage.pdf

U.S. Environmental Protection Agency. “Report: Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2005,” 2007(c) http://www.epa.gov/climatechange/emissions/downloads07/07CR.pdf

University of Maryland. Interindustry Forecasting Project at the University of Maryland (Inforum). “Interindustry Large-Scale Integrated And Dynamic Model of the U.S. (Iliad).” Accessed February 18, 2010. http://www.inforum.umd.edu/services/models/iliad.html