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# Towards consistent and reliable Dutch and international energy statistics for the chemical industry

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ABSTRACT

Consistent and reliable energy statistics are of vital importance for proper monitoring of energy-efficiency policies. In recent studies, irregularities have been reported in the Dutch energy statistics for the chemical industry. We studied in depth the company data that form the basis of the energy statistics in the Netherlands between 1995 and 2004 to find causes for these irregularities. We discovered that chemical products have occasionally been included, resulting in statistics with an inconsistent system boundary. Lack of guidance in the survey for the complex energy conversions in the chemical industry in the survey also resulted in large fluctuations for certain energy commodities. The findings of our analysis have been the basis for a new survey that has been used since 2007. We demonstrate that the annual questionnaire used for the international energy statistics can result in comparable problems as observed in the Netherlands. We suggest to include chemical residual gas as energy commodity in the questionnaire and to include the energy conversions in the chemical industry in the international energy statistics. In addition, we think the questionnaire should be explicit about the treatment of basic chemical products produced at refineries and in the petrochemical industry to avoid system boundary problems.



## 1. Introduction

Consistent and reliable energy statistics are of vital importance for the proper monitoring of policies aiming to improve energy efficiency and/or to reduce $CO_2$ emissions. Energy statistics are, for example, one of the key inputs into the yearly National Inventory Reports submitted by countries under the Kyoto protocol (UNFCCC, 2007) and are also essential for monitoring energy-intensity developments of countries and sectors over time (e.g. OECD/IEA, 2004). The compilation of consistent and reliable energy statistics requires a good statistical system with good reporting mechanisms, clear definitions and sound procedures for data checking.

This paper zooms in on the compilation of reliable energy statistics for the chemical industry. In 2003, the final energy use of the chemical industry worldwide amounted to 32 EJ (excluding energy conversion losses, but including the use of fossil fuels as feedstock). This is approximately 1/3rd of the final energy use of the total industrial sector and more than any other single sector of the industry. Total worldwide $CO_2$ emissions in the chemical industry amounted to approximately 1 Gt $CO_2$ (excluding upstream emissions from the production of electricity), 18% of the total industrial $CO_2$ emissions (OECD/IEA, 2006).

A number of studies report a lack of clarity and inconsistencies related to energy statistics for the chemical industry in both international and national energy statistics, especially in relation to the reporting of the use of fossil fuels as feedstock. Worrell et al. (1994) concluded already in 1994 that the quality of international statistics for the petrochemical industry was insufficient to draw robust conclusions about energy-efficiency developments. Patel et al. (1999) found considerable differences in the statistical definition of fossil fuel consumption for feedstock purposes between Italian, German and Dutch energy statistics. More in-depth country studies on feedstock energy use and related $CO_2$ emissions for Italy, Japan, Korea, the Netherlands and the USA summarized by Patel et al. (2005) confirmed that feedstock energy use data in the energy statistics are incomparable across countries, resulting in significant uncertainties in $CO_2$ emission accounting. For the Dutch energy statistics, irregularities are also reported in publications on the monitoring of energy-efficiency developments in the Netherlands. In a study analyzing energy-efficiency trends in the Dutch manufacturing industry between 1980 and 1995, Farla and Blok (2000) reported that feedstock use was not ‘properly (or uniformly) defined’ in the statistics. Neelis et al. (2004, 2005a) draw a similar conclusion when trying to reproduce the feedstock energy use data in the Dutch energy

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statistics using independent physical production trends for the chemical industry.

The studies mentioned challenged us to study in depth the causes for the observed irregularities in the Dutch energy statistics for the chemical industry. We did this by analyzing the energy statistics surveys as returned to Statistics Netherlands by the most important chemical companies in the Netherlands between 1995 and 2004. These surveys form the basis for the energy statistics for the Dutch chemical industry. Based on the findings of this analysis, we aimed to improve the survey used in the compilation of the statistics to avoid irregularities in the future. We visited the chemical companies returning the survey to better understand the procedures followed at the companies and to ensure commitment from the side of the companies in responding correctly to the improved questionnaire. With our study, we also aimed to derive lessons based on the analysis for the Netherlands for international improvement and harmonization of energy statistics for this important sector of the industry.

In this paper, we present an overview of our findings. We first make clear in general terms why the compilation of energy statistics for the chemical industry is such a difficult task (Section 2). To introduce the reader into the way the energy statistics for the chemical industry are made in the Netherlands, we then summarize in Section 3 the survey used for the compilation of the Dutch energy statistics in the chemical industry. In Section 4, we summarize the most important findings of our in-depth analysis of the surveys returned by the most important chemical firms in the Netherlands between 1995 and 2004. Based on our findings, we prepared a new improved energy statistics survey that has been in use since January 2007. The changes made in this improved survey are discussed in Section 5, as well as some remaining challenges in relation to the changes made. In Section 6, we draw lessons towards consistent and reliable energy statistics for the chemical industry also in the international energy statistics. We end with conclusions in Section 7.

## 2. Energy statistics for the chemical industry—why is it so difficult

We can clarify the difficulties related to the compilation of good energy statistics in the chemical industry using the example of three representative process types in the chemical industry.

### 2.1. Process type 1—feedstock to chemical products and fuels

In the steam cracking process, hydrocarbon feedstock (e.g. ethane, naphtha or gas oil) is cracked to lower olefins (ethylene,

**Table 1**
Simplified mass, energy and carbon balance of a steam cracker using naphtha or gas oil as feedstock

| | Calorific value (GJ/t)[a] | Carbon content ($t\,CO_2/t$)[b] | Mass (t)[c] | Energy (GJ) | Carbon ($t\,CO_2$) |
|---|---|---|---|---|---|
| **Input:** | | | | | |
| Naphtha as feedstock | 44.5 | 3.08 | 1000 | 44,500 | 3084 |
| **Output:** | | | | | |
| Ethylene | 47.2 | 3.14 | 324 | 15,283 | 1018 |
| Propylene | 45.8 | 3.14 | 168 | 7688 | 528 |
| Butadiene | 44.5 | 3.25 | 50 | 2227 | 163 |
| *Sub-total basic chemical products* | | | *542* | *25,197* | 1709 |
| Pyrolysis gasoline | 43.0 | 3.30 | 156 | 6708 | 514 |
| Hydrogen | 120.0 | 0.00 | 11 | 1319 | 0 |
| Methane | 50.0 | 2.75 | 139 | 6954 | 382 |
| Other products returned to refinery | 43.0 | 3.15 | 152 | 6536 | 479 |
| *Sum of all products* | | | *1000* | *46,715* | 3084 |
| Total residual gas (hydrogen/methane | 55.2 | 2.55 | 150 | 8274 | 382 |
| Total residual gas (standard tonnes)[d] | 45.2 | 2.09 | 183 | 8274 | 382 |
| **Input:** | | | | | |
| Gas oil as feedstock | 43.0 | 3.11 | 1000 | 43,000 | 3106 |
| **Output:** | | | | | |
| Ethylene | 47.2 | 3.14 | 250 | 11,793 | 786 |
| Propylene | 45.8 | 3.14 | 144 | 6589 | 453 |
| Butadiene | 44.5 | 3.25 | 50 | 2227 | 163 |
| *Sub-total basic chemical products* | | | *444* | *20,608* | *1401* |
| Pyrolysis gasoline | 43.0 | 3.30 | 166 | 7138 | 547 |
| Hydrogen | 120.0 | 0.00 | 8 | 960 | 0 |
| Methane | 50.0 | 2.75 | 114 | 5703 | 314 |
| Other products returned to refinery | 43.0 | 3.15 | 268 | 11,524 | 845 |
| *Sum of all products* | | | *1000* | *45,933* | *3106* |
| Total residual gas (hydrogen/methane | 54.6 | 2.57 | 122 | 6663 | 314 |
| Total residual gas (standard tonnes)[d] | 45.2 | 2.13 | 147 | 6663 | 314 |

[a] Values for ethylene, propylene, butadiene, hydrogen and methane based on the pure chemical compounds. Values for naphtha, gas oil, pyrolysis gasoline and other products based on 2006 IPCC guidelines (IPCC, 2006).

[b] Values for ethylene, propylene, butadiene, hydrogen and methane based on the pure chemical compounds. Values for pyrolysis gasoline and other products based on 2006 IPCC guidelines (IPCC, 2006). Naphtha and gas oil calculated to close the overall carbon balance.

[c] Yields based on Neelis et al. (2005b). Other C4, $<430\,^{\circ}C$ and $>430\,^{\circ}C$ included in other products. Aromatics, C5/C6 and C7+non-aromatics included in pyrolysis gasoline.

[d] In the Dutch statistics, residual gas should be reported as standard tonnes with a calorific value of 45.2 GJ/tonne (Section 3). In this row, we calculate these standard tonnes and the resulting 'standardized' emission factors.

propylene and butadiene), pyrolysis gasoline and a number of by-products. The light by-products of the process (hydrogen and methane) are normally used as fuel in the cracker furnaces to sustain the endothermic cracking reactions. Worldwide, the energy use by steam crackers is estimated by Ren et al. (2006) and Neelis et al. (2007) to be close to 3 EJ, approximately 10% of the total energy consumption of the total chemical industry (including feedstock use). To a very large extent (over 80%), the fuels used to supply heat for the steam cracking process are feedstock-derived. The liquid heavy by-products that are produced in the steam cracker are in many cases used as fuel elsewhere, e.g. in steam boilers or furnaces at the same site or elsewhere, for example in the refinery. The mass, energy and carbon balance of a steam cracker using gas oil and naphtha as feedstock are provided in Table 1. In the table, we assume the pyrolysis gasoline being delivered to a nearby basic aromatic plant (see below) and the other fuel by-products being returned to a nearby refinery to be blended into the fuel oil pool. The pyrolysis gasoline produced in steam crackers is, together with reformate from catalytic reforming in refineries, the main source for chemical-grade aromatics, which are separated in aromatic plants. The non-aromatic parts of the input flows to aromatic plants are normally either returned to refineries or used as feedstock in the steam cracking process. In Fig. 1, we present typical simplified mass flows of aromatic plants processing either pyrolysis gasoline or reformate, assuming that the non-aromatic products are returned to refineries.

### 2.2. *Process type 2—chemical products to by-product fuels*

The basic chemical products (lower olefins and aromatics) produced in steam crackers and aromatics plants are further processed and converted. Functional groups are added to the double bonds in the olefins and aromatics and via a variety of unit processes, plastics and other consumer end products are produced. None of these chemical conversions are 100% selective towards the desired product and by-products are formed. The by-products are often used as fuel in e.g. steam boilers or as fuel in furnaces to directly heat processes. One example of a non-selective process with by-product fuel production is the production of acrylonitrile from propylene and ammonia. In other processes, fuel by-products are produced as a result of the desired chemical reaction. An example is the production of hydrogen in dehydrogenation reactions.

### 2.3. *Process type 3—chemical products to additives*

In a few specific processes, chemical products are blended into fuel products and are therefore finally used as an energy commodity. An important representative of this process type are additives for gasoline, such as ethyl-tertiary-butyl-ether, an anti-knock agent that is produced from ethanol and butylene.

### 2.4. *Conclusions from the three process types*

In relation to the compilation of energy statistics for the chemical industry, we draw the following conclusions:

A. The energy commodities that are used as feedstock in the petrochemical industry are converted to basic chemical products and to by-products that are used as fuel either in the same process, in other processes in the chemical industry or in other sectors, e.g. refineries. The energy commodities that are used as feedstock are thus indirectly also used as fuel. The figures given in the steam cracker example show that this feedstock-derived fuel use represents a significant share of the total fuel consumption in the chemical industry.
B. Next to the fuels derived from feedstock, the conversion of basic chemical products and their derivatives to other chemical products results in low-value by-products, which are also used as fuels in the chemical industry.
C. In a few specific processes, chemical products are converted into products (e.g. additives for gasoline) that are finally used as energy commodities.

To summarize, we conclude that in the chemical industry, various types of conversions take place between energy commodities, and

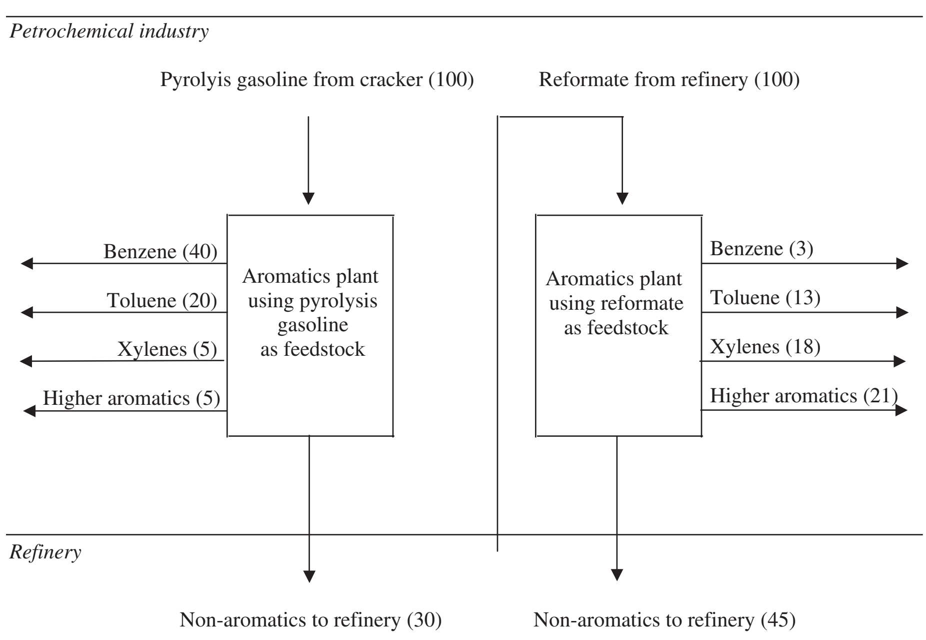


**Fig. 1.** Typical feedstock composition (%) for aromatics recovery (based on Emmrich et al., 1999).

**Table 2**
Survey used in Dutch energy statistics (Statistics Netherlands, 2006, translation by authors)

| Code | Product | Initial stock | Receipts | Production via | | | Total | Input into | | | Final use | | Deliveries | Losses[a] | Final stock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | CHP[b] | Blending | Other[c] | | CHP[b] | Blending | Other[c] | Feedstock | Heat, light, power | | | |
| | | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
| … | … | | | | | | | | | | | | | | |
| 5 | Chemical residual gas[d] | | | | | | | | | | | | | | |
| 8 | Naphthas | | | | | | | | | | | | | | |
| 9 | Aromatics | | | | | | | | | | | | | | |
| … | … | | | | | | | | | | | | | | |
| 36 | Other products not Chapter 27 | | | | | | | | | | | | | | |
| … | … | | | | | | | | | | | | | | |
| 40 | Steam | | | | | | | | | | | | | | |
| 41 | Electricity (1000 kWh) | | | | | | | | | | | | | | |

[a] Including flares and measurement differences.
[b] Combined Heat and Power (CHP) production.
[c] Other conversions, including steam and hot water not produced via CHP production.
[d] Report as 1000 kg calculated with a lower calorific value of 45.1962 GJ/tonne.

also between energy commodities and chemical products. In the course of these conversions, the boundary between energy commodities and chemical products is crossed in both directions. The complexity of these conversions makes the compilation of good and consistent energy statistics for the chemical industry a difficult task.

## 3. Dutch energy statistics for the chemical industry—structure of the survey

In the Netherlands, monthly balances for oil products are prepared by Statistics Netherlands based on a general energy survey with a detailed focus on oil products. The survey is sent to the refineries and oil traders in the Netherlands and to the main chemical companies producing basic chemical products from hydrocarbon feedstock (Statistics Netherlands, 2006). A simplified outline of the survey that had been in use until January 2007 is presented in Table 2.[1]

The oil products survey is, together with various other energy use surveys, also used in the compilation of the annual Dutch energy statistics (Statistics Netherlands, 2007).[2] The energy balance for each company and for each of the products included in the oil statistics survey consists of the following items (column number in brackets):

$$\begin{aligned} &\text{Total plant boundary consumption of energy commodity} \\ &\text{by the company } (F) \\ &= \text{Product receipts } (B) - \text{Product Deliveries } (L) \\ &\quad - \text{Stock changes } (A - N) \\ &= \text{Production } (C,\ D \text{ and } E) - \text{Input conversions } (G, H \text{ and } I) \\ &\quad - \text{Final use } (J \text{ and } K) - \text{Losses } (M) \end{aligned}$$

The product list used in the survey consists of 41 numbered product groups and contains for each product group references to the 8-digit product codes[3] of the Combined Nomenclature (CN) classification used within the European Union for international trade (European Commission, 2005). We give a part of the product list from the survey in Table 3.

**Table 3**
Fragment of product list used in Dutch oil statistics survey until 2007 (Statistics Netherlands, 2006, translation by authors)

| Code | Product | Statistical code from combined nomenclature (European Commission, 2005)[a] |
|---|---|---|
| … | … | … |
| 5 | Chemical residual gas | – |
| … | … | … |
| 7 | Liquefied gases | … |
| 7a | Propane | 2711 1211– 2711 1219– 2711 1291 EX– 2711 1293 EX– 2711 1294 |
| … | … | … |
| 7e | Other liquefied gases | 2711 1400 |
| … | … | … |
| 9 | Aromatics | 2707 1010– 2707 1090– 2707 2010– 2707 2090– 2707 3010– 2707 3090– 2707 5010– 2707 5090– 2707 9911– 2707 9919– 2707 9930– 2902 2000– 2902 3000– 2902 4100– 2902 4200– 2902 4300– 2902 4400– 2902 5000– 2902 6000– 2902 7000 2902 9010– 2902 9030– 2902 9090 |
| … | … | |
| 29 | Other products from Chapter 27 of CN | 2707 4000– 2707 6000– 2707 9100– 2707 9950– 2707 9970– 2707 9999– 2708 1000– 2708 2000 |
| … | … | … |
| 36 | Other products not from Chapter 27 of CN | To be specified |
| … | … | … |

[a] Means "part of".

The product list includes references to product codes from five different chapters of this CN:

- Chapter 25: Salt; sulphur; earths and stone; plastering materials, lime and cement (product group 37: sulphur)
- Chapter 27: Mineral fuels, mineral oils and products of their distillation; bituminous substances; mineral waxes (majority of product groups).

[1] Over the years, the survey has been changed is a number of ways (e.g. a switch from a paper survey with separate files for each individual product to an electronic survey with all products on one sheet). The basic layout and structure of the survey have however remained unchanged since 1980.

[2] To limit the scope and size of this paper, we do not discuss the other surveys that are used in the compilation of the Dutch energy balances and the methodology to prepare the energy statistics based on the response to the surveys. This will, however, receive some attention when we summarize the remaining challenges in relation to the changes made in the oil statistics survey (Section 5).

[3] To avoid confusion between references to products from the oil statistics (numbered from 1 to 41, Table 3) and chapters and codes from the CN, we refer to the products from the oil statistics as product groups and to the CN chapters and codes as chapter and product codes.

- Chapter 29: Organic chemical products (product group 9: aromatics and 31-33: GTBA, MTBE and methanol).
- Chapter 34: Soap, organic surface-active agents, washing preparations, lubricating preparations, artificial waxes, prepared waxes, polishing or scouring preparations, candles and similar articles, modelling pastes, 'dental waxes' and dental preparations with a basis of plaster (product group 22: lubricants).
- Chapter 38: Miscellaneous chemical products (product group 22: lubricants, product 30 and 34: anti-knock agents with or without lead).

**Box 1**–Definition of items in the Dutch energy statistics survey (Statistics Netherlands, 2006, translation by authors)

*Column D/H: Blending*
If a product is blended or administratively transferred from one or several other products, the quantities should be reported here. Totalized over all products, there should therefore be always equal amounts in columns D and H.

*Column E: Production via other conversions, inclusive steam and hot water not produced via CHP*
Report the total quantity of product that is produced crude oil and/or other oil products by processing. Quantities of intermediate products that have been produced in the reporting period and are further converted into other products in the same reporting period, do not have to be reported. If, however, stock of these products is build up or if these products are sold, this has to be reported.

*Column I: Input into other conversions, inclusive steam and hot water not produced via CHP*
Report the quantity of product that is used in the process to produce other products included in the survey.

*Column J: final use as feedstock*
Report in this column the quantity of product that is used as a feedstock in the production of (basic) chemical products that do not occur in this survey, because they are not regarded as energy carriers.

*Column K, final use as a source for heat, light or power*
The use as a source for heat, light or power after which no energy carriers are left. For example, report here the amount of products used as fuel in furnaces. Also report here the quantities of product that, via conversion into live steam, are used as source of heat or power (e.g. turbine-driven pumps) for own use. The produced steam in that case does not have to be reported under production of other energy carriers (column E).

The default unit of reporting for all products is 1000 kg with the exception of electricity (MWh) and natural gas (1000 $m^3$). Refinery gas (product 4) and chemical residual gas (product 5) should be reported in standardized tonnes with a calorific value of 45.2 GJ/tonne. In Box 1, we give the definition of the most important items in the survey.

## 4. Dutch energy statistics for the chemical industry—main findings of the in-depth analysis of company surveys

For reasons of confidentiality, we cannot disclose in detail quantitative findings for each of the individual companies, described in an internal confidential report published by Statistics Netherlands (Neelis, 2006a). In qualitative terms, we discovered the following three problems in the energy statistics for the chemical industry.

1. unclear guidance for energy conversion processes in the chemical industry,
2. occasional inclusion of chemical products in the energy statistics,
3. insufficient acknowledgement of the complexity of the industry, in processing the data and in the statistical process in general.

### 4.1. Problem 1—unclear guidance for complex energy conversion processes

#### 4.1.1. Lack of guidance for processes with energy conversions in the chemical industry

In the oil statistics survey, it is possible to report conversions between energy commodities. Inputs into energy conversion processes should be reported in Column I and production from energy conversions should be reported in Column E (Table 2). However, clear guidance is lacking for the conversion process discussed in Section 2 where either the input or (part of) the output is a chemical product rather than an energy commodity. In certain processes such as steam cracking, an energy commodity is converted into both energy commodities and chemical products. The input into these processes is therefore partly used as an input into energy conversions and is partly used as feedstock for the production of (basic) chemical products. The input into energy conversions should be reported in Column I and the use as feedstock should be reported in Column J. In the explanatory notes to the survey, there is no clear guidance on how to make the division over the two columns. The only guidance given is that companies responding to the survey are asked by Statistics Netherlands to check whether the conversion loss, i.e., the difference in mass units between inputs into conversions (column I) and production from conversions (column E), is within the norm. The norm as such is not specified, but in practice, a norm of close to 0% has been in use internally at Statistics Netherlands.[4] This minimal guidance ignores the complexity of the energy conversions in the steam cracker. For example, in many cases multiple feedstocks are used in the cracker. The same product

[4] Companies were requested to correct their survey in case the conversion efficiency was far from 100% or Statistics Netherlands manually corrected the survey by shifting entries from column I to column J (feedstock use).

**Table 4**
Two methods of responding to the oil statistics survey in case of multiple feedstock (arbitrary mass units)

| | Receipts B | Production via other conversions E | Input into other conversions I | Final use as feedstock J | Final use as source for heat, light, power K | Deliveries L | Total consumption F |
|---|---|---|---|---|---|---|---|
| *Method A:* | | | | | | | |
| Naphtha | 1000 | 0 | 1000 | 0 | 0 | 0 | 1000 |
| Gas oil | 1000 | 0 | 72 | 928 | 0 | 0 | 1000 |
| Aromatics | 0 | 322 | 0 | 0 | 0 | 322 | −322 |
| Residual gas | 0 | 330 | 0 | 0 | 330 | 0 | 0 |
| Other products | 0 | 420 | 0 | 0 | 0 | 420 | −420 |
| Total | 2000 | 1072 | 1072 | 928 | 330 | 742 | 1258 |
| *Method B:* | | | | | | | |
| Naphtha | 1000 | 0 | 72 | 928 | 0 | 0 | 1000 |
| Gas oil | 1000 | 0 | 1000 | 0 | 0 | 0 | 1000 |
| Aromatics | 0 | 322 | 0 | 0 | 0 | 322 | −322 |
| Residual gas | 0 | 330 | 0 | 0 | 330 | 0 | 0 |
| Other products | 0 | 420 | 0 | 0 | 0 | 420 | −420 |
| Total | 2000 | 1072 | 1072 | 928 | 330 | 742 | 1258 |

(e.g. chemical residual gas) is thus produced from multiple inputs (e.g. naphtha and gas oil) in the same monthly reporting period. In these cases, the survey can be completed in various ways, which all comply with the guidance that the conversion losses are within the norm. Take as an example a company operating a steam cracker that uses in a month, equal amounts of gas oil and naphtha as feedstock for the cracker (Table 1). If we assume that the cracker uses its own residual gas (hydrogen and methane) as fuel in the process and that the process does not require additional fuel, there are various ways of reporting to the survey. The two extreme cases of returning the survey for such a cracker are shown in Table 4: the conversion balance is closed first using naphtha and then using gas oil for the remaining part (situation a) or first using gas oil and using naphtha for the remaining part (situation b). Both methods (a) and (b) shown in Table 4 comply with the guidance given in the questionnaire, but result in different entries for gas oil and naphtha in the various columns and therefore, via multiplication with the calorific value, also in different energy balances. Other, more realistic options are that companies divide the inputs into conversion over gas oil and naphtha in accordance with the ratio in the input or in accordance with the respective amounts of residual gas produced from gas oil and naphtha, respectively. Analysis of the surveys returned by the firms confirmed that the companies did not use a consistent division over the conversion and feedstock columns over the years. Another problem in dividing the input into a single process over two columns is that 0% conversion losses (in mass units) do not necessarily result in 0% conversion losses in energy units and that the use of standard tonnes for refinery gas and chemical residual gas results in an energy balance that lacks a physical basis to the process involved.

*4.1.2. Consequences for the resulting energy statistics*

The lack of guidance with respect to energy conversion processes in the chemical industry and the practice of using mass units in the oil statistics survey with some products included in standard tonnes have had the following consequences for the resulting energy statistics in the years of study:

1. Large fluctuations in the columns 'input into energy conversions' and 'final use as feedstock' for various energy commodities over the years (due to the lack of guidance in case of multiple inputs).
2. Mass, energy and $CO_2$ balances that lack a clear physical relation to the actual process (due to the use of standard tonnes for gaseous fuels).
3. Difficulties in using the energy statistics for $CO_2$ emission accounting (due to the use of mass units in the survey).

The second and third consequences are best explained using the example of the naphtha cracker specified in Table 1. The energy balance is constructed from the entries in mass units provided by the individual companies by multiplication with the net calorific values of the fuels involved. The resulting carbon dioxide ($CO_2$) balance can be constructed by multiplication with the emission factors. We show the results in Table 5, assuming that the correct calorific values and emission factors are used (Table 1). Table 1 and the balances shown in Table 5 make clear that:

- The steam cracking process is an endothermic process. The energy content (calorific value) of the products leaving the cracker exceeds the energy content of the cracker feedstock (Table 1). To sustain the endothermic cracker reaction, the residual gas (and other fuels) is burned in the cracker furnaces. Part of this final energy use is therefore converted to chemical energy embodied in the chemical products of the process. The final use as feedstock for conversion into chemical products (22.6 TJ, Table 5) is for this reason smaller than the energy content of the chemical products ethylene, propylene and butadiene (25.2 TJ, Table 1).
- The $CO_2$ emissions from the cracker (382 tonne $CO_2$, Table 5) can be calculated by multiplying the amount of residual gas used in the furnace with the correct emission factor. The remainder of the carbon present in the feedstock is in our simplified example embodied in the energy commodities sold and in the chemical products (1709 tonne $CO_2$, Table 1). In the carbon balance, this is the sum of the difference between input into and production from conversions (1515–1376 = 139 tonne $CO_2$) and the reported use as feedstock of naphtha (1570 $CO_2$).
- The use of actual tonnes (150 tonnes) rather than standard tonnes (183 tonnes) would result in different mass, energy and carbon balances, making the feedstock use dependent on the definition of the standard tonne.
- The energy and carbon balances that can be calculated from the mass balance are sensitive to the correct calorific values

**Table 5**
Mass, energy and $CO_2$ balance for the naphtha cracker of Table 1

| | Receipts B | Production via other conversions E | Input into other conversions I | Final use as feedstock J | Final use as source for heat, light, power K | Deliveries L | Total consumption F |
|---|---|---|---|---|---|---|---|
| *Mass (t)* | | | | | | | |
| Naphtha | 1000 | 0 | 491 | 509 | 0 | 0 | 1000 |
| Aromatics | 0 | 156 | 0 | 0 | 0 | 156 | −156 |
| Residual gas | 0 | 183 | 0 | 0 | 183 | 0 | 0 |
| Other products | 0 | 152 | 0 | 0 | 0 | 152 | −152 |
| Total | 1000 | 491 | 491 | 509 | 183 | 308 | 692 |
| *Energy (GJ)* | | | | | | | |
| Naphtha | 44,500 | 0 | 21,851 | 22,649 | 0 | 0 | 44,500 |
| Aromatics | 0 | 6708 | 0 | 0 | 0 | 6708 | −6708 |
| Residual gas | 0 | 8274 | 0 | 0 | 8274 | 0 | 0 |
| Other products | 0 | 6536 | 0 | 0 | 0 | 6536 | −6536 |
| Total | 44,500 | 21,518 | 21,851 | 22,649 | 8274 | 13,244 | 31,256 |
| *$CO_2$ (t)* | | | | | | | |
| Naphtha | 3084 | 0 | 1515 | 1570 | 0 | 0 | 3084 |
| Aromatics | 0 | 514 | 0 | 0 | 0 | 514 | −514 |
| Residual gas | 0 | 382 | 0 | 0 | 382 | 0 | 0 |
| Other products | 0 | 479 | 0 | 0 | 0 | 479 | −479 |
| Total | 3084 | 1376 | 1515 | 1570 | 382 | 993 | 2091 |

and emission factors applied. Especially for product groups with strongly varying composition (e.g. chemical residual gas), this could easily result in errors.

### 4.2. Problem 2—inclusion of chemical products in the energy statistics

Feedstock use is defined as the use of energy commodities for the production of (basic) chemical products that are not included in the survey, because they are not regarded as energy commodities (Box 1, Column J). This definition implies that only those products should be included in the response to the survey that are regarded energy commodities in line with the product list (Table 3). Products that can be regarded (basic) as chemical products should not be included. In the analysis of the surveys from the period 1995–2004, we discovered that in several cases, (basic) chemical products have been included by the chemical companies in response to the survey. Partly, this has been due to methodological weaknesses in the product definition in the survey and partly this has been due to erroneous reporting by the companies.

#### 4.2.1. Methodological weakness—basic aromatics included in the survey

In the product group aromatics (product 9), reference is made to product codes from both Chapter 27 and 29 of the CN. Chapter 27 includes mixtures of hydrocarbon compounds, whereas the product codes in Chapter 29 refer to chemical-grade well-defined organic compounds. The 12 product codes from Chapter 29 that are included in the definition of product group 9 (Table 3) thus refer to separate chemically defined organic compounds. The products include the basic aromatics such as benzene (code 2902 2000) and toluene (code 2902 3000) that are separated from aromatic mixtures, but also more downstream products such as ethylbenzene (code 2902 6000) and cumene (2902 7000) that are produced out of basic aromatics and other basic chemical products such as ethylene (for ethylbenzene) and propylene (for cumene). It is hard to regard those separate chemically defined organic aromatic compounds as energy commodities, because their use is in principle limited to the use as chemical product. The inclusion of these (basic) chemical products in a survey used for oil and energy statistics is illogical[5] and also contradicts the wording of the feedstock definition according to which the (basic) chemical products are not part of the survey. It should be noted that formally there is no contradiction, because (basic) chemical products are, in the feedstock definition, defined as those products that do not occur in the survey, classifying all products that are included (including the separate chemically defined aromatics from Chapter 29) automatically as energy commodities. It was not possible to check whether in the years of study the five companies indeed included the (basic) aromatics that are mentioned in the survey consistently in their response to the survey, since it was not possible to decisively judge whether the reported aromatics refer to mixtures or to chemically defined aromatic compounds.

There is one explanation for the illogical inclusion of at least some of the (basic) aromatics in the oil statistics survey product list. The most important companies processing oil are the oil refineries. Product lists used in energy statistics therefore normally include all the products that are produced by petroleum refineries, including those that are not used as energy commodity, but for non-energy purposes. Examples of such products are bitumen (product group 25) and lubricants (product group 22). To ensure that an overall conversion balance of a refinery can be made, it is necessary to monitor the total output of the refinery, including also these non-energy products. The fact that basic aromatics are also produced within refineries from reformate produced in catalytic reforming therefore offers an explanation for the inclusion of these aromatics in the product list used in energy statistics (Table 3). Benzene, toluene and xylene are, for this reason, also mentioned as 'other products' in the international oil statistics survey (Section 6). Although this is most probably historically the reason to include some of the aromatic products in

[5] In European legislation on the taxation of energy products (European commission, 2003), the definition of the term 'energy products' includes the products with CN codes 2901 and 2902 (basic chemical products, including the aromatics, but also e.g. ethylene and propylene). In many cases, financial and tax departments within companies return the survey and in view of this legislation, it is for them not directly counter-intuitive or illogical to consider basic chemical products as energy product. We further discuss as part of problem 3 (Section 3).

the survey, it offers no direct explanation for the inclusion of also more downstream aromatic products such as ethylbenzene, styrene and cumene in the survey. In addition, it also results in a potentially selective coverage of these products in the energy statistics, because some of these products (e.g. styrene) are also processed by companies receiving the more general 'industrial energy use' survey in which these aromatics are not included.

#### *4.2.2. Methodological weakness—'other products not from Chapter 27 of the CN'*

To deal with products that cannot easily be classified into the defined product groups in the survey, two product groups are included for 'other products'. Product group 29 is included for other products that can be classified within one of the product codes of Chapter 27 of the CN, but which product codes are not mentioned at one of the other product groups in the survey. Product group 36 is included for other products that cannot be classified into one of the product codes from Chapter 27 of the CN. The latter product group 36 was never intended to be used for the various (basic) chemical products produced by the chemical firms responding to the survey such as ethylene and propylene. However, ethylene (product code 2901 2100 in the CN) and propylene (code 2901 2200) do fall under the definition of product group 36 (Other products not belonging to Chapter 27 of the CN). In fact, all product and materials processed by the chemical companies do fall under this definition.[6] In the analysis of the surveys returned by the companies, it was found out that some (basic) chemical products from Chapter 29 of the CN such as ethylene, propylene, cyclohexane and phthalic anhydride have been included in the response to the survey as product group 36. During the company visits it became clear that one of the reasons to do so was that some other (basic) chemical products classified in Chapter 29 of the CN (the basic aromatics, see above) were also included in the product list.

#### *4.2.3. Erroneous reporting—(basic) chemical products also in other product groups*

In the detailed analysis of the survey returned, it was discovered that occasionally the chemical companies reported some (basic) chemical products also erroneously in other product groups. Quantitatively, the most important example in the years of study 1995–2004 has been the inclusion of ethylene, propylene and butadiene in product group 7e (other liquefied gases). This mistake was caused by the reference to product code 2711 1400 in the CN for product group 7e (Table 3). This product is in the CN defined as *Ethylene*, *Propylene*, *Butylene and Butadiene*, *liquefied* (European Commission, 2005). From the notes in the introduction to Chapter 27 of the CN, it becomes clear that this product group does not include quantities of separate chemically defined ethylene, propylene, butylene or butudiene, which are included in Chapter 29 of the CN,[7] but this has not been understood properly by the company responding. As a result of a lack of detailed knowledge about the company at the side of Statistics Netherlands (see Problem 3), this erroneous reporting remained undiscovered for many years.

[6] The addition 'to be specified' in the definition of product group 36 (Table 3) could be used as a control check by Statistics Netherlands to ensure that only energy commodities are included in this product group. In the analysis it became clear, however, that the specification was not always given and that (basic) chemical products , if reported, have not been removed in the resulting statistics (see also problem 3).

[7] This is also clear from Eurostat publications on the linkage between the CN and the PRODCOM classification, where the following remark is included for CN product group 2711 1400: excl. ethylene with a purity $\geqslant$95% and propylene, butylene and butadiene with a purity $\geqslant$90% (Eurostat, 2006).

#### *4.2.4. Quantitative consequences for the resulting energy statistics*

The occasional inclusion of chemical products within the energy statistics results in energy statistics with an inconsistent system boundary. This results in an inconsistent and erroneous total energy use and feedstock use. We clarify this using again the example of a naphtha cracker (Table 1). We assume the company operating this cracker to erroneously regard the propylene produced in the steam cracker as an energy commodity rather than as a chemical product and reporting this propylene as 'other liquefied gases'. The resulting mass, energy and $CO_2$ of this company are presented in Table 6.

Including propylene as energy commodity results in the following changes compared to the balance in which propylene is regarded as a chemical product (Table 5):

- The total energy consumption of the company drops with 7.7 TJ, the energy content of propylene, which is erroneously regarded as an energy carrier.
- The output from energy conversion (Column E) increases with exactly the same amount.
- Input into energy conversions increases and final use as feedstock decreases with 7.5 TJ. The small difference with the 7.7 TJ mentioned above results from the different calorific value of propylene compared to naphtha. In mass units, the changes in all three columns are identical.

The occasional inclusion of chemical products thus results in differences for the total energy consumption, the energy conversion columns and the feedstock column of the energy statistics. The final use for energy purposes (column K) is not influenced. In the example, we assume the propylene erroneously included to be exported by the company in question. This raises the question as to what would happen if the propylene had been delivered domestically to another company. At Statistics Netherlands, the domestic consumption of the relevant products (e.g. liquefied gases, aromatics, etc.) is shifted to the column for feedstock use and therefore does not result in errors in the total energy consumption and the total feedstock use. Only in case of exports of erroneously incorporated chemical products, the national energy use is influenced. The overall quantitative effect for the Netherlands can therefore be estimated looking at the net export of the occasionally included chemical products by the companies involved. For the chemical products included under product groups 36 (other products, not from Chapter 27 of the CN) and for the company erroneously reporting ethylene, propylene and butadiene under product group 7 (liquefied gases), we have been able to determine the net export in the period 1995–2004 and the resulting error in feedstock and total energy consumption use in the petrochemical industry (Table 7). For details, we refer to Neelis (2006a, b).

The large underestimation of feedstock use in the Dutch energy statistics by 14–28% between 1995 and 2004 as a result of the inclusion of chemical products in the energy statistics confirms the findings by Neelis et al. (2004, 2005a, b). In these studies, it was concluded that the observed feedstock use in the Netherlands was unexpectedly low when compared to estimates for feedstock use based on the production of relevant chemical products in the Netherlands. The total energy consumption of the chemical industry has been underestimated by 5–13% between 1995 and 2004. Expressed as percentage of the total energy consumption in the Netherlands, the underestimation has been approximately 1–2%, given the fact that the total energy consumption in the Netherlands was approximately 3000 PJ in the years of study.

**Table 6**
Mass, energy and $CO_2$ balance for the naphtha cracker of Table 1 in case propylene is regarded an energy commodity

| | Imports<br>B | Production via other conversions<br>E | Input into other conversions<br>I | Final use as feedstock<br>J | Final use as source for heat, light, power<br>K | Exports<br>L | Total consumption<br>F |
|---|---|---|---|---|---|---|---|
| *Mass (t)* | | | | | | | |
| Naphtha | 1000 | 0 | 659 | 341 | 0 | 0 | 1000 |
| Liquefied gases | 0 | 168 | 0 | 0 | 0 | 168 | −168 |
| Aromatics | 0 | 156 | 0 | 0 | 0 | 156 | −156 |
| Residual gas | 0 | 183 | 0 | 0 | 183 | 0 | 0 |
| Other products | 0 | 152 | 0 | 0 | 0 | 152 | −152 |
| Total | 1000 | 659 | 659 | 341 | 183 | 476 | 524 |
| *Energy (GJ)* | | | | | | | |
| Naphtha | 44,500 | 0 | 29,327 | 15,173 | 0 | 0 | 44,500 |
| Liquefied gases | 0 | 7688 | 0 | 0 | 0 | 7688 | −7688 |
| Aromatics | 0 | 6708 | 0 | 0 | 0 | 6708 | −6708 |
| Residual gas | 0 | 8274 | 0 | 0 | 8274 | 0 | 0 |
| Other products | 0 | 6536 | 0 | 0 | 0 | 6536 | −6536 |
| Total | 44,500 | 29,205 | 29,327 | 15,173 | 8274 | 20,932 | 23,568 |
| *$CO_2$ (t)* | | | | | | | |
| Naphtha | 3084 | 0 | 2033 | 1052 | 0 | 0 | 3084 |
| Liquefied gases | 0 | 528 | 0 | 0 | 0 | 528 | −528 |
| Aromatics | 0 | 514 | 0 | 0 | 0 | 514 | −514 |
| Residual gas | 0 | 382 | 0 | 0 | 382 | 0 | 0 |
| Other products | 0 | 479 | 0 | 0 | 0 | 479 | −479 |
| Total | 3084 | 1904 | 2033 | 1052 | 382 | 1521 | 1563 |

**Table 7**
Quantitative effects of occasional inclusion of chemical products in the energy statistics on the final use as feedstock (excl. electricity) and total energy consumption in the chemical industry (excl. fertilizers)

| Year | Total energy consumption reported[a] | Feedstock use reported[a] | Underestimation due to inclusion of chemical products | Corrected total energy consumption | Corrected feedstock use |
|---|---|---|---|---|---|
| 1995 | 523 | 233 | 66 | 589 | 299 |
| 1996 | 496 | 211 | 47 | 543 | 258 |
| 1997 | 515 | 237 | 36 | 543 | 273 |
| 1998 | 499 | 227 | 44 | 543 | 271 |
| 1999 | 545 | 255 | 53 | 598 | 308 |
| 2000 | 572 | 291 | 33 | 605 | 324 |
| 2001 | 595 | 307 | 59 | 654 | 365 |
| 2002 | 614 | 306 | 75 | 689 | 381 |
| 2003 | 659 | 347 | 63 | 722 | 411 |
| 2004 | 683 | 364 | 51 | 734 | 414 |

All values in PJ.
[a] Statistics Netherlands (2007).

Based on our detailed analysis, we also estimated the total export of the pure chemical-grade aromatics included in Chapter 29 of the CN and the resulting change in the energy statistics in case the system boundary of the energy statistics would exclude these chemical-grade aromatics from the energy statistics. If chemical-grade aromatics would be outside the system boundary, we estimate the total energy use and the feedstock use of the chemical industry to further increase by approximately 50 PJ, since the Netherlands is a net exporter of these chemical-grade aromatics. This estimate is based on an own interpretation of the type aromatic flows (mixtures or chemical-grade pure aromatics) at the companies included in the survey and should be regarded only as a rough estimate for the order of magnitude.

### *4.3. Problem 3—complexity of the petrochemical industry not acknowledged in the statistical process*

In our analysis, we also discovered as an underlying problem that the complexity of the petrochemical industry has not been acknowledged by Statistics Netherlands in the statistical process. There was no involvement from chemical industry experts in the compilation of the statistics and there was insufficient contact between Statistics Netherlands and the companies responding to the survey on the purpose of the oil statistics survey and on the response to the survey. As a result, errors, once made, could remain for a long time within the system, before being discovered. This has, for example, been the case for the reporting of ethylene, propylene and butadiene in the product group ‘liquefied gases’ as discussed above. It was also found out that complete and accessible methodological descriptions of the statistical system that are used to process the returned company surveys into published oil and energy statistics were not available at the side of Statistics Netherlands. As a result, personnel changes at the side of the companies filling the survey and at the side of the Statistics resulted in small differences in the methodologies used, which were not documented in detail. As a result, a full quantitative analysis of the various identified problems was not always possible.

Also, at the side of the petrochemical industries, the complexity of the conversions in the chemical industry in relation to good and reliable energy statistics has been insufficiently acknowledged. Without any doubt, the companies have a clear view on the various hydrocarbon flows within their companies. The oil statistics survey is, however, normally filled in and returned by financial/tax departments using business accounting software. These departments often lack specific technical knowledge about the complex hydrocarbon flows within the companies, the nature of energy conversions and the use of energy commodities as feedstock. The information exchange within units of the company that do have this knowledge, e.g. the energy coordinator, is not always optimal, partly because the survey is in general not given much priority compared to reports to the government with a more formal legislative background such as environmental reports, emission reports for the emission trading system (ETS), etc.

## 5. Changes implemented in the oil statistics survey

### 5.1. Implemented changes

To cope with the three problems discussed above, the survey used in the Dutch oil statistics survey has been changed in the following ways:

#### 5.1.1. Clearer guidance for energy conversions

To better cope with conversion processes where hydrocarbon feedstock is converted into chemical products and energy commodities, the following changes were implemented:

A. The columns for 'final use as feedstock' (column J, Table 2) and the column for 'input into energy conversions' (column I) are combined into a single column. As a result, companies no longer artificially have to split inputs into a single process (e.g. naphtha and gas oil into the steam cracker process) into different columns in the oil statistics survey. Yet it would be possible to allocate a fraction of the input to feedstock use internally by Statistics Netherlands. They are in the position to ensure that the allocation is made in a consistent way. To date, no decision has been made about separate reporting of feedstock use in the published statistics.

B. The mass balance principle is no longer used as a check for the conversion losses. Instead, using standard or company-specific (see next point) calorific values, the mass balance is converted into an energy balance and the conversion loss in energy units is used as check for the conversion losses. In the guidance it is explained that for refineries, the loss should be close to 0%. For chemical companies, the 'conversion loss' can be substantially higher, because in the conversion in the chemical industry, a large fraction of the input is converted to chemical products that are no longer regarded as energy carriers and are therefore not included. The term 'loss' should therefore strictly be interpreted as the difference between input and output of energy commodities.

C. Companies are explicitly asked to provide calorific values of the energy carriers in case the calorific values differ from the standard calorific values provided.

The resulting survey that should be returned by the steam cracker of our example is given in Table 8.

The difference between inputs into and outputs from energy conversions equals 23.0 TJ. This equals the calorific value of the chemical products produced (25.2 TJ) minus the endothermicity of the process (2.2 TJ, see Table 1, difference between naphtha input and the sum of all outputs). The difference in carbon content between input into and output from conversions is 1709 t $CO_2$, equal to the carbon content of the chemical products produced. Another solution to better cope with those processes where hydrocarbon feedstock is converted to energy commodities and chemical products would be to ask in the survey for the total mass, energy and carbon balance of inputs and outputs for these processes, including also the chemical products. The statisticians at Statistics Netherlands could use this information as a cross-check for the reported data by matching the three balances (mass, energy and carbon) and could then include only the energy commodities in ;the reported energy statistics. Although theoretically better, this solution would further increase the administrative burden on the companies and would bring chemical products back into the survey, which caused significant problems in the past (Problem 2). The decision was therefore made to solely focus on the energy commodities and to use the energy balance as a check.

**Table 8**
Mass, energy and carbon balance for steam cracker company responding to the new survey

| | Receipts<br>B | Production via other conversions<br>E | Input into other conversions<br>I | –<br>– | Final use as source for heat, light, power<br>K | Deliveries<br>L | Total consumption<br>F |
|---|---|---|---|---|---|---|---|
| *Mass (t)* | | | | | | | |
| Naphtha | 1000 | 0 | 1000 | | 0 | 0 | 1000 |
| Aromatics | 0 | 156 | 0 | | 0 | 156 | −156 |
| Residual gas | 0 | 183 | 0 | | 183 | 0 | 0 |
| Other products | 0 | 152 | 0 | | 0 | 152 | −152 |
| Total | 1000 | 491 | 1000 | | 183 | 308 | 692 |
| *Energy (GJ)* | | | | | | | |
| Naphtha | 44,500 | 0 | 44,500 | | 0 | 0 | 44,500 |
| Aromatics | 0 | 6708 | 0 | | 0 | 6708 | −6708 |
| Residual gas | 0 | 8274 | 0 | | 8274 | 0 | 0 |
| Other products | 0 | 6536 | 0 | | 0 | 6536 | −6536 |
| Total | 44,500 | 21,518 | 44,500 | | 8274 | 13,244 | 31,256 |
| *$CO_2$ (t)* | | | | | | | |
| Naphtha | 3084 | 0 | 3084 | | 0 | 0 | 3084 |
| Aromatics | 0 | 514 | 0 | | 0 | 514 | −514 |
| Residual gas | 0 | 382 | 0 | | 382 | 0 | 0 |
| Other products | 0 | 479 | 0 | | 0 | 479 | −479 |
| Total | 3084 | 1376 | 3084 | | 382 | 993 | 2091 |

*5.1.2. Exclusion of chemical products from the energy statistics*

To avoid reporting of chemical-grade products in the energy statistics (Problem 2), the following changes have been made in the product classification:

D. The pure chemical-grade aromatic products from Chapter 29 of the CN are no longer included in the product list, because they cannot reasonably be regarded as energy commodities.
E. Entries in the product group 'other products not from Chapter 27 of the CN' are since January 2007 only possible for refineries and no longer for the companies in the chemical industry responding to the survey. The inclusion of this product group for refineries allows refineries to report the total refinery output and hence the correct calculation of refinery losses. However, since these products (e.g. propylene, aromatics, bitumen and lubricants) cannot reasonably be regarded as energy commodities anymore, the production of chemical products at refineries (i.e. other products, not from Chapter 27 of the CN) in the final energy balances could be included as a separate item: production of chemical products at refineries.

*5.1.3. More frequent involvement of expertise in statistical process*

The study as such has helped Statistics Netherlands to develop a better view on the complexity of compiling reliable energy statistics for the chemical industry. The outcome of the study and the set-up of the new survey have been discussed with the chemical companies that receive the survey. This helped Statistics Netherlands to better understand the production processes taking place in the chemical industry and helped the companies to better understand the aim of the survey. It is planned to organize yearly meetings between Statistics Netherlands and the respondents to the questionnaire. At these meetings, not only the contact person responsible for responding to the questionnaire but also the energy coordinator of the companies will be invited to these meeting in order to stimulate a more optimal exchange of relevant information within the firms.

*5.2. Remaining challenges/recommendations for further improvement of energy statistics for the chemical industry*

The new oil statistics survey has been in use since January 2007. In relation to the implementation of the changes into the total energy statistics system in the Netherlands and the resulting $CO_2$ emission accounting, which is based to a large extent on these energy statistics, we identify the following important remaining challenges:

1. energy commodities derived from chemical products (Section 2, process types 2 and 3),
2. total coverage of fuels combusted,
3. implementation into the resulting energy statistics—treatment of other sectors with feedstock use.

*5.2.1. Energy commodities derived from chemical products (process types 2 and 3)*

In some cases, the inputs into processes where energy commodities are produced are not energy commodities as in the steam cracker example, but chemical products that are not included in the survey. In Section 2, we distinguished by-product fuels derived from chemical conversions and chemical products that are blended into fuel products. For the Netherlands, carbon losses in the first category were estimated by Neelis et al. (2007) at 1.6 Mt $CO_2$ for the Netherlands in 2000 (i.e. approximately 10% of the reported $CO_2$ emissions of the chemical industry in 2005; Brandes et al., 2007).[8] Partly these losses result in direct $CO_2$ emissions, e.g. in ethylene oxide production where over-oxidation of the ethylene used as raw material results in $CO_2$. In the Dutch $CO_2$ emission inventory methodology, these emissions are estimated independently using relevant activity data. When the carbon losses are in the form of fuel-grade by-products that are used as fuel, the production of these fuels could be regarded as a form of 'primary energy production' from raw materials that are not regarded as energy commodities. This is comparable to common reporting methodologies for waste incineration where either the waste itself or the steam produced from waste is regarded as primary energy consumption. The company visits made it clear that it is difficult for the companies responding to the survey to distinguish in the internal accounting systems between fuels produced from energy commodities and from chemical products. In practice, fuels derived from conversion between chemical products will therefore be reported as production from conversions in response to the survey. The production of these fuels thus lowers the observed 'conversion loss', which is in line with the interpretation of 'conversion loss' given above (the difference in a company between the input and output of energy commodities in conversion processes). The disadvantage is that these fuels produced from conversions between chemicals are not separately visible in the statistics.

In line with international practice (see Section 6), the production of chemical products such as additives, that are blended into e.g. gasoline and that are therefore finally used as energy commodities, will be reported as 'primary production' in the energy statistics by Statistics Netherlands.

*5.2.2. Total coverage of fuels combusted*

The total coverage of fuels combusted is especially important, because the national $CO_2$ emission inventory is to a large extent based on the energy statistics. The guiding principle in the emission accounting in the Netherlands is that, for the chemical industry, the difference in carbon content between inputs to conversions and output from conversions is assumed to be stored in chemical products, thereby not resulting in $CO_2$ emissions. For the steam cracker in our example, this is a valid assumption as becomes clear from Table 8. The difference in carbon content between input to conversions and production from conversions equals exactly the carbon embodied in the chemical products (compare Table 1). This assumes, however, that all fuels are indeed reported in response to the survey in the column 'production from energy conversions', subsequently put under final consumption and accounted for as $CO_2$ emissions. It should be checked on a regular basis whether companies indeed report all fuels produced on-site in response to the survey.

*5.2.3. Implementation in the energy statistics—other sectors with feedstock use*

In the preparation of the annual Dutch energy balances, also a decision should be made about the treatment of flows in other sectors of the industry that are currently included as feedstock and non-energy flows. An important example is the use of coal and coke in the blast furnaces. In analogy with the chemical industry, this input is currently partly reported as 'input into conversions' and partly as 'feedstock use' in the energy balances. The part included in the 'input into conversions' is taken equal to

[8] This estimate excludes conversions where the fuel by-products is a result of the desired chemical reaction (e.g. dehydrogenations).

the amount of blast furnace gas produced (in energy units). Other examples are the use of petroleum coke for the production of anodes used for aluminium production and the use of natural gas for ammonia production. The type of use and the size order of the relevant flows are well known at Statistics Netherlands and it is planned that as much as possible a uniform approach should be used for the various conversion processes.

#### 5.2.4. Next step—detailed carbon and energy balances based on all available sources

As a next step for further improvement of the energy statistics and as check for the resulting $CO_2$ balances, we strongly recommend conducting regular checks on the mass, energy and $CO_2$ balances of the most important chemical firms in the Netherlands. These checks should involve all source data from these firms to the government such as production data, direct emission reports provided as part of the ETS and environmental reports. These checks could help to identify whether the various flows are properly accounted for the energy statistics and whether it can help to guarantee that $CO_2$ emissions for the chemical industry are calculated based on the best-available information.

## 6. Similar problems in international energy statistics

What lessons can be drawn from our analysis of the Dutch situation for a more consistent treatment of the chemical industry also in the international energy statistics? For the compilation of the yearly international energy statistics, five annual questionnaires are used for oil, natural gas, coal, renewables and electricity/heat (Eurostat/IEA/UN, 2006a–e). The questionnaires are often referred to as the joint annual questionnaires since they are used jointly by Eurostat, the International Energy Agency (IEA) and the United Nations (UN). The three institutions, however, separately process and publish statistics. The questionnaires are structured from the perspective of the main energy supplying and energy conversion sectors. The chemical industry is, together with other industrial sectors, regarded as a final energy-consuming sector. In the natural gas and coal questionnaire, the consumption of fuels in these final energy-consuming sectors should be classified either as final energy or as final non-energy use. Non-energy use in these two surveys is defined as in Box 2 with special reference to the use of natural gas and coals as feedstock for the production of chemical products.

**Box 2–**Definition of non-energy use in the Eurostat/IEA/UN natural gas and coal questionnaire (Eurostat/IEA/UN, 2006b, c)

> Report by sector and sub-sector non-energy use of natural gas. This category includes feedstocks in processes such as cracking and reforming for the purpose of producing ethylene, propylene, butylene, aromatics, butadiene and other non-energy hydrocarbon-based raw materials. Do not include amounts of energy consumed as fuel for petrochemical processes such as steam cracking, ammonia production and methanol production.
>
> Non-energy use of coal includes uses as feedstocks to produce fertilizer and as feedstocks for other petrochemical products.

In the oil statistics survey, a separate table (Table 2B) is included dealing with the petrochemical industry. This is shown in Table 9. The definitions of the four items in this table are provided in Box 3. It is recognized that backflows exist from the petrochemical industry to refineries. To obtain a closed balance for the refinery, these backflows should be accounted for by correcting the total gross deliveries to the petrochemical sector with the quantities that are delivered back to the refinery. These backflows are subsequently included as refinery input under the product group 'refinery feedstock'. The correction from gross deliveries to net deliveries in the petrochemical sector is done by introducing the petrochemical industry as one of the transformation sectors in Table 3 of the survey. In this transformation sector, the backflows should be reported. The product allocation is calculated using the same proportion of product split for gross deliveries to the petrochemical sector (see Box 3 for an example). The net deliveries (i.e. the gross deliveries corrected for the backflows) is to be included in Table 3 under final consumption in the chemical industry, split into non-energy use and energy use, in accordance with the entries in Table 2B.

The product list included in the oil statistics survey included is provided in Table 10. Regarding the oil products survey used for the compilation of the international energy statistics, we draw the following conclusions:

1. The fuels derived from feedstock that are used in the petrochemical industry (e.g. from steam cracking and aromatics production) are not included in the product list used in the questionnaire.
2. A number of products are included in the questionnaire that are produced not only within the refinery sector but also within the chemical industry (additives/oxygenates, lubricants and the chemical products listed under 'other products').

**Table 9**
Survey used in international energy statistics (Eurostat/IEA/UN, 2006a)

| | | Crude oil A | Natural gas liquids B | … … | Naphtha F | … … | Other products Y | Total Z |
|---|---|---|---|---|---|---|---|---|
| Total gross inland deliveries (observed) | 1 | | | | | | | |
| Of which: petrochemical flows: | | | | | | | | |
| Gross deliveries to petrochemical sector | 2 | | | | | | | |
| Energy use in petrochemical sector | 3 | | | | | | | |
| Non-energy use in petrochemical sector | 4 | | | | | | | |
| Backflows from petrochemical sector to refineries | 5 | | | | | | | |
| Total net deliveries | 6 | | | | | | | |
| Of which: net deliveries to petrochemical sector | 7 | | | | | | | |

**Box 3**–Definition of items for the petrochemical industry in the Eurostat/IEA/UN oil questionnaire (Eurostat/IEA/UN, 2006a)

*Table 2B: Gross inland deliveries*
Report only those quantities of fuels delivered to the petrochemical sector.

*Table 2B: Energy use in the petrochemical sector*
Report quantities of oil used as fuel for petrochemical processes such as steam cracking.

*Table 2B: Non-energy use in the petrochemical sector*
Report quantities of oil used in the petrochemical sector for the purpose of producing ethylene, propylene, butylene, synthesis gas, aromatics, butadiene and other hydrocarbon-based raw materials in processes such as steam cracking, aromatics plants and steam reforming. Exclude amounts of fuel used for fuel purposes.

*Table 2B: Backflows from petrochemical sector to refineries*
These are finished or semi-finished products, which are returned from final consumers to refineries for processing, blending or sale. They are usually by-products of petrochemical manufacturing.

*Table 3: Petrochemical industry in the transformation sector*
Report quantities of backflows returned from the petrochemical sector, whether returned to refineries for further/processing blending or used directly. The product allocation is calculated using the same proportion of product split for Gross deliveries to the petrochemical sector. Example: 500 units (430 of naphtha and 70 of LPG) are input to the Petrochemical industry. Of the 500, 300 are used as feedstock for the production of petrochemical, 200 units are returned. The total amount of input into the Transformation sector is 200, which is split over Naphtha and LPG (e.g. for LPG backflows: $(70/500) \times 200 = 28$, for Naphtha backflows: $(430/500) \times 200 = 172$).

*Table 3: Final consumption in the chemical industry*
This heading includes petroleum products used for energy purposes and as feedstocks. However, consumption should be net, after deduction of backflows. The breakdown of net consumption by-product should be calculated applying the same proportion of product split for gross deliveries. Example: 500 units (430 of naphtha and 70 of LPG) are input to the Petrochemical industry. Of the 500, 300 are used as feedstock for the production of petrochemicals, 200 are returned. The total amount reported for the Petrochemical industry consumption is 300 (500–200), which is split over naphtha and LPG (e.g. for LPG consumption: $(70/500) \times 300 = 42$, for Naphtha consumption: $(430/500) \times 300 = 258$).

**Table 10**
Product list used in international energy statistics (Eurostat/IEA/UN, 2006a)

| Number | Product |
|---|---|
| 1 | Crude oil |
| 2 | Natural gas liquids (NGL) |
| 3 | Refinery feedstocks |
| 4 | Additives/oxygenates |
| 5 | Other hydrocarbons |
| 6 | Refinery gas (not liquefied) |
| 7 | Ethane |
| 8 | Liquefied petroleum gases (LPG) |
| 9 | Naphtha |
| 10 | Motor gasoline |
| 11 | Aviation gasoline |
| 12 | Gasoline type jet fuel |
| 13 | Kerosene type jet fuel |
| 14 | Other kerosene |
| 15 | Gas/diesel oil |
| 16 | Fuel oil |
| 17 | White spirit and industrial spirit |
| 18 | Lubricants |
| 19 | Bitumen |
| 20 | Paraffin waxes |
| 21 | Petroleum coke |
| 22 | Other products[a] |

[a] All products not specifically mentioned above, for example: tar and sulphur. This category also includes aromatics (e.g. BTX or benzene, toluene and xylene) and olefins (e.g. propylene) produced within refineries.

Except for the additives/oxygenates,[9] clear guidance on the inclusion of the products when produced outside the refinery is missing.[10]

3. It is confusing that in the description of 'energy use in the petrochemical industry' (Box 3), reference is made to the steam cracking process. The main fuel actually being used in this process is not included in the questionnaire (first bullet point) and the production of this fuel cannot be reported in the questionnaire, because no reference is made whatsoever to the

[9] According to the oil survey, receipts of additives/oxygenates by refineries and blending plants from outside the refinery sector (note authors: the chemical sector) should be included as indigenous production (domestic receipts) or imports (receipts from foreign origin).

[10] The survey is ambiguous on this point. The addition 'produced within the refineries' in the definition of 'other products' seems to imply that the production of these products within the chemical sector should not be included. Also, the format of the survey points in this direction since production of finished products can only be included as refinery output in the survey. However, in the guidance on reporting imports and exports, it is stated that also 'petroleum products imported or exported directly by the petrochemical industry should be included'. Whether this refers only to direct imports and exports of hydrocarbon feedstock such as naphtha or also to the other products such as propylene and aromatics is not fully clear. This ambiguity could therefore easily result in an inconsistent system boundary comparable to what has been observed in the Netherlands, especially because refineries are often integrated with the production of basic chemicals.

conversion from feedstock to energy carriers that are used as fuel within the industry.
4. In none of the questionnaires, explicit reference is made to fuels where the input is not another energy carrier, but a chemical product.[11]

Because an important fuel that is used in the petrochemical industry (i.e. feedstock-derived chemical residual gas) is not included in the energy statistics, it is not possible to directly calculate $CO_2$ emissions based on the international energy statistics. To our knowledge, this is one of the largest sources of fossil $CO_2$ emissions that cannot be calculated based on the energy statistics. Calculations of $CO_2$ emissions in the chemical industry for national inventories should therefore be based on the reported feedstock use, e.g. via the use of storage fractions, or should be based on methodologies independent of the energy statistics. Regardless of the exact methodology used, for a consistent and full accounting methodology for $CO_2$ emissions in the chemical industry, it is vital to have a clear view how feedstock use, energy use and energy conversions in the chemical industry are included in the energy statistics used for the national inventory. This is also stressed in the new 2006 IPCC Guidelines for greenhouse gas inventories (IPCC, 2006). As a result of the current ambiguity in the questionnaire as summarized in the four points above, this clear view is currently lacking. As a result, it is also difficult to make reliable cross-country comparisons of the energy use of the chemical industry and to compare energy-efficiency levels for this industry among countries.

To improve this situation, consideration can be made to change the oil statistics survey and the resulting international energy statistics in the following way:

- inclusion of a product category 'chemical residual gas',
- inclusion of a row where conversions in the chemical industry can be reported to acknowledge the fact that the petrochemical industry is a sector where important energy conversions take place,
- more explicit guidance on the reporting of production of chemical products at refineries in relation to production of the same products within the petrochemical industry (e.g. comparable to the suggested approach for the Netherlands discussed in Section 5.1).

Incorporating the first two changes would make it possible to report how an important fraction of the energy in the chemical industry is actually being consumed (i.e. via the conversion of feedstock material to fuels) and which fuels are actually being used (chemical residual gas). The treatment of the petrochemical industry becomes, in such a way, comparable to the treatment of the coal transformation sectors (blast furnaces, coke ovens), where the coal input is transformed into derived gases (blast furnace gas, coke oven gas). Our analysis for the Netherlands as well as the analysis by Farla and Blok (2001) on the quality of the energy statistics for the iron and steel industry show that inclusion of energy conversion and derived gases in the statistics as such does not automatically result in good-quality statistics. Some countries might, for example, not be capable of delivering data on conversions within the chemical industry, because their data structure is based on surveying only refineries and not on surveying also important industrial end users. They will only report the total feedstock delivery to the chemical industry (i.e. a gross definition of feedstock use that includes the final use of part of the feedstock as fuel). The international organizations publishing international energy statistics based on the joint questionnaire could, for the time being, estimate for such countries the production of chemical residual gas from the gross delivery of feedstock, comparable to what is done for blast furnaces and coke ovens. Alternatively, they could adjust the data for countries that do deliver the data on energy conversions to a gross definition of feedstock use to make the reported feedstock data comparable among countries.[12] We would like to stress, however, that he Dutch experience with energy statistics for the petrochemical shows that monitoring of the key energy conversions in the petrochemical industry (i.e. at least steam cracking and aromatics processing) is well possible. Also in other countries (e.g. the USA), the residual fuel production in the petrochemical industry is already being monitored. Inclusion of these conversions also in the published international energy statistics would contribute to a better understanding of energy use in the chemical industry and can be an impetus for countries to start collecting these data as well.

## 7. Conclusions

The chemical industry is a very complex industry for the compilation of energy statistics, because of the multiple conversions between energy commodities and chemical products. Based on our analysis for the Netherlands, we conclude that for a consistent treatment of the energy conversions between energy commodities and chemical products in national or international energy statistics for the chemical industry, it is essential to:

1. define clearly in which way the various conversion processes in the chemical industry are included in the energy statistics,
2. define clearly which products are seen as energy commodities and which products are seen as chemical products, i.e., to define clearly the system boundaries of the energy statistics,
3. acknowledge the complexity of the petrochemical industry by involving expert knowledge in the statistical process.

Our analysis has made it clear that none of these prerequisites has been fully met in the years of our study in the Netherlands, resulting in inconsistencies and large quantitative errors in the statistics. We conclude that the joint questionnaire used to compile international energy statistics is also ambiguous with respect to both the system boundaries and the treatment of energy conversions. The changes in the Dutch questionnaire used to compile the Dutch energy statistics and the suggested changes in the international questionnaire provide important improvements towards better and more consistent energy statistics for the chemical industry.

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[11] One way of including these fuels is via the renewables questionnaire as 'production' of waste of non-renewable origin (solids or liquids) combusted directly for the production of electricity and/or heat.

[12] In the new 2006 IPCC Guidelines (IPCC, 2006) emissions from key processes that use feedstock-derived fuels are separately included with emission factors based on the output. If the statistics used to compile the inventory use a net definition of feedstock use (i.e. excluding parts that are used as fuel), the inventory maker should make sure that he does not double-count emissions (i.e. via the emission factors for the industrial processes and via the energy use of the fuels). In the case of a gross definition, there is no risk of such double counting.

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