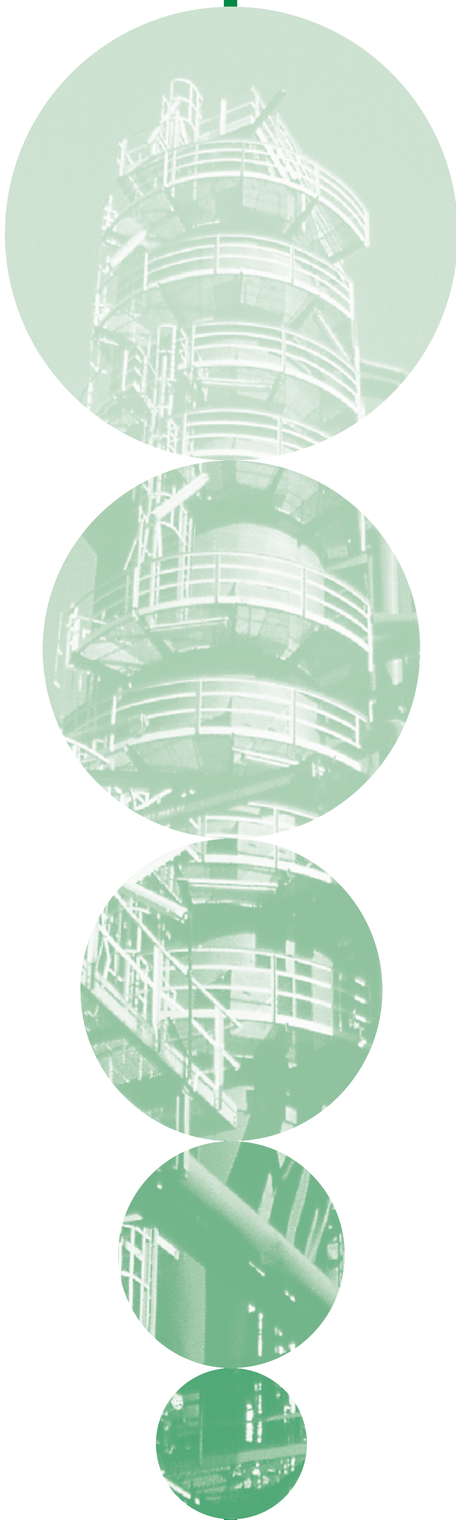

LIFE CYCLE INVENTORY: BITUMEN

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Executive Summary

In 2009 Eurobitume decided to update and enhance the bitumen life cycle inventory (LCI) originally published in 1999.

The bitumen LCI is a cradle to gate study. It covers:

- extraction of crude oil;
- transport to Europe including pipeline and ship transport;
- manufacturing of bitumen in a complex refinery; and
- hot storage of the product.
- It also takes into account the construction of production facilities (infrastructure).

The study covers paving grade bitumens from the product standard EN 12591 table 1, which includes penetration grades 20 to 220 1/10 mm. The main bitumen production route is straight-run distillation (atmospheric distillation + vacuum distillation). Other manufacturing processes such as semi-blowing, propane de-asphalting and vis-breaking were evaluated.

In addition to bitumen, LCIs for polymer modified bitumen (PMB) with 3,5% polymer and bitumen emulsion with 65% bitumen were calculated.

The report is based upon the most recent information available from the crude oil production and refining industry, European collated submissions and data collected by industry:

- Oil and Gas Producers data reported in 2009.
- Bitumen refining data from the Eurobitume survey in 2010.
- Bitumen crude supplies collated by Eurobitume.
- New SO_2 limits applying to the transport section.

Where primary data were not available, data from the ecoinvent database were used.

The allocation between bitumen and other co-products made from crude oil is based on mass balances at the crude oil extraction and the transport stages. At the refining level, the allocation is based on relative economic values.

The LCI is shown as a list of emissions and resource uses in this report and is also available as an electronic annex. The environmental impacts resulting from such emissions have not been assessed. The life cycle impact assessment (LCIA) based on these data would be the next step in a full life cycle assessment. The report gives recommendations how these data can be used.

The LCI has been conducted according to ISO 14040 and ISO 14044. As part of these standards, the report has been peer reviewed by an independent LCI expert.

1 Introduction

The importance of quantifying the impact of products and services on the environment is growing. Consumers and governments are increasingly demanding information about the sustainability of products and interest in comparing potential solutions based upon scientific data is necessary in order to do this.

The bitumen industry recognised the need for such information more than 10 years ago and produced the first eco-profile[1], or partial life cycle inventory (LCI). During 2009, it was decided to update the 1999 eco-profile[1], because more data had become available and LCI methodology had been developed further.

While the fundamental processes had not changed, the changes in operations over the 10-year period had been quite remarkable and emphasised the need for periodic updating of the LCI.

In comparison to the previous LCI, the main differences of this eco-profile are described below:

- The basket of crudes has been revised based upon recent European use.
- The data concerning consumptions and emissions have been updated based on the most recent information for crude oil extraction, transport to the refinery, bitumen production and storage.
- The allocation methodology for the refining process has been reviewed.
- The impact of alternative manufacturing routes has been considered, i.e. semi-blowing, propane de-asphalting and vis-breaking.
- Polymer modified bitumen and bitumen emulsion manufacture have been included in the scope of the study.

This study is in compliance with ISO 14040 and ISO 14044 and has been independently peer reviewed.

2 Goal and Scope of the Study

2.1. Intended application and intended audience

The aim of this eco-profile is to provide inventory data on the production of the most widely used paving grade bitumens in Europe.

The intended application can be seen as a building block in the calculations of the further life cycle inventory studies where paving grade bitumens are used.

The targeted audience consists of the customers of bitumen producers and organisations studying environmental issues, such as the European Commission, national official bodies, consultants, universities, etc.

The document is not suitable as a benchmark for inter-refinery comparison.

2.2. Product description

The general assumptions concerning the bitumen studied in this eco-profile are as follows:

- The bitumen is paving grade bitumen according to EN 12591[2]. This is the most widely used paving grade bitumen in Europe.
- The bitumen is made in a hypothetical complex refinery, located in the ARA (Amsterdam, Rotterdam, Antwerp) area. In a complex refinery a broad variety of petroleum products are produced, including bitumen.
- The bitumen is manufactured by straight-run distillation of crude oil, which is the most common production route for bitumen manufactured in Europe. During this process the residue from the atmospheric distillation of crude oil is further distilled in a vacuum tower to produce paving grade bitumen.

Polymer modified bitumen and bitumen emulsion manufacture are also analysed in the study.

2.3. Functional unit

The functional unit of this eco-profile is 1 tonne of paving grade bitumen.

For polymer modified bitumen the functional unit is also 1 tonne of product. However, for bitumen emulsion, the functional unit is 1 tonne of residual bitumen which corresponds to 1,54 tonne of emulsion.

2 Goal and Scope of the Study

2.4. System boundaries

This study covers the bitumen production chain, starting from raw material extraction and ending with a bitumen product ready for delivery to a customer. The process is divided into four stages: crude oil extraction, transport to Europe, production and storage. A schematic description of the system boundary is given in figure 1.

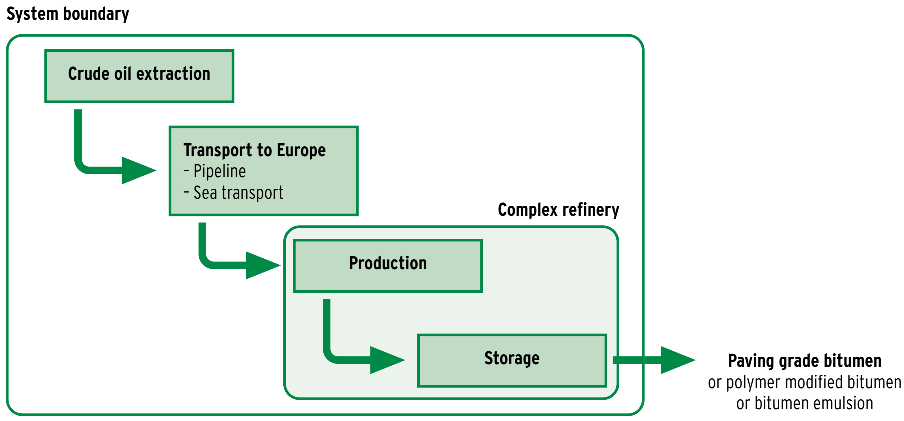

Figure 1. System boundaries for the bitumen eco-profile (cradle-to-gate approach)

2.5. Allocation procedures

Bitumen is a co-product of the crude oil refining process. In order to assess the environmental impact of bitumen, one must define a way to allocate the impacts of the production chain between bitumen and the other co-products: gasoline, heavy fuel oil, liquefied petroleum gas, etc.

The aim of the allocation procedure is to find a suitable parameter so that the inputs and the outputs of the system studied can be assigned to the product under consideration.

According to ISO 14040 & ISO 14044, there are different ways to address allocation issues: the preference is physical allocation (based on mass, calorific value, etc.) or when this is not possible, economic allocation (based on relative values).

In this eco-profile, the allocations of the inputs and outputs at the different stages of the production chain are made as follows:

- The allocation at the crude oil extraction and the transport stages is based on mass balances. At these stages, all the constituents of crude oil, from gasoline to heavy fuel oil, are still co-mingled and can be considered as raw materials for which a mass relationship (yield) can be established.

2 Goal and Scope of the Study

- The allocation at the refining level is based on economic factors. More precisely, the allocation is based on the physical yield of bitumen and the relative standard values of the products manufactured in the refinery's production units. At the refining level, no physical relationship can be established between the bitumen and the other co-products. Firstly, it is not possible to change the ratio between bitumen and other co-products without a significant change in the process. And secondly, the co-products have different functions: bitumen is intended to be a construction raw material and the other co-products are used as fuels. That is why ISO TR 14049 recommends an economic allocation for bitumen.

However, other options concerning allocation could be possible and would change the results. For that reason, a sensitivity analysis on allocation procedure has been carried out and is discussed in appendix 3.

2.6. Source of data

For the main processes (crude oil extraction, straight-run distillation and storage), this eco-profile is based upon:

- The most recent reports of the crude oil and refining industry
  - For crude oil extraction, the data come from the annual report produced by the International Association of Oil & Gas Producers[3] (OGP). In the latest publication for 2009 (on data from 2008), the survey covers 2,146 million tonnes well head production, about 32% of the global production.
  - For specific aspects of refinery emissions such as sulphur emissions and refinery fuels usage, specific reports published by CONCAWE (Association for the Conservation of Clean Air and Water in Europe) have been used. All the European refiners are members of CONCAWE. This broad membership is particularly useful when assessing the European position.
- European collated submissions and data collected by industry*
  - For the average supply distribution of the crudes used specifically for bitumen manufacture, anonymous questionnaires to Eurobitume members have been used. The results, for 2008 or 2009, represent 33% of the European market. Experience indicates that the mix of companies that responded is a good representation of the overall European supply.

* Confidential internal data provided by Eurobitume member companies

2 Goal and Scope of the Study

- For energy consumption of refining, anonymous questionnaires to Eurobitume members were used to collect precise refinery data from 7 bitumen producing refineries. The results obtained from the survey have been validated by comparison with a methodology developed for CONCAWE to calculate the CO_2 emissions associated with each type of refinery. It was considered that for the 2 units used to manufacture straight-run bitumen, atmospheric and vacuum distillation, the CO_2 emissions were a good proxy for energy consumption.
- For transport by pipeline and ships, actual data from pipeline companies and a ship owner (Neste Oil Shipping) was used. These data have been completed with further data from the US Environmental Protection Agency (EPA) concerning emissions to air.

For other processes (electricity production) and infrastructure (oil wells and platforms, ships, pipelines, oil refinery), information from the ecoinvent 2.2 database[4] has been used.

2.7. Data quality

2.7.1. Temporal, geographical and technological representativeness

The representativeness of data is in accordance with the goal and scope of the study which is to give environmental information on the current production chain of the most widely used paving grade bitumen in Europe. Data for principal processes come from recent reports (for example, data from 2008 for crude oil extraction) or have been collected in 2010.

Data for principal processes are representative of the European context. The crude oil slate for bitumen production is typical of European supply. Transport is representative of the different routes used to bring the crude oil into a refinery located on the coast of Western Europe. The electricity model used is adapted to the geographical location (Europe for the refinery stage).

Data for principal processes are representative of the worldwide technology for crude oil extraction and transport and of the European technology for refinery processes. In particular:

- Data for crude oil extraction are representative of 32% of the worldwide oil and gas production.
- Refinery consumptions and emissions data for the refinery are representative of around 20% of the bitumen production in Europe through 7 refineries. The locations of the refineries are spread over North West Europe, which fits the starting assumptions.

2 Goal and Scope of the Study

- For refinery fuel usage and sulphur emissions, the survey covers 68% of the European crude throughout (CONCAWE report on sulphur emissions).

Other process data from the ecoinvent 2.2 database are representative of the current average technology in Europe.

2.7.2. Precision and accuracy

A quantitative uncertainty assessment of the LCI results cannot be provided since the standard deviation for each input and output of the process is not available.

Instead of using a statistical approach for uncertainty assessment, data quality has been considered. An overall qualitative assessment of accuracy can be given by taking into account the reliability and the completeness of data used (data from literature, measured data or estimated data). This assessment can be given as follows:

- There is high accuracy for the most relevant flows in the bitumen production chain: crude oil consumption, natural gas consumption, emission to air of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_x), methane (CH_4) and non-methane volatile organic compounds (NMVOC).
- There is satisfactory accuracy for the other flows.
- There is concern about the quality of the infrastructure data as few data are available.
- In several of the data tables the total values may show small inconsistencies due to rounding of values.

3 Inventory Analysis

3.1. Crude oil extraction

Crude oil extraction data is based on the Oil & Gas Producers (OGP) data from 2008 and ecoinvent 2.2 database[4].

3.1.1. Raw material

The European average crude oil slate used for bitumen production was estimated based on a Eurobitume internal questionnaire using the same regions as in the OGP report.

The crude oil slate for bitumen production is as follows:

- Former Soviet Union (FSU) 61%
- Middle East (ME) 18%
- South America (SAm) 11%
- Europe (Eur) 10%

These crude oils are not necessarily used together in any specific refinery, but they represent the approximate proportions used in aggregated European bitumen production.

1 tonne of crude oil is allocated as a raw material, representing that part of the initial crude oil, which, after processing, becomes 1 tonne of bitumen.

3.1.2. Consumption of energy resources

For the oil extraction process, the energy consumption given in the OGP report ranges from 490 MJ/t to 1 580 MJ/t depending on the type of crude oil and the location. Most of the energy is locally produced. The split between gas and diesel depends on the crude oil type and is given by the ecoinvent 2.2 database. The reported energies are converted into masses with the calorific values of 40,0 MJ/kg for diesel and 49,4 MJ/kg for gas.

	Unit	Former Soviet Union	Middle East	South America	Europe
Energy	MJ/t	960	490	1 580	1 090
Gas	%	12	0	50*	90
Diesel	%	88	100	50*	10

* No data available, 50/50 is estimated

3 Inventory Analysis

3.1.3. Emissions

Gaseous emissions arise mainly from flaring, venting and processing. Emission of carbon dioxide (CO_2) is the largest gaseous release from crude oil extraction. CO_2 emissions occur from flaring and combustion of fuels for energy production. Methane emissions come mostly from the process and tank vents. The main emission sources of Non-Methane Volatile Organic Compounds (NMVOC) are venting and flaring. NMVOCs are mainly hydrocarbons having a carbon number between C2 – C6. Sulphur dioxide (SO_2) emissions arise through oxidation during combustion of sulphur naturally contained within hydrocarbon fuels or flared gas. Emissions of nitrogen oxides, principally nitric oxide and nitrogen dioxide, expressed as NO_X, occur almost exclusively from the combustion of fuels.

Water used in the extraction process is often injected back into reservoirs to improve hydrocarbon recovery or into other geological strata for disposal. Onshore, where disposal to soil is often constrained by regulatory and environmental concerns, injection of extracted water is the principal disposal route with 87% of water being returned below ground. Offshore, the majority of treated water can be discharged to sea.

Non-aqueous drilling fluids (NADF) contain typically 50% – 80% of non-aqueous base fluid as a continuous phase. The remainder consists of brine, barite and other materials such as gels and emulsifiers. The data on NADF relate to material adhering to cuttings that are discharged to the marine environment. NADF as such is not discharged.

3.1.4. Crude oil extraction data

	Unit	Former Soviet Union	Middle East	South America	Europe	Total
Crude oil source	%	61	18	11	10	100
Raw material						
Crude oil	kg/t	1 000	1 000	1 000	1 000	1 000
Consumption of energy resources						
Diesel [1]	kg/t	21,1	12,3	19,8	2,7	17,5
Natural gas [1]	kg/t	2,3		16,0	19,9	5,2
Losses						
Natural gas, flared	kg/t	14,8	13,5	13,3	2,9	13,2
Natural gas, vented [2]	kg/t	0,56	0,17	1,36	0,26	0,55

1) Burned in the process

2) The amount of gas vented has been taken equal to CH_4 emissions

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3 Inventory Analysis

	Unit	Former Soviet Union	Middle East	South America	Europe	Total
Emissions to air						
CO_2	g/t	102 870	70 140	148 900	73 800	99 135
CO [3]	g/t	627	366	597	97	524
SO_2	g/t	230	760	80	40	290
NO_x	g/t	240	140	670	250	270
CH_4	g/t	560	170	1 360	260	548
NMVOC	g/t	210	350	730	260	297
Particulates [3]	g/t	158	93	152	26	133
Emissions to water						
Oil	g/t	4,58	4,11	23,07	8,29	6,90
Emissions to soil						
Oil spills	g/t	0,07	10,23	55,23	1,77	8,14

3) Data from ecoinvent 2.2 database

The data concerning infrastructure for crude oil extraction (well for exploration and production, platforms and plants) are presented in Appendix 1.

3.2. Transport to Europe

The crude oils for European bitumen production are mainly transported to Europe by ship. The exception is Former Soviet Union crude oil that may be transported by pipeline. In this study, we assume that the Former Soviet Union crude oil is transported from the Samara area to the Baltic Sea by the Baltic Pipeline System (BPS) and then, from the Baltic Sea to the ARA region by ship.

3.2.1. Transport by pipeline

The energy requirement of the BPS was not available. As a consequence, an estimate was calculated using data from another known pipeline and a topographical analysis as the main energy requirement depends on the topography and length of the route. The topography of various pipelines was modelled[5].

The SPSE pipeline between Lavera, France and Karlsruhe, Germany is regarded as having the closest topographic profile to the BPS. The same amount of energy per tonne of crude oil and per 100 km needed by the SPSE was used to calculate the energy needed by the BPS.

3 Inventory Analysis

Pipeline	End points	Distance km	Electricity kWh/t/100 km	Electricity kWh/t
SPSE*	Lavera - Karlsruhe	769	0,75	5,8
BPS	Samara - Primorsk	1 800	0,75	13,5

* Eurobitume source

We assume that the electricity is produced by a diesel generator consuming 0.2 l of diesel per kWh. This is a conservative assumption as we know that some of the power consumed is also produced by gas driven generator and some comes directly from the electric grid.

The consumptions and emissions attributable to the diesel burned are given in the life cycle inventory "Diesel, burned in diesel-electric generating set/GLO" of the ecoinvent 2.2 database.

The data concerning pipeline infrastructure are presented in Appendix 1.

3.2.2. Transport by ship

In the calculations, crude oil is transported to Europe in 106 000 Dead Weight Tonne (DWT) vessels. This is a typical vessel size for Former Soviet Union and South America. For Middle East crude oil using the route via Suez, the size varies between 250 000 DWT and 130 000 DWT, and for Europe the size is 70 000 DWT. The use of a 106 000 DWT ship for all regions is considered to be a conservative compromise.

3.2.2.1. Consumption of energy resources

The vessel data and fuel oil consumption data are taken from Neste Oil Shipping[6].

Average speed		13,5 knots (25 km/h)
Fuel consumption,	fully loaded	56 t/day
	ballasted	40 t/day
	loading	3,5 t (10 hours)
	discharging	19 t (12 hours)

The transportation distance is calculated with a port to port distance calculation tool[7]. The duration of the voyage is calculated using an average speed of 13,5 knots.

The fuel consumption is calculated with one way ballasted and a return trip fully loaded including loading and discharging.

The consumptions and emissions due to the production of marine fuel are given in the life cycle inventory "Heavy fuel oil at regional storage/RER" of the ecoinvent 2.2 database.

3 Inventory Analysis

3.2.2.2. Emissions to air

CO_2, NO_x, CO and hydrocarbon emissions are calculated based on the US Environmental Protection Agency's (EPA) marine engine emission factors[8], from which the factors have been calculated for 1 kg fuel used.

	EPA emission factors g/kWh	Emission factors of fuel g/kg fuel
Fuel consumption	220,78	1 000
CO_2	690	3 125
CO	0,79	3,56
NO_x	10,5	47,8
Hydrocarbon	0,06	0,27

SO_2 emissions are calculated directly from the sulphur content of the fuels burned by the ship.

High sulphur fuel oil has a maximum sulphur content of 4,5%, which will be lowered to 3,5% in 2012. The typical highest value in use today is 2,7% sulphur. In SECA (Sulphur Oxide Emission Control Area), to which the Baltic Sea, the English Channel and the North Sea belong, the maximum sulphur content was lowered to 1% on 1 July 2010. In EU harbours, only MGO (marine gas oil) or MDO (marine diesel oil) containing less than 0,1% sulphur have been allowed since 1 January 2010.

In the calculation 0,1% sulphur fuel is used during loading and discharging; 1% sulphur fuel is used in transporting crude oil from Former Soviet Union and Europe; and 2,7% sulphur fuel is used in transport from South America and the Middle East.

Fuel type	Sulphur content of the fuel %	SO_2 emission factors of fuel g/kg fuel
High sulphur fuel oil	2,7	54
Medium sulphur fuel oil	1	20
Low sulphur fuel oil	0,1	2

3.2.2.3. Emissions to water

Ballast and tank cleaning waters are discharged from the tanker to the refinery for treatment and they are included in the refinery emissions.

3 Inventory Analysis

3.2.2.4. Transport by ship data

Energy use and emissions due to the combustion of marine fuels are calculated separately for each supply port and the total is a weighted sum of the different supply points.

Crude oil source	Unit	Former Soviet Union	Middle East	South America	Europe	Total
	%	61	18	11	10	100
Sea transport to ARA from		St. Petersburg Russia [1)]	Ras Tanura Saudi Arabia [2)]	Maracaibo Venezuela	Bergen North Sea	
Data on sea transport						
Vessel	DWT (t)	106 000	106 000	106 000	106 000	106 000
Distance	km	2 406	11 794	8 312	1 007	4 605
Speed	km/h	25	25	25	25	
Duration	h	96	473	333	41	185
Fuel consumption, total	t/trip	407	1 915	1 355	187	761
- Fuel 2,7% S	t/trip		1 892	1 332		487
- Fuel 1,0% S	t/trip	385			164	251
- Fuel 0,1% S	t/trip	22,5	22,5	22,5	22,5	23
Consumption of energy resources						
Heavy fuel oil	kg/t	3,8	18,1	12,8	1,8	7,2
Emissions to air						
CO_2	g/t	12 011	56 443	39 933	5 498	22 429
CO	g/t	13,7	64,3	45,5	6,3	26
SO_2	g/t	73	964	679	31	296
NO_x	g/t	184	864	611	84	343
Hydrocarbon	g/t	1,05	4,95	3,50	0,48	1,97

1) Around Denmark, not via the Kiel Canal
2) Via Suez

The data concerning ship infrastructure are presented in Appendix 1.

3

Inventory Analysis

3.3. Bitumen production

The straight-run distillation process is shown in Figure 2. In this process, the residue from the atmospheric distillation of crude oil is further distilled in a vacuum tower to produce paving grade bitumen. In a complex refinery a broad range of petroleum products is produced, bitumen being a minor product compared with the more valuable transport fuels.

The bitumen yield from the average European bitumen crude blend is 22,3% by mass.

The process unit emission values include a share of common resources such as crude oil handling, desalting, flaring, loading area, general heating and lighting.

No chemicals are added to paving grade bitumen or to the straight-run distillation process.

Other manufacturing processes using vacuum residue as a feedstock may also be used to produce bitumen such as semi-blowing, propane de-asphalting and vis-breaking. Their impact on the LCI is evaluated separately.

The data concerning refinery infrastructure are presented in Appendix 1.

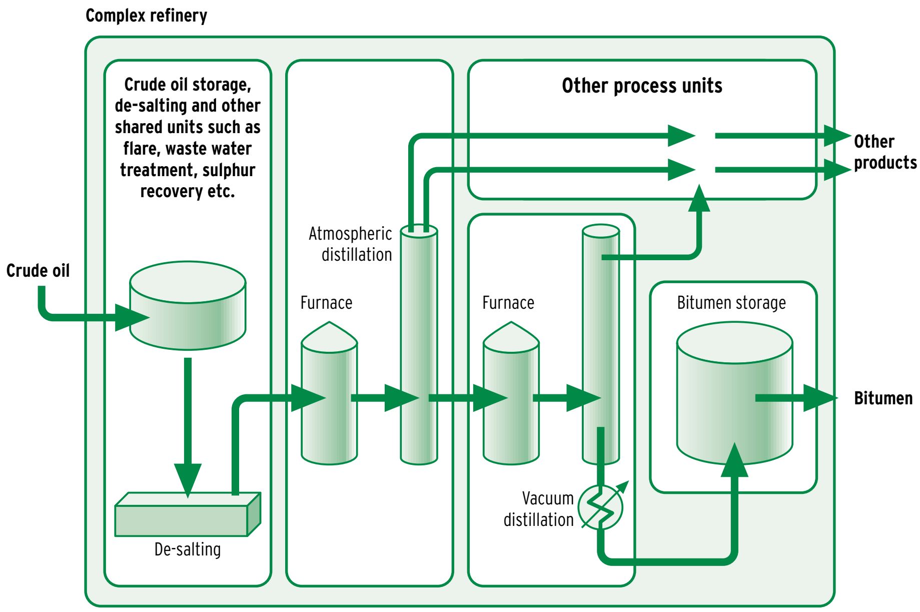

Figure 2. Straight-run distillation of bitumen within a complex refinery

3 Inventory Analysis

3.3.1. Consumption of energy resources

The estimation of the energy used for the distillation processes is based on a Eurobitume internal questionnaire. Its results have been validated by comparison with the "CO_2 weighted tonne" (CWT) approach developed by CONCAWE and Europia[9] (see footnote*).

The allocation of energy for the production of straight-run bitumen is based on the yields of the products arising from the distillation processes and their relative values, which are the average standard refinery values obtained in North West Europe for 2002 to 2008. The energy required for the production of straight-run bitumen is 510 MJ/t.

Energy allocation for production of straight-run bitumen (see Appendix 2)	Units	Crude Distillation Unit	Vacuum Distillation Unit
Energy	MJ/t of feed	581	477
Residue yield	%m of feed	49,5	45,1
Value allocation, residue fraction (weighting factor for yield by mass)	-	0,63	0,61
Bitumen fraction of the feed	%m of feed	22,3	45,1
Energy	MJ/ t bitumen	221	289
Energy for bitumen production	MJ/ t bitumen	510	

The energy mix used by the refining processes is based on CONCAWE data from 2006[10]. 98,3% of the total energy (steam, heat and internal electricity) needed for the production is produced in the refinery from refinery gas (79,2%) and heavy fuel oil (19,1%). The remaining 1,7% of the total energy is assumed to be electricity from the grid.

Distribution of energy sources for bitumen production in refinery	%	MJ/t bitumen
Heavy fuel oil	19,1	97
Refinery gas	79,2	404
Electricity	1,7	8,7
Total	100	510

* This methodology was developed for setting up the European (Carbon) Trading Scheme (ETS) and aims to represent the relative CO_2 emissions of the various units found in a refinery. For the process units considered here, CO_2 emissions can be considered a proxy for energy requirement as the only source of CO_2 emissions is energy consumption.

3 Inventory Analysis

The calorific values of the heavy fuel oil (40,0 MJ/kg) and refinery gas (49,4 MJ/kg) allow the calculation of the consumption of energy for the production of bitumen by straight-run distillation.

Energy consumption for bitumen production in refinery	
Heavy fuel oil	2,44 kg/t bitumen
Refinery gas	8,18 kg/t bitumen
Electricity	2,41 kWh/t bitumen

The consumptions and emissions due to the production of electricity are given in the following life cycle inventory of the ecoinvent 2.2 database: "Electricity, medium voltage, production UCTE, at grid/UCTE".

3.3.2. Emissions to air

The consumptions and emissions due to the production and combustion of heavy fuel oil and refinery gas are given in the following life cycle inventories of the ecoinvent 2.2 database:

- Refinery gas, burned in furnace/RER
- Heavy fuel oil, burned in refinery furnace/RER

An exception has been made for the sulphur dioxide emissions linked to the combustion of heavy fuel oil. These data have been obtained from a CONCAWE report on sulphur dioxide emissions from oil refineries in Europe (2006)[11]. The sulphur content of heavy fuel oil used in the refinery is 1,33% and the SO_2 emissions are 26,6 g SO_2/kg fuel.

Refinery fugitive emissions are mostly coming from light oil products other than bitumen and are thus not included in this inventory.

3.3.3. Emissions to water

Emissions to water covering total hydrocarbon content, biological oxygen demand, chemical oxygen demand, total nitrogen and total suspended solids have been taken from the CONCAWE report no 1/10[11]. The reported annual data are from year 2005 and include all the refineries in EU countries. The mean value of the load per tonne of feed is used.

Data on total organic carbon, phenol, total phosphorous, BTEX, PAH-16 and heavy metal emissions were given by CONCAWE but they have not been published yet.

Emissions to water due to bitumen production have been calculated from the load per tonne of feed using the value allocation factor (0,63*0,61 = 0,38).

3 Inventory Analysis

Emissions to water[11]	g/t bitumen
Total organic carbon	2,1
Total hydrocarbon (oil)	0,27
Chemical oxygen demand	10,3
Biological oxygen demand	2,7
Total nitrogen	2,1
Total suspended solids	2,7
Total phosphorous	0,11
Phenol	<0,01
BTEX*	<0,01
PAH16	0,0001
Heavy metals	0,04

* Benzene, Toluene, Ethylbenzene, Xylenes

3.3.4. Other bitumen manufacturing processes

3.3.4.1. Semi-blowing

Semi-blowing is used to produce a harder bitumen from a softer bitumen feedstock, typically vacuum residue. Based on a Eurobitume questionnaire, the energy consumption is relatively low, accounting for about 33 MJ/t. Therefore, it can be considered as a relatively small addition to the straight-run bitumen LCI.

The oxidation process is exothermic and generates gases, i.e. CO_2, CO, vapor, light hydrocarbons and sulphur compounds. These off-gases are burned to CO_2, water and SO_2.

Emissions to air	CO_2	3 000 g/t bitumen
	SO_2	13 g/t bitumen

3.3.4.2. De-asphalting

The de-asphalting process is used to produce de-asphalted oil for the manufacture of lubricating oils. The feedstock for the de-asphalting unit is vacuum residue (or bitumen). The energy consumption and emissions from the de-asphalting process are fully allocated to the de-asphalted oil fraction. The precipitated asphaltene fraction, a by-product from the process, may be used in bitumen production and is deemed to have the same energy consumption and emissions as the feedstock, i.e. vacuum residue.

3 Inventory Analysis

3.3.4.3. Vis-breaking and vacuum flashing

The vis-breaking and vacuum flashing processes are primarily used to produce vacuum flashed distillates for use as fuels. The feedstock for the vis-breaking unit is vacuum residue. The energy consumption and emissions from the vis-breaking and vacuum flashing processes are fully allocated to the vacuum flashed distillate fraction.

The vacuum flashed vis-broken residue fraction, a by-product from the processes, may be used in bitumen production and is deemed to have the same energy consumption and emissions as the feedstock, i.e. vacuum residue.

3.3.4.4. Conclusion on other bitumen manufacturing processes

The above analysis indicates that the impact of secondary processes used in bitumen manufacture represents a relatively small contribution to the environmental impacts of the refining process. This contribution is even smaller if one considers the overall production chain (less than 3% increase for the main flows). It can therefore be considered that the impacts calculated for straight-run bitumen are representative of the whole bitumen manufacture chain.

3.4. Bitumen storage

Directly after production, bitumen is transferred by pipework into heated storage tanks at the refinery where it is held at the required temperature. The bitumen remains within these tanks until loaded for subsequent transfer.

An average size storage tank of about 6 200 m^3 in volume is used for the study. A typical storage temperature is 175°C; bitumen is also transferred from the production process at this temperature. Bitumen in the storage tank is circulated constantly using a pump powered by an electric motor. The same pump is also used for loading. The annual throughput of the tank is fixed at 40 000 tonnes.

3.4.1. Consumption of energy resources

The mean energy losses from the storage tanks and pipework were calculated by three independent sources using standard engineering methodology and calculations. The average energy use was as follows:

- Maintain the bitumen temperature within the storage tank 70,1 MJ/t
- Maintain the temperature within the pipework 20,2 MJ/t
- Circulate and load bitumen 9,7 MJ/t
- Total storage energy 100 MJ/t

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3 Inventory Analysis

Refinery fuels are used in heating the tank and pipework. The split between refinery gas and heavy fuel oil is the same as in the refinery. The circulation and loading pump utilises electricity from the grid.

Energy source	Split %	Energy MJ/t	Fuel kg/t bitumen	Energy kWh/t bitumen
Refinery gas	80,6	72,8	1,47	
Heavy fuel oil	19,4	17,5	0,44	
Electricity	-	9,7		2,69

The consumptions and emissions due to the production of electricity and to the production and combustion of heavy fuel oil and refinery gas are calculated in the same way as in the refining step.

3.4.2. Emissions

Hydrocarbon emissions from hot storage tanks are assumed to be 38 g/t bitumen[12]. Water emissions and solid wastes, e.g. coke from the tank cleanings, are included in the refinery emissions.

4 Life Cycle Inventory of Bitumen

The life cycle inventory for the production of 1 tonne of paving grade bitumen is presented in the tables below. The tables present the most relevant flows and an aggregation of the other flows. A complete inventory is available on the Eurobitume website: www.eurobitume.eu

The table below presents the life cycle inventory for the process.

Production of 1 tonne of bitumen (process without infrastructure)	Unit	Crude oil extraction	Transport	Refinery	Storage	Total
Raw material						
Crude oil	kg	1 000				1 000
Consumption of energy resources						
Natural gas	kg	18,9	0,4	0,58	0,19	20,1
Crude oil	kg	17,5	9,3	11,9	2,2	40,9
Coal	kg	0	0,21	0,49	0,33	1,03
Uranium	kg	0	0,00001	0,00003	0,00002	0,0001
Consumption of non energy resources						
Water 1)	l	0	48	72	24	143
Emissions to air						
CO_2	g	99 135	30 078	37 200	7 831	174 244
SO_2	g	290	334	130	27	781
NO_x	g	270	436	52	11	770
CO	g	524	70	16	3	613
CH_4	g	548	16	25	6	595
Hydrocarbon	g	0,015	4,6	3,5	38,7	46,8
NMVOC	g	297	15	15	3	331
Particulates	g	132,6	12,7	12,6	3,4	161,2
Emissions to water						
Chemical Oxygen Demand	g	0	130	176	30	336
Biological Oxygen Demand	g	0	128	166	30	324
Suspended solids	g	0	9,4	16,4	4,1	30,0
Hydrocarbon	g	6,9	40,9	52,5	9,5	109,8
Phosphorous compounds	g	0	2,52	6,77	4,79	14,1
Nitrogen compounds	g	0	0,95	4,40	1,51	6,86
Sulphur compounds	g	0	63	166	119	348
Emissions to soil						
Hydrocarbon (oils)	g	8,1	42,6	54,9	10,0	116

1) Excluding water cooling and turbine use

4 Life Cycle Inventory of Bitumen

The table below presents the life cycle inventory for process and infrastructure. It includes the flows associated with the building of the infrastructure required to produce, transport and refine crude oil.

Production of 1 tonne of bitumen (process with infrastructure)	Unit	Crude oil extraction	Transport	Refinery	Storage	Total
Raw material						
Crude oil	kg	1 000				1 000
Consumption of energy resources						
Natural gas	kg	21,0	0,66	0,59	0,19	22,5
Crude oil	kg	26,2	10,2	12,0	2,2	50,5
Coal	kg	8,2	1,8	0,6	0,3	10,9
Uranium	kg	0,00018	0,00003	0,00003	0,00002	0,0003
Consumption of non energy resources						
Water [1)]	l	1 024	117	74	24	1 239
Emissions to air						
CO_2	g	144 563	36 352	37 422	7 831	226 167
SO_2	g	395	346	131	27	899
NO_x	g	604	474	53	11	1 142
CO	g	887	132	18	3	1 040
CH_4	g	659	28	25	6	719
Hydrocarbon	g	4,8	5,4	3,5	38,7	52,4
NMVOC	g	364	22	16	3	404
Particulates	g	249	34,0	13,6	3,4	300
Emissions to water						
Chemical Oxygen Demand	g	317	151	177	30	675
Biological Oxygen Demand	g	171	144	166	29,8	511
Suspended solids	g	190	13,3	16,6	4,1	224
Hydrocarbon	g	43,5	44,8	52,5	9,5	150
Phosphorous compounds	g	54,91	10,21	7,49	4,79	77,4
Nitrogen compounds	g	14,78	2,88	4,54	1,51	23,70
Sulphur compounds	g	1 279	219	184	119	1 801
Emissions to soil						
Hydrocarbon (oils)	g	43,7	46,5	54,9	10,0	155

1) Excluding water cooling and turbine use

4 Life Cycle Inventory of Bitumen

Remarks

- In this LCI, it is important to note that the crude oil is used in two different ways:
  - as an energy that is consumed when extracting , transporting and refining of crude oil;
  - as a raw material to produce bitumen, which is the heaviest fraction of crude oil. This part of crude oil is not an energy use.
- This LCI is based on a mass allocation for extraction and transport and on an economic allo cation for the refinery stage.
- Considering the reliability and the completeness of data used to establish the LCI, Eurobitume estimates that this LCI is suitable for analysing environmental impact indicators such as: abiotic depletion, global warming potential, acidification, photochemical oxidation. This LCI is less accurate for the analysis of toxicity and eco-toxicity indicators.

See Appendix 3 for sensitivity analysis on allocation procedure and see Appendix 4 for considerations on moving from life cycle inventory to life cycle assessment.

5 Polymer Modified Bitumen (PMB)

Polymer modified bitumen is widely used throughout Europe for both road and industrial applications. The range of polymer types and the range of polymer contents used in the bitumen vary depending on the technical requirements of the application. This study is a base case considering one polymer type and content. The most common polymer type used in Europe is styrene butadiene styrene (SBS) in its granular form.

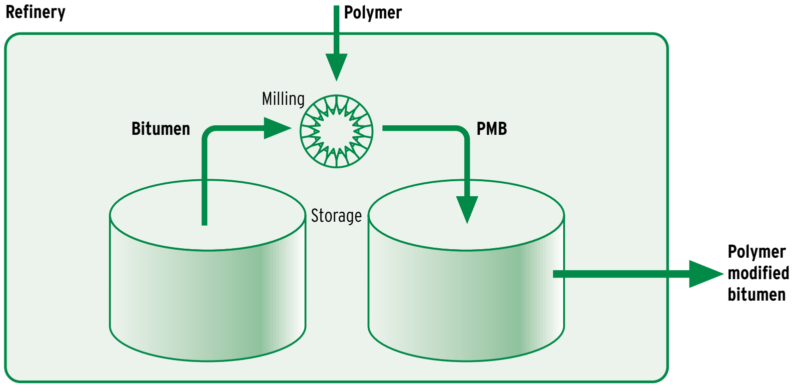

Figure 3. PMB Production

Paving grade bitumen is used as the base bitumen.

An internal industry review of polymer modified products within Europe determined that a typical SBS polymer content is around 3,5%m in the final product.

The PMB plant in this study is located within the refinery.

It is assumed that all the necessary heat energy for the production process is from the hot bitumen at 175°C plus the added frictional heat energy from the high shear milling. This is the case in many PMB plants.

The storage step is already included in the bitumen eco-profile.

5.1. Raw materials

Formulation	%m	kg/t PMB
Bitumen	96,5	965
SBS	3,5	35

The energy and emissions used to produce, store and pump the base bitumen is referenced in Section 4.

5 Polymer Modified Bitumen (PMB)

Values for the production of SBS polymer are taken from the eco-profile of SBS[13].

It is assumed that the polymer is produced about 500 km from the refinery.

The inputs and outputs attributable to the transport come from the life cycle inventory "Transport, lorry >16t, fleet average/RER" of the ecoinvent 2.2 database.

5.2. Consumption of energy resources

A high shear mill, powered by electricity, is used for the milling of the polymer into the bitumen. Plant data sets gave mean calculated energy figures for the high shear milling of 72,0 MJ/t PMB*.

The consumption and emissions due to the production of electricity are given in the following life cycle inventory "Electricity, medium voltage, production UCTE, at grid/UCTE" of the ecoinvent 2.2 database.

5.3. Emissions

Hydrocarbon emissions from PMB storage are included within the bitumen eco-profile data.

Water emissions and solid wastes, e.g. coke from tank cleaning, are included in the refinery emissions.

5.4. Life cycle inventory of PMB

The table below presents the life cycle inventory for the process.

Production of 1 tonne of PMB (process without infrastructure)	Unit	Bitumen	SBS (production & transport)	PMB milling	Total
Raw material					
Crude oil	kg	965	22,6		988
Consumption of energy resources					
Natural gas	kg	19,4	29,8	0,78	50,0
Crude oil	kg	39,5	20,1	0,3	59,9
Coal	kg	1,0	5,4	2,1	8,5
Uranium	kg	0,00006	0,00000	0,00015	0,0002

table continued overleaf

* Eurobitume confidential information from member questionnaire

5 Polymer Modified Bitumen (PMB)

Production of 1 tonne of PMB (process without infrastructure)	Unit	Bitumen	SBS (production & transport)	PMB milling	Total
Consumption of non energy resources					
Water [1]	l	138	6 843	97	7 078
Emissions to air					
CO_2	g	168 146	117 719	10 046	295 910
SO_2	g	754	842	34	1 630
NO_X	g	743	614	18	1 375
CO	g	591	76	3	671
CH_4	g	574	493	18	1 085
Hydrocarbon	g	45,2	1 017	1	1 063
NMVOC	g	319	10	1	331
Particulates	g	155,6	99,8	9,9	265
Emissions to water					
Chemical Oxygen Demand	g	324	42	4	370
Biological Oxygen Demand	g	313	8	4	325
Suspended solids	g	29	56,6	14,4	100
Hydrocarbon	g	106,0	10,2	1,3	117
Phosphorous compounds	g	13,6	0,85	31,8	46,2
Nitrogen compounds	g	6,62	0,89	9,66	17,16
Sulphur compounds	g	336	35	788	1 159
Emissions to soil					
Hydrocarbon (oils)	g	111,6	1,9	1,3	115

1) Excluding water cooling and turbine use

5 Polymer Modified Bitumen (PMB)

The table below presents the life cycle inventory for the PMB process and infrastructure. It includes the flows associated with the building of the infrastructure required to produce, transport and refine crude oil.

Production of 1 tonne of PMB (process with infrastructure)	Unit	Bitumen	SBS (production & transport)	PMB milling	Total
Raw material					
Crude oil	kg	965	22,6		988
Consumption of energy resources					
Natural gas	kg	21,7	29,8	0,78	52,3
Crude oil	kg	48,7	20,1	0,3	69,1
Coal	kg	10,5	5,4	2,1	18,0
Uranium	kg	0,00025	0,00000	0,00015	0,0004
Consumption of non energy resources					
Water [1)]	l	1 195	6 843	97	8 135
Emissions to air					
CO_2	g	218 252	117 719	10 046	346 016
SO_2	g	867	842	34	1 744
NO_x	g	1 102	614	18	1 734
CO	g	1 004	76	3	1 083
CH_4	g	694	493	18	1 205
Hydrocarbon	g	50,5	1 017	1	1 068
NMVOC	g	390	10	1	401
Particulates	g	290,1	99,8	9,9	400
Emissions to water					
Chemical Oxygen Demand	g	652	42	4	698
Biological Oxygen Demand	g	493	8	4	506
Suspended solids	g	216	56,6	14,4	287
Hydrocarbon	g	145,2	10,2	1,3	157
Phosphorous compounds	g	74,70	0,85	31,80	107,3
Nitrogen compounds	g	22,87	0,89	9,66	33,42
Sulphur compounds	g	1 738	35	788	2 561
Emissions to soil					
Hydrocarbon (oils)	g	149,8	1,9	1,3	153

1) Excluding water cooling and turbine use

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6 Bitumen Emulsion

Bitumen emulsion formulations vary depending upon application requirements. Bitumen emulsions are composed of three basic ingredients: bitumen, water and an anionic, cationic or non-ionic emulsifying agent.

The emulsion for the study is a cationic emulsion formulation incorporating bitumen, an amine type emulsifier and hydrochloric acid. This is the most widely used type of emulsion in Europe.

The emulsion plant in this study is located within the refinery boundary.

Energy and emissions associated with storage of the emulsion were not considered as the bitumen functional unit is already taken into account in the life cycle inventory. Emulsions are stored at low temperature, normally without added heat and the only emission from the storage tank is water.

The functional unit is 1 tonne of residual bitumen corresponding to 1,54 tonne of bitumen emulsion.

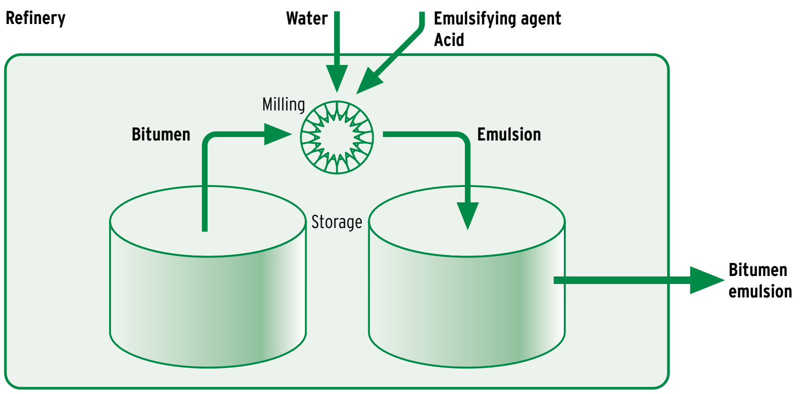

Figure 4. Bitumen emulsion production

6.1. Raw materials

The formulation is as follows:

Item	%m	kg/t residual bitumen
Paving grade bitumen	65,0	1 000
Emulsifier	0,3	4,615
Hydrochloric acid (28 %m)	0,3	4,615
Water	34,4	529,2

6 Bitumen Emulsion

The energy and emissions used to produce, store and pump the base bitumen are referenced in Section 4.

Values for the production of the emulsifier are taken from the eco-profile of the emulsifier[14].

Values for the production of hydrochloric acid are given in the following life cycle inventory "Hydrochloric acid, 30% in H_2O, at plant/RER" of the ecoinvent 2.2 database.

It is assumed that the emulsifier and hydrochloric acid are produced around 500 km from the refinery.

The inputs and outputs attributable to the transport for the emulsifier and hydrochloric acid come from the life cycle inventory "Transport, lorry >16t, fleet average/RER" of the ecoinvent 2.2 database.

The water is supplied from the local area. The inputs and outputs are taken from the following life cycle inventory "Tap water, at user/RER" of the ecoinvent 2.2 database.

6.2. Consumption of energy resources

6.2.1. Water heating

In the production phase, it is assumed that the water is heated from 10°C to 40°C using an inline heater prior to milling of the emulsion. The energy required to raise the water temperature is equal to 140 MJ/t water, i.e. 74 MJ/t residual bitumen.

The former value of heating energy has been calculated using the specific heat capacity of water and an energy efficiency of 90%. The refinery energy split has been used.

Energy source	Split %	Energy MJ/t bitumen	Fuel kg/t bitumen
Refinery gas	80,6	59,6	1,21
Heavy fuel oil	19,4	14,3	0,36

6

Bitumen Emulsion

6.2.2. Emulsion production

A high shear mill, powered by electricity sourced from the local grid is used for the milling of the emulsion.

The milling equipment is similar to the high shear milling of PMB. It is assumed that the milling energy is the same as that for PMB production referenced in this report. Plant data sets gave mean calculated energy figures for the high shear milling of 72,0 MJ/t emulsion (111 MJ/t residual bitumen).

The consumption and emissions due to the production of electricity are given in the following life cycle inventory "Electricity, medium voltage, production UCTE, at grid/UCTE" of the ecoinvent 2.2 database.

6.3. Emissions

The consumptions and emissions due to the production and combustion of heavy fuel oil and refinery gas are given in the following life cycle inventories of the ecoinvent 2.2 database:

- Refinery gas, burned in furnace/RER
- Heavy fuel oil, burned in refinery furnace/RER

An exception has been made for the sulphur dioxide emissions linked to the combustion of heavy fuel oil. These data have been obtained from a CONCAWE report on sulphur dioxide emissions from oil refineries in Europe (2006)[10]. The sulphur content of heavy fuel oil used in the refinery is 1,33% and the SO_2 emissions are 26,6 g SO_2/kg fuel.

6

Bitumen Emulsion

6.4. Life cycle inventory of bitumen emulsion

The table below presents the life cycle inventory for the process.

Production of bitumen emulsion – 1 tonne of residual bitumen (process without infrastructure)	Unit	Bitumen	Emulsifier (production & transport)	HCl (production & transport)	Hot water (water & heating)	Emulsion milling	Total
Raw material							
Crude oil	kg	1 000	1,1				1 001,1
Consumption of energy resources							
Natural gas	kg	20,1	0,22	0,34	0,08	1,21	21,9
Crude oil	kg	40,9	1,4	0,4	1,8	0,4	44,9
Coal	kg	1,03	0,30	0,67	0,07	3,25	5,32
Uranium	kg	0,00006	0,00002	0,00004	0,00000	0,00023	0,0004
Consumption of non energy resources							
Water [1]	l	143	15	62	608	149	977
Emissions to air							
CO_2	g	174 244	4 602	3 985	5 459	15 455	203 746
SO_2	g	781	7,1	16	19	53	876
NO_x	g	770	20	10	8	27	835
CO	g	613	4,9	4,1	2,9	5,1	629
CH_4	g	595	6,0	7,7	3,7	28	640
Hydrocarbon	g	46,8	14,0	0,3	0,5	1,0	63
NMVOC	g	331	0,9	1,4	2,3	2,1	338
Particulates	g	161,2	3,0	4,2	1,9	15,2	185,5
Emissions to water							
Chemical Oxygen Demand	g	336	93	6	24	6,7	467
Biological Oxygen Demand	g	324	1,4	4,4	24	6,3	360
Suspended solids	g	30	2,1	7,9	1,9	22	64
Hydrocarbon	g	110	0,4	1,1	7,7	1,9	121
Phosphorous compounds	g	14,08	4,40	10,76	0,82	48,92	79,0
Nitrogen compounds	g	6,86	5,03	4,35	0,29	14,85	31,38
Sulphur compounds	g	348	127	320	21,5	1 213	2 029
Emissions to soil							
Hydrocarbon (oils)	g	116	0,2	1,2	8,1	2,0	127

1) Excluding water cooling and turbine use

6 Bitumen Emulsion

The table below presents the life cycle inventory for the bitumen emulsion process and infrastructure. It includes the flows associated with the building of the infrastructure required to produce, transport and refine crude oil.

Production of bitumen emulsion - 1 tonne of residual bitumen (process with infrastructure)	Unit	Bitumen	Emulsifier (production & transport)	HCl (production & transport)	Hot water (water & energy)	Emulsion milling	Total
Raw material							
Crude oil	kg	1 000	1,1				1 001,1
Consumption of energy resources							
Natural gas	kg	22,5	0,22	0,34	0,08	1,21	24,3
Crude oil	kg	50,5	1,4	0,4	1,8	0,4	54,4
Coal	kg	10,92	0,30	0,67	0,07	3,25	15,21
Uranium	kg	0,00026	0,00002	0,00004	0,00000	0,00023	0,0006
Consumption of non energy resources							
Water [1)]	l	1 239	15	62	608	149	2 073
Emissions to air							
CO_2	g	226 167	4 602	3 985	5 459	15 455	255 669
SO_2	g	899	7,1	16	19	53	993
NO_x	g	1 142	20	10	7,7	27	1 207
CO	g	1 040	4,9	4,1	2,9	5	1 057
CH_4	g	719	6,0	7,7	3,7	28	764
Hydrocarbon	g	52,4	14,0	0,3	0,5	1,0	68
NMVOC	g	404	0,9	1,4	2,3	2,1	410
Particulates	g	300,6	3,0	4,2	1,9	15,2	324,9
Emissions to water							
Chemical Oxygen Demand	g	675	93	6,3	24	6,7	806
Biological Oxygen Demand	g	511	1,4	4,4	24	6,3	547
Suspended solids	g	224	2,1	7,9	1,9	22	258
Hydrocarbon	g	150	0,4	1,1	7,7	1,9	162
Phosphorous compounds	g	77,41	4,40	10,76	0,82	48,92	142,3
Nitrogen compounds	g	23,70	5,03	4,35	0,29	14,85	48,22
Sulphur compounds	g	1 801,0	127,1	319,7	21,5	1 212,8	3 482
Emissions to soil							
Hydrocarbon (oils)	g	155	0,2	1,2	8,1	2,0	167

1) Excluding water cooling and turbine use

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References

1 Partial Life Cycle Inventory or "Eco-Profile" for Paving Grade Bitumen, Eurobitume Report 99/007, May 1999

2 EN 12591:2009; Bitumen and bituminous binders – Specifications for paving grade bitumens. Table 1.

3 International Association of Oil & Gas Producers, Environmental performance in the Exploration & Production industry, Report No. 429, November 2009.

4 www.ecoinvent.org

5 Mineralölversorgung mit Pipelines, www.MWV.de

6 www.nesteoil.com, Mastera crude oil carrier

7 www.searates.com, port to port distances

8 U.S. Environmental Protection Agency, Analysis of Commercial Marine Vessels, Emissions and Fuel Consumption Data, EPA420-R-00-002, February 2000

9 Ecofys (Methodology for the free allocation of emission allowances in the EU ETS post 2012 Sector report for the refinery industry, 2009

10 CONCAWE report no. 1/10. Sulphur dioxide emissions from oil refineries in Europe, 2006.

11 CONCAWE report no. 2/10, Refinery BREF related environmental parameters for aqueous discharges from refineries in Europe. April 2010.

12 Deygout, F. Volatile emissions from hot bitumen storage tanks. Environmental Progress & Sustainable Energy, n/a. doi: 10.1002/ep.10444

13 Eco-Profile of SBS, The International Institute of Synthetic Rubber Producers, I. Boustead & D.L. Cooper, July 1998

14 A Life Cycle Inventory of the production of Redicote E-9, Akzo Nobel Surface Chemistry

A1 Appendix 1 - Infrastructure

Infrastructure data

Very few data are available on infrastructure and the quality of the available data is not easy to assess.

In this eco-profile, infrastructure data come from the ecoinvent 2.2 database which gives information on infrastructure for:

- Crude oil extraction (well, platform, etc.)
- Transport of crude (pipeline, tanker)
- Refinery.

Infrastructure for crude oil extraction

The life cycle inventories used for infrastructure for crude oil extraction are:

- Well for exploration and production, onshore/GLO/I
- Pipeline, crude oil, onshore/RER/I
- Production plant crude oil, onshore/GLO/I
- Well for exploration and production, offshore/OCE/I
- Platform, crude oil, offshore/OCE/I

There are different data according to the geographic area of the production. The quantity of infrastructure in the functional unit has been calculated based on the crude oil slate.

- For crude oil from Europe, the data used in this eco-profile are representative of the offshore production in Norway and come from the following life cycle inventory: crude oil, at production offshore/NO.
- For crude oil from Middle East, the data used in this eco-profile are representative of the onshore production in Middle East and come from the following life cycle inventory: crude oil, at production onshore/RME
- For crude oil from South America, no data are available in the ecoinvent 2.2 database and the data used in this eco-profile are representative of the onshore production in Middle East.
- For crude oil from Former Soviet Union, the data used in this eco-profile are representative of the onshore production in Russia. The data given in the ecoivent database 2.2 have been modified with up-to-date data by using the following sources of information:
    - Production and development data, Rosneft, 2009 (www.rosneft.com/Upstream/ProductionAndDevelopment/)
    - Oil field development and production, LUKOIL Group, Annual report 2009
    - West Siberia Oil Industry Environmental and Social Profile, IWACO, 2001

A1 Appendix 1 – Infrastructure

Infrastructure for offshore extraction in Europe	Quantity per kg of crude oil	Unit
Offshore well for exploration and production	2,60E-06	m
Offshore platform	5,11E-11	Plant

Infrastructure for onshore extraction in Middle East and South America	Quantity per kg of crude oil	Unit
Onshore well for exploration and production	1,63E-06	m
Onshore pipeline	7,70E-09	km
Onshore production plant	1,38E-10	Plant

Infrastructure for onshore extraction in Former Soviet Union	Quantity per kg of crude oil	Unit
Onshore well for exploration and production	2,50E-05	m
Onshore pipeline	3,30E-08	km
Onshore production plant	5,13E-09	Plant

The crude oils of this study are split as follows; 900 kg onshore (FSU, ME and SAm) and 100 kg offshore (Europe).

Infrastructure for crude oil extraction	Quantity for 1 t of bitumen	Unit
Onshore well for exploration and production	1,57E-02	m
Onshore pipeline	2,24E-05	km
Onshore production plant	3,17E-06	Plant
Offshore well for exploration and production	2,60E-04	m
Offshore platform	5,11E-09	Plant

Infrastructure for transport by pipeline

The life cycle inventory used for pipeline is: pipeline, crude oil, onshore/RER/I.

The quantity of pipeline in the functional unit has been calculated based on the data given in the life cycle inventory: transport, crude oil pipeline, onshore/RER.

Pipeline	Quantity per t of crude oil and per km	Unit
Pipeline	9,46E-09	km

A1 Appendix 1 – Infrastructure

For 1 tonne of bitumen, 610 kg of crude oil (part of crude oil from Former Soviet Union) is transported by pipeline on a distance of 1 800 km.

Pipeline	Quantity for 1 t of bitumen	Unit
Pipeline	1,04E-05	km

Infrastructure for transport by ship

The life cycle inventory used for ship is: transoceanic tanker/OCE/I.

The quantity of tanker in the functional unit has been calculated based on the data given in the life cycle inventory: transport, transoceanic tanker/OCE.

Tanker	Quantity per t of crude oil and per km	Unit
Tanker	3,58E-12	Tanker

1 tonne of bitumen is transported by ship on a distance of 9 210 km (4605 x 2 km).

Tanker	Quantity for 1 t of bitumen	Unit
Tanker	3,3E-08	Tanker

Infrastructure for refinery

The life cycle inventory used for refinery is: refinery/RER/I.

The quantity of refinery in the functional unit is given in the life cycle inventory: bitumen, refinery/RER.

Refinery	Quantity per kg of bitumen	Unit
Refinery	1,88E-11	Refinery

Refinery	Quantity for 1 t of bitumen	Unit
Refinery	1,88E-08	Refinery

A2

Appendix 2 - Economic Allocation at the Refinery Step

The economic allocation at the refinery step is based on a combination of co-product yields and relative values.

Co-products yields

Overall bitumen yield was calculated using a model simulating the crude oil distillation unit (CDU) and the vacuum distillation unit (VDU). The model calculated the various yields across the units for the manufacture of paving grade bitumen using the crude slate defined by the Eurobitume questionnaire.

Relative values

For these calculations, the annual average for the international quotations published daily for the NWE market over the 7 years from 2002 to 2008 were used. The quotations covered all main products and typical crudes. Where no quotations are available, values were calculated using standard alternative methods.

All values are expressed as a ratio between product value and the specific crude value. When products have to be grouped, the products' yields for the specific crude are used to calculate the weighted average value for that product group. A specific crude was selected and the yield for this crude obtained from crude oil assay to calculate the various standard refinery values,

The following ratios have been calculated: CDU distillates, CDU residue, VDU distillates and bitumen (VDU residue).

These are averaged over the 7 years. While the market values vary substantially over the years, the products to crude ratios remain within a narrow range. The average over the 7 years is a good representation of the value.

Economic allocation coefficients

The economic allocation coefficient for a distillation unit residue is calculated as follows:

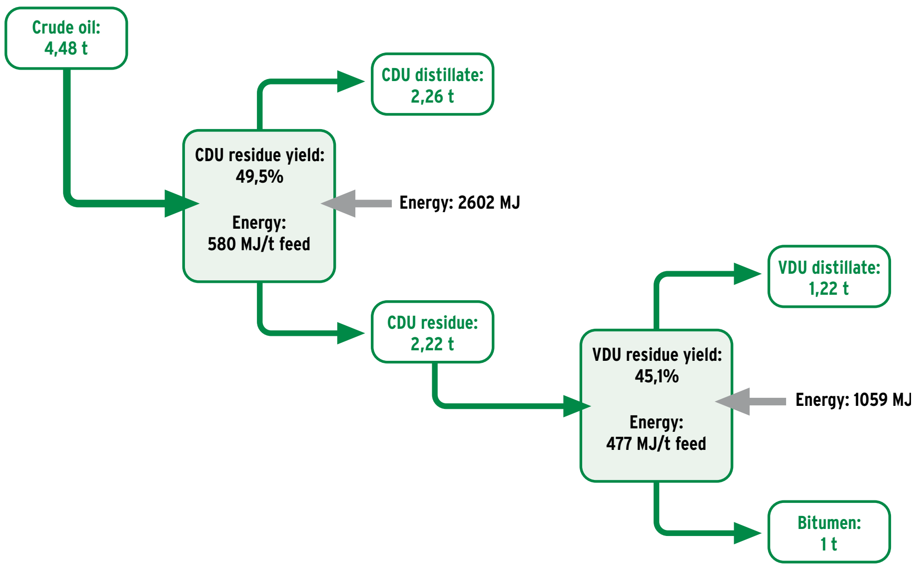
$$\textit{Residue coefficient} = \frac{\textit{Residue price x Residue yield}}{\textit{Residue price x Residue yield + Distillates price x Distillates yield}}$$

A2 Appendix 2 – Economic Allocation at the Refinery Step

Considering the yields and the relative prices of the co-products, the economic allocation coefficients for the CDU and VDU residues are given in the table below:

Economic allocation coefficient of the residue	
CDU residue	0,31
VDU residue = bitumen	0,27

Calculation of the energy consumption at the refinery step



The following formula is used to calculate the energy consumption for the production of 1 tonne of residue:

$$\textit{Energy for 1 t residue} = \textit{Economic allocation coefficient for residue} \times \frac{\textit{Energy per t of feed}}{\textit{Residue yield}}$$

The results of the energy consumption calculation are the following:

$$\textit{Energy consumption for 2,22 t CDU residue} = 2{,}22 \times 0{,}31 \times \frac{580}{0{,}495} = 0{,}31 \times 2602 = 810 \text{ MJ}$$

$$\textit{Energy consumption for 1 t bitumen} = 0{,}27 \times \left(\frac{477}{0{,}451} + 810\right) = 0{,}27 \times (1059 + 810) = 510 \text{ MJ}$$

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A3

Appendix 3 – Sensitivity Analysis on Allocation Procedures

As written in chapter 2.5, in order to assess the environmental impact of bitumen, one must define a way to allocate the impacts of the production chain (extraction, transport and refinery) between bitumen and the other co-products of crude oil: gasoline, heavy fuel oil, liquefied petroleum gas, etc.

The aim of the allocation procedure is to find a suitable parameter so that the inputs and the outputs of the system studied can be assigned to the product under consideration.

According to ISO 14040 & ISO 14044, there are different ways to address allocation issues based on physical parameters (mass, calorific value, etc.) or economic parameters (relative values).

In this eco-profile, the choices concerning allocation are different depending on the stage of the bitumen life cycle[1].

Regarding crude oil extraction and transport, a mass allocation has been carried out. At these stages all the constituents of crude oil can be considered as material and a mass relationship can be established. This allocation method takes into account the extraction of 1 tonne of crude oil and the transport of 1 tonne of crude oil in order to produce 1 tonne of bitumen.

Regarding the refinery step, no physical relationship can be established between the co-products as bitumen is intended to be used as a material and other co-products are intended to be used as fuels. For this reason, an economic allocation has been carried out in order to share the consumptions and emissions at the refinery stage (as recommended in ISO TR 14049).

However, other options concerning allocation could be justifiable and could change the results. In order to assess the significance of the allocation method on results, a sensitivity analysis has been made considering the two following alternative options:

- Economic allocation for the whole production chain
- Mass allocation for the whole production chain

1 The allocation procedure concerns the following stages of the bitumen life cycle: extraction, transport and refinery. The storage stage does not include allocation procedure since the bitumen is stored as a final product and all the consumption and emission for bitumen storage are fully attributable to bitumen.

A3

Appendix 3 – Sensitivity Analysis on Allocation Procedures

Allocation based on energy content has not been considered since bitumen is never used as fuel. Moreover, according to Eurobitume, energy content is a poor indicator of the motivation to produce an oil product as seen in the difference in market values compared to differences in energy contents. However, if an "energy content" allocation method were carried out, the results would be intermediary between the economic allocation and the mass allocation.

The table below compares the results with the different allocation methods. One can notice that the mass allocation method gives the greatest environmental impacts for bitumen and the economic approach gives the lowest environmental impacts. The choices made by Eurobitume concerning the allocation give intermediary results and this is considered to be a quite conservative approach.

Production of 1 tonne of bitumen (process without infrastructure)	Unit	100% Mass allocation	Allocation in this study	100% Economic allocation
Raw material				
Crude oil	kg	1 000	1 000	1 000
Consumption of energy resources				
Natural gas	kg	20,7	20,1	8,36
Crude oil	kg	53,7	40,9	27,6
Coal	kg	1,55	1,03	0,90
Uranium	kg	0,00010	0,000064	0,000058
Consumption of non energy resources				
Water 1)	l	220	143	114
Emissions to air				
CO_2	g	214 123	174 244	95 811
SO_2	g	920	781	402
NO_x	g	826	770	341
CO	g	629	613	252
CH_4	g	621	595	253

table continued overleaf

1) Excluding water cooling and turbine use

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A3 Appendix 3 – Sensitivity Analysis on Allocation Procedures

Production of 1 tonne of bitumen (process without infrastructure)	Unit	100% Mass allocation	Allocation in this study	100% Economic allocation
Hydrocarbon	g	50,5	46,8	44,0
NMVOC	g	347	331	141
Particulates	g	174,7	161,2	73,0

Emissions to water

Chemical Oxygen Demand	g	530	336	257
Biological Oxygen Demand	g	503	324	246
Suspended solids	g	48,8	30,0	24,2
Hydrocarbon	g	166	110	80,8
Phosphorous compounds	g	21,4	14,1	12,5
Nitrogen compounds	g	12,5	6,86	6,28
Sulphur compounds	g	526	348	310

Emissions to soil

Hydrocarbon (oils)	g	174,4	115,6	84,8

A4

Appendix 4 – Moving from LCI to LCA

LCA, a tool for the assessment of impacts on the environment

The life cycle inventory is a phase of the life cycle assessment involving the compilation of inputs and outputs for a product throughout its life cycle. An environmental impact assessment is conducted on the basis of the inventory flows. Different methods can be used to deal with impact assessment (e.g. Ecoindicator 99, CML, Impact 2002+, ReCiPe).

These methodologies mainly deal with impacts on "Human health", "Ecosystem quality", "Climate change" and "Resource depletion" and they differ in the definition, calculation and aggregation of impacts.

Specific considerations for bitumen regarding LCA and consumption of energy resources

Some clarification regarding bitumen and its main use, asphalt, is needed.

On one hand, the production of bitumen implies the consumption of energy sources such as natural gas, electricity or heavy fuel oil for the extraction, transportation and refining process.

On the other hand, the production of bitumen implies the use of energy resources (crude oil) as raw material from which final products are composed.

It is important not to confuse energy resources used for processing (process energy) and energy resources used as raw material (feedstock energy). Indeed, the part of crude oil which is used as raw material to produce bitumen is not burned, it does not emit greenhouse gas and its energy content is not lost.

Recommendations

- In some documents, and in particular in the French building standards NFP01010, it is required to assess primary energy as the sum of process energy and feedstock energy. Based on the previous remarks, Eurobitume believes that this methodology is confusing the representation of the environmental impact. It is more informative to separate these indicators, allowing an analysis of the efficiency of the processes on one side and the impact on the depletion of the Earth's resources on the other.

A4

Appendix 4 - Moving from LCI to LCA

- Considering the reliability and the completeness of data used to establish the LCI, Eurobitume estimates that there is high accuracy for the most relevant flows in the bitumen production chain: crude oil consumption, natural gas consumption, emission to air of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_x), methane (CH_4) and non-methane volatile organic compounds (NMVOC). For that reason, this LCI is suitable for analysing environmental impact indicators such as: abiotic depletion, global warming potential, acidification, photochemical oxidation. This LCI is less accurate for analysing toxicity and eco-toxicity indicators.

A5

Appendix 5 - Reviewer's Report

Critical review of a life cycle inventory analysis of European bitumen production

Critical Review Report according to

ISO 14040 and 14044

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Contents

Imprint	
Title	Critical review of a life cycle inventory analysis of European bitumen production
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Commissioner	Eurobitume
Publications	Each reference to this review statement is only allowed if the same publication shows also the full review statement without alterations.
Liability Statement	Information contained herein have been compiled or arrived from sources believed to be reliable. Nevertheless, the authors nor their organizations do not accept liability for any loss or damage arising from the use thereof. Using the given information is strictly your own responsibility.
Version	379-Draft-Review-bitumen-2.4.docx, 11/02/2011 11:37:00

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1. Background and Objectives

Eurobitume has elaborated in cooperation with the consultancy Bio Intelligence Service a life cycle inventory (LCI) study for bitumen produced in Europe. Some up-to-date inventory data were collected for crude oil production (4 main producing countries), transportation to Europe, and actual crude oil throughput for bitumen production and refining in Europe. Only bitumen is considered as a final product of the refinery. Further processing to bitumen products is included in the analysis.

The final report has 31 pages. The aim is to update and publish life cycle inventory data that can be used by public and in LCI databases such as ecoinvent. As a main background database ecoinvent data are used. All calculations are made in Excel.

The customer has asked Dr. Niels Jungbluth (ESU-services Ltd.) for a critical review of this study. This includes the review and feedback on a draft report of the final report. International Organization for Standardization (ISO) (2006b:6.2) states the following concerning the procedure:

"A critical review may be carried out by an internal or external expert. In such a case, an expert independent of the LCA shall perform the review. The review statement, comments of the practitioner and any response to recommendations made by the reviewer shall be included in the LCA report."

2. Standards and review criteria

The critical review was carried out according to the international Standards ISO 14040 and 14044 (International Organization for Standardization (ISO) 2006a; b). This is not a comparative study. Thus, it is not necessary to conduct the critical review in a review panel and only one external expert has been commissioned (ISO 2006b:6.1).

The LCA is reviewed according to the following five aspects outlined in ISO 14040. It is assessed whether

- "the methods used to carry out the LCA are consistent with this International Standard,
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent."

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3. Tasks of the reviewer

The critical review was carried out by Dr. Niels Jungbluth, ESU-services Ltd., Uster, Switzerland.

The following interactions between the commissioner, the practitioner and the reviewer took place:

- Draft LCI report, dated 18th of October 2010 has been send to the review together with 4 Excel tables including further results of the study and the modelling of the LCI based on cumulative results from the ecoinvent database.
- Telephone conference for discussing the comments has been held on the 9.11.2010.
- Revised LCI report and Excel calculation sheet, dated 26th November 2010 and answers to initial comments has been sent to the reviewer.
- Revised LCI report, dated 5th January 2011 and answers to initial comments has been sent to the reviewer.
- Final LCI report, dated 20th January 2011 has been sent to the reviewer.

Further discussions have taken place by email. All questions of the reviewer were answered sufficiently. Upon reviewer's request revisions had taken place concerning background data, allocation description and discussion of inventory results. The critical review process took place in an open and constructive atmosphere.

The final study report includes almost all of the comments of the reviewers and the commissioner given in the earlier stages of the review process.

The present final version of the review report takes into account the revisions made by the practitioner after submitting the feedback on the pre-final report.

The goal of the study as such was not reviewed as this lies in the responsibility of the commissioner. However, it was reviewed whether or not the goal is stated explicitly and transparently. The definition of the scope was part of the critical review, in particular the definition of the functional unit, the system definition and its boundaries and the allocation approaches.

The review of the inventory analysis includes the inventory raw data (input data), the modeling approaches and selected inventory results. It was possible to review the modeling of the LCI data in Excel data sheets.

There is no explicit impact assessment and interpretation of the data in the study and thus no review on these aspects.

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4. Critical review report according to ISO 14040ff

4.1. Consistency of the methods with the ISO standards

The functional unit is the production of 1000 kg of bitumen and bitumen products. Functional unit and reference flow are considered appropriate for the goal and scope of this study.

No impact assessment methods are used in this study.

4.2. Scientific and technical validity of the methods applied

In general the inventory models established chosen are scientifically and technically valid.

A critical issue for the final results is the allocation procedure. The authors choose a mass allocation for the crude oil input to the refinery and an economic allocation for sub-processes within the refinery. Both are possible options according to the ISO standard. But, other options e.g. applying economic or energy allocation would be justifiable as well. The report showed in a sensitivity analysis in the annexe that this can change the results considerably.

For some methodological choices like allocation and uncertainty assessment literature information has been provided during the review, and was considered partly in the final report.

4.3. Appropriateness of data

All data, including the whole modelling and calculations were presented to the reviewers in Excel format and are documented in the report. Most data used in the foreground and in the background are appropriate and reasonable in view of the goal and scope of the study. The geographical reference is Europe.

The study used mainly data sources from international organisations and statistics such as Concawe. Some data from environmental reports or publications were considered as well. There was no extensive review of data sources e.g. in environmental reports of oil companies or published articles in order to better assess the validity of single assumptions.

A main point of the discussion was the inclusion of infrastructure in the assessment, which has not been considered in a former study. The evaluation of older data in the ecoinvent database showed that infrastructure can have some relevance especially in countries with low productivity per borehole.

Finally it was decided to show both data without and with infrastructure.

The comparison shows that infrastructure has to be considered in order to get a full view on the emissions and resource uses in the life cycle. Thus, the reviewer

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recommends using in most cases the results that include infrastructure. Data without the infrastructure cannot be compared or used together with data from other databases, such as ecoinvent, that systematically include the infrastructure.

The life cycle inventory of the foreground processes covers major air pollutants and some water pollutants. Further emissions e.g. of heavy metals can be expected, but are not covered fully in the LCI. This has to be considered in the interpretation of results as outlined by the authors in an annexe.

There is no quantitative uncertainty assessment in the report. The data quality has been discussed qualitatively. Thus, it is not possible to calculate a quantitative uncertainty e.g. by Monte-Carlo simulation.

It was difficult to cross check all data and modelling in Excel because they could not be evaluated easily in an LCA software. It was not possible to ensure fully the correctness and validity of the calculations within the review process. However, the errors and shortcomings revealed in the review process were corrected in view of the final version of the report. Results have also been crosschecked in the review with other available data sources.

4.4. Assessment of the interpretation in view of limitations and goal and scope

There is no interpretation of the data in the report as this was not a goal of this study. It is important to note the limitation of this life cycle inventory while using it. Therefore the annexe 4 provides valuable information. It is important to consider that the LCI can only be used for limited list of life cycle impact assessment methods as described in this annexe. Also the sensitivity due to allocation methods and the importance of infrastructure are issues that need to be considered while interpreting results calculated based on these data.

4.5. Transparency and consistency of study report

The report is clearly structured and well-readable. It is not a full LCA according to ISO 14040ff, but a presentation of life cycle inventory results. Confidential life cycle inventory data were fully available for the review. Together with this information, the report is acknowledged as transparent and consistent.

4.6. Conclusions

The reviewed LCA study complies with the requirements of the ISO standards 14040 and 14044. The goal and scope are appropriately defined. The methods used are scientifically and technically valid. The data used are appropriate and reasonable in view of the goal and scope of the study. The report is complete, clearly structured and well-readable. Conclusions and recommendations are based on the results of the analyses, respecting the limitations in an annexe.

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I recommend publishing the entire report including this review report.

Niels Jungbluth
Managing Partner ESU-services Ltd.
Uster, Friday, 11 February 2011

5. References

1 International Organization for Standardization (ISO) 2006a

2 International Organization for Standardization (ISO) (2006a) Environmental management - Life cycle assessment - Principles and framework. ISO 14040:2006; Second Edition 2006-06, Geneva.

3 International Organization for Standardization (ISO) 2006b

4 International Organization for Standardization (ISO) (2006b) Environmental management - Life cycle assessment - Requirements and guidelines. ISO 14044:2006; First edition 2006-07-01, Geneva.

6. The Reviewer and his company

6.1. ESU-services Ltd.

ESU-services Ltd. was founded in 1998. Its core business is research, consulting, review and training in the field of Life Cycle Assessment (LCA). This methodology aims to investigate environmental aspects of products and services from cradle to grave, from resource extraction to manufacture, use and end of life treatment. We also work with related methods such as carbon footprinting and Substance Flow Analysis (SFA).

Fairness, independence and transparency are the main characteristics of our consulting philosophy. We work issue-related and accomplish our analyses without prejudice. We document our studies and our work in a transparent and comprehensible manner. We offer a fair and competent consultation, which enables our clients to control and continuously improve their environmental performance.

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ESU-services covers several economic sectors such as energy, basic minerals, metals and chemicals, biomass, transportation, waste management, information technology, food and lifestyles. ESU-services also contributes to the development of impact assessment methods such as ecological scarcity 2006. Since 2007, ESU-services runs the Regional SimaPro Centre of Switzerland. Liechtenstein and Austria.

6.2. Dr. Niels Jungbluth

Niels Jungbluth studied environmental engineering at the Technical University of Berlin. He made his diploma thesis during a six-month stay at the TATA Energy Research Institute in New Delhi, where he prepared a life cycle inventory for cooking fuels in India. Between 1996 and 2000 he worked on a Ph.D. Project at the Swiss Federal Institute of Technology (ETH) in Zurich at the chair of Natural and Social Science Interface. The German Öko-Institut has awarded his Ph. D. thesis on the environmental consequences of food consumption with the Greenhirn Price 2000. In this thesis he investigated food consumption patterns by means of life cycle assessment. He is managing partner of ESU-services Ltd. with emphasis on energy systems, agriculture, biofuels and food production. Niels is in the editorial board of the "Int. Journal of LCA" and in the scientific committee of the Int. Conf. LCA in foods.

6.3. Reference projects (selection)

With respect to the project and the services required, the following projects are of special interest:

ecoinvent database: ESU-services was project leader to design, build-up and introduce v1.0 of the international, harmonised and quality controlled life cycle inventory database. We elaborated the LCIs of about 900 out of 4000 datasets in v2.0. Dr. Niels Jungbluth elaborated the life cycle inventories of oil products for this database.

Biofuels: LCA study on biomass based fuels, including sugar cane, soybean and palm oil, commissioned by several Swiss Federal Offices and private organizations under the project lead of ESU-services. The study forms the basis for tax exemption of biomass fuels in Switzerland.

RENEW (Renewable fuels for advanced powertrains): Integrated Project including major European car manufacturers (DaimlerChrysler, Renault, Volkswagen, Volvo) commissioned by the European Commission and Swiss Federal Offices. ESU-services acts as the central data manager and is responsible for the peer reviewed LCA of Biomass-to-Liquid technologies developed by project partners.

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See below for a short list of the most recent and relevant projects. A full description of the company including a list of project references can be found on the Internet (www.esu-services.ch).

Year	Project title	Commissioned by
2009	Life cycle assessment of grass refinery	Biowert AG
2008	LCA of using biomass-to-liquid fuels	Swiss Federal Office of Energy (SFOE)
2007	Environmental optimization of traffic	öbu, SBB
2007	Life cycle assessment of rapeseed biorefinery	RESAG-Power
2007	Emission factors of fossil and renewable fuels	SBB Swiss railways
2006	Key-parameter model for the certification of electricity made with vegetable oil	Jürg Schwaller, Engineering and Consulting
2005–2006	Import and Export of embodied greenhouse gas emissions of Switzerland (Update of the Grey greenhouse gas emissions report, Umwelt-Materialer No. 128)	Federal Office for the Environment (FOEN)
2005	Synopsis of the LCA comparisons of fuel oil and natural gas as combustible	Erdöl-Vereinigung, EV (Switzerland), unpublished
2004	Review of an LCA study for an advanced biodiesel production process	Fortum, FL
2004	Critical review accordin to ISO 14040ff of different LCA studies for biofuel production and use	Various
2004–2007	Project leader "Life cycle assessment of bioenergy products"	Bundesamt für Energie, Bundesamt für Landwirtschaft and Bundesamt für Umwelt, Wald und Landschaft
2004–2008	RENEW: Renewable fuels for advanced powertrains. LCA of BtL-fuel (Biomass-to-Liquid) production including critical review according to ISO 14040, 44	The European Commission, Bundesamt für Energie and Bundesamt für Bildung und Wissenschaft
2003	ecoinvent 2000: life cycle inventories of crude oil, natural gas, photovoltaics, solar collectors, electricity mixes, etc.	Federal Office for the Environment (FOEN)
2001	Life cycle inventory for fuels in Germany Methanol, ethanol, rape seed methyl ester, low sulphur gasoline and diesel oil, biogas, natural gas	German automobile manufacturer
1994–1995	Life Cycle Assessment for Cooking with Kerosene and Liquefied Petroleum Gas in India	In cooperation with TATA Energy Research Institute, New Delhi, India

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