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Energy Allocation And Energy Intensity Estimates For The U.S. Organic Chemicals Industry

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Manufacturing energy intensity is a measure of energy consumption per unit of manufacturing output. In this paper, we examine energy intensities in the U.S. Organic Chemicals industry. Process end uses that were included in the model are: process heating, process cooling & refrigeration, machine drive, electro-chemical processes, and other process uses. The main federal database that we used for constructing energy end-use models is the U.S. Energy Information Administration Manufacturing Energy Consumption Survey (MECS). The secondary federal database used is the U.S. Energy Information Administration 860B: Annual Electric Generator Report. The estimates and models are created for the most recent data which is given for 2002. The data for 2006 is still under progress by the U.S. Energy Information Administration.

1. Introduction

The U.S. Chemical Industry is considered as the "keystone" of the U.S. economy because it manufactures the largest amount and vast variation of products that are $440 billion annually with respect to shipment (EIA, 2009). As it may expected, manufacturing processes for about 70,000 different products of the U.S. Chemical Industry requires a lot of energy consumption, which makes this industry the 2nd largest energy user in the nation. The U.S. Chemical Industry has 56 subsectors based on the industry classifications and descriptions defined by the North American Industrial Classification System (NAICS) (NAICS, 2009). NAICS uses a 6-digit numbering system, which defines the Chemical Industry as NAICS-325. However, the U.S. Department of Energy's (DOE) Manufacturing Energy Consumption Survey (MECS) provides energy data only for the following 11 subsectors of the U.S. Chemical Industry: NAICS-325110 Petrochemicals, NAICS-325120 Industrial Gas Manufacturing, NAICS-325181 Alkalies and Chlorine, NAICS-325188 Other Basic Inorganic Chemicals, NAICS-325192 Cyclic Crudes and Intermediates, NAICS-325199 Other Basic Organic Chemicals, NAICS-325211 Plastic Materials and Resins, NAICS-325212 Synthetic Rubber, NAICS-325222 Noncellulosic Organic Fibers, NAICS-325311 Nitrogenous Fertilizers, and NAICS-325312 Phosphatic Fertilizers (MECS, 2009). In this paper, we are presenting energy end-use models and energy intensity estimates for the Organic Chemicals, e.g. NAICS-325110, NAICS-325192, and NAICS-325199.

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2. Industrial Energy Flow Models

The Manufacturing energy flow analysis can be characterized by two types of models: an energy process-step model and an energy end-use model. An energy process-step model shows energy inputs and outputs at each step of an industrial process, which is obtained from an engineering analysis for a typical plant in the sector. Alternatively, an energy end-use model provides basis to calibrate the energy process-step model using national data. It allocates combustible fuel and renewable energy inputs among generic end-uses including intermediate conversions through onsite power and steam generation. The main federal database to construct energy end-use models in this paper is the Energy Information Administration's (EIA) Manufacturing Energy Consumption Survey (MECS) (MECS, 2009). The secondary federal database is the Energy Information Administration's EIA-860B: Annual Electric Generator Report (EIA860B, 2009). The estimates and models are created for the most recent data which is given for 2002. The data for 2006 is still under progress by the U.S. Energy Information Administration. Detailed information about the quality of these databases and other available databases are discussed in elsewhere along with highlights of their similarities and differences (Ozalp, 2005).

3. Energy End-use Model

"The concept of energy end-use analysis emerged in the 1970s in response to some of the failures of supply-side energy planning." (Feder, 2004). An energy end-use model provides the basis to scale energy process-step model based on national data. It allocates combustible fuel and renewable energy inputs among generic end-uses including intermediate conversions through onsite power and steam generation. End uses are defined as process end-uses and non-process uses. The process uses, based on standardized MECS definitions, are (MECS-Glossary, 2009):

- Process heating: "The direct process end use in which energy is used to raise the temperature of substances involved in the manufacturing process. Examples are many and include the use of heat to melt scrap for electric-arc furnaces in steel-making, to separate components of crude oil in petroleum refining, to dry paint in automobile manufacturing, and to cook packaged foods. Not included are heat used for heating of buildings or for cafeteria and personal cooking"
- Process cooling and refrigeration: "The direct process end use in which energy is used to lower the temperature of substances involved in the manufacturing process. Examples include freezing processed meats for later sale in the food industry and lowering the temperature of chemical feedstocks below ambient temperature for use in reactions in the chemical industries. Not included are uses such as air-conditioning for personal comfort and cafeteria refrigeration."
- Machine drive: "The direct process end use in which thermal or electric energy is converted into mechanical energy. Motors are found in almost every process in manufacturing. Therefore, when motors are found in equipment that is wholly contained in another end use (such as process cooling and refrigeration), the energy is classified there rather than in machine drive."
- Electrochemical processes: "The direct process end use in which electricity is used to cause a chemical transformation. Major uses of electrochemical process occur in the aluminum industry in which alumina is reduced to molten aluminum metal and oxygen, and in the alkalies and chlorine industry, in which brine is separated into caustic soda, chlorine, and hydrogen."
- Other process uses.

4. Onsite Steam and Power Generation

The onsite power and steam generation model used in the energy end-use models given in this paper have six different modes based on the most common technologies used in the manufacturing industry. Four modes involve both electricity generation and heat production and two modes represents steam generation with no associated electricity generation. Each mode is described by energy balance equations according to the first law of thermodynamics and efficiency equations including, as needed, boiler efficiency, turbine efficiency, internal combustion engine efficiency, and waste heat recovery efficiency. The six modes of power and steam production are:

- Internal combustion engine (ICE) with heat recovery
- Gas turbine with heat recovery
- Steam turbine with heat recovery
- Combined cycle
- Steam generation in fuel fired boiler
- Steam generation in electric boiler

More details on construction of onsite steam and power generation model and how to incorporate it into an energy end-use model can be found elsewhere (Ozalp and Hyman, 2005; Ozalp and Hyman, 2006a).

5. End-use Data Table

Energy end-use data table for Organic Chemicals Industry is created by collecting from the aforementioned federal data sources. Since there are missing data points in the datasource, before constructing the energy end-use model, missing data needs to be fixed. Detailed explanations of the procedures for filling in the missing values are given elsewhere (Giraldo and Hyman, 1995; Andersen and Hyman, 2001; Giraldo and Hyman, 1996), while the methodology to use the data in this table and the onsite steam models to construct energy end-use model can be found in (Ozalp and Hyman, 2006b).

6. Energy End-use model for the U.S. Organic Chemicals Industry

Fig. 1 presents an energy end-use model for the U.S. Organic Chemicals Industry in 2002. It is seen that the majority of the fuel is used for the end-uses in this manufacturing industry. In this figure, energy sources are located in the left side in the form of electricity, steam and fuels. The middle section of the figure contains onsite steam and power generation. The end-uses are located on the right side of the figure as process uses and non-process usage. The fuel input values on the left lower corner of the model are obtained from the MECS data. These fuel values combined with EIA-860B data are used in calculating the electricity conversion, and waste heat recovery of the internal combustion engines, gas turbines, steam turbines and combined cycles used in this industry. These conversion efficiencies are used to calculate the total amount of steam and waste heat that goes to end-uses. Therefore, the onsite electricity and steam generation part of the energy end-use model is a key to explain energy consumed by end-uses.

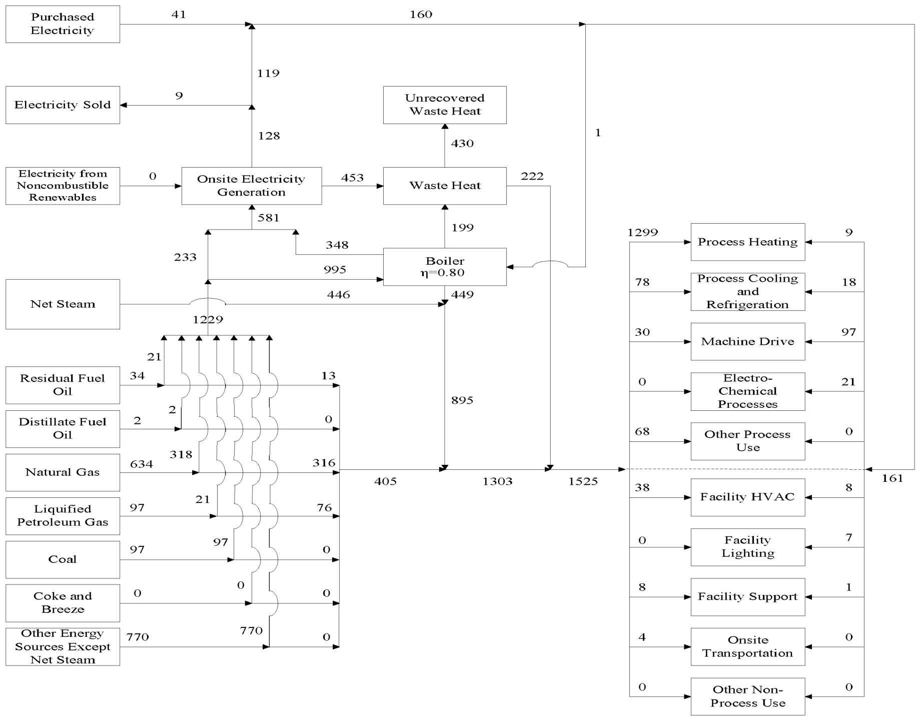

Figure 1 Energy end-use model of the Organic Chemicals industries in 2002, TBtu

7. Production Totals in the U.S. Organic Chemicals Industry

Production totals for the U.S. Organic Chemicals Industry is collected from the Current Industrial Reports of the U.S. Census Bureau (CIR), Chemical and Engineering News (C&E News) and Chemical Market Reporter (CMR). As aforementioned, the Organic Chemicals industry group consists of Petrochemicals, Cyclic Crudes and Intermediates, and Other Basic Organics. In this section, amount of the products manufactured by these sectors are given.

7.1 NAICS 325110 Petrochemicals Manufacturing

Production amounts of petrochemicals in 2002 are given in Table 1.

Table 1 Petrochemical Manufacturing sector production totals in 2002, lb

Product	**Amount**	**Source**	**Product**	**Amount**	**Source**
Ethylene	5.21×10^{10}	[15]	Ethyl benzene	1.19×10^{10}	[15]
Propylene	3.18×10^{10}	[15]	Styrene	1.08×10^{10}	[15]
Ethylene dichloride	2.06×10^{10}	[15]	Cumene	7.72×10^{9}	[15]
Benzene	1.58×10^{10}	[15]	Butadiene	4.61×10^{9}	[16]
Grand Total	***1.55×10^{11}***				

7.2 NAICS 325192 Cyclic Crudes and Intermediates

Amount of chemicals manufactured in the Cyclic Crudes and Intermediates sector in 2002 are given in Table 2.

Table 2 Cyclic Crudes and Intermediates sector production totals in 2002, lb

Product	Amount	Source
Nitrobenzene	$2.66x10^9$	[17]
Aniline	$2.03x10^9$	[15]
2-Ethylhexanol	$8.49x10^8$	[15]
Total	***$5.54x10^9$***	

7.3 NAICS 325199 Other Basic Organics

Production totals of Other Basic Organics in 2002 are given in Table 3.

Table 3 Other Basic Organics and Intermediates sector production totals in 2002, lb

Product	Amount	Source	Product	Amount	Source
Ethylene oxide	$7.60x10^9$	[15]	Methyl ethyl ketone	$6.90x10^8$	[18]
1,3-Butadiene	$4.12x10^9$	[15]	Trichloroethylene	$2.97x10^8$	[19]
Vinyl acetate	$2.97x10^9$	[15]	Ethyl acetate	$2.65x10^8$	[20]
Acrylonitrile	$2.73x10^9$	[15]	***Total***	***$1.87x10^{10}$***	

8. Energy Intensities

Energy intensities of Organic Chemicals manufacturing for 2002 were calculated by taking the ratio of process energy end-uses to product totals and given in Table 4.

Table 4 Energy intensity of the U.S. Organic Chemicals Industry in 2002, Btu/lb

End-use	Energy type	Energy intensity
Process Heating	Steam and waste heat	5328.05
	Electricity	50.21
	Fuel	1919.21
	Subtotal	**7297.48**
Process Cooling and Refrigerating	Steam and waste heat	312.43
	Electricity	100.42
	Fuel	122.74
	Subtotal	**535.59**
Machine Drive	Steam and waste heat	122.74
	Electricity	541.17
	Fuel	44.63
	Subtotal	**708.55**
Electro-chemical processing	Steam and waste heat	0.00
	Electricity	117.16
	Fuel	0.00
	Subtotal	**117.16**
Other process uses	Steam and waste heat	278.96
	Electricity	0.00
	Fuel	100.42
	Subtotal	**379.38**

9. Conclusions

Energy end-use model and energy intensity of the U.S. Organic Chemicals Industry was presented. Energy intensity calculations made based on the energy allocations obtained from the end-use model and the production totals found in literature. Since the energy intensity estimates heavily relies on the end-use model, the accuracy of the model is very important. The strengths of this energy end-use model can be listed as follows:

→This kind of representative energy end-use model for an industry can identify opportunities to improve energy efficiencies especially once similar models are developed for various years.

→They can serve as a basis for other studies such as an energy process-step model, energy cost analysis and exergy analysis for manufacturing industries and other sectors.

→The approach to building energy end-use models is applicable to other industries, which provides a consistent picture of the entire industry in the nation once they are constructed for each industry.

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