NEU-CO_2 – III

Continuation of the "International Network Non-energy use and CO_2 emissions (NEU-CO_2)", Phase III

Pooling and Analysis of Information on Materials with Complicated Pathways (WP 1)

Part: Industrial processes

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August 2006

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Continuation of the “International Network Non-energy use and CO_2 emissions (NEU-CO_2)”, Phase III

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1 General Introduction

The NEU-CO_2 network has been working since 1999 on the issue of CO_2 emissions from the non-energy use of fossil fuels. The project is currently in its **third phase** continuing from **July 2004 to June 2006** . During the first phases of the project, the NEAT model was developed which is a tool for estimating the CO_2 emissions from non-energy use of fossil fuels. The model was applied by several project partners in the network. The goals of the third phase of the network are, amongst others, the development of a simpler version of the NEAT model that is less data intensive, and to pool detailed bottom-up information from the countries of the partners where and if available.

The purpose of Work package 1 (**WP1**) consists in pooling and analysis of information on materials with complicated pathways. Vito has coordinated the work on the data request and analysis on non-energy by-products as fuels (‘recovered fuels’, ‘non-spec’s’) and non-fuel CO_2 emissions from industrial (chemical) processes. This work package was carried out between **October 2004 and June 2005**.

The anticipated results of the WP1 were:

- An overview of recommended activity indicators (for example production data) and emission factors with indications about uncertainties.
- A selection of average values or value ranges of these activity indicators and emission factors for use in the NEAT model and the simplified approach (in WP 2).

The added value that was anticipated:

- Each partner in the network assesses the availability of studies in his or her own country. Some material which is probably only available in the countries’ own language, is made available by using a data request format
- Different methodologies can be identified and the most convincing will be filtered out.
- A comparison of activity indicators, emission factors (EF) and uncertainty ranges is possible. Averages can be used as ‘default’ values in a simplified approach (see WP2) to calculate NEU- CO_2 emissions.
- Possible extension of the included processes/sources of CO_2 in the current NEAT 2 model.

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1.1 Context of WP1 coordinated by Vito

(energy by-products used as fuels and emissions from industrial processes)

This WP1 is aimed at collecting data on CO_2 –emissions that occur during the production of intermediate and end products in the chemical industry. Fossil fuels can be used during the production of organic synthetic materials. These products may or may not contain carbon.

An example of a chemical product **not containing carbon** would be ammonia. Ammonia production is based on synthesis gas commonly produced from natural gas. None of the carbon initially contained in the natural gas is stored in ammonia. Recuperation of the emitted CO_2 for other uses is possible (e.g. production of urea). The emissions from ammonia production can be considered to be process emissions.

In **products that do contain carbon**, some of the carbon contained in the fossil feedstock used as raw material in the production of synthetic organic materials will be stored, some will be emitted. Several emission sources are possible:

(i) recovered fuels (or non spec's)

Recovered fuels are generally referred to all products that are recovered from flows during the production of materials and that are used as fuels.

Example 1: Dehydrogenation: mostly important in the cracking process, where hydrogen is removed from an organic compound to form other chemicals. Well-known is the use of naphtha as feedstock in steam crackers. Large hydrogen – rich streams are produced and they can be used also as recovered fuel.

Example 2: Production of carbon black, for example by a partial oxidation of liquid hydrocarbons. The end flow consists of pure carbon and a mix of other products, which can be used as fuels. During the production of carbon black, also CO2 emissions during production are possible. In that case, the example also belongs under section (ii).

Example 3: by – products in the production of polystyrene, cyclohexanone and other chemicals

The emissions resulting from the combustion of fuel-grade by-products are considered to be emissions from fuel combustion according to the current IPCC guidelines for emission inventories (IPCC 1996).

(ii) oxidation of a part of the carbon during chemical transformations

Examples are processes in which an oxidation take place. Carbon dioxide emissions are omnipresent as by-product in the oxidation of organic compounds since it is inevitable to prevent the partial oxidation of some carbon. In most cases, oxidation reactions are exothermic and they provide possibilities to recover and re-use heat.

Example 1: the partial oxidation (as a side reaction) of ethylene to CO_2 during the production of ethylene oxide from ethylene.

Example 2: during production of terephtalate from p-xylene; isoftalic acid from m-xylene; acrylic acid from propylene; cyclyhexanone from cyclohexane.

Example 3: production of methanol: methanol is formed by a catalytic conversion of synthesis gas. CO_2 is one of the main emissions. CO_2 emissions can also occur during production of other alcohols (e.g. phenol).

Example 4: production of CO (through synthesis gas) from natural gas that is used in the production of phosgene (= base material for production of isocyanate or polycarbonate) or used for carbonylation reaction (combination of an organic compound with CO). Part of the C-carbon is emitted as CO_2

(iii) Incineration of evaporated reaction products

Products can evaporate during production and/or storage of chemicals. These evaporated products (mostly VOC) can be removed by on-plant incineration with energy recovery.

(iv) Flares

In emergency situations or in altering process conditions, start or shut down of chemical processes, part of the reaction products can be diverted to flares..

The allocation of emissions from these sources according to the IPCC 1996 guidelines [i] is not always clear. Parts of the emissions can be allocated under emissions from fuel combustion, processes emissions or waste incineration. However, the revised 2006 IPCC guidelines [ii] strongly recommend accounting for all of these emissions as industrial process emissions.

In the following figure, the sequestration and emissions of carbon during the chain of production, use and waste treatment is presented .

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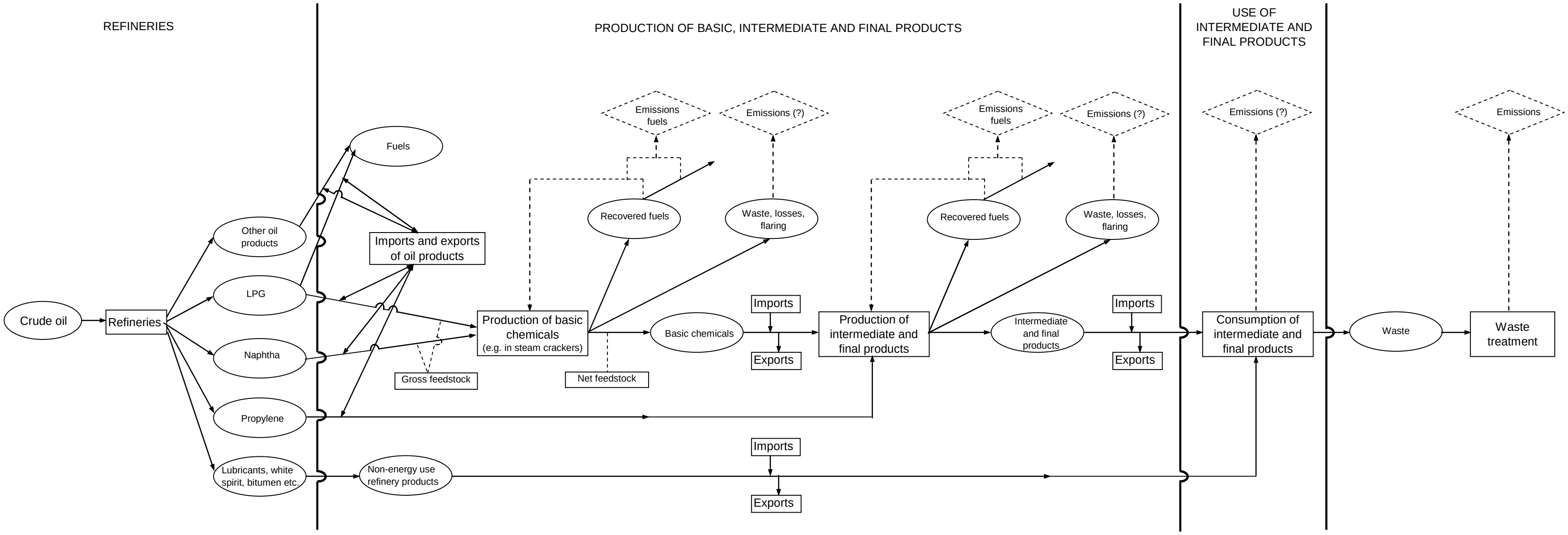

Figure 1: Carbon sequestration and carbon emissions during the chain of production, end use and waste treatment

1.2 Acquiring relevant data

A questionnaire (see Annex 1) was prepared and send out to the network partners . The questionnaire was divided into 4 parts: 'steam cracking', 'recovered fuels', 'processes' and 'incineration and flaring'. The questionnaire was sent to the relevant project partners in **January 2005.**

The following work was carried out:

- Each partner in the network has assessed the availability of studies in his own country and has filled out the requested data in the forms that were presented to them to the extent possible.
- Since there were problems in some countries to gather the requested information, a supplementary request was made in **March 2005** to gather data (for Annex I countries) from the CRF tables and National Inventory Reports reported by the countries of the partners in the network to the UNFCCC under the Kyoto protocol. The following CRF tables were requested:
    - Table 1.A(a)s2 : sectoral background data on energy, sector 1.A.2 'manufacturing industry and construction'.
    - Table 1.A(d): sectoral background data on energy, 'feedstocks and non-energy use of fuels'
    - Table 2(I).A-Gs1: sectoral background data for industrial processes, sector 2B 'chemical industry'.
    - And other tables considered relevant

  NOTE: if the partners did not send the info themselves, the available CRF tables of Annex I countries used in March 2005 were the ones reported to the UNFCC in April 2004 [iii].

The partners in the network to whom the data request formats from Annex I were sent are:

Table 1: List of partners in the network to whom the data request form in Annex 1 was sent

Participant name	**Participant short name**	**Country for which they reported**
Utrecht University, Department of Science, Technology and Society (STS)/Copernicus Institute	STS	NL/D
Italian Agency for New Technologies, Energy and Environment	ENEA	IT
Avonlog	Avonlog	UK
Institute of Industrial Ecology	IIÖ	AU
Risoe	Risoe	DK
Centre Interprofessionel Technique d'Etudes de la Pollution Atmosphérique	CITEPA	FR
Vlaamse Instelling voor Technologisch Onderzoek	VITO	BE
Center for Energy Efficiency	CENEF	RU
Ecofys	Ecofys	PO
The Energy and Resources Institute	TERI	IN
INHA University	INHA University	KO
ICF Consulting	ICF	UK
University of Cape Town	UCT	SA

In the next section of this document, the relevant information and data gathered are listed and compared if and where possible.

2 Steam cracking

2.1 Overview

A data questionnaire (see Annex 1) was made up, asking for data and relevant studies on steam cracking in the countries of the partners.

2.2 Data questionnaire: responses

- No steam cracking is present in **Denmark**.
- Problems to access data due to confidentiality, no data for **France** in the requested format.
- Data are available in **Italy**. (source: monthly questionnaires with individual companies (Ministry of Industry); results are published in a yearly report on energy in Italy "Bollettino Petrolifero" (Source: www.minindustria.it). The data published in the Bollettino Petrolifero refer to the whole petrochemical sector. In order to single out the steam cracker feedstock it was necessary to carry out an analysis of the statistical questionnaires filled in by each petrochemical plant).
- Data are available for **Korea**. Data calculated based on information on Quarterly Reports of 19 naphtha using petrochemicals firms to the government to get petroleum import taxes reimbursed. Data are for the year 2003. Additional information was given (see Annex 2).
- Data for **Germany** are based on the NEAT model.
- Data for the **Netherlands** are also based on the NEAT model. Where possible, data have been cross-checked with the Dutch energy balance. A good agreement was found.
- Data for **Austria** come from general statistics. It is not always clear what is included where.
- For **Poland**, data are not at present available to fill out the requested format. There is no Polish data base with detailed information on emissions from steam cracking. The national emission registry uses only aggregated data
- For **Russia,** data on input are filled out, backflows or recovered fuels are unknown. No data source is mentioned.
- In **South-Africa**, the data request format was not relevant because the chemical industry in South-Africa is largely coal-based; The coal-based gasification and Fischer-Tropsch synthesis (FTS) industries (Sasol) consume about 40 Mt of coal per year, and there are large carbon flows associated with production of chemicals.
- For the **UK**, no data are present at the moment. The reporting of downstream oil statistics is currently being revised in the UK and, under the NEU-CO_2 network program, a survey of the type of feedstock information available to companies is being undertaken. The outcome of both of these projects should provide better estimates of feedstock supplies to petrochemistry and the returned oils.
- Data on steam cracking units are not present for the **US** inventory as asked for in the present questionnaire . The US has developed a specific methodology to calculates their

CO_2 emissions for the total of their petrochemical industry (see Annex 4 and Section 2.3 for more information)

- No data for **India** are presently available.
- Flanders (= **Belgium** for steam cracking units). Data (input + recovered fuels) are available for the industry itself, obtained from yearly questionnaires by Vito in cooperation with Fedichem (federation of the chemical companies in Belgium). However, no data on backflows are available.

In the following table, results are listed for countries where data were available.

Table 2 : Overview of results from questionnaire on WP1 (part steam cracking)

DATA	**Feedstock input (GJ) (column B)**	**backflows to refineries (GJ) (column C)**	**recuperated fuels in steam crackers (GJ) (column D)**	**Key data**	
				=column C/B	=column D/B
NL 99 national E-balance	326.630.200	NA	91.830.000		28,1
	Data derived from NEAT model calculations for the Netherlands 1999; Net caloric values obtained from NEAT model except for LPG, which was directly obtained from the Reference Manual of the IPCC Guidelines for National GHG Inventories, Volume 3, 1995		1999 data for chemical “restgas” from Dutch Energy Balance		
NL 99 (NEAT model)	326.630.200		67.603.840		20,7
	Data derived from NEAT model calculations for the Netherlands 1999; Net caloric values obtained from NEAT model except for LPG, which was directly obtained from the Reference Manual of the IPCC Guidelines for National GHG Inventories, Volume 3, 1995		Values from NEAT steam cracker model, calculations for the Netherlands for 1999		
GER 03	686.108.400	NA	119.497.825		17,4
	Data derived from NEAT model calculations for Germany 2003; Net caloric values obtained from NEAT model except for LPG, which was directly obtained from the Reference Manual of the IPCC Guidelines for National GHG Inventories, Volume 3, 1995	Data derived from NEAT model calculations for Germany 2003, Backflows given in t CO2 equivalents	Values from NEAT steam cracker model, calculations for Germany 2003		
DK	NO	NO	NO		
RU 03	284.541.204	NA	NA		
	no info on source				
IT 02	293.300.020	76.784.170	43.091.795	26,2	14,7
IT 97	287.216.763	38.860.426	50.012.751	13,5	17,4

	source: monthly questionnaires with individual companies (Ministry of Industry); results are published in a yearly report on energy in Italy "Bollettino Petrolifero" (www.minindustria.it). The data published in the Bollettino Petrolifero refer to the whole petrochemical sector. in order to single out the steam cracker feedstock it was necessary to carry out an analysis of the statistical questionnaires filled in by each petrochemical plant.	source: monthly questionnaires with individual companies (Ministry of Industry); results are published in a yearly report on energy in Italy "Bollettino Petrolifero" (www.minindustria.it). The data published in the Bollettino Petrolifero refer to the whole petrochemical sector. in order to single out the steam cracker feedstock it was necessary to carry out an anlysis of the statistical questionnaires filled in by each petrochemical plant	source: monthly questionnaires with individual companies (Ministry of Industry); results are published in a yearly report on energy in Italy "Bollettino Petrolifero" (www.minindustria.it). The data published in the Bollettino Petrolifero refer to the whole petrochemical sector. in order to single out the steam cracker feedstock it was necessary to carry out an analysis of the statistical questionnaires filled in by each petrochemical plant.		
Korea	1.554.020.342	336.289.503	241.806.803	21,6	15,6
	Calculated based on information on Quarterly Reports of 19 naphtha using petrochemicals firms to the government to get petroleum import taxes reimbursed. Data are for the year 2003.	Calculated based on information on Quarterly Reports of 19 naphtha using petrochemicals firms to the government to get petroleum import taxes reimbursed. Data are for the year 2003.	Calculated based on information on Quarterly Reports of 19 naphtha using petrochemicals firms to the government to get petroleum import taxes reimbursed. Data are for the year 2003.		
Flanders 02	257.982.836	NA	53.377.455		20,7
	source: yearly questionnaires with individual companies (Vito in cooperation with Fedichem); results are published in a yearly report on energy in Flanders (www.emis.vito.be); the estimate om uncertainties is based on expert judgement		source: yearly questionnaires with individual companies (Vito in cooperation with Fedichem); results are published in a yearly report on energy in Flanders (www.emis.vito.be). The NCV is the weighed average of the results for 2002. This can vary from year to year.		

Next to data on steam cracker input, backflows, recovered fuel use, and uncertainty ranges thereof were asked for. No information was given by the project partners in the questionnaire.

As far as can be judged from the information on the questionnaire, the ‘feedstock input’ is the gross input into the steam cracking units.

Also, as far as can be judged from the information given in the questionnaires, the recovered fuels above are recuperated fuels from steam cracking (certainly the case for Flanders, Italy, Korea). In the case of the Netherlands, the data from the energy balance could possibly include more then just recovered fuels from steam crackers.

2.3 CRF and NIR

As a result of the relatively little information that was acquired with the questionnaire from Annex 1, the partners were asked to send relevant CRF tables and additional information as given in the National Inventory reports (if no info was received, latest available information used comes from the website of the UNFCCC in March 2005, which is the submission of April 2004, except for Belgium (NIR 2005 already available)). From Table 1.A(d) of the NIR, feedstock data and information on where related emissions are allocated (either under the source categories of energy or industrial processes) were requested. Part of the feedstock given in the CRF Table 1.A(d) is used as feedstock in steam crackers. Parties can indicate in Table 1.A(d) what the allocation of these emissions is (either to the source categories of energy or industrial processes)

- **Denmark**: No steam cracking occurring in Denmark
- **UK:** The sectoral approach only includes emissions from the non-energy use of fuel where they can be specifically identified and estimated such as with fertilizer production and iron and steel production. It is indicated in table 1.A(d) that “certain emissions from non-energy use of fuels are included (such as catalytic crackers, the feedstock use of natural gas and the combustion of waste lubricants for energy”. However, the naphtha used as feedstock was 72 PJ, the other fuels under 1.A.2 (energy section, chemical industry) were 0,6 PJ, so it seems that emissions from feedstock use are not allocated in the source category of ‘energy’. It is not clear whether these fuels are allocated elsewhere.
- **France**: In the French NIR 2004, different sources for energy data are described. A distinction is made between non-energy use and energy use of fuels. Data for large combustion plants are based on individual data. In the chemical sector, ‘other fuels’ are reported (21 PJ, leading to emissions of 1,2 Mt CO_2 and assuming an emission factor of 59,8 kton CO2/PJ.) In the CRF, Table 1.A(d) is filled out. It is indicated that some of the emissions are allocated under ‘solvent and other product use’, ‘waste’ or ‘fugitive emissions from fossil fuels’. However, it is not clear, if parts of the emissions from naphta (recovered fuels use in the steam cracking units) are allocated under Section 1.A. or anywhere else in the CRF tables (21 PJ ‘other fuel’ is low compared to 359 PJ of naphta).
- **Italy**: In the Italian NIR 2004, it is indicated that very specific information per plant is available from the ministry of industry and that a verification with the NEAT model has been done and this gives similar results. Data are for the petro-chemical industry as a whole in the NIR (see

Table 3).

Table 3: Data on the Italian petro-chemistry from the Italian NIR 2004
(Table 3.27 Other non energy uses, year 2002)

BREAKDOWN OF TOTAL PETROCHEMICAL FLOW				
	Petroch. Input	Returns to refin./market	Internal consumption / losses	Quantity stored in products
ALL ENERGY CARRIERS, kt	11362	3808	2268	5286
% of total input		33.5%	20.0%	46.5%
% of net input			30.0%	70.0%

For the total petro-chemistry in Italy, 20% of the total feedstock-input is lost due to internal consumption (probably mostly energy recovery?). For our questionnaire, Italy analyzed specific data on steam cracking from the total of the petro-chemical industry (see *Table 2*). The results for steam cracking only gave about 14,7 % to 17,4% of the feedstock-input that was recovered as fuel (depending on the year of the data).

- **Germany.** It is indicated in the NIR 2004 that for the reference approach estimates were made by the Fraunhofer institute (using inputs from the NEU-CO2 network). These data are filled out for the period of 1990-1999 (1999 is the last year where data are available). In Table 1.A(d) no indication is made on where the corresponding CO2 emissions are reported. There was a naphtha use as feedstock of 491 PJ (storage factor indicated was 57%), only 12, 7PJ 'other fuels' were listed in manufacturing industries (no data for the chemical sector alone) Perhaps emission are allocated elsewhere, but this is not clear and they have well been omitted.
- **The Netherlands.** In Table 1.A(d) is indicated that corresponding emissions are reported under Table 1.A.2 c or under industrial processes or waste incineration. Information from SenterNovem (personal communication) in March 2005 indicates that the Netherlands have recalculated their emissions from NEU and used the NEAT methodology since the latest submission (March-April 2005).
- **Austria.** No naphtha used as feedstock is reported. The carbon fraction stored is for all products 100%, but it is indicated that this will be revised
- **Poland.** An extensive list is filled out for products and they are indicated to have been subtracted from data as given in Table 1.A.2c. For naphta, it is indicated in Table 1.A(d) that the estimate is 'IE'(included elsewhere). No documentation box is available.
- **USA.** In table 1.A(d) it is clearly indicated which products are involved, what % of carbon stored are used and where corresponding CO_2emissions are allocated under. The USA has used a country specific methodology and pragmatic approach to calculate NEU CO_2emissions (full text see Annex 4). The methodology calculates an overall storage factor for feedstocks, based on a mass balance of the carbon contained in feedstocks, products, other releases. Either the carbon is considered to be stored, or the carbon is emitted. For 2003, the storage factor of 7 fuel categories of petrochemical feedstocks was 65% (65% is considered to be stored in products in the long-term, including products combusted as waste). What is also interesting (regarding a possible comparison with data from Korea and Flanders) is the amount of energy recovery. The

EIA (Energy Information Administration) has for several years data from the ‘Manufacturers Energy Consumption Survey ‘MECS)” on the amount of feedstock used as energy recovery. For 2003, 7,6 Tg carbon was reported as ‘waste gas’, 7,58 Tg C (resulting from the use of naphtha) as ‘other fuels’ (considered to be resulting from petrochemical feedstocks) and 0,67 Tg ‘waste, oils and tars’. In total these recovered products amount to 58,1 Tg CO_2 equivalents or 26% of the total amount of carbon stored and emitted from feedstocks (58,1 /(145 stored + 77,8 emitted) = 26%)

- **Belgium.** In the latest NIR of April 2005 , the calculation and allocation of emissions from NEU is explained. For the reference approach, data from the national energy balances are used. These data do not correspond with the data from the bottom-up approach used for NEU and process emissions, so Table 1.A(d) is filled out but does not correspond with the actual sectoral emission-inventory. A specific study was conducted in 2003 to identify sources of CO_2emissions from NEU in Flanders. The study uses bottom-up data from surveys conducted in cooperation with Fedichem (the federation of the chemical industry in Belgium). The recalculation was made for all years. The largest part of the resulting emissions is reported under Table1.A.2 c (= other fuels of the chemical industry). This includes other fuels in the chemical sector, a result of recovered fuels in the cracking units in petrochemical industry (approx. 2/3) and other recovered fuels from the chemical industry (approx. 1/3). The steam crackers in Antwerp are the main sources of non-energy use of naphta and LPG. The default % of carbon stored for the non-energy use of fuels in the IPCC Guidelines were considered to be inaccurate in the Flemish situation. Therefore, a study was conducted in 2003, where the major sources of CO_2emissions form processes and non-energy use in the chemical industry were surveyed in more detail with the help of the industry itself. The results are indicated in the NIR of Belgium 2005.

2.4 Conclusion on steam cracking data

The results of the questionnaires established under WP1 and the additional data from the CRF tables (of Annex I countries) show:

- not all partners / countries have detailed data on steam cracking in their country
- if data are available (in questionnaires or in the CRF), it is not always clear what the boundaries are of the system or what definitions for non-energy use are used. It is also not clear in several CRF tables where emissions (if any are calculated and included) are allocated.
- Italy, Korea and Flanders use surveys with individual companies in their industry. The UK is using a similar approach of individual surveys with the companies involved.
- The USA has developed its own pragmatic methodology to be able to calculate CO_2emissions from feedstock use in steam crackers and other petro-chemistry. They also use survey results from the EIA’s “Manufacturers Energy Consumption Survey (MECS)”.

Germany and the Netherlands use NEAT methodology to calculate these emissions

In the following table, a comparison is made on the amount of recovered fuels from steam cracking processes based on the information above.

Table 4: Recovered fuels from steam cracking

	% recovered fuels in steam cracking	**PJ recovered fuels**	**Mton CO_2 recovered fuels from steam cracking**	**Implied EF of the recovered fuels (kton CO_2/PJ)**	**Source and comments**
Netherlands	*20,7 (NEAT)– 28,1 (energy balance)*	*67 (NEAT) – 91 (energy balance)*	*3,5 (NEAT)*	*51,1 (NEAT)*	*NEAT/energy balance*
Germany	17,4	119	6	50,5 (NEAT)	NEAT
Italy	17,4 (‘97) – 14, 7 (‘02)	50 (‘97)- 43 (‘02)			Surveys
Flanders	20,7	53	2,8	53,1	Surveys
Korea	15,6	241			Surveys
USA	*26*		*58,1*		*Total petro-chemistry; source EIA survey*

The data for the USA are for the total petro-chemistry, not only for steam cracking. Also the data for the Netherlands based on the energy balance include probably more then just steam cracking. The data from surveys that are only on steam cracking (Italy, Korea and Flanders) lie somewhere between 14,7 – 20,7% of the feedstock input of steam crackers that is used as energy. The results form the NEAT model for the Netherlands and for Germany lie also between this range.

In the table, the amount of PJ and Mton CO_2 involved is included to indicate that this energy recovery is considerable in absolute figures. For example for Flanders, the 2,8 Mton of CO_2 from steam cracking represent approximately 3,6 % of the total CO_2 emissions in 2002. For the Netherlands, 3,5 Mton of CO_2 from steamcracking represents about 2% of the total CO_2-emissions in 2002 (175 Mton). For Germany, the CO_2-emissions represent about 0,7% of the total CO_2 emissions in 2002 (6 Mton to 878 Mton). Where possible, the implied emission factors for the recovered fuels from steam cracking are calculated.

3 Recovered fuels

3.1 Overview

A data questionnaire (see Annex I) was made up, asking for data and relevant studies on recovered fuel use in the countries of the partners.

3.2 Data questionnaire: response

- **Germany:** reports data on the fuel-grade by-products occurring in the production of phenol, propylene oxide, toluene diisocyanate and n-butanol. The data sources are: Production data from Statistisches Bundesamt, Fachserie 4, Reihe 3.1: Produzierendes Gewerbe; Specific process data from Neelis et al. [iv].
- **The Netherlands:** Data on process specific by-products, losses and fuel use of by-products are available from a database called ‘PIE-database’ at Utrecht University (see results for Germany). However, Dutch production data are confidential.

In the following table, data received from Germany and the Netherlands are presented: Specific process data from Neelis et al (2005) [iv]. This study uses data from the PIE-database from the Netherlands, which comprises specific information for chemical processes from various sources.

Table 5: Data from forthcoming “Analysis of energy use and carbon losses in the chemical and refinery industries, Utrecht University; Neelis et al.” [iv]

description of process	process input for each process route	specific feedstock consumption in t/t product*	byproducts	specific by-product generation in t/t product	specific losses in t CO_2/t product	**fuel grade by-products in t CO_2/t product**	total specific loss in t CO_2/t product	fraction of product produced via this production route
production of phenol	cumene	1.35 cumene	aceton	0.61 acetone	0	**0,28**	0,28	1
production of propylene oxide	propylene	0.88 propylene	dichloropropane, dichloroethylether	0.11 dichloropropane, 0.03 dichloroethylether	0,33	**0**	0,33	0,53
	propylene, isobutene	0.9 propylene, 2.35 isobutene	misc. acetone, butylalcohol	0.25 misc. acetone, 2.45 butylalcohol	0,97	**0,31**	1,28	0,26
	propylene, ethylbenzene	0.74 propylene, 2.52 ethylbenzene	styrene	2.29 styrene	0,68	**0**	0,68	0,21
production of toluene diisocyanate	toluene, carbon monoxide	0.67 toluene, 0.43 carbon monoxide	heavy products	0.08 heavy products	0,44	**0,18**	0,62	1
production of n-butanol	propylene, carbon monoxide	0.66 propylene, 0.44 carbon monoxide	i-buteraldehyde	0.09 i-buteraldehyde	0,09	**0,07**	0,16	1

- **Flanders**: reports data on production of carbon black (see also process emissions), production of products based on coal tars and miscellaneous processes. Reported recovered fuels from following processes have been reported: 'fuel gas' from the production of paraxylene, tricyclic hydrocarbons from phenol production, recovered fuel from poly-ethylene production, and several other recovered fuels from which the origin is not always indicated. Since no production data are reported, no specific fuel grade by-products per ton of product can be calculated. The data source is the yearly energy and CO_2 survey by Fedichem. In total, the amount of CO_2 from recovered fuels in the chemical sector in Flanders, apart from the recovered fuels from steam cracking is about 900 kton a year (approximately 1% of the total CO_2 emissions in Flanders in 2002).
- **Korea:** reports backflows to refineries and process fuel use in this section. It is not clear what exactly is reported in the questionnaire.
- **USA**: in the methodology described in Annex 4, these fuel grade by-products are included. The information is available from the MECS database from the Energy Information Administration. Other fuels in the database include amongst others: waste gas, waste oils, tars and related materials and other uncharacterized fuels. No further details are available.

3.3 CRF and NIR

No further data on recovered fuels were extracted from CRF tables.

3.4 Conclusion on recovered fuels (other than from steam cracking)

Not much information is available to compare between the countries of the partners. Some of the information is confidential or is not available at present. The results of the yearly surveys in Flanders do not include production data, so no comparison was possible with the Dutch/German data on specific fuel grade by-products per ton of product.

4 Chemical processes

4.1 Overview

In the data request format (see Annex I) , relevant CO_2 emission data were asked for. For some processes, data were collected. The collected data are compared with what was found in the CRF on the website of the UNFCCC [iii] (CRF tables in March 2005 were the ones reported in April 2004 to the UNFCCC). In the following table, a summary of possible processes is listed based on the processes mentioned in the IPCC guidelines and info that was acquired in the CRF or questionnaires. It is indicated if CO_2 emissions may occur. The list is not exhaustive.

Table 6: Possible processes where CO_2 emissions can occur (not exhaustive)(X indicates possible emissions)

Production processes	**CO_2**
Ammonia production	X
Nitric Acid production	(x)
Adipic Acid production	(x)
Carbide production	X
Silicon Carbide production	X
Calcium Carbide production	X
Other *(please specify)*	
Carbon Black production	X
Ethylene production	X
Dichloroethylene production	X
Styrene production	X
Methanol production	X
Caprolactam production	(x)
ethylene oxide production	X
Cyclohexanone production	X
catalysts/fertilizers and pesticides production	X

In the following paragraphs, data for some processes for which information was received in the questionnaires or information was found in the CRF tables, are presented.

4.2 Ammonia Production

4.2.1 Data questionnaire

We received results from Italy, Germany (from NEAT model), no data from the Netherlands due to confidentiality. For Italy, the amount of CO_2 formed per ton of product (NH_3) is 1,5 t/t ammonia. It is not clear if this is the default IPCC value that was used. For Germany, the reported data are listed below.

Table 7: Data on the CO_2 emissions resulting from the production of ammonia for Germany

description of process	process input for each process route	specific feedstock consumption in t/t product*	**total specific loss in t CO_2/t product**	fraction of product produced via this production route	recuperation of CO_2 for other use (tonnes)
production of ammonia	heavy fuels	0.45 heavy fuels	**1,43**	0,34	0.75 t CO_2 per t urea produced
production of ammonia	natural gas	0.48 natural gas	**1,04**	0,67	

4.2.2 Data CRF

In table 2(I).A-Gs1 of the CRF of several countries in the network (source:[iii] data for 2001 except for Poland 2002). The following data for ammonia production were found.

Table 8: Data on CO_2 emissions from the production of ammonia

	ACTIVITY DATA		**IMPLIED EMISSION FACTORS**	
	Production/Consumption quantity		**CO_2**	
ammonia production	**Description (1)**	**(kt)**	**(t /t)***	**(Gg CO_2)**
Belgium		C	C	1.819,24
the Netherlands		C		IE
France	kt Production	1.429,27	1,538	2.197,69
Italy	kt Production	430,18	1,500	645,26
Germany	kt Production	2.603,00	0,690	1.796,07
Austria	kt Production	448,18	0,986	442,00
Poland	kt Production	758,10	1,000	758,10

UK	natural gas consumption in PJ	34,54		1.233,46
USA	production	12.336,11	1,43	17.652,33

*depending on activity data!!

Only Germany filled out our own questionnaire. They give emission factors of 1,04 – 1,43 ton CO_2 per ton of ammonia produced depending on the type of process input.

Data from the CRF tables indicated values between 0,69 (Germany) to 1,538 (France) ton CO_2 per ton of ammonia produced. In the CRF tables however, only emissions are reported, not the part of CO_2 that’s is perhaps recovered for other purposes (like urea production). Therefore, the implied emissions factors in the CRF tables can *not* be compared between countries without more information on the presence of recovery of CO_2. *note: information from M. Weiss (Utrecht University) indicates that the data in the German CRF are too low and will be corrected in later submissions of the CRF tables.*

The type of process input was not always mentioned in the CRF tables. For the UK, the amount of natural gas input (in PJ) for the production of ammonia was given (35,7 ton CO_2/PJ of natural gas input).

4.3 Carbon black production

4.3.1 Data questionnaire

Only Flanders has data on CO_2 emissions form the production of carbon black (considered as recovered fuels emissions, but could be reported under process emissions). About 50% of the heavy fuel oil that is the feedstock, is considered to be used as ‘fuel’. In the over-all emissions, this is not an important source.

4.3.2 Data CRF

Several countries (France, Italy, Germany, Poland, USA, C for the Netherlands) report carbon black production in their countries, but no CO_2 emissions have been included (field in IPCC format is gray).

Since no data for CO_2 emissions from the production of carbon black were mentioned, no comparison of data is possible. Only for Flanders an estimate of 50% of the total fuel input would be used as fuel and result in CO_2 emissions.

4.4 Carbide production

4.4.1 Data questionnaire

No one reported carbide production and corresponding CO_2.

4.4.2 Data CRF

In table 2(I).A-Gs1 of the CRF of several countries in the network (source: [iii] data for 2001 except for Poland 2002). The following data for carbide production were found.

Table 9: Data on CO_2 emissions from the production of carbides in the CRF tables

	ACTIVITY DATA		IMPLIED EMISSION FACTORS	
	Production/Consumption quantity		CO_2	
country	**Description** (1)	**(kt)**	**(t/t)**	**(Gg CO_2)**
France: calcium carbide	kt Production	30,00	2,19	65,70
The Netherlands: Ca and Si carbide		C		IE
Germany: calcium carbide		C		14,90
Austria: calcium carbide	kt Production	36,03	1,30	46,68
Poland: calcium carbide	kt Production	27,70	1,10	30,50
USA: Si carbide	kt Production	30,00		NE

Several countries reported CO_2 emissions from carbide production in the CRF tables. Emission factors of CO_2 per ton of produced Calcium carbide vary between 1,1 (Poland) and 2,19 (France). The reported amounts of CO_2 (a few dozen ktons) don't seem to be important in the over-all inventories.

4.5 Methanol production

4.5.1 Data questionnaire

Only data for Germany from the NEAT model were available.

Table 10: Data on CO_2-emissions from the production of Methanol in the questionnaires

description of process	process input for each process route	specific feedstock consumption in t/t product*	specific losses in t CO_2/t product	fraction of product produced via this production route
production of methanol	oxidation of residues	0.49 residues	0,16	0,09

4.5.2 Data CRF

Only the USA reported data in the CRF tables on methanol production, but no corresponding CO_2.

4.6 TiO_2 production

4.6.1 Data questionnaire

No relevant data are reported in our own questionnaire.

4.6.2 Data CRF

Italy and the USA report data and CO_2 emissions from the production of titanium dioxide

Table 11: Data on CO_2 emissions from TiO_2 in the CRF tables

	ACTIVITY DATA		**IMPLIED EMISSION FACTORS**	
	Production/Consumption quantity		**CO_2**	
country	**Description (1)**	**(kt)**	**(t/t)**	**(Gg CO_2)**
Italy	Production	60,50	0,7769	47
USA	titanium dioxide production	1.410,00	1,4160	1.997

Only for Italy and the USA, CO_2 emissions were found in the CRF tables. The implied emission factor for CO_2 in ton per ton of TiO_2 produced was between 0,78 (Italy) an 1,42 (USA).

4.7 Other

4.7.1 Data questionnaire

Only Germany and the Netherlands reported data from the NEAT model on other processes Not all data are specific for Germany, but may be estimates for Western Europe. In *Table 12*, all information received from Germany and the Netherlands is listed.

Flanders has information on CO_2 emissions from processes in the yearly questionnaires from Fedichem (Federation of the chemical industry in Balgium). CO_2 emissions are reported for or during the production of: ethylene oxide, cyclohexanone, acrylic acid, paraxylene, metaxylene (partial oxidation), 1,2-dichloroethane (oxidation of ethylene). Since no production data are surveyed, it is not possible to compare the results with the data in *Table 12* for the Netherlands/Germany on specific losses in terms of CO_2/ton of product formed.

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Table 12: Data on process emissions of CO$_2$ from the questionnaire of Germany/the Netherlands (still to be verified)

description of process	process input for each process route	specific feedstock consumption in t/t product*	byproducts	specific by-product generation in t/t product	**specific losses in t CO$_2$/t product**	fuel grade by-products in t CO$_2$/t product	total specific loss in t CO$_2$/t product	fraction of product produced via this production route	recuperation of CO$_2$ for other use (tonnes)	Source
production of phenol	cumene	1.35 cumene	aceton	0.61 acetone	**0**	0,28	0,28	1		Specific process data from Neelis et al., forthcomming 2005: Analysis of energy use and carbon losses in the chemical and refinery industries, Utrecht University. This sudies uses data from the PIE-database, which comprises specific information for chemic
production of propylene oxide	propylene	0.88 propylene	dichloropropane, dichloroethylether	0.11 dichloropropane, 0.03 dichloroethylether	**0,33**	0	0,33	0,53		
	propylene, isobutene	0.9 propylene, 2.35 isobutene	misc. acetone, butylalcohol	0.25 misc. acetone, 2.45 butylalcohol	**0,97**	0,31	1,28	0,26		
	propylene, ethylbenzene	0.74 propylene, 2.52 ethylbenzene	styrene	2.29 styrene	**0,68**	0	0,68	0,21		
production of caprolactam	cyclohexane	1.03 cyclohexane	-	-	**0,88**	0	0,88	0,54		
	phenol	0.92 phenol	-	-	**0,25**	0	0,25	0,46		
production of phthalic anhydride	o-xylol	0.92 o-xylol	maleic acid	0.05 maleic acid	**0,6**	0	0,60	0,94		
	naphthalene	0.92 naphthalene	-	-	**0,78**	0	0,78	0,06		
production of hexamethylene diamine	acrylonitrile	1.13 acrylonitrile	-	-	**0,54**	0	0,54	0,23		
	adipic acid	1.48 adipic acid	-	-	**0,4**	0	0,40	0,52		
	butadiene, hydrogencyanide	0.63 butadiene, 0.6 hydrogencyanide	-	-	**0,76**	0	0,76	0,25		
production of acrylonitrile	propylene	1.06 propylene	hydrogen cyanide	0.08 hydrogen cyanide	**0,71**	0	0,71	1		
production of adipic acid	cyclohexane	0.75 cyclohexane	-	-	**0,55**	0	0,55	1		
production of ethylene oxide	ethylene	0.78 ethylene	-	-	**0,45**	0	0,45	1		
production of toluene diisocyanate	toluene, carbon monoxide	0.67 toluene, 0.43 carbon monoxide	heavy products	0.08 heavy products	**0,44**	0,18	0,62	1		
production of bisphenol-A	phenol, acetone, toluene	0.88 phenol, 0.29 acetone, 0.04 toluene	-	-	**0,37**	0	0,37	1		

production of dimethylterephthalate	p-xylene, methanol	0.63 p-xylene, 0.38 methanol	-	-	**0,34**	0	0,34	1	
production of polyamide 6	caprolactam	1.11 caprolactam	-	-	**0,26**	0	0,26	1	
production of isopropanol	propylene	0.78 propylene	-	-	**0,25**	0	0,25	1	
production of polycarbonate	bisphenol-A, carbon monoxide	0.90 bisphenol-A, 0.23 carbon monoxide	-	-	**0,19**	0	0,19	1	
production of dioctylphthalate	2-ethylhexanol, phthalic anhydride	0.73 2-ethylhexanol, 0.38 phthalic anhydride	-	-	**0,17**	0	0,17	1	
production of terephthalic acid	p-xylene, acetic acid	0.66 p-xylene, 0.05 acetic acid	-	-	**0,14**	0	0,14	1	
production of MDI	aniline, formaldehyde, carbon monoxide	0.76 aniline, 0.14 formaldehyde, 0.26 carbon monoxide	-	-	**0,13**	0	0,13	1	
production of formaldehyde	methanol	1.15 methanol	-	-	**0,12**	0	0,12	1	
production of acetaldehyde	ethylene	0.67 ethylene	-	-	**0,11**	0	0,11	1	
production of acetic acid	acetaldehyde	0.76 acetaldehyde	-	-	**0,06**	0	0,06	0,2	
	methanol, carbon monoxide	0.54 methanol, 0.53 carbon monoxide	-	-	**0,1**	0	0,10	0,8	
production of n-butanol	propylene, carbon monoxide	0.66 propylene, 0.44 carbon monoxide	i-buteraldehyde	0.09 i-buteraldehyde	**0,09**	0,07	0,16	1	
production of vinylchloride	ethylene	0.47 ethylene	-	-	**0,07**	0	0,07	1	
production of aniline	nitrobenzene	1.35 nitrobenzene	-	-	**0,06**	0	0,06	1	
production of ethyleneglycol	ethylene oxide	0.83 ethylene oxide	diethylene glycol, triethylene glycol	0.1 diethylene glycol, 0.01 triethylene glycol	**0,05**	0	0,05	1	
production of styrene	ethylbenzene	1.07 ethylbenzene	benzene, toluene	0.01 benzene, 0.02 toluene	**0,05**	0	0,05	0,85	
production of polyvinylchloride	vinylchloride	1.03 vinylchloride	-	-	**0,04**	0	0,04	1	

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production of PET	ethylene glycol, terephthalic acid	0.33 ethylene glycol, 0.87 terephthalic acid	-	-	**0,03**	0	0,03	1	
production of cumene	propylene, benzene	0.35 propylene, 0.66 benzene	-	-	**0,03**	0	0,03	1	
production of polystyrene	styrene	1.01 styrene	-	-	**0,03**	0	0,03	1	
production of acetone	isopropanol	1.05 isopropanol	-	-	**0,03**	0	0,03	0,17	
production of polyethylene	ethylene	1.01 ethylene	-	-	**0,03**	0	0,03	1	
production of polyetherpolyol	glycerol, propylene oxide	0.03 glycerol, 1.00 propylene oxide	-	-	**0,02**	0	0,02	1	
production of urea	ammonia, carbon dioxide	0.57 ammonia, 0.75 carbon dioxide	-	-	**0,02**	0	0,02	1	
production of cyclohexane	benzene	0.93 benzene	-	-	**0,02**	0	0,02	1	
production of polypropylene	propylene	1.01 propylene	-	-	**0,02**	0	0,02	1	
production of ethylbenzene	benzene, ethylene	0.74 benzene, 0.27 ethylene	-	-	**0,01**	0	0,01	1	

data source/description of used methodology:

Comment: We changed the headings of some columns in order to adapt the table to the available information! Data sources are stated in the last two columns of the table. PLEASE Production data are partly not available and partly confidential. Therefore we did not include them in the table at this stage. The process specific information are not specific for German plants but represent estimates for processes used world wide to produce chemicals. The fractions, to which the several feedstocks contribute to the production of a certain chemical (in case of multiple feedstock options) are estimates for Western Europe (except for ammonia, which is a specific value for Germany).

4.7.2 CRF

In the CRF tables of the countries of some of the partners, other process emissions are mentioned.

Table 13: Data on other chemical processes and the related CO_2 emissions

	ACTIVITY DATA		**IMPLIED EMISSION FACTORS**	
	Production/Consumption quantity		**CO_2**	
country	**Description (1)**	**(kt)**	**(t/t)**	**(Gg CO_2)**
DK: Catalysts/Fertilizers and Pesticides		100,26	0,03	3,10
F: styrene	kt Production	641,37		
F: other ((Glyoxylic acid production, …))	kt Production	10.798,73	0,002	24,59
It : styrene	kt Production	563,40		
It: dichloorethylene	kt Production	4,60		
Austria: other	Other Chemical Products [kt]			20,01
Poland: nitrates	production	1.092,40	0,00146	1,60
USA: dichloorethylene	dichloroethylene	9.287,85		
USA : styrene	styrene	4.974,14		
USA: phosphoric acid	phosphate rock production	37.381,00	0,036	1.339,12
USA: CO_2 consumption	carbon dioxide consumption	11.313,48	0,112	1.272,33
Italy: adipic acid	production	75,29	0,027	2,03

Again, the present data do not allow a comparison of results from different countries.

4.8 Conclusions on chemical processes

The results from our own questionnaire did not gather much new information. Sometimes data are available, but due to confidentiality, these data could not be communicated. As a second option, data from available CRF tables were gathered by the partners themselves or on the website of the UNFCCC. In the following table, data (on some processes for which data were available are summarized.

Table 14: Overview of data on CO_2-emissions for chemical processes from the questionnaires or from CRF tables

Production processes	**data**	**unit**	**Number of data**
Ammonia	0,69- 1,538	Ton CO_2/ton ammonia produced	6
Calcium Carbide	1,1 -2,19	Ton CO_2/ton Ca carbide	3
Carbon Black	50%	% of carbon from heavy fuel as input that is oxidized	1
Methanol	0,16	Ton CO_2/ton methanol	1
TiO_2	0,78-1,42	Ton CO_2/ton TiO_2	2
Miscellaneous: see table 10			

In terms of importance in absolute terms of CO_2 emissions, the production of ammonia is the most important source for industrial process emissions. However, part of the CO_2 formed in the production of ammonia can be recovered for other uses (e.g. for urea production) as is indicated in the Dutch results. It is also the case in Flanders (but no exact data are available). Therefore, the range of values is large and cannot be compared as such without additional information.

5 Incineration and flaring

The questionnaire on incineration and flaring did not yield many results. For these emissions, no further data were gathered from the CRF tables either.

6 Conclusions

The purpose of WP1 was to collect data from the partners in the network on specific information they might have on by-products in the chemical industry used as fuels and resulting emissions thereof. Questionnaires were established and send out to all project partners to help collecting these data. The results were limited, and as a second option, information already available in CRF tables reported to the UNFCCC and National Inventory Reports was studied (the information available in March 2005 are the reported CRF and NIR to the UNFCCC from April 2004) . Not always was the same information present in the questionnaire as in the CRF tables and NIR, probably due to the fact that different people are working in the network and on the national GHG inventories. Or perhaps not all information was easily accessible to the partners due to confidentiality reasons. Additional to the requested data, uncertainty ranges for activity data and emission factors were asked for. No data were communicated in the questionnaires.

Some countries in the network have already developed their own methodology to calculate CO_2 emissions resulting from non-energy use of fossil fuels (for example USA). Methodologies are then mainly based on individual data from surveys or reporting from the industry itself and are country- specific. Other countries have used the NEAT methodology to calculate these emissions (for example the Netherlands).

For steam cracking, it is not always clear in the CRF tables whether data for recovered fuels from steam cracking are included in the CRF tables or where they are allocated to (either to the source categories of ‘energy’ or ‘industrial processes’). Its is quite well possible that some countries like Germany, the UK or France have omitted to report these emissions (in the CRF tables of April 2004). It is also not always possible to see whether all relevant process emissions are reported. Countries where the partners have access to plant specific data , have the best (summarized) data and/or methodology (for example Italy). The available data indicate that recovered fuels from steam cracking is an important source of CO_2 emissions in countries where this type of industry is situated. Since in most countries the number of plants or companies is limited, we recommend to the countries to ask these companies for information (in a survey on voluntary basis or in some other perhaps obliged form).

Data on **recovered fuel use** from other processes is limited in the questionnaire and in the CRF tables. Only Germany/The Netherlands reported data from literature and studies. In Flanders, the emissions from this type of fuel is reported, but no production data are included in the yearly surveys. Therefore, is was not possible to compare data with the results from the Netherlands or Germany. The most important source of recovered fuels seems to be steam cracking, however the overall emissions from other sources are not negligible: for example in Flanders about 2/3 of recovered fuel use in the chemical industry results from steam cracking, 1/3 originates from other sources (about 900 kton/y). The information on fuel grade by-products in t CO_2/t products from the Netherlands/Germany indicate that the production of phenol and production of propylene oxide also give relatively high values of ton CO_2/ton product (0,28 ton CO_2/ton phenol; 0,31 ton CO_2/ton propylene oxide). These could be important processes to focus on in future work and surveys.

Data on CO_2 emissions from **chemical processes** were also asked for in the questionnaire and additional information was gathered from the CRF tables. Several processes result in CO_2 emissions, the most important process in terms of kton CO_2 emitted in the questionnaire and CRF tables, being the production of ammonia. However, except for the Netherlands and Germany, data are limited. In some cases, the production of *ammonia* is accompanied by the use of the released CO_2 for other purposes, as for example urea production.

Possibly other processes, depending on the production scale, could also result in non-negligible emissions. One example for Flanders is the emissions during the production of *ethylene oxide*.

For **incineration and flaring**, no further information was gathered.

Annex 1: Data request format January 2005

(see excel upon request file)

Annex 2: Additional information received

Korea: file with table

Table : Korean naphtha flow in 2003, a survey result in 1000t (SOURCE?)

	NCC, BTX (6)	Refineries BTX (4)	Refinery with NCC (1)	Others (8)	Total (19)
Gross naphtha input	17,341.6	8,772.2	6,651.9	881.3	33,647.0
Backflows to refineries	1,117.6	4,019.8	2,142.6	1.2	7,281.2
(in % of gross input)	(6.4)	(45.8)	(32.2)	(0.1)	(21.6)
Net naphtha consumption	16,224.0	4,752.4	4,509.3	880.1	26,365.8
(in % of gross input)	(93.6)	(54.2)	(67.8)	(99.9)	(78.4)
- Feedstock use	12,473.6	3,920.4	3,741.8	678.9	20,814.7
(in % of gross input)	(71.9)	(44.7)	(56.3)	(77.0)	(61.9)
- Fuel use & losses	3,782.5	586.7	746.3	120.0	5,235.5
(in % of gross input)	(21.8)	(6.7)	(11.2)	(13.6)	(15.6)

Source: Quarterly Reports of the petrochemical firms to the government to get petroleum taxes reimbursed.

NCC + BTX(6): 6 petrochemical firms with steam cracker (NCC) and aromatics plant (BTX).

BTX (4): 4 refineries with aromatics plants.

Refinery with NCC(1): 1 refinery with steam cracker (petrochemical operation).

Others (8): 8 petrochemical firms using naphtha to produce basic chemicals

Annex 3: Additional information received

- **Germany/Netherlands:** draft version of Neelis et al. 2005 [iv]. The results base mainly on the outcome of a literature review and were used to built a database (PIE - data base).

- **Netherlands: [v]**

- **USA (forwarded by the Netherlands)** (CO_2 losses of catalytic processes in the USA which may be viewed as independent estimate of recovered fuels/non spec's . The data source is, however, from the 1970-1980 and might therefore be used as reference only). These data were not included in the text.

Losses during catalytic production of Chemicals in kt CO_2 equivalents

Chemical	Feedstock - 1	Losses - 1 in kt CO_2 equivalents per year	Feedstock - 2	Losses - 2 in kt CO_2 equivalents per year	Total in kt CO_2 equivalents per year
sulfuric acid	sulfur dioxide				
ammonia	methane				
propylene	propane				
nitric acid	ammonia				
ethylene dichloride	ethylene	372,40	chlorine		372,40
vinyl chloride	ethylene dichloride	626,42			626,42
benzene	naphtha				
ethylbenzene	ethylene	41,73	benzene	252,20	293,93
MTBE	methanol	43,55	isobutylene	0,00	43,55
styrene	ethylbezene	1042,37			1042,37
methanol	carbon monoxide	96,62	hydrogen		96,62
formaldehyde	methanol	489,88			489,88
xylene	naphtha				
toluene	naphtha				
p-xylene	xylenes				
terephthalic acid	p-xylene	285,31			285,31
ethylene oxide	ethylene	1593,03			1593,03
ethylene glycol	ethylene oxide	37,19			37,19
cumene	benzene	0,00	propylene	0,00	0,00
phenol	cumene	219,09		0,00	219,09
acetic acid	methanol	12,25	carbon monoxide	146,51	158,76
butadiene	butene	2263,45		0,00	2263,45
acrylonitrile	propylene	738,91	ammonia		738,91

propylene oxide	propylene	309,81	iso-butane	412,77	722,58
vinyl acetate	ethylene	136,99	acetic acid	0,00	136,99
acetone	cumene				
cyclohexane	benzene	6,35	hydrogen		6,35
adipic acid	cyclohexane	159,67	nitric acid		159,67
caprolactam	cyclohexane	157,85			157,85
idobutylene	n-butane	37,19			37,19
Total		**8670,05**		**811,49**	**9481,54**

Source: U.S. Department of Commerce, National Technical Information Service (1995): Top 50 Commodity Chemicals: Impact of Catalytic Process Limitations on Energy, Environment, and Economics

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Annex 4: US methodology for estimating carbon emitted from non-energy uses of fossil fuels

(prepared by ICF Consulting)

Carbon storage associated with the non-energy use of fossil fuels was calculated by multiplying each fuel’s potential emissions (i.e., each fuel’s total carbon content) by a fuel-specific storage factor, as listed in Table 1. This Annex explains the methods and data sources employed in developing the storage factors for petrochemical feedstocks (industrial other coal, natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha), asphalt and road oil, lubricants, waxes, and miscellaneous products. The storage factors for the remaining non-energy fuel uses are either based on values recommended for use by IPCC (1997), or when these were not available, assumptions based on the potential fate of carbon in the respective NEU products.

Table 1: Fuel Types and Percent of Carbon Stored for Non-Energy Uses

Sector/Fuel Type	Storage **Factor**
Industry	**-**
Industrial Coking Coal	0.75
Industrial Other Coal	0.65
Natural Gas to Chemical Plants	0.65
Asphalt & Road Oil	1.00
LPG	0.65
Lubricants	0.09
Pentanes Plus	0.65
Naphtha (<401 deg. F)	0.65
Other Oil (>401 deg. F)	0.65
Still Gas	0.65
Petroleum Coke	0.50
Special Naphtha	0.65
Distillate Fuel Oil	0.50
Waxes	0.58
Miscellaneous Products	0.00
Transportation	
Lubricants	0.09
U.S. Territories	
Lubricants	0.09
Other Petroleum (Misc. Prod.)	0.10

- Not applicable

[a] Includes processes for which specific coking coal consumption and emission factor data are not available. Consumption of coking coal for production of iron and steel is covered in the Industrial Processes chapter.

[b] The storage factor listed is the value for 2003. As described in this annex, the factor varies over time.

[c] Includes processes for which specific petroleum coke consumption and emission factor data are not available (e.g., carbon fibers and textiles, refractory, electric motor parts, brake parts, batteries). Consumption of petroleum coke for production of primary aluminum anodes, electric arc furnace anodes, titanium dioxide, ammonia, urea, and ferroalloys is covered in the Industrial Processes chapter.

The following sections describe the selected non-energy uses in greater detail, outlining the methods employed and data used in estimating each storage factor. Several of the fuel types tracked by EIA are used in organic chemical synthesis and in other manufacturing processes, and are referred to collectively as "petrochemical feedstocks." Because the methods and data used to analyze them overlap, they are handled as a group and are discussed first. Discussions of the storage factors for asphalt and road oil, lubricants, waxes, and miscellaneous products follow.

1. Petrochemical Feedstocks

Petrochemical feedstocks – other industrial coal, natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha – are used in the manufacture of a wide variety of man-made chemicals and products. Plastics, rubber, synthetic fibers, solvents, paints, fertilizers, pharmaceuticals, and food additives are just a few of the derivatives of these fuel types. Chemically speaking, these fuels are diverse, ranging from simple natural gas (i.e., predominantly methane, CH_4) to heavier, more complex naphthas and other oils.[1]

After adjustments for (1) use in industrial processes and (2) net exports, the eight fuel categories constituted approximately 216.6 Tg CO_2 Eq., or 60 percent, of the 360.5 Tg CO_2 Eq. of non-energy fuel consumption in 2003. For 2003 the storage factor for the seven fuel categories was 65 percent. In other words, of the net consumption, 65 percent was destined for long-term storage in products—including products subsequently combusted for waste disposal—while the remaining 35 percent was emitted to the atmosphere directly as CO_2 (e.g., through combustion of industrial byproducts) or indirectly as CO_2 precursors (e.g., through evaporative product use). The indirect emissions include a variety of organic gases such as volatile organic compounds (VOCs) and carbon monoxide (CO), which eventually oxidize into CO_2 in the atmosphere. The derivation of the storage factor is described in the following sections.

2. Methodology and Data Sources

The petrochemical feedstocks storage factor is equal to the ratio of carbon stored in the final products to total carbon content for the non-energy fossil fuel feedstocks used in industrial processes, after adjusting for net exports of feedstocks. One aggregate storage factor was calculated to represent all eight fuel feedstock types. The feedstocks were grouped because of the overlap of their derivative products. Due to the many reaction pathways involved in producing petrochemical products (or wastes), it becomes extraordinarily complex to link individual products (or wastes) to their parent fuel feedstocks.

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[1] Naphthas are compounds distilled from petroleum containing 4 to 12 carbon atoms per molecule and having a boiling point less than 401° F. Other oils are distillates containing 12 to 25 carbon atoms per molecule and having a boiling point greater than 401° F.

Import and export data for feedstocks were obtained from the Energy Information Administration (EIA) for the major categories of petrochemical feedstocks. EIA's *Petroleum Supply Annual* (EIA 2001c) publication tracks imports and exports of petrochemical feedstocks, including butanes, butylenes, ethane, ethylene, propane, propylene, LPG, and naphthas (i.e., most of the large volume primary chemicals produced by petroleum refineries). These imports and exports are already factored into the U.S. fuel consumption statistics. However, EIA does not track imports and exports of chemical intermediates and products produced by the chemical industry (e.g., xylenes, vinyl chloride, polypropylene resins), which are derived from the primary chemicals produced by the refineries. These products represent very large flows of carbon derived from fossil fuels (i.e., fossil carbon), so estimates of net flows not already considered in EIA's dataset were developed for the entire time series from 1990 to 2003.

The approach to estimate imports and exports involves three steps:

Step 1. Identify commodities derived from petrochemical feedstocks, and calculate net import/export for each.
Step 2. Estimate the carbon content for each commodity.
Step 3. Sum the net carbon imports/exports across all commodities.

Step 1 relies heavily on information provided by the National Petrochemical and Refiners Association (NPRA) and trade statistics published by the U.S. Bureau of the Census (BoC). NPRA provided a spreadsheet of the ten-digit BoC Harmonized Tariff Schedule (HTS) Commodity Codes used to compile import-export data for periodic reports issued to NPRA's membership on trade issues. Additional feedstock commodities were identified by HTS code in the BoC data system and included in the net import/export analysis.

One of the difficulties in analyzing trade data is that a large portion of the outputs from the refining industry are fuels and fuel components, and it was difficult to segregate these from the outputs used for non-energy uses. The NPRA-supplied codes identify fuels and fuel components, thus providing a sound basis for isolating net imports/exports of petrochemical feedstocks. Although MTBE and related ether imports are included in the published NPRA data, these commodities are not included in the total net imports/exports calculated here, because it is assumed that they are fuel additives and do not contribute to domestic petrochemical feedstocks. Net exports of MTBE and related ethers *are* included in the totals, however, as these commodities are petrochemicals produced from fossil fuels for export, and deplete domestic petrochemical feedstocks. Imports and exports of commodities for which production and consumption data are provided by EIA (e.g., butane, ethylene, liquefied petroleum gases) are also not included in the totals, to avoid double counting.

The BoC trade statistics are publicly available[2] and cover a complete time series from 1990 to 2001. These statistics include information on imports and exports of thousands of commodities. After collecting information on annual flows of the more than 100 commodities identified by NPRA, Step 2 involves calculating the carbon content for each

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[2] See the U.S International Trade Commission (USITC) Trade Dataweb at <http://dataweb.usitc.gov/>.

commodity from its chemical formula. In cases where the imports and exports were expressed in units of volume, rather than mass, they were converted to mass based on the commodities’ densities.

Step 3 involves summing the net carbon imports/exports across all commodities. The results of this step are shown in Table 2. As shown in the table, the United States has been a net exporter of chemical intermediates and products throughout the 1990 to 2003 period.

Table 2: Net Exports of Petrochemical Feedstocks, 1990 – 2003 (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	2003*
Net Exports	28.7	34.5	29.1	31.1	27.0	26.9	26.3	32.6	24.3	22.9	23.5	9.5	9.5	9.5

* Data for 2002 and 2003 were not yet available, so they were held constant at the 2001 value

After adjusting for imports and exports, the carbon budget is adjusted for the quantity of carbon that is used in the industrial processes sector of the GHG Inventory. Fossil fuels used for non-energy purposes in industrial processes – and for which carbon emissions and storage have been characterized through mass balance calculations and/or emission factors that directly link the non-energy use fossil fuel raw material and the industrial process product – are not included in the non-energy use sector. These industrial processes (and their non-energy use fossil fuel raw materials) include iron and steel (coal coke), primary aluminum (petroleum coke), titanium oxide (petroleum coke), ferroalloys (petroleum coke), and ammonia and urea (petroleum coke and natural gas).

For each year in the Inventory, the total carbon content of non-energy uses was calculated by starting with the EIA estimate of non-energy use, and reducing it by the adjustment factor for net exports (see Table 2) to yield net domestic fuel consumption for non-energy. The balance was apportioned to either stored carbon or emissive carbon, based on a storage factor.

The overall storage factor for the feedstocks was determined by developing a mass balance on the carbon in feedstocks, and characterizing products, uses, and environmental releases as resulting in either storage or emissions. The total carbon in the system was estimated by multiplying net domestic consumption for non-energy by the carbon content of each of the feedstocks (i.e., industrial other coal, natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha). Carbon content values for the fuel feedstocks are discussed in Annexes A and B.

Next, carbon pools and releases in a variety of industrial releases, energy recovery processes, and products were characterized. The carbon fate categories are plastics, energy recovery, synthetic rubber, synthetic fibers, organic solvents, carbon black, detergents and personal cleansers, industrial non-methane volatile organic compound (NMVOC) emissions, hazardous waste incineration, industrial toxic chemical (i.e., TRI) releases, pesticides, and refinery wastewater discharges.[3]

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[3] For the most part, the releases covered by the U.S. Toxic Release Inventory (TRI) represent air emissions or water discharges associated with production facilities. Similarly, VOC emissions are generally associated with production facilities. These emissions could have been accounted for as part of the Waste chapter, but because they are not necessarily associated with waste management, they were included here. Toxic releases are not a “product” category, but they are referred to as such for ease of discussion.

The carbon in each product or waste produced was categorized as either stored or emitted. The aggregate storage factor is the carbon-weighted average of storage across fuel types. As discussed later in the section on uncertainty, the sum of stored carbon and emitted carbon (i.e., the outputs of the system) exceeded total carbon consumption (the inputs to the system) for some years in the time series.[4] To address this mass imbalance, the storage factor was calculated as carbon storage divided by total carbon outputs (rather than carbon storage divided by carbon inputs).

Note that the system boundaries for the storage factor do not encompass the entire life-cycle of fossil-based carbon consumed in the United States insofar as emissions of CO_2 from waste combustion are accounted for separately in the Inventory and are discussed in the Waste Combustion section of the Energy chapter.

The following sections provide details on the calculation steps, assumptions, and data sources employed in estimating and classifying the carbon in each product and waste shown in Table 3. Summing the carbon stored and dividing it by total carbon outputs yields the overall storage factor, as shown in the following equation for 2003:

$$\text{Overall Storage Factor} = \text{Carbon Stored} / (\text{Carbon Stored} + \text{Carbon Emitted}) =$$
$$145.0 \text{ Tg } CO_2 \text{ Eq.} / (145.0 + 77.8) \text{ Tg } CO_2 \text{ Eq.} = 65\ \%$$

Table 3: Carbon Stored and Emitted by Products from Feedstocks in 2003 (Tg CO_2 Eq.)

Product/Waste Type	Carbon Stored	Carbon Emitted
Industrial Releases	0.1	5.4
TRI Releases	*0.1*	*1.0*
Industrial VOCs	-	*2.0*
Non-combustion CO	-	*0.9*
Refinery wastewater	-	*0.1*
Hazardous Waste Incin.	-	*1.4*
Energy Recovery	-	58.1
Products	144.9	13.6
Plastics	*123.1*	-
Synthetic Rubber	*10.9*	-
Abraded tire rubber	-	*0.7*
Synthetic Fiber	*10.6*	-
Pesticides	*0.3*	*0.2*
Soaps, shampoos, detergents	-	*4.9*
Solvent VOCs	-	*8.5*
Total	145.0	77.8

- Not applicable

Note: Totals may not sum due to independent rounding.

The three categories of carbon accounted for in the table are industrial releases, energy recovery, and products. Each is discussed below.

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[4] Overall, there was fairly close agreement between inputs and outputs; for the entire 1990 – 2003 time series, outputs exceeded inputs by 0.2 percent. During the period 1993 – 1999, carbon inputs exceeded carbon outputs (i.e., the sum of carbon stored and carbon emitted), and for those years, the assumption was made that the “missing” carbon was lost through fates leading to emissions.

(i) Industrial Releases

Industrial releases include toxics reported through the Toxics Release Inventory, industrial emissions of volatile organic compounds (VOCs), carbon monoxide emissions (other than those related to fuel combustion), treatment of refinery wastewater, and hazardous waste incineration.

(ii) TRI Releases

Fossil-derived carbon is found in many toxic substances released by industrial facilities. The Toxics Release Inventory (TRI), maintained by EPA, tracks these releases by chemical and environmental release medium (i.e., land, air, or water) on a biennial basis (EPA 2000b). By examining the carbon contents and receiving media for the top 35 toxic chemicals released, which account for 90 percent of the total mass of chemicals, the quantity of carbon stored and emitted in the form of toxic releases can be estimated.

The TRI specifies releases by chemical, so carbon contents were assigned to each chemical based on molecular formula. The TRI also classifies releases by disposal location as either off-site or on-site. The on-site releases are further subdivided into air emissions, surface water discharges, underground injection, and releases to land; the latter is further broken down to disposal in a RCRA Subtitle C (i.e., hazardous waste) landfill or to “Other On-Site Land Disposal.”[5] The carbon released in each disposal location is provided in Table 4.

Each on-site classification was assigned a storage factor. A one hundred percent storage factor was applied to disposition of carbon to underground injection and to disposal to RCRA-permitted landfills, while the other disposition categories were assumed to result in an ultimate fate of emission as CO_2 (i.e., a storage factor of zero was applied to these categories.) The release allocation is not reported for off-site releases; therefore, the approach was to develop a carbon-weighted average storage factor for the on-site carbon and apply it to the off-site releases.

For the remaining 10 percent of the TRI releases, the weights of all chemicals were added and an average carbon content value, based upon the top 35 chemicals’ carbon contents, was applied. The storage and emission allocation for the remaining 10 percent of the TRI releases was carried out in the same fashion as for the 35 major chemicals.

Data on TRI releases for the full 1990-2003 time series were not readily available. Since this category is small (less than 1 MMTC emitted and stored), the 1998 value was applied for the entire time series.

Table 4: 1998 TRI Releases by Disposal Location (Gg CO_2 Eq.)

Disposal Location	Carbon Stored	Carbon Emitted
Air Emissions	-	924.0
Surface Water Discharges	-	6.7
Underground Injection	89.4	-
RCRA Subtitle C Landfill Disposal	1.4	-

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[5] Only the top 9 chemicals had their land releases separated into RCRA Landfills and Other Land Disposal. For the remaining chemicals, it was assumed that the ratio of disposal in these two categories was equal to the carbon-weighted average of the land disposal fate of the top 9 chemicals (i.e., 8 percent attributed to RCRA Landfills and 92 percent in the “Other” category).

Other On-Site Land Releases	-	15.9
Off-site Releases	6.4	36.0
Total	97.2	982.6

- Not applicable

Note: Totals may not sum due to independent rounding.

(i) Volatile Organic Compound Emissions from Industrial Processes and Solvent Evaporation Emissions

Data on annual non-methane volatile organic compound (NMVOC) emissions were obtained from National Air Quality and Emissions Trends Report data (EPA 2004). The 1990-2003 Trends Report data include information on NMVOC emissions by end-use category; some of these fall into the heading of "industrial releases" in Table 4 above, and others are related to "product use"; for ease of discussion, both are covered here. The end-use categories that represent "Industrial NMVOC Emissions" include chemical and allied products, metals processing, and other industrial processes. NMVOC emissions from solvent utilization (product use) were considered to be a result of non-energy use of petrochemical feedstocks. These categories were used to distinguish non-energy uses from energy uses; other categories where VOCs could be emitted due to combustion of fossil fuels were excluded to avoid double counting.

Because solvent evaporation and industrial NMVOC emission data are provided in tons of total NMVOCs, assumptions were made concerning the average carbon content of the NMVOCs for each category of emissions. The assumptions for calculating the carbon fraction of industrial and solvent utilization emissions were made separately and differ significantly. For industrial NMVOC emissions, a carbon content of 85 percent was assumed. This value was chosen to reflect the carbon content of an average volatile organic compound based on the list of the most abundant NMVOCs provided in the Trends Report. The list contains only pure hydrocarbons, including saturated alkanes (carbon contents ranging from 80 to 85 percent based upon carbon number), alkenes (carbon contents approximately 85.7 percent), and some aromatics (carbon contents approximately 90 percent, depending upon substitution).

An EPA solvent evaporation emissions dataset (Tooly 2001) was used to estimate the carbon content of solvent emissions. The dataset identifies solvent emissions by compound or compound category for six different solvent end-use categories: degreasing, graphic arts, dry cleaning, surface coating, other industrial processes, and non-industrial processes. The percent carbon of each compound identified in the dataset was calculated based on the molecular formula of the individual compound (e.g., the carbon content of methylene chloride is 14 percent; the carbon content of toluene is 91 percent). For solvent emissions that are identified in the EPA dataset only by chemical category (e.g., butanediol derivatives) a single individual compound was selected to represent each category, and the carbon content of the category was estimated based on the carbon content of the representative compound. The overall carbon content of the solvent evaporation emissions for 1998, estimated to be 56 percent, is assumed to be constant across the entire time series.

The results of the industrial and solvent NMVOC emissions analysis are provided in Table 5 for 1990 through 2003. Solvent evaporation emissions in 2003 were 8.5 Tg CO$_2$ eq., and industrial NMVOC emissions in 2003 were 2.0 Tg CO$_2$ eq. In 2004, NMVOC and solvent activity data were revised across the entire time series to reflect updated information from the 2003 National Air Quality and Emissions Trends Report.

Table 5: Industrial and Solvent NMVOC Emissions

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Industrial NMVOCs[a]														
NMVOCs ('000 Short Tons)	1,157	1,224	1,254	1,267	1,254	1,235	896	904	915	755	775	753	689	702
Carbon Content (%)	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%
Carbon Emitted (Tg CO_2 Eq.)	3.3	3.5	3.5	3.6	3.5	3.5	2.5	2.6	2.6	2.1	2.2	2.1	1.9	2.0
Solvent Evaporation[b]														
Solvents ('000 Short Tons)	5,750	5,782	5,901	6,016	6,162	6,183	5,477	5,622	5,149	5,037	4,832	5,012	4,692	4,562
Carbon Content (%)	56%	56%	56%	56%	56%	56%	56%	56%	56%	56%	56%	56%	56%	56%
Carbon Emitted (Tg CO_2 Eq.)	10.8	10.8	11.0	11.3	11.5	11.6	10.3	10.5	9.6	9.4	9.0	9.4	8.8	8.5

[a] Includes emissions from chemical and allied products, petroleum and related industries, and other industrial processes categories.

[b] Includes solvent usage and solvent evaporation emissions from degreasing, graphic arts, dry cleaning, surface coating, other industrial processes, and non-industrial processes.

(i) Non-Combustion Carbon Monoxide Emissions

Carbon monoxide (CO) emissions data were also obtained from the 2003 National Air Quality and Emissions Trends Report (EPA 2004). There are four categories of CO emissions in the report that are classified as process-related emissions not related to fuel combustion. These include chemical and allied products manufacturing, metals processing, and other industrial processes. Some of these CO emissions are accounted for in the Industrial Processes section of this report, and are therefore not accounted for in this section. These include total carbon emissions from the primary aluminum, titanium dioxide, iron and steel, and ferroalloys production processes. The total carbon (CO and CO_2) emissions from oil and gas production and asphalt manufacturing are also accounted for elsewhere in this Inventory. Sustainably harvested biogenic emissions (e.g., pulp and paper process emissions) are also excluded from calculation of CO emissions in this section. Those CO emissions that are not accounted for elsewhere are considered to be byproducts of non-fuel use of feedstocks and are included in the calculation of the petrochemical feedstocks storage factor. Table 6 lists the CO emissions that remain after taking into account the exclusions listed above.

Table 6: Non-Combustion Carbon Monoxide Emissions[a]

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Thousand short tons CO	489	441	454	486	481	481	552	570	567	605	623	650	633	656
Carbon Emitted (Tg CO_2 Eq.)	0.7	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9

[a] Includes emissions from chemical and allied products, petroleum and related industries, metals processing, and other industrial processes categories.

(i) Refinery Wastewater

Carbon flows associated with the treatment and discharge of refinery wastewater are included in the mass balance. To develop an estimate of annual emissions associated with the wastewater, it was assumed that the average concentration of Total Organic Carbon in refinery effluents was 10.5 mg/L, based on 1992 data reported in EPA's Permit Compliance System. It was also assumed that (a) the overall treatment efficiency (excluding recycling of oil back to the refinery) was 90 percent, (b) average flow is about 1 million gallons per day (3,800 m^3/day), there are 192 operating refineries in the United States, (c) the majority of organic compounds in refinery wastewater are not covered by the TRI requirements (and thus there is no significant double-counting of releases with the TRI estimate), and (d) all of the carbon in the raw wastewater is destined for emission as CO_2. Based on these assumptions, annual emissions are roughly 0.1 Tg CO_2 Eq. Note that fugitive air emissions of methane from treatment of refinery wastewater are already accounted for in the Inventory in the category of "Petroleum Systems," but other fugitive air emissions and discharges of wastewater to surface water or publicly owned treatment works are not included elsewhere in the Inventory. More recent data on refinery effluents has not been found, and thus the entire time series has been assumed to have the same value as 1992.

(ii) Hazardous Waste Incineration

Hazardous wastes are defined by the EPA under the Resource Conservation and Recovery Act (RCRA).[6] Industrial wastes, such as rejected products, spent reagents, reaction by-products, and sludges from wastewater or air pollution control, are federally regulated as hazardous wastes if they are found to be ignitable, corrosive, reactive, or toxic according to standardized tests or studies conducted by the EPA.

Hazardous wastes must be treated prior to disposal according to the federal regulations established under the authority of RCRA. Combustion is one of the most common techniques for hazardous waste treatment, particularly for those wastes that are primarily organic in composition or contain primarily organic contaminants. Generally speaking, combustion devices fall into two categories: incinerators that burn waste solely for the purpose of waste management, and boilers and industrial furnaces (BIFs) that burn waste in part to recover energy from the waste. More than half of the hazardous waste combusted in the U.S. is burned in BIFs; these processes are included in the energy recovery calculations described below.

EPA's Office of Solid Waste requires biennial reporting of hazardous waste management activities, and these reports provide estimates of the amount of hazardous waste burned for incineration or energy recovery. EPA stores this information in its Biennial Reporting System (BRS) database (EPA 2000a, 2004). Combusted hazardous wastes are identified based on EPA-defined management system types M041 through M049 (incineration). Combusted quantities are grouped into four representative waste form categories based on the form codes reported in the BRS: aqueous liquids, organic liquids and sludges, organic solids, and inorganic solids. To relate hazardous waste quantities to carbon emissions, "fuel equivalent" factors were derived for hazardous waste by assuming that the hazardous wastes

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[6] [42 U.S.C. §6924, SDWA §3004]

are simple mixtures of a common fuel, water, and noncombustible ash. For liquids and sludges, crude oil is used as the fuel equivalent and coal is used to represent solids.

Fuel equivalent factors were multiplied by the tons of waste incinerated to obtain the tons of fuel equivalent. Multiplying the tons of fuel equivalent by the carbon content factors (discussed in Annex A) yields tons of carbon emitted. Implied carbon content is calculated by dividing the tons of carbon emitted by the associated tons of waste incinerated.

Waste quantity data for hazardous wastes were obtained from EPA's BRS database for reporting years 1989, 1991, 1993, 1995, 1997, 1999, and 2001 (EPA 2000a, 2004). Values for years after 2001 were held constant at the 2001 level. Combusted waste quantities were obtained from Form GM (Generation and Management) for wastes burned on site and Form WR (Wastes Received) for waste received from off-site for combustion. For each of the waste types, assumptions were developed on average waste composition (see Table 7). Regulations require incinerators to achieve at least 99.99 percent destruction of organics; this formed the basis for assuming the fraction of carbon oxidized.

Table 7: Assumed Composition of Combusted Hazardous Waste by Weight (Percent)

Waste Type	Water	Noncombustibles	Fuel Equivalent
Aqueous Waste	90	5	5
Organic Liquids and Sludges	40	20	40
Organic Solids	20	40	40
Inorganic Solids	20	70	10

(i) Energy Recovery

The amount of feedstocks combusted for energy recovery was estimated from data included in EIA's Manufacturers Energy Consumption Survey (MECS) for 1991, 1994, and 1998 (EIA 1994, 1997, 2001b). Some fraction of the fossil carbon exiting refineries and designated for use for feedstock purposes actually ends up being combusted for energy recovery (despite the designation of feedstocks as a "non-energy" use) because the chemical reactions in which fuel feedstocks are used are not 100 percent efficient. These chemical reactions may generate unreacted raw material feedstocks or generate byproducts that have a high energy content. The chemical industry and many downstream industries are energy-intensive and often have boilers or other energy recovery units on-site, and thus these unreacted feedstocks or byproducts are often combusted for energy recovery. Also, as noted above in the section on hazardous waste incineration, regulations provide a strong incentive—and in some cases require—burning of organic wastes generated from chemical production processes.

Information available from the MECS include data on the consumption for energy recovery of "other" fuels in the petroleum and coal products, chemicals, primary metals, nonmetallic minerals, and other manufacturing sectors. These "other" fuels include refinery still gas; waste gas; waste oils, tars, and related materials; petroleum coke, coke oven and blast furnace gases; and other uncharacterized fuels. Fuel use of petroleum coke is included separately in the fuel use data provided annually by EIA, and energy recovery of coke oven gas and blast furnace gas (i.e., byproducts of the iron and steel production process) is addressed in the Iron and Steel production section in the Industrial Processes chapter. Consumption of refinery still gas in the refinery sector is also included separately in the fuel use data from EIA. Consumption of net steam, assumed to be generated from fossil fuel combustion, is also included separately in the fuel use data from EIA. Therefore these categories of "other" fuels are addressed elsewhere in the Inventory and not considered as part of the petrochemical feedstocks energy recovery analysis. The remaining categories of fuels, including waste gas; waste oils, tars, and related materials; and other uncharacterized fuels are assumed to be petrochemical feedstocks burned for energy recovery (see Table 8). The conversion factors listed in Annex A were used to convert the Btu values for each fuel feedstock to Tg CO_2. Petrochemical feedstocks combusted for energy recovery corresponded to 42.2 Tg CO_2 Eq. in 1991, 35.4 Tg CO_2 Eq. in 1994, and 58.1 Tg CO_2 Eq. in 1998. Values for petrochemical feedstocks burned for energy recovery for years between 1991 and 1994 and between 1994 and 1998 have been estimated by interpolation. The value for 1990 is assumed to be the same as the value for 1991, and values for years subsequent to 1998 are assumed to be the same as the value for 1998 (Table 9).

Table 8: Carbon Emitted from Fuels Burned for Energy Recovery (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Emissions	42.2	42.2	40.0	37.7	35.4	41.1	46.8	52.4	58.1	58.1	58.1	58.1	58.1	58.1

Table 9: Summary of 1998 MECS Data for Other Fuels Used in Manufacturing/Energy Recovery (Trillion Btu)

Subsector and Industry	NAICS CODE	Waste Gas[a]	Waste Oils/Tars[b]	Refinery Still Gas[c]	Net Steam[d]	Other Fuels[e]
Printing and Related Support	323	0	1	0	0	1
Petroleum and Coal Products	324	0	1	1399	93	231
Chemicals	325	416	16	0	194	118
Plastics and Rubber Products	326	0	0	0	5	0
Nonmetallic Mineral Products	327	2	9	0	0	14
Primary Metals	331	2	2	0	17	5
Fabricated Metal Products	332	1	0	0	2	4
Machinery	333	0	1	0	1	2
Computer and Electronic Products	334	0	0	0	1	0
Electrical Equip., Appliances, Components	335	1	1	0	2	0
Transportation Equipment	336	1	2	0	7	19
Miscellaneous	337	0	0	0	0	2
Total (Trillion BTUs)		423	33	1399	323	395
Average Carbon Content (Tg/QBTU)		18.14	20.62	17.51	0	19.37
Fraction Oxidized		0.99	0.99	0.99	0	0.99
Total Carbon (Tg)		7.60	0.67	24.25		7.58
Total Carbon (Tg) (exc still gas from refining)		7.60	0.67	0.00		7.58

[a] Carbon content: Waste Gas is assumed to be same as naphtha <401 deg. F

[b] Carbon content: Waste Oils/Tars is assumed to be same as asphalt/road oil

[c] Refinery "still gas" fuel consumption is reported elsewhere in the Inventory and is excluded from the total carbon content estimate

[d] Net steam fuel consumption is reported elsewhere in the Inventory and is excluded from the total carbon content estimate

[e] Carbon content: "Other" is assumed to be the same as petrochemical feedstocks

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(i) Products

More carbon is found in products than in industrial releases or energy recovery. The principal types of products are plastics; synthetic rubber; synthetic fiber; carbon black; pesticides; soaps, detergents, and cleansers; and solvents. Solvent evaporation was discussed previously along with industrial releases of NMVOCs; the other product types are discussed below.

Plastics

Data on annual production of plastics were taken from the American Plastics Council (APC), as published in *Chemical & Engineering News* and on the APC and Society of Plastics Industry (SPI) websites, and through direct communication with the APC (APC 2000, 2001, 2003, 2004; SPI 2000; Eldredge-Roebuck 2000). These data were organized by year and resin type (see Table 10). Several of the resin categories included production from Canada and/or Mexico, in addition to the U.S. values for part of the time series. The data for the affected resins and years were corrected using an economic adjustment factor, based on the percent of North American production value in this industry sector accounted for by the United States. A carbon content was then assigned for each resin. These contents were based on molecular formulas and are listed in Table 11 and Table 12. In cases where the resin type is generic, referring to a group of chemicals and not a single polymer (e.g., phenolic resins, other styrenic resins), a representative compound was chosen. For engineering resins and other resins, a weighted carbon content of 65 percent was assumed (i.e., it was assumed that these resins had the same content as those for which a representative compound could be assigned).

There were no emissive uses of plastics identified, so 100 percent of the carbon was considered stored in products. However, an estimate of emissions related to the combustion of these plastics in the municipal solid waste stream can be found in the Waste Combustion section of the Energy chapter.

Table 10: 2003 Plastic Resin Production (Tg dry weight) and Carbon Stored (Tg CO_2 Eq.)

Resin Type	2003 Production[a]	Carbon Stored
Epoxy	0.27	0.7
Urea	0.68	0.9
Melamine	0.68	0.7
Phenolic	1.90	5.3
Low-Density Polyethylene (LDPE)	3.35	10.5
Linear Low-Density Polyethylene (LLDPE)	4.77	15.0
High Density Polyethylene (HDPE)	6.70	21.1
Polypropylene (PP)	7.50	23.6
Acrylonitrile-butadiene-styrene (ABS)	0.50	1.6
Styrene-acrylonitrile (SAN)	0.06	0.2
Other Styrenics	0.66	2.2
Polystyrene (PS)	2.75	9.3
Nylon	0.53	1.3
Polyvinyl chloride (PVC) [b]	6.28	8.8
Thermoplastic Polyester	3.13	7.2
Engineering Resins	1.12	2.7
All Other (including Polyester (unsaturated))	4.95	12.0
Total	45.83	123.1

[a] Originally included production from Canada for Urea, Melamine, LDPE, LLDPE, HDPE, PP, ABS, SAN, Phenolic, Other Styrenics, PS, Nylon, PVC, Thermoplastic Polyester, and Engineering Resins, and production from Mexico for ABS, SAN, Other Styrenics, Nylon, and Thermoplastic Polyester. Values have been adjusted to account just for U.S. production.

[b] Includes copolymers

Note: Totals may not sum due to independent rounding.

Table 11: Assigned Carbon Contents of Plastic Resins (by weight)

Resin Type	Carbon Content	Source of Carbon Content Assumption
Epoxy	76%	Typical epoxy resin made from epichlorhydrin and bisphenol A
Polyester (Unsaturated)	63%	Poly (ethylene terepthalate) (PET)
Urea	34%	50% carbamal, 50% N-(hydroxymethyl) urea *
Melamine	29%	Trimethylol melamine *
Phenolic	77%	Phenol
Low-Density Polyethylene (LDPE)	86%	Polyethylene
Linear Low-Density Polyethylene (LLDPE)	86%	Polyethylene
High Density Polyethylene (HDPE)	86%	Polyethylene
Polypropylene (PP)	86%	Polypropylene
Acrylonitrile-Butadiene-Styrene (ABS)	85%	50% styrene, 25% acrylonitrile, 25% butadiene
Styrene-Acrylonitrile (SAN)	80%	50% styrene, 50% acrylonitrile
Other Styrenics	92%	Polystyrene
Polystyrene (PS)	92%	Polystyrene
Nylon	65%	Average of nylon resins (see Table 12)
Polyvinyl Chloride (PVC)	38%	Polyvinyl chloride
Thermoplastic Polyester	63%	Polyethylene terephthalate
Engineering Resins	66%	Weighted average of other resin production
All Other	66%	Weighted average of other resin production

*Does not include alcoholic hydrogens.

Table 12: Major Nylon Resins and their Carbon Contents (by weight)

Resin	Carbon Content
Nylon 6	64%
Nylon 6,6	64%
Nylon 4	52%
Nylon 6,10	68%
Nylon 6,11	69%
Nylon 6,12	70%
Nylon 11	72%

(i) Synthetic Rubber

Data on synthetic rubber in tires were derived from data on the scrap tire market and the composition of scrap tires from the Rubber Manufacturers' Association's (RMA) Scrap Tire Management Council (STMC). The market information is presented in the report *U.S. Scrap Tire Markets 2001* (RMA 2002), while the tire composition information is from the "Scrap Tires, Facts and Figures" section of the organization's website (STMC 2003). No data were available for 2002 and 2003, so tire consumption for these years was assumed to equal 2001 consumption. Data on synthetic rubber in other products (durable goods, nondurable goods, and containers and packaging) were obtained from EPA's *Municipal Solid Waste in the United States* reports (1996, 1997, 1998a, 1999a, 2000c,d, 2001a, 2002b, and 2003). The abraded rubber from scrap passenger tires was assumed to be 5 lbs per scrap tire while the abraded rubber from scap truck tires was assumed to be 20 lbs per scrap tire. Data on abraded rubber weight were obtained by calculating the average weight difference between new and scrap tires (STMC 2003).

A carbon content for synthetic rubber (90% for tire synthetic rubber and 85% for non-tire synthetic rubber) was assigned based on the weighted average of carbon contents (based on molecular formula) by elastomer type consumed in 1998 (see Table 13). The 1998 consumption data were obtained from the International Institute of Synthetic Rubber Producers (IISRP) press release "Synthetic Rubber Use Growth to Continue Through 2004, Says IISRP and RMA" (IISRP 2000).

The rubber in tires that is abraded during use (the difference between new tire and scrap tire rubber weight) was considered to be 100 percent emitted. Other than abraded rubber, there were no emissive uses of scrap tire and non-tire rubber identified, so 100 percent was assumed stored. Emissions related to the combustion of rubber in scrap tires and consumer goods can be found in the Waste Combustion section of the Energy chapter.

Table 13: 1998 Rubber Consumption and Carbon Content

Elastomer Type	1998 Consumption (Thousand Metric Tons)*	Carbon Content
SBR Solid	908	91%
Polybutadiene	561	89%
Ethylene Propylene	320	86%
Polychloroprene	69	59%
NBR Solid	87	77%
Polyisoprene	78	88%
Others	369	88%
Weighted Average	-	90%
Total	2,392	-

* Includes consumption in Canada.

- Not applicable
Note: Totals may not sum due to independent rounding.

(ii) Synthetic Fibers

Annual synthetic fiber production data were obtained from the Fiber Economics Bureau, as published in *Chemical & Engineering News* (2001, 2003). These data are organized by year and fiber type. For each fiber, a carbon content was assigned based on molecular formula (see Table 14). For polyester, the carbon content for poly(ethylene terephthalate) (PET) was used as a representative compound. For nylon, the average carbon content of nylon 6 and nylon 6,6 was used, since these are the most widely produced nylon fibers. Cellulosic fibers, such as acetate and rayon, have been omitted from the synthetic fibers' carbon accounting because much of their carbon is of biogenic origin. These fibers account for only 4 percent of overall fiber production by weight.

There were no emissive uses of fibers identified, so 100 percent of the carbon was considered stored. Note that emissions related to the combustion of textiles in municipal solid waste are accounted for under the Waste Combustion section of the Energy chapter.

Table 14: 2003* Fiber Production, Carbon Content, and Carbon Stored

Fiber Type	Production (Tg)	Carbon Content	Carbon Stored (Tg CO_2 Eq.)
Polyester	1.5	63%	3.4
Nylon	1.1	64%	2.6
Olefin	1.4	86%	4.2
Acrylic	0.2	68%	0.4
Total	4.1	-	10.6

* 2003 production data were not available yet, so these values are set equal to 2002 production
- Not applicable
Note: Totals may not sum due to independent rounding

(iii) Pesticides

Pesticide consumption data were obtained from the *1994/1995, 1996/1997, and 1998/1999 Pesticides Industry Sales and Usage Market Estimates* (EPA 1998b, 1999b, 2002c) reports. The most recent data available were for 1999, so it was assumed that 2000—2003 consumption was equal to that of 1999. Active ingredient compound names and consumption weights were available for the top 25 agriculturally-used pesticides and top 10 pesticides used in the home and garden and the industry/commercial/government categories. The report provides a range of consumption for each active ingredient; the midpoint was used to represent actual consumption. Each of these compounds was assigned a carbon content value based on molecular formula. If the compound contained aromatic rings substituted with chlorine or other halogens, then the compound was considered persistent and the carbon in the compound was assumed to be stored. All other pesticides were assumed to release their carbon to the atmosphere. Over one-third of 1999 total pesticide active ingredient consumption was not specified by chemical type in the *Sales and Usage* report (EPA 2002c). This unspecified portion of the active ingredient consumption was treated as a single chemical and assigned a carbon content and a storage factor based on the weighted average of the known chemicals' values.

Table 15: Active Ingredient Consumption in Pesticides (Million lbs.) and Carbon Emitted and Stored (Tg CO$_2$ Eq.)

Pesticide Use*	Active Ingredient	Carbon Emitted	Carbon Stored
Agricultural Uses [a]	475.0	0.1	0.2
Non-Agricultural Uses [b]	80.5	+	+
Home & Garden	33.5	+	+
Industry/Gov't/Commercial	47.0	+	+
Other	356.5	0.1	0.1
Total	912.0	0.2	0.3

+ Less than 0.05 Tg CO$_2$ Eq.
*1999 estimates (EPA 2002c).
Note: Totals may not sum due to independent rounding.

(iv) Soaps, Shampoos, and Detergents

Cleansers—soaps, shampoos, and detergents—are among the major consumer products that may contain fossil carbon. All of the carbon in cleansers was assumed to be fossil-derived, and, as cleansers eventually biodegrade, all of the carbon was assumed to be emitted. The first step in estimating carbon flows was to characterize the “ingredients” in a sample of cleansers. For this analysis, cleansers were limited to the following personal household cleaning products: bar soap, shampoo, laundry detergent (liquid and granular), dishwasher detergent, and dishwashing liquid. Data on the annual consumption of household personal cleansers were obtained from the U.S. Census Bureau 1997 Economic Census. Due to resource constraints, and the small mass of carbon in this category, the year 1997 was taken to be representative of the entire time series.

Chemical formulae were used to determine carbon contents (as percentages) of the ingredients in the cleansers. Each product’s overall carbon content was then derived from the composition and contents of its ingredients. From these values the mean carbon content for cleansers was calculated to be 21.9 percent.

The Census Bureau presents consumption data in terms of quantity (in units of million gallons or million pounds) and/or terms of value (thousands of dollars) for eight specific categories, such as “household liquid laundry detergents, heavy duty” and “household dry alkaline automatic dishwashing detergents.” Additionally, the report provides dollar values for the total consumption of “soaps, detergents, etc.—dry” and “soaps, detergents, etc.—liquid.” The categories for which both quantity and value data are available is a subset of total production. Those categories that presented both quantity and value data were used to derive pounds per dollar and gallons per dollar conversion rates, and they were extrapolated (based on the Census Bureau estimate of total value) to estimate the total quantity of dry and liquid[7] cleanser categories, respectively.

Next, the total tonnage of cleansers was calculated (wet and dry combined). Multiplying the mean carbon content (21.9 percent) by this value yielded an estimate of 4.9 Tg CO$_2$ Eq. in cleansers.

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[7] A density of 1.05 g/mL—slightly denser than water—was assumed for liquid cleansers.

(v) Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the estimates of the feedstocks carbon storage factor and the quantity of carbon emitted from feedstocks in 2003. Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. Uncertainty estimates for production data (the majority of the variables) were assumed to exhibit a normal distribution with a moderate relative error of ±35 percent, in part, due to assumptions relating to the feedstock exporting. The greatest uncertainty range, ±45 and an associated standard deviation of 121.7 TBtu, was applied to the production of other oils (>401 deg. F). A narrow uniform distribution was applied to each carbon coefficient.

The Monte Carlo analysis produced a storage factor distribution that approximates a normal curve around a mean of 64.9 percent, with a standard deviation of 1 percent and 95 percent confidence limits of 63 percent and 67 percent. This compares to the calculated estimate, used in the Inventory, of 65 percent. The analysis produced a carbon emission distribution approximating a normal curve with a mean of 75.45 Tg CO_2 eq, standard deviation of 2.0 Tg CO_2 eq, and 95% confidence limits of 61.0 and 90.5 Tg CO_2 eq. This compares with a calculated estimate of 75.26 Tg CO_2 Eq. The uncertainty emission distribution does not currently capture additional emissions from industrial other coal, which constitutes less than 0.5 Tg CO_2 to the overall estimate of feedstocks emissions; improvements to include other industrial coal in the uncertainty analysis will be made in future Inventories.

The apparently tight confidence limits for the storage factor and carbon storage probably understate uncertainty, as a result of the way this initial analysis was structured. As discussed above, the storage factor for feedstocks is based on an analysis of five fates that result in long-term storage (e.g., plastics production), and ten that result in emissions (e.g., volatile organic compound emissions). Rather than modeling the total uncertainty around all 15 of these fate processes, the current analysis addresses only the storage fates, and assumes that all carbon that is not stored is emitted. As the production statistics that drive the storage factors are relatively well-characterized, this approach yields a result that is probably biased toward understating uncertainty.

As far as specific sources of uncertainty, there are several cross-cutting factors that pervade the characterization of carbon flows for feedstocks. The aggregate storage factor for petrochemical feedstocks (industrial other coal, natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha) is based on assuming that the ultimate fates of all of these fuel types —in terms of storage and emissions—are similar. In addition, there are uncertainties associated with the simplifying assumptions made for each end use category carbon estimate. Generally, the estimate for a product is subject to one or both of the following uncertainties:

- The value used for estimating the carbon content has been assumed or assigned based upon a representative compound.

- The split between carbon storage and emission has been assumed based on an examination of the environmental fate of the products in each end use category.
- Environmental fates leading to emissions are assumed to operate rapidly, i.e., emissions are assumed to occur within one year of when the fossil carbon enters the non-energy mass balance. Some of the pathways that lead to emissions as CO2 may take actually place on a time-scale of several years or decades. By attributing the emissions to the year in which the carbon enters the mass balance (i.e., the year in which it leaves refineries as a non-energy fuel use and thus starts being tracked by EIA), this approach has the effect of “front-end loading” the emission profile.

Another cross-cutting source of uncertainty is that for several sources the amount of carbon stored or emitted was calculated based on data for only a single year. This specific year may not be representative of storage for the entire Inventory period. Sources of uncertainty associated with specific elements of the analysis are discussed below.

Import and export data for petrochemical feedstocks were obtained from EIA, the National Petroleum Refiners Association, and the U.S. BoC for the major categories of petrochemical feedstocks (EIA 2001a, NPRA 2001, and U.S. BoC 2003). The list of commodities for which imports and exports were analyzed is not comprehensive in tracking fossil fuel-derived feedstocks and may underestimate net exports of carbon.

Oxidation factors have been applied to non-energy uses of petrochemical feedstocks in the same manner as for energy uses. However, this “oxidation factor” may be inherent in the storage factor applied when calculating emissions from non-energy consumption, which would result in a double-counting of the unoxidized carbon. Oxidation factors are small corrections, on the order of 1 percent, and therefore application of oxidation factors to non-energy uses may result in a slight underestimation of carbon emissions from non-energy uses.

The major uncertainty in using the TRI data are the possibility of double counting of emissions that are already accounted for in the NMVOC data (see above) and in the storage and emission assumptions used. The approach for predicting environmental fate simplifies some complex processes, and the balance between storage and emissions is very sensitive to the assumptions on fate. Extrapolating from known to unknown characteristics also introduces uncertainty. The two extrapolations with the greatest uncertainty are: 1) that the release media and fate of the off-site releases were assumed to be the same as for on-site releases, and 2) that the carbon content of the least frequent 10 percent of TRI releases was assumed to be the same as for the chemicals comprising 90 percent of the releases. However, the contribution of these chemicals to the overall estimate is small. The off-site releases only account for 3 percent of the total releases, by weight, and, by definition, the less frequent compounds only account for 10 percent of the total releases.

The principal sources of uncertainty in estimating CO_2 emissions from solvent evaporation and industry are in the estimates of total NMVOC emissions and in the application of factors for the carbon content of these emissions. Solvent evaporation and industrial NMVOC emissions reported by EPA are based on a number of data sources and emission factors, and may underestimate or overestimate emissions. The carbon content for solvent evaporation emissions is calculated directly from the specific solvent compounds identified by EPA as being emitted, and is thought to have relatively low uncertainty. The carbon content for industrial emissions has more uncertainty, however, as it is calculated from the average carbon content of an average volatile organic compound based on the list of the most abundant measured NMVOCs provided in EPA (2002a).

Uncertainty in the hazardous waste combustion analysis is introduced by the assumptions about the composition of combusted hazardous wastes, including the characterization that hazardous wastes are similar to mixtures of water, noncombustibles, and fuel equivalent materials. Another limitation is the assumption that all of the carbon that enters hazardous waste combustion is emitted—some small fraction is likely to be sequestered in combustion ash—but given that the destruction and removal efficiency for hazardous organics is required to meet or exceed 99.99 percent, this is a very minor source of uncertainty. Carbon emission estimates from hazardous waste should be considered central value estimates that are likely to be accurate to within ±50 percent.

The amount of feedstocks combusted for energy recovery was estimated from data included in the Manufacturers Energy Consumption Surveys (MECS) for 1991, 1994, and 1998 (EIA 1994, 1997, 2001b). Data from the MECS conducted for calendar year 2002 and 2003 was not yet available. MECS is a comprehensive survey that is conducted every four years and intended to represent U.S. industry as a whole, but because EIA does not receive data from all manufacturers (i.e., it is a sample rather than a census), EIA must extrapolate from the sample. Also, the "other" fuels are identified in the MECS data in broad categories, including refinery still gas; waste gas; waste oils, tars, and related materials; petroleum coke, coke oven and blast furnace gases; and other uncharacterized fuels. Moreover, the industries using these "other" fuels are also identified only in broad categories, including the petroleum and coal products, chemicals, primary metals, nonmetallic minerals, and other manufacturing sectors. The "other" fuel consumption data are reported in BTUs (energy units) and there is uncertainty concerning the selection of a specific conversion factor for each broad "other" fuel category to convert energy units to mass units. Taken as a whole, the estimate of energy recovery emissions probably introduces more uncertainty than any other element of the non-energy analysis.

Uncertainty in the carbon storage estimate for plastics arises primarily from three factors. First, the raw data on production for several resins include Canadian and/or Mexican production and may overestimate the amount of plastic produced from U.S. fuel feedstocks; this analysis includes adjustments to "back out" the Canadian and Mexican values, but these adjustments are approximate. Second, the assumed carbon content values are estimates for representative compounds, and thus do not account for the many formulations of resins available. This uncertainty is greater for resin categories that are generic (e.g., phenolics, other styrenics, nylon) than for resins with more specific formulations (e.g., polypropylene, polyethylene). Lastly, the assumption that all of the carbon contained in plastics is stored ignores certain end uses (e.g., adhesives and coatings) where the resin may be released to the atmosphere; however, these end uses are likely to be small relative to use in plastics.

The quantity of carbon stored in synthetic rubber only accounts for the carbon stored in scrap tire synthetic rubber. The value does not take into account the rubber stored in other durable goods, clothing, footwear, and other non-durable goods, or containers and packaging. This adds uncertainty to the total mass balance of carbon stored. There are also uncertainties as to the assignment of carbon content values; however, they are much smaller than in the case of plastics. There are probably fewer variations in rubber formulations than in plastics, and the range of potential carbon content values is much narrower. Lastly, assuming that all of the carbon contained in rubber is stored ignores the possibility of volatilization or degradation during product lifetimes. However, the proportion of the total carbon that is released to the atmosphere during use is probably negligible.

A small degree of uncertainty arises from the assignment of carbon content values; however, the magnitude of this uncertainty is less than that for plastics or rubber. Although there is considerable variation in final textile products, the stock fiber formulations are standardized and proscribed explicitly by the Federal Trade Commission.

For pesticides, the largest source of uncertainty involves the assumption that an active ingredient's carbon is either 0 percent stored or 100 percent stored. This split is a generalization of chemical behavior, based upon active-ingredient molecular structure, and not on compound-specific environmental data. The mechanism by which a compound is bound or released from soils is very complicated and can be affected by many variables, including the type of crop, temperature, delivery method, and harvesting practice. Another smaller source of uncertainty arises from the carbon content values applied to the unaccounted for portion of active ingredient. Carbon contents vary widely among pesticides, from 7 to 72 percent, and the remaining pesticides may have a chemical make-up that is very different from the 32 pesticides that have been examined. Additionally, pesticide consumption data were only available for 1987, 1993, 1995, 1997, and 1999; the majority of the time series data were interpolated or held constant at the latest (1999) value.

It is important to note that development of this uncertainty analysis is a multi-year process. The current feedstocks analysis examines NEU fuels that end in storage fates Thus only carbon stored in pesticides, plastics, synthetic fibers, synthetic rubbers, and TRI releases to underground injection and Subtitle C landfills is accounted for in the uncertainty estimate above. In the next two years this analysis will be expanded to include the uncertainty surrounding emitted fates in addition to the storage fates. Estimates of variable uncertainty will also be refined where possible to include fewer assumptions. With these major changes in future Inventories, the uncertainty estimate is expected to change, and likely increase. An increase in the uncertainty estimate in the coming years will not indicate that the Inventory calculations have become less certain, but rather that the methods for estimating uncertainty have become more comprehensive; thus, potential future changes in the results of this analysis will reflect a change in the uncertainty analysis, not a change in the Inventory quality.

i. Asphalt and Road Oil

Asphalt is one of the principal non-energy uses of fossil fuels. The term "asphalt" generally refers to a mixture of asphalt cement and a rock material aggregate, a volatile petroleum distillate, or water. For the purposes of this analysis, "asphalt" is used interchangeably with asphalt cement, a residue of crude oil. According to EPA (2000e), approximately 100 Tg CO_2 Eq. has been used in the production of asphalt cement annually. Though minor amounts of carbon are emitted during production, asphalt has an overall carbon storage factor of almost 100 percent, as discussed below.

Paving is the primary application of asphalt cement, comprising 86 percent of production. The three types of asphalt paving produced in the United States are hot mix asphalt (HMA), cut-backs, and emulsified asphalt. HMA, which makes up 90 percent of total asphalt paving (EPA 2000c), contains asphalt cement mixed with an aggregate of rock materials. Cut-back asphalt is composed of asphalt cement thinned with a volatile petroleum distillate (e.g., naphtha). Emulsified asphalt contains only asphalt cement and water. Roofing products are the other significant end use of asphalt cement, accounting for approximately 14 percent of U.S. production (Kelly 2000). No data were available on the fate of carbon in asphalt roofing; it was assumed that it has the same fate as carbon in asphalt paving applications.

a. Methodology and Data Sources

A carbon storage factor was calculated for each type of asphalt paving. The fraction of carbon emitted by each asphalt type was multiplied by consumption data for asphalt paving (EPA 2000c, EIIP 1998) to come up with a weighted average carbon storage factor for asphalt as a whole.

The fraction of carbon emitted by HMA was determined by first calculating the organic emissions (volatile organic compounds [VOCs], carbon monoxide, polycyclic aromatic hydrocarbons [PAHs], hazardous air pollutants [HAPs], and phenol) from HMA paving, using emission factors reported in EPA (2000e) and total HMA production.[8] The next step was to estimate the carbon content of the organic emissions. This calculation was based on the carbon content of carbon monoxide (CO) and phenol, and an assumption of 85 percent carbon content for PAHs and HAPs. The carbon content of asphalt paving is a function of (1) the proportion of asphalt cement in asphalt paving, assumed to be 5 percent asphalt cement content based on personal communication with an expert from the National Asphalt Paving Association (Connolly 2000), and (2) the proportion of carbon in asphalt cement. For the latter factor, all paving types were characterized as having a mass fraction of 85 percent carbon in asphalt cement, based on the assumption that asphalt is primarily composed of saturated paraffinic hydrocarbons. By combining these estimates, the result is that over 99.99 percent of the carbon in asphalt cement was retained (i.e., stored), and less than 0.01 percent was emitted.

Cut-back asphalt is produced in three forms (i.e., rapid, medium and slow cure). All three forms emit carbon only from the volatile petroleum distillate used to thin the asphalt cement (EPA 1995). Because the petroleum distillates are not included in the EIA fuel use statistics for asphalt, the storage factor for cut-back is assumed to be 100 percent.

It was also assumed that there was no loss of carbon from emulsified asphalt (i.e., the storage factor is 100 percent) based on personal communication with an expert from Akzo Nobel Coatings, Inc. (James 2000).

Data on asphalt and road oil consumption and carbon content factors were supplied by EIA. Hot mix asphalt production and emissions factors were obtained from "Hot Mix Asphalt Plants Emissions Assessment Report" from EPA's *AP-42* (EPA 2000e) publication. The

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[8] The emission factors are expressed as a function of asphalt paving tonnage (i.e., including the rock aggregate as well as the asphalt cement).

asphalt cement content of HMA was provided by Una Connolly of National Asphalt Paving Association (Connolly 2000). The consumption data for cut-back and emulsified asphalts were taken from a Moulthrop, et al. study used as guidance for estimating air pollutant emissions from paving processes (EIIP 1998). "Asphalt Paving Operation" *AP-42* (EPA 1995) provided the emissions source information used in the calculation of the carbon storage factor for cut-back asphalt. The storage factor for emulsified asphalt was provided by Alan James of Akzo Nobel Coatings, Inc. (James 2000).

b. Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the estimates of the asphalt carbon storage factor and the quantity of carbon stored in asphalt in 2003. Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. Uncertainty estimates for asphalt production were assumed to be ±20 percent, while the asphalt property variables were assumed to have narrower distributions. A narrow uniform distribution, with maximum 5% uncertainty around the mean, was applied to the carbon content coefficient.

The Monte Carlo analysis, given a 95 percent confidence interval, produced a storage factor distribution that approximates a normal curve skewed to the right, around a mean of 99.5 percent, with a standard deviation of 0.2 percent and boundaries between 99.1 and 99.8 percent. This compares to the storage factor value used in the Inventory of 100 percent. The analysis produced an emission distribution, skewed to the left, with an uncertainty range slightly below 100 percent. The emission uncertainty range is not applicable since the Inventory calculation estimates that zero carbon is emitted from asphalts and road oil.

The principal source of uncertainty is that the available data are from short-term studies of emissions associated with the production and application of asphalt. As a practical matter, the cement in asphalt deteriorates over time, contributing to the need for periodic re-paving. Whether this deterioration is due to physical erosion of the cement and continued storage of carbon in a refractory form or physicochemical degradation and eventual release of CO_2 is uncertain. Long-term studies may reveal higher lifetime emissions rates associated with degradation.

Many of the values used in the analysis are also uncertain and are based on estimates and professional judgment. For example, the asphalt cement input for hot mix asphalt was based on expert advice indicating that the range is variable—from about 3 to 5 percent—with actual content based on climate and geographical factors (Connolly 2000). Over this range, the effect on the calculated carbon storage factor is minimal (on the order of 0.1 percent). Similarly, changes in the assumed carbon content of asphalt cement would have only a minor effect.

The consumption figures for cut-back and emulsified asphalts are based on information reported for 1994. More recent trends indicate a decrease in cut-back use due to high VOC emission levels and a related increase in emulsified asphalt use as a substitute. However, because the carbon storage factor of each is 100 percent, use of more recent data would not affect the overall result.

Future improvements to this uncertainty analysis, and to the overall estimation of a storage factor for asphalt, include characterizing the long-term fate of asphalt.

ii. Lubricants

Lubricants are used in industrial and transportation applications. They can be subdivided into oils and greases, which differ in terms of physical characteristics (e.g., viscosity), commercial applications, and environmental fate. According to EIA (2004), the carbon content from U.S. production of lubricants in 2003 was approximately 6.4 Tg C. Based on apportioning oils and greases to various environmental fates, and characterizing those fates as resulting in either long-term storage or emissions, the overall carbon storage factor was estimated to be 9 percent; thus, emissions in 2003 were about 5.8 Tg C, or 21.1 Tg CO_2 Eq.

a. Methodology and Data Sources

For each lubricant category, a storage factor was derived by identifying disposal fates and applying assumptions as to the disposition of the carbon for each practice. An overall lubricant carbon storage factor was calculated by taking a production-weighted average of the oil and grease storage factors.

iii. Oils

Regulation of used oil in the United States has changed dramatically over the past 15 years.[9] The effect of these regulations and policies has been to restrict landfilling and dumping, and to encourage collection of used oil. Given the relatively inexpensive price of crude oil, the economics have not favored re-refining—instead, most of the used oil that has been collected has been combusted.

Table 16 provides an estimated allocation of the fates of lubricant oils (Rinehart 2000), along with an estimate of the proportion of carbon stored in each fate. The ultimate fate of the majority of oils (about 84 percent) is combustion, either during initial use or after collection as used oil. Combustion results in 99 percent oxidation to CO_2 (EIIP 1999), with correspondingly little long-term storage of carbon in the form of ash. Dumping onto the ground or into storm sewers, primarily by “do-it-yourselfers” who change their own oil, is another fate that results in conversion to CO_2 given that the releases are generally small and most of the oil is biodegraded (based on the observation that land farming—application to soil—is one of the most frequently used methods for degrading refinery wastes). In the landfill environment, which tends to be anaerobic within municipal landfills, it is assumed that 90 percent of the oil persists in an underrated form, based on analogy with the

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[9] For example, the U.S. EPA “RCRA (Resource Conservation and Recovery Act) On-line” web site (<http://www.epa.gov/rcraonline/>) has over 50 entries on used oil regulation and policy for 1994 through 2000.

persistence of petroleum in native petroleum-bearing strata, which are both anaerobic. Re-refining adds a recycling loop to the fate of oil. Re-refined oil was assumed to have a storage factor equal to the weighted average for the other fates (i.e., after re-refining, the oil would have the same probability of combustion, land-filling, or dumping as virgin oil), i.e., it was assumed that about 97 percent of the carbon in re-refined oil is ultimately oxidized. Because of the dominance of fates that result in eventual release as CO_2, only about 3 percent of the carbon in oil lubricants goes into long-term storage.

Table 16: Commercial and Environmental Fate of Oil Lubricants (Percent)

Fate of Oil	Portion of Total Oil	Carbon Stored
Combusted During Use	20	1
Not Combusted During Use	80	-
Combusted as Used Oil*	64	1
Dumped on the ground or in storm sewers	6	0
Landfilled	2	90
Re-refined into lube oil base stock and other products	8	3
Weighted Average	-	2.9

* (e.g., in boilers or space heaters)
- Not applicable

iv. Greases

Table 17 provides analogous estimates for lubricant greases. Unlike oils, grease is generally not combusted during use, and combustion for energy recovery and re-refining is thought to be negligible. Although little is known about the fate of waste grease, it was assumed that 90 percent of the non-combusted portion is landfilled, and the remainder is dumped onto the ground or storm sewers. Because much of the waste grease will be in containers that render it relatively inaccessible to biodegradation, and because greases contain longer chain paraffins, which are more persistent than oils, it was assumed that 90 percent and 50 percent of the carbon in landfilled and dumped grease, respectively, would be stored. The overall storage factor is 82 percent for grease.

Table 18: Commercial and Environmental Fate of Grease Lubricants (Percent)

Fate of Grease	Total Grease	Carbon Stored
Combusted During Use	5	1
Not Combusted During Use	95	-
Landfilled	85.5	90
Dumped on the ground or in storm sewers	9.5	50
Weighted Average	-	81.8

- Not applicable

Having derived separate storage factors for oil and grease, the last step was to estimate the weighted average for lubricants as a whole. No data were found apportioning the mass of lubricants into these two categories, but the U.S. Census Bureau (1999) does maintain records of the value of production of lubricating oils and lubricating greases. Assuming that the mass of lubricants can be allocated according to the proportion of value of production (92 percent oil, 8 percent grease), applying these weights to the storage factors for oils and greases (3 percent and 82 percent) yields an overall storage factor of 9 percent.

a. Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the estimates of the lubricants weighted average carbon storage factor and the quantity of carbon emitted from lubricants in 2003. The Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. Uncertainty estimates for oil and grease variables were assumed to have a moderate variance, in triangular or uniform distribution. Uncertainty estimates for lubricants production were assumed to be rather high (±20 percent). A narrow uniform distribution, with maximum 6% uncertainty around the mean, was applied to the lubricant carbon content coefficient.

The Monte Carlo analysis, given a 95 percent confidence interval, produced a storage factor distribution that approximates a normal curve, around a mean of 10.2 percent, with a standard deviation of 3.7 percent and 95 percent confidence limits of 3.9 and 17.5 percent. This compares to the calculated estimate, used in the Inventory, of 9.2 percent. The analysis produced an emission distribution approximating a normal curve with a mean of 20.9 Tg CO_2, standard deviation of 0.5, and 95 percent confidence limits of 17.4 and 24.4 Tg CO_2. This compares with a calculated estimate of 21.2 Tg CO_2.

The principal sources of uncertainty for the disposition of lubricants are the estimates of the commercial use, post-use, and environmental fate of lubricants, which, as noted above, are largely based on assumptions and judgment. There is no comprehensive system to track used oil and greases, which makes it difficult to develop a verifiable estimate of the commercial fates of oil and grease. The environmental fate estimates for percent of carbon stored are less uncertain, but also introduce uncertainty in the estimate.

The assumption that the mass of oil and grease can be divided according to their value also introduces uncertainty. Given the large difference between the storage factors for oil and grease, changes in their share of total lubricant production have a large effect on the weighted storage factor.

Future improvements to the analysis of uncertainty surrounding the lubricants carbon storage factor and carbon stored include further refinement of the uncertainty estimates for the individual activity variables.

v. Waxes

Waxes are organic substances that are solid at ambient temperature, but whose viscosity decreases as temperature increases. Most commercial waxes are produced from petroleum refining, though "mineral" waxes derived from animals, plants, and lignite [coal] are also used. Previous *Inventories* have assumed that all carbon contained in this source is stored (i.e., an assumed storage factor of 100 percent). An analysis of wax end uses in the US, and the fate of carbon in these uses, suggests that about 42 percent of carbon in waxes is emitted, and 58 percent is stored.

a. Methodology and Data Sources

At present, the National Petroleum Refiners Association (NPRA) considers the exact amount of wax consumed each year by end use to be proprietary (Maguire 2004). In general, about thirty percent of the wax consumed each year is used in packaging materials, though this percentage has declined in recent years. The next highest wax end use, and fastest growing end use, is candles, followed by construction materials and firelogs. There are many other wax end uses, which the NPRA generally classifies into cosmetics, plastics, tires and rubber, hot melt (adhesives), chemically modified wax substances, and other miscellaneous wax uses. (NPRA 2002)

A carbon storage factor for each wax end use was estimated and then summed across all end uses to provide an overall carbon storage factor for wax. Because no specific data on carbon contents of wax used in each end use were available, all wax products are assumed to have the same carbon content. Table 20 categorizes wax end uses identified by the NPRA, and lists each end ues’s estimated carbon storage factor.

Table 19: Wax End Uses by Fate, Percent of Total Mass, Percent Stored, and Percent of Total Mass Stored

Use	Percent of Total Mass	Percent Stored	Percent of Total Mass Stored
Candles	20%	10%	2%
Firelogs	7%	1%	+
Hotmelts	3%	50%	2%
Packaging	30%	79%	24%
Construction Materials	18%	79%	14%
Cosmetics	3%	79%	2%
Plastics	3%	79%	2%
Tires/Rubber	3%	47%	1%
Chemically Modified	1%	79%	1%
Other	12%	79%	10%
Total	100%	NA	58%

+ Does not exceed 0.5 percent

Source, mass percentages: NPRA 2002. Estimates of percent stored are based on professional judgment, ICF Consulting.

Emissive wax end uses include candles, firelogs (synthetic fireplace logs), hotmelts (adhesives), matches, and explosives. At about 20 percent, candles consume the greatest portion of wax among emissive end uses. As candles combust during use, they release emissions to the atmosphere. For the purposes of the *Inventory*, it is assumed that 90 percent of carbon contained in candles is emitted as CO$_2$. In firelogs, petroleum wax is used as a binder and as a fuel, and is combusted during product use, likely resulting in the emission of nearly all carbon contained in product. Similarly, carbon contained in hotmelts is assumed to be emitted as CO$_2$ as heat is applied to these products during use. It is estimated that 50 percent of the carbon contained in hot melts is stored. Together, candles, firelogs, and hotmelts constitute approximately 30 percent of annual wax production (NPRA 2002).

All of the wax utilized in the production of packaging, cosmetics, plastics, tires and rubber, and other products is assumed to remain in the product (i.e., it is assumed that there are no emissions of CO_2 from wax during the production of the product.) Wax is used in many different packaging materials including: wrappers, cartons, papers, paperboard, and corrugated products (NPRA 2002). Davie (1993) and Davie et al. (1995) suggest that wax coatings in packaging products degrade rapidly in an aerobic environment, producing CO_2; however, because packaging products ultimately enter landfills typically having an anaerobic environment, most of the carbon from this end use is assumed to be stored in the landfill.

In construction materials, petroleum wax is used as a water repellent on wood-based composite boards, such as particle board (IGI 2002). Wax used for this end-use should follow the life-cycle of the harvested wood used in product, which is classified into one of 21 categories, evaluated by life-cycle, and ultimately assumed to either be disposed of in landfills or be combusted (EPA 2003).

The fate of wax used for packaging, in construction materials, and most remaining end uses is ultimately to enter the municipal solid waste (MSW) stream, where they are either combusted or sent to landfill for disposal. Most of the carbon contained in these wax products will be stored. It is assumed that approximately 21 percent of the carbon contained in these products will be emitted through combustion or at landfill. With the exception of tires and rubber, these end uses are assigned a carbon storage factor of 79 percent.

Waxes used in tires and rubber follow the life cycle of the tire and rubber products. Used tires are ultimately recycled, landfilled, or combusted. The life-cycle of tires is addressed elsewhere in this annex as part of the discussion of rubber products derived from petrochemical feedstocks. For the purposes of the estimation of the carbon storage factor for waxes, wax contained in tires and rubber products is assigned a carbon storage factor of 47 percent.

b. Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the estimates of the wax carbon storage factor and the quantity of carbon emitted from wax in 2003. Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. Uncertainty estimates for wax variables were assumed to have a moderate variance, in normal, uniform, or triangular distribution; uniform distributions were applied to total consumption of waxes and the carbon content coefficients.

The Monte Carlo analysis produced a storage factor distribution that approximates a normal curve around a mean of 57.7 percent, with a standard deviation of 6.5 percent and 95 percent confidence limits of 44 percent and 69 percent. This compares to the calculated estimate, used in the Inventory, of 58 percent. The analysis produced an emission distribution approximating a normal curve with a mean of 1.1 Tg CO_2, standard deviation of 0.05 Tg CO_2, and 95 percent confidence limits of 0.72 and 1.46 Tg CO_2. This compares with a calculated estimate of 0.95 Tg CO_2. This value is within the range of 95 percent confidence limits established by this quantitative uncertainty analysis. Uncertainty associated with the wax storage factor is considerable due to several assumptions pertaining to wax imports/exports, consumption, and fates.

vi. Miscellaneous Products

Miscellaneous products are defined by the U.S. Energy Information Administration as: "all finished [petroleum] products not classified elsewhere, e.g. petrolatum; lube refining byproducts (e.g., aromatic extracts and tars); absorption oils; ram-jet fuel; petroleum rocket fuel; synthetic natural gas feedstocks; and specialty oils."

a. Methodology and Data Sources

Data are not available concerning the distribution of each of the above-listed subcategories within the "miscellaneous products" category. However, based on the anticipated disposition of the products in each subcategory, it is assumed that all of the carbon content of miscellaneous products is emitted rather than stored. Petrolatum and specialty oils (which include greases) are likely to end up in solid waste or wastewater streams rather than in durable products, and would be emitted through waste treatment. Absorption oil is used in natural gas processing and is not a feedstock for manufacture of durable products Jet fuel and rocket fuel are assumed to be combusted in use, and synthetic natural gas feedstocks are assumed to be converted to synthetic natural gas that is also combusted in use. Lube refining byproducts could potentially be used as feedstocks for manufacture of durable goods, but such byproducts are more likely to be used in emissive uses. Lube refining byproducts and absorption oils are liquids and are would be precluded from disposal in landfills. Because no sequestering end uses of any of the miscellaneous products subcategories have been identified, a zero percent storage factor is assigned to miscellaneous products. According to EIA (2004) U.S. production of miscellaneous petroleum products in 2003 was 88.7 TBtu. One hundred percent of the carbon content is assumed to be emitted to the atmosphere, where it is oxidized to CO_2.

b. Uncertainty

A separate uncertainty analysis was not conducted for miscellaneous products, though this category was included in the uncertainty analysis of other non-energy uses discussed in the following section.

vii. Other Non-Energy Uses

The remaining fuel types use storage factors that are not based on U.S.-specific analysis. For industrial coking coal and distillate fuel oil, storage factors were taken from the IPCC *Guidelines for National Greenhouse Gas Inventories*, which in turn draws from Marland and Rotty (1984). For the remaining fuel types (petroleum coke, miscellaneous products, and other petroleum), IPCC does not provide guidance on storage factors, and assumptions were made based on the potential fate of carbon in the respective NEUs. For all these fuel types, the overall methodology simply involves multiplying carbon content by a storage factor, yielding an estimate of the mass of carbon stored. To provide a complete analysis of uncertainty for the entire NEU subcategory, the uncertainty around the estimate of "other" NEUs was characterized, as discussed below.

a. Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the weighted average of the remaining fuels' carbon storage factors and the total quantity of carbon emitted from these other fuels in 2003. Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for some of the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. A uniform distribution was applied to coking coal consumption, while the remaining consumption inputs were assumed to be normally distributed. The carbon content coefficients were assumed to have a uniform distribution; the greatest uncertainty range, 10 percent, was applied to coking coal and miscellaneous products. Carbon coefficients for distillate fuel oil ranged from 19.52 to 20.15 Tg C/QBtu. The fuel-specific storage factors were assigned wide triangular distributions indicating greater uncertainty.

The Monte Carlo analysis produced a storage factor distribution that approximates a normal curve around a mean of 41.1 percent, with a standard deviation of 12.4 percent and 95 percent confidence limits of 18 percent and 67 percent. This compares to the calculated, weighted average (across the various fuels) storage factor of 23.8 percent. The analysis produced an emission distribution approximating a normal curve with a mean of 16.2 Tg CO_2 and a standard deviation of 1.0 Tg CO_2, and 95 percent confidence limits of 9.0 Tg CO_2 and 23.2 Tg CO_2. This compares with the Inventory estimate of 20.9 Tg CO_2, which falls closer to the upper boundary of the confidence limit. The uncertainty analysis results are driven primarily by the very br

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