LIFE CYCLE INVENTORY: BITUMEN

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ABSTRACT

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 deasphalting 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 SO2 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.

Keywords: Life Cycle Inventory, Responsible sourcing, Environment, Carbon

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 bitumen eco-profile[1] or life cycle inventory (LCI) in 1999. During 2009, it was decided to update the 1999 eco-profile, because more data has become available and LCI methodology has been developed further.

This eco-profile provides inventory data on the production of the most widely used paving grade bitumens in Europe. The intended application is to give data for the calculations of the further LCI or life cycle assessment (LCA) studies where paving grade bitumens are used.

While the fundamental processes have not changed, the changes in the operations over a 10 year period are quite remarkable and emphasise the need for periodic updating of the LCI. This paper presents the main parts of the Eurobitume LCI report[2] published in 2011. In comparison to the previous LCI, the main differences of this eco-profile are described below:

- The basket of crude oils 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.
- A sensitivity analysis on allocation procedures has been performed.
- The impact of the alternative manufacturing routes has been considered.
- Manufacturing of polymer modified bitumen (PMB) and bitumen emulsion have been included.
- The impact of infrastructure of extraction wells, ships, pipeline and refinery, is also reported.

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

The tables presented in this paper show the most relevant flows and an aggregation of the other flows. A complete Ecoinvent-enable inventory is available on the Eurobitume website: www.eurobitume.eu.

2. GOAL AND SCOPE OF THE STUDY

2.1 Product descriptions and functional units

Three products are studied:

- Bitumen: paving grade bitumen according to EN 125912. This is the most widely used paving grade bitumen in Europe. The functional unit is 1 tonne of paving grade bitumen.
- PMB: paving grade bitumen as the base bitumen and a typical styrene butadiene styrene (SBS) polymer (up to 3,5%m) in its granular form. Polymer Modified Bitumen is widely used throughout Europe for both road and industrial applications and the SBS is the most common polymer type used in Europe. The functional unit is 1 tonne of PMB.
- Bitumen emulsion: cationic emulsion formulation incorporating bitumen, an amine type emulsifier and hydrochloric acid. The emulsion for the study is a cationic emulsion formulation incorporating bitumen (65%m), an amine type emulsifier (0,3%m) and hydrochloric acid (0,3%m). This is the most widely used type of emulsion in Europe. The functional unit is 1 tonne of residual bitumen which corresponds to 1,54 tonne of emulsion.

2.2 System boundaries

The 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 4 stages: crude oil extraction, transport to Europe, production and storage. A schematic description of the system boundary is given in figure 1.

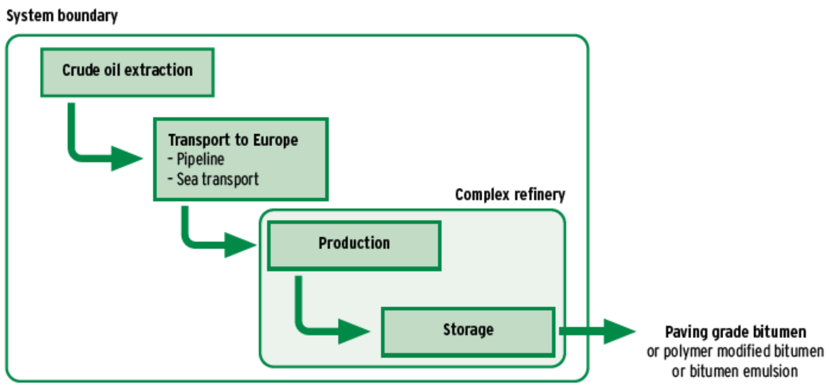

Figure 1. System boundaries for the bitumen eco-profile (cradle-to-gate approach)

The bitumen is made in a hypothetical but typical refinery, located in the ARA (Amsterdam, Rotterdam, Antwerp) area. This refinery is complex and produces a broad variety of petroleum products including bitumen.

2.3 Allocation procedures and source of data

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. Consequently, 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.

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. According to ISO 14044, there are different ways to address allocation issues: the preference is physical allocation (e.g. mass) and when this is not feasible, other relations such as economic allocation. Because the refinery co-products have different functions: bitumen is intended to be a construction raw material and the other co-products are used as fuels, the technical report ISO TR 14049 recommends to use an economic allocation (based on relative values) for bitumen.

The allocation at the refining level is based on economic factors (based on relative values), which is based on the physical yield of bitumen and the relative standard values of the products manufactured in the refinery’s production units.

The allocation procedure was subject to sensitivity analysis considering the two following alternative options: economic allocation for the whole production chain and mass allocation for the whole production chain. 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.

Data for the main processes is based on the most recent reports, for crude oil extraction, the data come from the International Association of Oil & Gas Producers[3], refinery emissions and refinery fuels usage come from specific reports published by CONCAWE[4,5]. The used crude oils and energy consumption of refining comes from anonymous questionnaires to Eurobitume members. For transport by pipeline and ships, actual data from pipeline companies and a ship owner was used.

3. INVENTORY ANALYSIS

3.1 Crude oil

The crude oil slate for bitumen production was estimated to be as follows:

➢ Former Soviet Union	61%
➢ Middle East	18%
➢ South America	11%
➢ Europe	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.

Table 1. 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						
Process 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
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

1) Burned in the process
2) The amount of gas vented has been taken equal to CH_4 emissions.
3) Data from ecoinvent 2.2 database

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 Baltic Sea to the ARA region by ship. The energy requirement of the BPS was estimated to be 13,5 kWh/t.

In the calculations, crude oil is transported to Europe in 106 000 DWT vessels, which is considered to be a conservative compromise for all regions. The transportation distance is calculated with a port to port distance calculation tool[6]. The fuel consumption is calculated with one way ballasted and a return trip fully loaded including loading and discharging.

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.

Table 2. Transport by ship data

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	
Transport distance	km	2 406	11 794	8 312	1 007	4 605
Use of heavy fuel oil	kg/t	3,8	18,1	12,8	1,8	7,2

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

3.3 Bitumen production

The bitumen is manufactured by straight-run distillation of crude oil, 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 process unit emission values include a share of common resources such as crude oil handling, desalting, flaring, loading area, general heating and lighting.

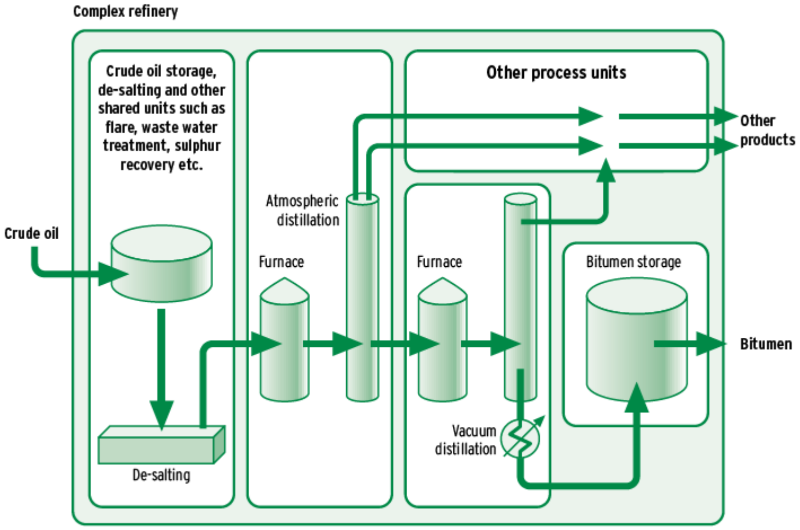

Figure 2. Straight-run distillation of bitumen within a complex refinery

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[4].

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.

Consumption of energy and non energy resources, emissions to air and water are given in the summary table 3.

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 has been assessed in this study. It appears 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, hot bitumen is transferred by pipe work into heated storage tanks at the refinery where it is held at the required temperature. An average size storage tank of about 6 200 m^3 is used for the study. A typical storage temperature is 175°C. 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.

3.5. Life cycle inventory of bitumen

Table 3. Life cycle inventory of bitumen

Production of 1 tonne of bitumen	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		0,21	0,49	0,33	1,03
Uranium	kg		0,00001	0,00003	0,00002	0,0001
Consumption of non energy resources						
Water[1]	l		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		130	176	30	336
Biological Oxygen Demand	g		128	166	30	324
Suspended solids	g		9,4	16,4	4,1	30,0
Hydrocarbon	g	6,9	40,9	52,5	9,5	109,8
Phosphorous compounds	g		2,52	6,77	4,79	14,1
Nitrogen compounds	g		0,95	4,40	1,51	6,86
Sulphur compounds	g		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

When comparing the different process steps the importance of the crude oil extraction comes up. More than 50% of the CO_2 emissions come from crude oil extraction. The transport step is responsible for the main emissions of SO_2 and NO_X. The bitumen refining part produces less than 20% of the main emissions.

4. POLYMER MODIFIED BITUMEN

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.

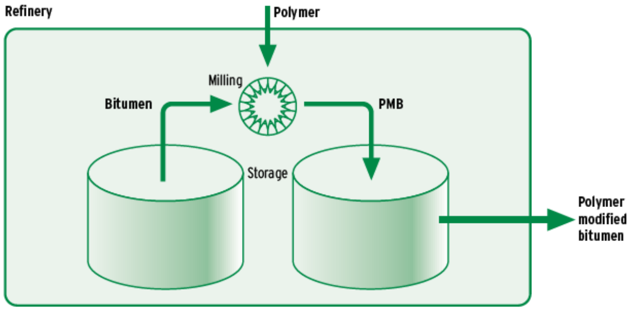

Figure 3. PMB Production

A high shear mill, powered by electricity is used for the milling of the polymer into the bitumen. 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.

Table 4. Life cycle inventory of PMB.

Production of 1 tonne of PMB	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
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. BITUMEN EMULSION

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

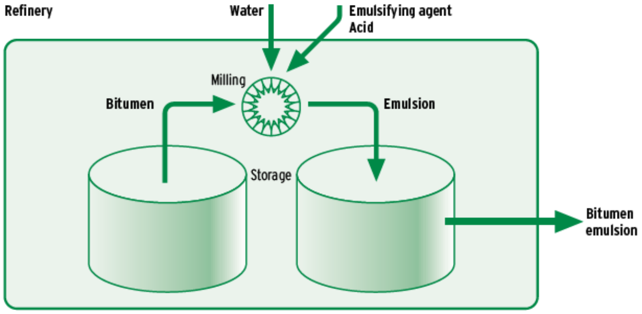

Figure 4. Bitumen emulsion production

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 milling equipment is similar to the high shear milling of PMB.

Table 5. Life Cycle Inventory of Bitumen emulsion.

Production of bitumen emulsion - 1 tonne of residual bitumen	**Unit**	**Bitumen**	**Emulsifier[1]**	**HCl [1]**	**Hot water**	**Emulsion milling**	**Total**
Raw material, Crude oil	kg	1 000	1,1				1 001
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[2]	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	1213	2029
Emissions to soil, Hydrocarbon (oils)	g	116	0,2	1,2	8,1	2,0	127

[1] **Production & transport**

[2] Excluding water cooling and turbine use

6. INFRASTRUCTURE

Very few data are available on infrastructure and in this study infrastructure data come from the ecoinvent 2.2 database[9]. The following life cycle inventories for infrastructure were used:

- Well for exploration and production, onshore and offshore
- Production plant and offshore platform
- Crude oil pipeline
- Transoceanic tanker
- Refinery

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.

Table 6. Life cycle inventory of bitumen for process and infrastructure.

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	1279	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

Infrastructure has a largest effect on emissions in crude oil extraction and transport, but not in the refining.

7. COMPARISON TO THE LCI FROM 1999

The more recent and precise data show improvements in the system covered by LCI compared to the previous report from 1999, figure 5. The improvements are mainly caused by the tighter sulphur limits in the fuel, more restrictive limits for the refinery emissions and increased energy efficiency.

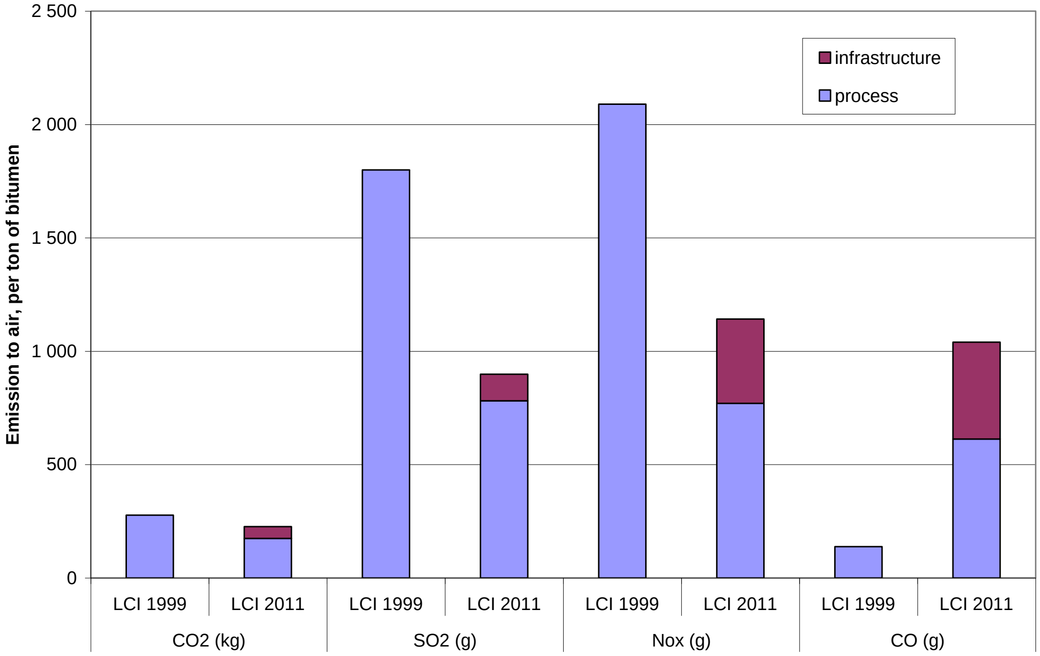

Figure 5. LCI 1999 and LCI 2011, comparison of some emissions to air, LCI 2011 includes both the process and the infrastructure.

When looking at the development in different steps for CO2 emissions to air, the main improvement has been in the refining step, figure 6.

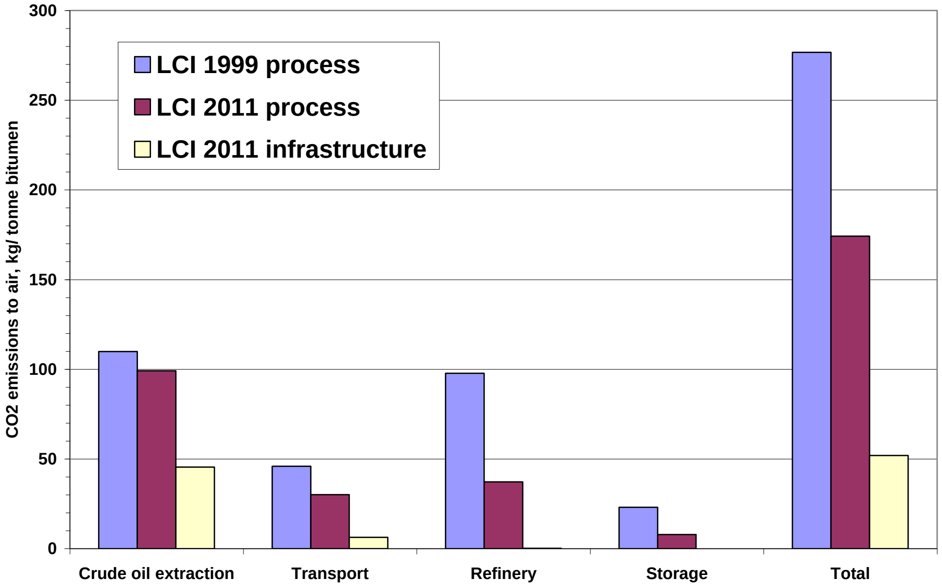

Figure 6. Comparison of CO_2 emissions in the different process steps including infrastructure.

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