Environmental Manual for Power Development

Data Sources and Data Compilation for the Indian Dataset

Dokumentation for the Indian Database for the ENVIRONMENTAL MANUAL

by

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Eschborn

Introduction

The **Indian database** for the **Environmental Manual for Power Development** (EM) offers data for energy technologies in India. These data are based on a study[2] on the environmental impacts of cooking with fossil fuels. The EM India database contains processes for

- fossil fuels (oil, natural gas, coal),
- end-uses (cooking),
- upstream- and downstream fuel-cycles,
- transport devices

All data given in this report are based on metric (SI) units, cost data are given in 1994 US $. Because a variety of data sources have been used to compile the EM India data, all cost figures have been converted from original values into 1994 US $ using currency exchange rates (1 US $ = 31 Indian Rupees). All data concerning the energy content of fuels (e.g. heating values, emission factors, efficiencies) are based on the **higher heating values**.

To access the EM India Database Documentation, select one of the following items:

General information

Product data

Processes in upstream fuel cycles (mining, petroleum extraction)

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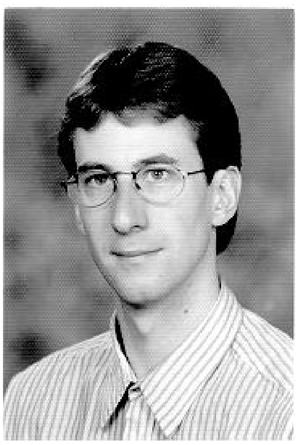
[1]  Niels Jungbluth - Nollendorfstraße 21 - D-10777 Berlin - Ph. & Fax **49 30 2166457 - email: jungblut@itu101.ut.tu-berlin.de

[2] The study „Restricted Life Cycle Assessment for the Use of Liquefied Petroleum Gas and Kerosene as Cooking Fuels in India“ (by Niels Jungbluth) can be received with an FTP (file transfer protocol) server via the INTERNET in the following way: TELNET *itu106.ut.tu-berlin.de*, LOGIN *ftp*, PASS *ftp,* CD *india*, LS -L, FTP *own name*, LOGIN *own name*, PASS *own,* PUT *.* *.* Use *pkunzip.exe* for extracting the files

General information

This chapter gives general information about:

India's Society and Economy

The next table gives some important statistical factors concerning society and economy of India. With a per capita income of US $290 India belongs to the "Least Developed Countries". The industrial and service sectors shows disproportional fast growth rates, but this is not a solution for India's poverty problems. Due to the still high population growth rate the efforts to increase the GNP[3] have not led to higher per capita income. The devaluation of the Indian rupee in comparison to the US dollar has resulted in a decline in the GNP per capita. The economic and social circumstances present large differences in the living conditions of people of different classes (MANOMARA 1995; PAULUS 1992).

Table: Social and economic indicators for India

Area	3,287,263	km²
Population (mid 1994)	897	million
Annual population growth rate (1990 to 1995)	1.9	%
Urban population (1992)	26	%
Rural population (1992)	74	%
Population density	267	people/km²
Per capita GNP (1993)	290	US $
Growth of GNP (at 1980/81 prices)	5	%
Inflation rate (September 1994)	9.1	%
Fiscal deficit of the central government	7.3	% of GNP
Current account deficit	1.8	% of GNP
Per capita yearly consumption of commercial energy (1992)	235	kgoe[1]

***SOURCES**: MANOMARA 1995; TEDDY 1994; PAULUS 1992*

Energy Scene in India

About 55% of India's total energy requirement is supplied by *commercial* energy. That is electricity and fossil fuels that are bought by the consumer. The rest is contributed by *non-commercial* energy carriers. These are biomass fuels that are normally collected by the users themselves. The use of commercial energy at 235 kgoe per year and per capita is low in comparison to the developed countries with values of approximately 5,000 kgoe/a (TEDDY 1994).

The country has witnessed a rapid growth in energy needs owing to industrialization and the changing demographic profile. A balance for the commercial energy availability and its consumption is shown in the next table. In the years from 1981/82 to 1991/92 the commercial available energy increased from 101 Mtoe[4] to 194

[3]GNP - Gross national product: The total monetary value of final goods and services produced in a country

[4]Mtoe - Million tones of oil equivalent

Mtoe. One third of this available energy was lost during conversion and transmission. Thus the total energy consumption in 1991/92 was 131 Mtoe (TEDDY 1994; WSN 1994).

Table: Commercial energy balance (Mtoe) for 1991/92 (TEDDY 1994)

	Coal	**Crude oil**	**Natural Gas**	**Electricity**	**Petroleum products**	**Total commercial energy**	**% Energy**
Production	112.4	30.3	16	6.6	-	165.3	85.34%
Imports-(Exports + Stock changes)	-0.2	21.1	0	0	7.5	28.4	14.66%
Availability	112.2	51.4	16	6.6	7.5	193.7	100.00%
Conversion, Transmission, Distribution, etc.							32.83%
Consumption	50.7	0	5.9	17.5	56	**130.1**	67.17%

The next figure shows the energy balance in India for the main sectors taking into account the availability of commercial energy (194 Mtoe) and the estimated total energy use (350 Mtoe). Main users of commercial energy are the industrial and the transport sectors. The household sector is the largest consumer of energy in India if all energy carriers are considered. It accounts for 40% to 50% of total energy consumption; That is 10 per cent of the commercial energy consumed (TEDDY 1994).

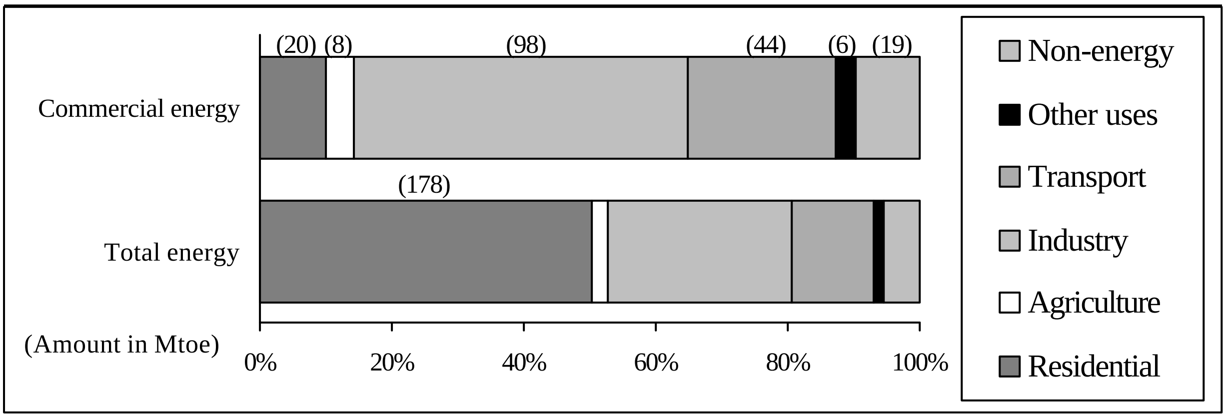


Figure: India's energy consumption and share by different sectors in percentages and Mtoe for 1991/92. Total energy estimated (TEDDY 1994; PAULUS 1992)

The proportion of the total residential energy use for cooking (including water and space heating) is 90% in rural and about 80% in urban areas is the main purpose. Thus cooking consumes about 35% to 45% of the total energy used in India. In developed countries cooking consumes less than 10 per cent of total national fuel consumption (AGARWAL/NARAIN 1990; TEDDY 1994).

The next figure shows by proportion the use of the different household fuels in India. The bulk of energy consumption in households consists of biomass (non-commercial) fuels, such as firewood (59%), dung (20%) and agricultural residues (14%). The main commercial energy carriers for residential use are kerosene and LPG (liquefied petroleum gas). Together these two have a 5.2% share of the energy consumed in households. This amounts to 79% of the total commercial energy consumption of 13.1 Mtoe in 1991/92. LPG consumption grew at annual rate of over 16% and this of kerosene by 6% between 1984/85 and 1991/92 (TEDDY 1994).

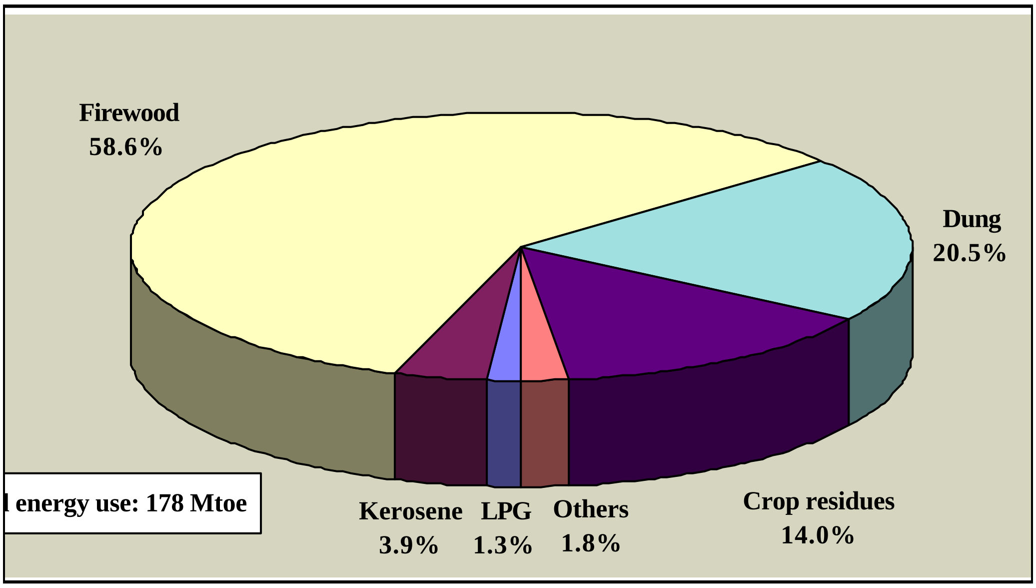


Figure: Use of household fuels in India (TEDDY 1994)

Life Cycle of Liquefied Petroleum Gas (LPG) and Kerosene in India

The life cycles for the two fuels LPG and kerosene are shown in the next figure. Boxes that compile different streams to one are virtual processes to explain the origin of the available **amount** of a product.

The original resource for the production of kerosene and LPG is crude oil. LPG is also derived from natural gas. These resources are extracted in India from onshore and offshore sources. The investigation concentrates on both the exploration activities and on the following exploitation of the resources. Crude oil is also imported with tankers into the country. All these aspects of the life cycle are investigated in the upstream fuel cycles.

The resources are transported by pipeline or with tankers to the processing facilities. The transport processes and connected aspects of the life cycle are investigated for the LCI.

The crude oil is processed in refineries. LPG and kerosene are two of the possible products. In gas processing plants LPG and other gases are extracted from the natural gas. LPG and kerosene are also imported in bulk by means of tankers from foreign refineries and processing plants. For cooking purposes the LPG is filled into steel-cylinders at bottling plants. These plants receive the product by rail or road tanker trucks. All the processing steps are summarized in the downstream fuel cycles.

The LPG-bottles are delivered to the retailers of the marketing organizations by road trucks. From the retailers they are transported to the end user by a variety of vehicles. The gas is burnt for cooking or lighting. The empty bottles are returned in the same way to the bottling plant by employees of the marketing organizations to be used again.

Kerosene is brought to the wholesaler by train or road tanker trucks. The latter are also used to transport the fuel from the storage of the wholesaler to the retailer. The retailer stores it in barrels. The product is refilled into containers brought by the customers. They use it for cooking or other purposes (e.g. lighting).

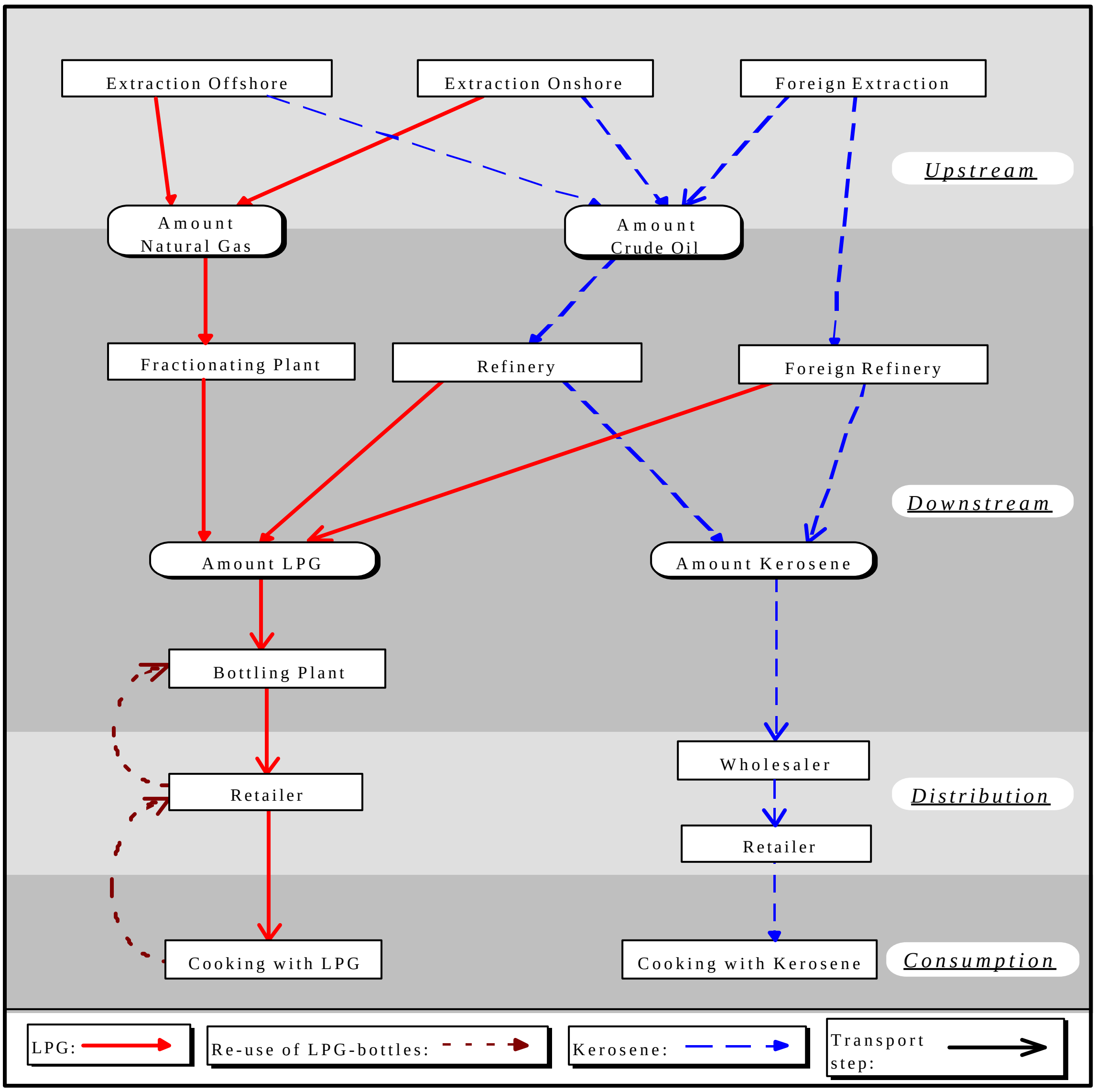


Figure: Stages in the life cycle for liquefied petroleum gas and kerosene in India. The arrow has a special head (as shown in the right bottom edge) if transportation is investigated between two stages

Investigated Indicators and their Meaning

The investigation for an LCA should be focused on a list of indicators that describe an important impact. Data should be available for the whole life-cycle of the compared processes in a comparable accuracy. The choice of indicators for this database was influenced by regulations for emissions from production sites in India. To make general estimations, enough data were available only for pollutants that are subject of these regulations. The following **indicators** are investigated in the database:

Energy use is classified by the quantity and type of the burnt fuels or the *electricity* used. Main categories of the fuels are *solid, gaseous and liquid*. For the calculations, assumptions are made about the average composition and type of the used fuels (see Product data).

Materials are an input in the life cycle. Investigated materials are *water*[5], *chemicals*[6], *steel* and *cement*. *Steel* and *cement* are used as construction materials for the processing facilities, transport devices and as materials

[5] The indicator *water* describes the use of ground, river, lake and sea water for production, cleaning and cooling. It does not include formation water, that is lifted up with the crude oil and natural gas and that is re-injected in the same production step.

[6] The indicator *chemicals* describes the use of chemical substances in the processes. The chemicals vary considerably in their attributes, e.g. energy requirement for their production or hazards for the environment. It was not possible to specify the chemicals further, due to the high number of different categories.

for the cookstoves. The production is calculated with generic EM data. Other materials used in these production facilities are not considered.

Water pollution is one sector to describe the environmental impacts of an activity. One indicator in this study is the discharged *effluent*. This includes the discharge of cooling water. Effluents are only evaluated if they are discharged into rivers and sea or irrigation schemes. Evaporated or re-injected effluents are not considered. The pollution is described by the indicators *BOD (biochemical oxygen demand* usually in 5 days*)* and *COD (chemical oxygen demand)* to give the impact on the oxygen balance in the receiving water body. *Total dissolved solids (TDS)* and *total suspended solids (TSS)* are sum indicators for solids discharged in the effluent. *Phenol* and *oil & grease* are measurements of toxic substances. The choice of these indicators considers the regulations made in MINAS (Minimal National Standards, CBWP 1985/07).

Air pollution mainly consists of flue gases emitted from combustion devices. *Sulfur dioxide (SO_2), Nitrogen oxides (NO_x)* and *Carbon monoxide (CO)* are hazardous substances for human beings, animals and plants. They are also destructive to buildings if they are dissolved in water and become acid rain. *Particulate matter (PM)* describes the emissions of particles[7] into the atmosphere which contain toxic chemicals and thus they are also hazardous to living beings. Information about other air pollutants as indicators was not available for India.

Wastes take different forms and require various forms of management. In this study two types of wastes are classified. One type is *cuttings*. These are mainly geologically based materials from drilling activities with related impurities from the drilling chemicals. Normally they are not dumped on landfills. The rest of possible *wastes* are for example sludge from effluent treatment plants, used drilling mud and oily sludge from storage facilities. These wastes are more hazardous.

Balance Room for the Environmental Manual

The LCI and the calculations of the impacts are made for a cooking session in Dhanawas, a small village in a rural region near New Delhi. The next figure shows the location of this village in India. Dhanawas is in the district of Gurgaon, 15 km from Gurgaon, in the state of Haryana. It is approximately 7 km from the neighbouring Faroukhnagar and about 45 km from Delhi (TERI 1994).

[7] The emission of particles is described in Indian publications with different terms. The expressions *particulate matter (PM)* and *particulates* are used in the National standards. The expression *suspended particulates* is used in the ambient air quality guidelines. Other authors use also *suspended particulate matter* (SPM) or *total suspended particulates* (TSP) for emissions and ambient air concentrations.

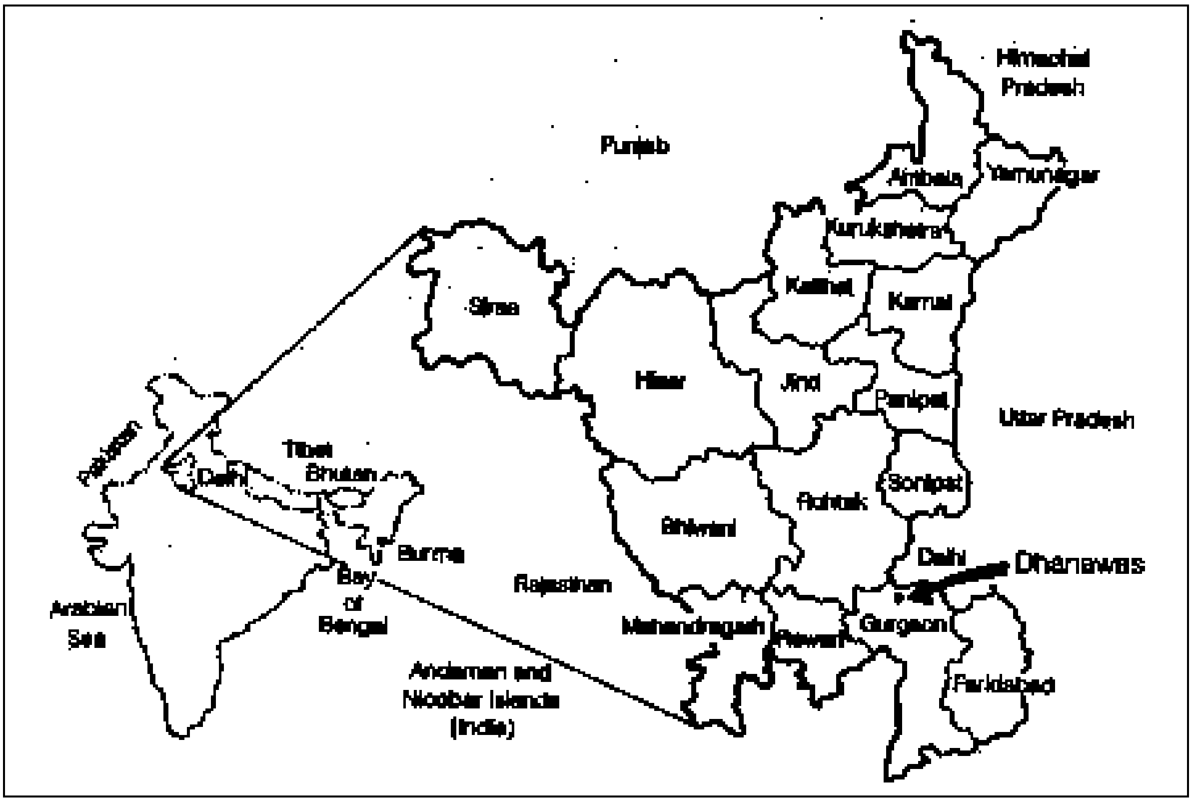


Figure: The location of Dhanawas (TERI 1994)

Product data

This section gives some important information for the fuel and product data. Detailed information regarding the content of elements, heating values, etc. are included in the product data of the Environmental Manual.

Coke

Coke is a by-product of some processes in the refinery. It is burned as a solid fuel for heating purposes in the refinery. Coke has a lower heating value of 39.8 MJ/kg (CFHT 1995).

Crude Oil (or **Crude**)

21 million tones of crude oil are imported from OPEC countries of the Gulf region: i.e. Iran, Saudi-Arabia, Dubai, Abu-Dhabi, and from Malaysia, Nigeria and in small amounts from Australia. In 1993/94, India produced 34 million tones domestically of the total crude oil processed(IOC 1995; OOC 1995).

The crude oil extracted in India contains small amounts of sulfur in the range of 0.2 to 0.4 wt%. The crude oil imported from the OPEC, except the 1 million tones low sulfur crude from Nigeria, contains between 2 and 2.5 wt% of sulfur. The sulfur content of the feed stock for refineries on average lies between 1.2 to 1.5 wt% (IOC 1995; OCC 1995). The content of water in the crude oil for the processing in the refinery should not exceed 1 wt% (CBWP 1985/12). In most cases, the content of nitrogen compounds does not exceed 0.3 wt% (SHARMA/AGNIHORTI 1992).

Diesel Oil (**High Speed Diesel** or **Light Diesel Oil**)

Motor vehicles require **HSD** (high speed diesel) as their source of fuel. **LDO** (light diesel oil) is used in a small amounts for agriculture. Six times more diesel is used than gasoline in India. The price is set at 8 Rs/l and it is subsidized. The product specification of Indian diesel is given in (ISI 1974a).

The content of sulfur in Indian diesel ranges between 0.3 and 0.7 wt% (in two refineries) with an average of 0.5 wt%. This is less than the legal specification of 1 wt%. For metropolitan cities this maximum will be reduced on April 1, 1996, to 0.5 wt%. The content of sulfur in diesel will be reduced to 0.25 wt% by the year 2000 (IIP 1994/12; HINDUSTAN TIMES 1994; IOC 1995). The carbon content of HSD and LDO is 86.1 wt% and 87.4 wt% respectively (SHARMA/SHARMA 1994/04).

Fuel gas

Fuel gas is a waste gas from the rectification unit. It basically contains methane and is a low grade fuel. It has a lower heating value of 46.9 MJ/m³ and is used in refineries (ALUER 1994; CFHT 1995).

Fuel Oil (also **Furnace Oil** or **F.O.**)

The sulfur content of fuel oil ranges between 0.5 wt% and the maximum of 4.5 wt% prescribed by the standard. Refineries normally use fuel oil with a sulfur content of 1 wt% to reduce the emissions of sulfur dioxide. The specified ash content is less than 0.1 wt% and the water content is less than 1 wt%. The carbon content of fuel oil is 88 wt%. It has a lower heating value of 41.72 MJ/kg (CFHT 1995; ISI 1988; IOC 1995; OCC 1995; SHARMA/SHARMA 1994/04).

Hardcoal

Hardcoal extracted in India and used for steam trains has a lower heating value of 20.93 MJ/kg. The ash content of this coal is 23 wt% and the moisture content is estimated to be 10 wt% (IPNGS 1992; TEDDY 1994). Hardcoal is used for power plants and has a relatively high ash content of 40 wt% and a moisture content of 10 wt%. The LHV estimated at 11.8 MJ/kg (HARANT ET AL. 1993; TEDDY 1994).

Kerosene (also SKO (Superior Kerosene Oil) or Kerosine)

Kerosene is a highly refined transparent fuel with a distinctive odour. It has clean and efficient burning qualities. Kerosene has many applications (BPCL 1994; BHANDARI/THUKRAL 1994):

- A fuel for wick fed lamps and pressure burner type lamps
- A fuel in cooking stoves, ranges, ovens, standby electricity generators and blow lamps
- Miscellaneous as a cleaning fluid, a solvent in paints or a raw material for the manufacture of printing inks
- Substitute to gasoline or diesel oil in the combustion motors of transport vehicles[8]

Kerosene mainly consists of saturated hydrocarbons with the molecule length of ten carbon atoms (C_{10}). Due to the flash point of 50°C, it is possible to handle it at room temperature without danger. Its low viscosity makes it easily possible to pump or to transport it by the capillary action of a wick (LAUTERBACH/SCHNAITER 1995).

The specifications for kerosene are given in the Indian standard 1459-1974. The fuel should be free of visible water, sediment and suspended matter. The char value shall not exceed 20 mg/kg of consumed oil. The minimum flash point (Abel) is 35°C. The total sulfur content shall not exceed 0.25 wt%. The lower heating value of kerosene is 40.8 to 43.5 MJ/kg (ISI 1974). The next table records the composition of kerosene investigated by different authors.

[8]Some drivers and gasoline retailers profit illegally from the highly subsidized price. The price of gasoline is five times higher than this of kerosene. It is estimated that about 15% of the total kerosene consumption in India is diverted for use as transport fuel (BHANDARI/THUKRAL 1994).

Table: Analysis of elements in kerosene (wt%)

	India	*India*	*Germany*	*Estimation for the LCI*
Carbon	86.15	85.7	84.36	**85.9**
Hydrogen		14.0	15.09	**13.8**
Oxygen		-	0.45	**0.05**
Nitrogen		-	0.10	**0.05**
Sulfur		0.5	(0.25)	**0.2**
Source:	SHARMA/ SHARMA 1994	PCRA 1994/12	LAUTERBACH/ SCHNAITER 1995[a]	

[a] *This analysis was made for German kerosene. The sulfur content is additional to 100%. It was estimated by using literature data.*

LPG (Liquefied Petroleum Gas)

The history of LPG is connected to the wider production history of the petroleum industry. The production of gasoline was disturbed by the presence of unstable materials in the fuel. These substances at first could not be kept easily in a liquid state and they boiled away at atmospheric pressure. The result being it was not possible to use them practically, and they were released into the atmosphere or burned as flares. In 1910 a process was developed to convert some of the gases into a liquid at a moderate pressure of 4,900 hPa. It was then possible to vaporize them again by reducing the pressure. This new fuel had both the compactness and portability of a liquid, yet it could be burned as a gas (MODAK 1995).

It is possible to convert 240 volumes of gas into one volume of liquid. The ability to compress LPG is a distinct advantage over natural gas where a relatively high pressure is required. This property makes it easy to store large volumes in small containers. In India LPG is produced in 12 refineries and 5 natural gas fractionating plants (MODAK 1995).

LPG is a basic mixture of propane (C_3H_8), n-butane, i-butane (C_4H_{10}) and plus small parts of propene (C_3H_6) and butene (C_4H_8). Requirements for LPG are prescribed in the Indian standard 4576-1978. The contents of volatile sulfur should be below 0.02 wt%. Commercial butane-propane mixture should have a maximum vapor pressure of 16,500 hPa (ISI 1978).

LPG that is produced in Indian refineries is butane rich (ratio butane/propane = 65:35) in comparison to other countries because of the lower demand for light distillates. Butane in other countries is an important resource for the petrochemical industry. The LPG produced from natural gas in fractionating plants has a high content of propane (50:50) (IIP 1994/12; MODAK 1995; TERI 1989/03). Gaseous LPG is estimated as a mixture of 45 vol% propane and 55 vol% butane. For the calculations it is treated as a liquid fuel (**LPG**) with 0.01 wt% of sulfur, 17.7 wt% of hydrogen and 82.29 wt% of carbon.

Natural Gas

Natural gas is a mixture of hydrocarbon and non-hydrocarbon gases. It is found in the porous formations beneath the earth surface, either in association with crude oil or as free gas. The heating values vary from 33 MJ/m³ to 45 MJ/m³ depending on the composition. It is used as a resource for fractionating plants and as a fuel in production (JAGGI 1994). Different analysis's of the components in Indian natural gases are shown in the next table.

Table: Composition of Natural Gas in India. The tables gives also minimum and maximum contents with different analysis's

	Vol%	Mol% min - max.		Mol% min - max.		Estimation Vol%
N_2	0.1	0.01	n.a.	0.4	10.3	**0.1**
H_2S	n.a.	0	0.0006	n.a.	n.a.	**0.0005**
CO_2	0.9	4.76	5.12	0.03	0.25	**1.0**
O_2	n.a.	n.a.	n.a.	0.02	1.24	**0.0**
CH_4	85.8	79	92	76.1	83.5	**86.8**
C_2H_6	7.2	5.12	7.7	2.6	10.1	**7.0**
C_3H_8	3.2	1.18	4.7	2.3	6.1	**3.0**
C_4H_{10}	1.8	0.1	2	1.4	2.4	**1.8**
C_4H_8	n.a.	n.a.	n.a.	n.a.	n.a.	**0.3**
C_5H_{12}	0.7	0	0.5	0.1	1.6	**-**
C_6+	0.3	0	0.03	0.1	1.3	**-**
Sources:	JAGGI 1994	PETROTECH 1995		SHARMA/CHAUDHARY 1992		

n.a. - data not available

Processes in upstream fuel cycles

Exploration and Exploitation of Crude Oil and Natural Gas

In India there are 26 large sedimentary territories that cover a total area of about 1.7 million km^2, including 700,000 km^2 in offshore area. The next figure shows the sedimentary basins in India. To date in one quarter of this area reserves of hydrocarbons have been discovered but half of the basins are virtually unexplored. There is certainly a good possibility of discovering much more commercial oil and gas in the remaining sedimentary basins. Much effort is being made towards this end (PETROTECH 1995).

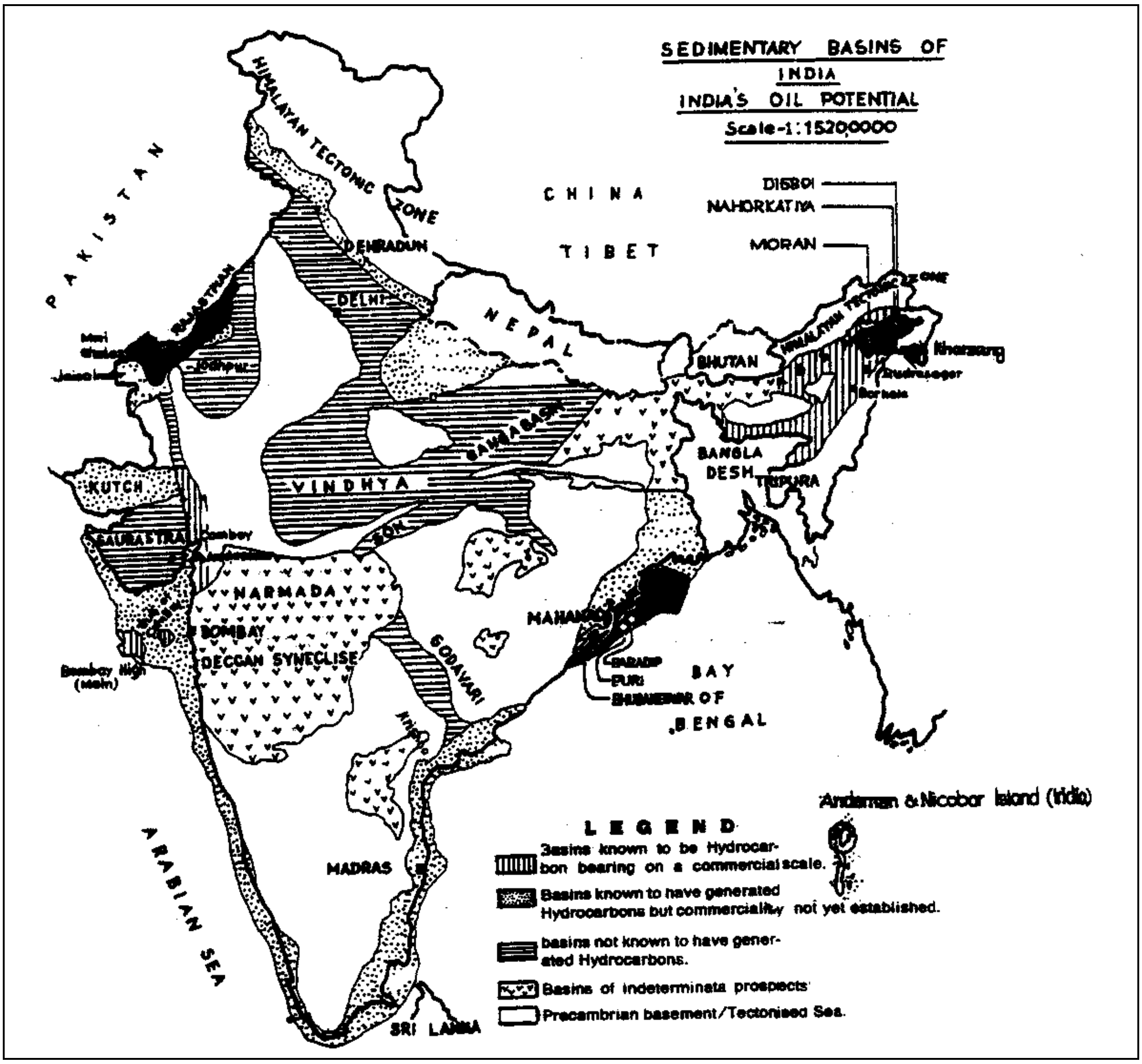


Figure: Map of India's potential sedimentary oil basins (OIL 1989)

The extraction and production of natural gas and crude oil can be divided into the following phases:

- Geographical and geophysical survey, seismic field studies
- Exploratory drilling with discovery wells
- Development drilling
- Well testing
- Construction of the processing facilities
- Production of natural gas and crude oil
- Dismantling and reclaiming of the production site

The production of crude oil and natural gas was investigated together for the EM.

Economical Background and Statistics for the Supply of Natural Gas and Crude Oil in India

In India there are two state controlled enterprises, the **Oil & Natural Gas Corporation Ltd.** (**ONGC**) and **Oil India Ltd.** (**OIL**) that undertake exploration, drilling and exploitation activities of crude oil and natural gas in the country in these days. A major initiative has been recently undertaken to form a new company through a consortium of three major downstream enterprises. The plan for the future is to open this field up to foreign companies. They will be invited to work in joint ventures with the Indian companies (SHARMA 1995).

The ONGC is the major company in India and among the world's top 15 profit-making companies. The erstwhile Oil & Natural Gas **Commission** was established in August 1956 and renamed at 1 February 1994. The ONGC was incorporated in June 1993 as a public limited company. Today it has a working staff of 48,000 people. Its activities are spread over 20 sedimentary basins, accounting for over 100 oil and gas fields. In 1988 it did 92.4% of drilling, and in 1991/92 the ONGC produced 92% of the total crude oil and natural gas produced in the country (ONGC 1994; PETROTECH 1995).

The formation of OIL dates back to 1959. On 14 October 1981 OIL was fully nationalized. OIL has its headquarters in Assam and is engaged in exploration, drilling and production from onshore areas in Assam, Rajasthan and Arunchal Pradesh. Nowadays OIL explores offshore basins in the Bay of Bengal and near the Andamans. It also runs a fractionating plant in Duljan. Today 9,000 persons are working for the company (JAGGI 1995; OIL 1989, 1995).

India is a net oil importing country and the annual bill for oil imports is increasing every year. The oil sector assumes a particular importance in the economy, as it accounts for more than 40% of the commercial energy consumed. It is primarily responsible for the capital exchange outflow which constitutes one half of the entire foreign trades bill over a year (RAMAN/UPADHYAY 1995; TEDDY 1994).

All the statistical data given in the next section for 1992/93 is provisional. The calculations for the EM are based on this data. The structure for crude oil and natural gas is shown in the next table. For the following calculations the products are converted into MJ because the calculations are based on their specific energy content. During the year 29 million tones (MT) of crude oil was imported, 16 MT was produced at the offshore basin Bombay High and 11 MT was produced at onshore fields. Natural gas extraction accompanies the oil exploitation. The large share of the total 18 billion cubic meters (Bm^3) is produced at the offshore fields (13 Bm^3). Today nearly 2 billion cubic meters of the natural gas is flared[9] without any usage. A small part of the gas is re-injected for storage and pressure maintenance. Accordingly the net production is 16 billion cubic meters (TEDDY 1994).

Table: Structure and total supply of natural gas and crude oil in 1992/93 (TEDDY 1994)

	Crude oil	Crude oil (10^9 MJ)	Natural gas	Natural gas (10^9 MJ)	Supply (10^9 MJ)
Import	53%	1,234	-	-	1,234
Production onshore net	20%	472	23%	209	681
Production offshore net	27%	663	77%	605	1,268
Flaring	-	-	1.85 Bm^3	83	-
Available amount	**57.8 MT**	**2,369**	**16.10 Bm^3**	**814**	**3,183**

Exploratory and Developmental Drilling and Well Testing

The drilling done in India during the last three years is shown in the next table. The average activity of these years is used for the following calculations. The specific drilling activity is 41 mm per tone of exploited crude oil. This is considerably more than the average value of 13 mm/t found by FRISCHKNECHT ET AL. (1995) for average crude oil imported to Europe.

Table: Number of exploratory and development wells and the drilled metreage in India during the years 1990/91 to 1992/93(TEDDY 1994)

	Exploratory Onshore		Development Onshore		Exploratory Offshore		Development Offshore		Total	
	(km)	(No.)	(km)	(No.)	(km)	(No.)	(km)	(No.)	(km)	(No.)
1990/91	434	176	455	220	184	73	92	66	1,165	535
1991/92	454	176	401	193	167	61	41	22	1,063	452
1992/93	413	172	441	196	176	69	75	31	1,105	468
Average	**434**	**175**	**432**	**203**	**176**	**68**	**69**	**40**	**1,111**	**485**

Artificial **drilling mud** is pumped down the drill-pipe and circulated continuously through holes in the bit and then back up at the sides of the hole. With the upcoming mud, rocky materials are brought to the surface. These **cuttings** are washed and separated from the drilling mud on the vibrating screens of the shale shaker.

[9]Since several years one aim of the oil exploiting companies is to increase the ratio between net and gross natural gas production. The main reasons that flaring could not be eliminated until now, are delays in commissioning downstream gas utilization facilities and the little flexibility in reducing the production of associated gases (TEDDY 1994).

The mud is reused for drilling. Near the drilling site there are waste pits located to store the produced effluents and the cuttings (OIL 1989).

The chemicals used to prepare the drilling mud vary considerably according to the different fluid systems. The next figure shows the composition of drilling fluid additives used in the western region of ONGC. The main ingredients of the fluids are fine solids like barite, bentonite clays, lignite or mica. They serve as lubricating, sealing and weighting materials. Other chemical additives like ferrochrome-lignosulfonate, polymers or thinners are used to give other properties. Some of the chemicals contain heavy metals. OIL uses low wax crude oil from the own oil production as a mud additive. About 250 to 350 tones of chemicals are used for one well. An average of five parts water is mixed with the chemicals to prepare the drilling mud. Drilling fluids are sometimes lost into the formation (ASTHA 1995; OIL 1995; GOEL 1995; SHARMA/SHARMA 1994/04; PETROTECH 1995).

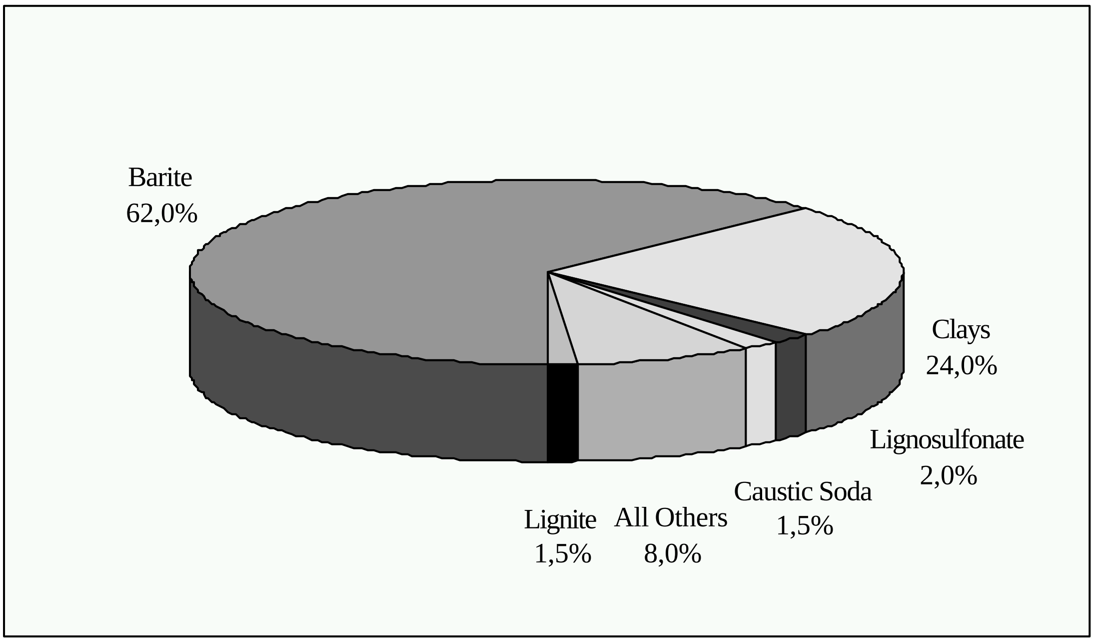


Figure: Share of the consumption rate for drilling fluid additives in the western region of ONGC (VELCHAMY/SINGH/NEGI 1992)

To stabilize the well, its inner wall is cemented. One well is cemented with 100 to 120 tones of **special cement**. For the activities of ONGC, this aggregates to a total of about 100 thousand tones of cement used every year. This cement needs a number of chemical additives to ensure certain properties. The cement should maintain for example a constant consistency before it hardens (ONGC 1994/12; PETROTECH 1995).

Energy Use

During drilling, the following gaseous emissions are encountered (DINESH 1994/04; ONGC 1994/12):

- Mainly exhaust gases from burners, engines and power generation sets powered by diesel oil
- Products of combustion due to burning of natural gas and diesel oil at the time of well testing
- Emissions of hydrocarbons from *cold flaring* (release into the atmosphere without burning) during the testing period
- Smoke from the derrick (the framework over the oil well)
- Fumes, odours and cement dust from cementing and mud preparation operations

Use of Water and Discharge of Effluents

During drilling operations, an enormous quantity of water is handled for operational purposes. The water is used in the preparation of drilling mud, cooling and the cleaning of equipment. The drilling mud can be reused in another well if transportation costs are not too expensive, otherwise it is treated with the other effluents of the drilling site. A widely used and simple method to get rid of water based drilling fluids from onshore sites, is to spread them thinly over the surrounding agricultural fields. The major pollutants in the effluents are soluble chemicals used with the drilling mud. Salt, hydrocarbons and heavy metals, found in the additives, accumulate in the waste pit (SINGH 1992; AGNIHORTI ET AL. 1992).

Cuttings and Waste

During drilling, different types of wastes are generated. The ratios as calculated by VELCHAMY/SINGH/NEGI (1992) are shown in the next figures. Settlelates are residues of the settling tanks (TERI 1993/01).

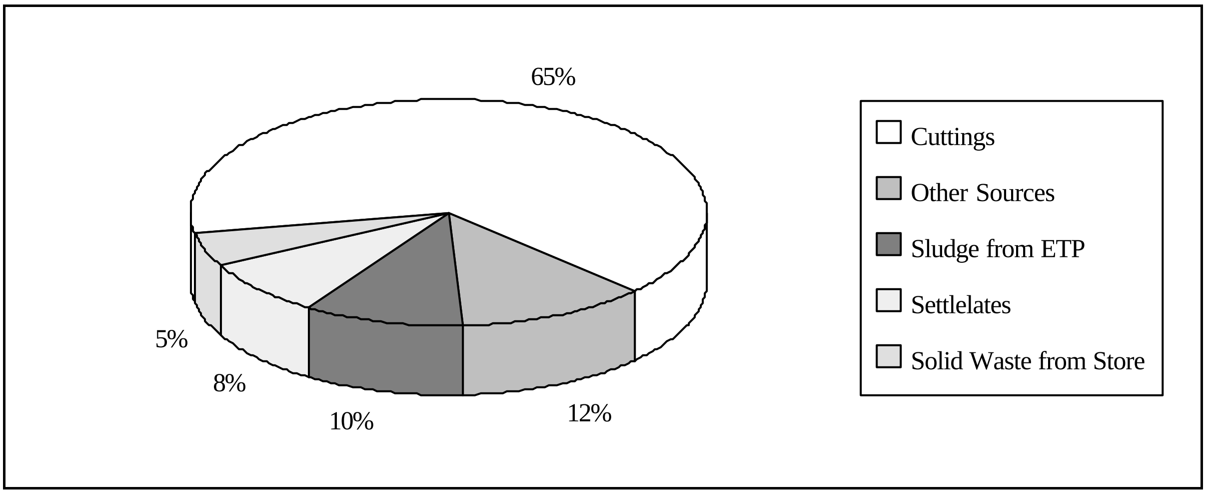


Figure: Solids generated and their distribution ratio (VELCHAMY/SINGH/NEGI 1992)

One of the environmental aspects of the drilling is the quantity and the characteristics of the produced drilling **cuttings**. This depends upon the nature of the formation, as well as upon the diameter and depth of the well. Cuttings generated average 10 tones per day at a drill site. The cuttings are inert rock materials with no toxicity. Problems are only assumed if heavy metals are washed out of the material. Similarly if remains of the drilling mud or traces of oil are discharged together with the cuttings. Onshore, the cuttings are used in agriculture, road construction or they are discarded in landfills. The cuttings from offshore platforms are discharged into the sea (BHARDWAJ 1994/04; CHAND 1992; TERI 1992/07).

Exploitation of Petroleum Resources in India

Exploitation from Onshore Areas

Onshore 30 to 40% of the crude oil can be recovered by means of natural pressure. Most of the crude oil in India is produced by means of this **primary recovery**. After 2 to 3 years the **secondary recovery** starts. To get up to 50 to 60% of the crude oil, pressure water or gas is pumped into the reservoir to support the natural pressure. If the crude oil is liquefied under help of heat, chemicals or biological additives the exploitation is termed as **tertiary recovery**. This has advantages for the recovery of very viscous oils and is called Enhanced Oil Recovery (EOR). The secondary and tertiary recovery methods are more energy intensive and they will be extended in India in the next years. To reduce the possibility of subsidence, the optimum oil recovery should normally not exceed 50% of the total stored amount (AGNIHORTI ET AL. 1992; ONGC 1994/12; WSN 1994).

The oil wells are connected by pipelines to a **Group Gathering Station** (GGS) which is located centrally in respect to a cluster of wells. These GGS facilities are set up for the processing the incoming well fluid that is usually a mixture of crude oil, associated natural gas and sometimes formation water. For the treatment in the GGS, additives are necessary. Crude oil containing water is called *wet crude,* otherwise it is termed *dry crude*. These types are processed individually in the GGS (ONGC 1994/12; WSN 1994).

In the GGS the gas, oil and water are separated. The crude oil is collected in a storage tank and then dispatched to the central tank farm for onward delivery to refineries. The separated gas is fed directly into the gas distribution network: For extraction of LPG, for generation of power, internal consumption and to supply the market demand. Free natural gas is fed into the distribution network after dehydration and removal of sulfur (WSN 1994).

Exploitation from Offshore Areas

In the western offshore area, there are 125 well platforms, each with 6 to 9 working wells that spread under the seabed. Since 1984 water has been injected for pressure maintenance. The majority of the wells are under secondary recovery. Presently 45% of the wells use production with gas lift. There are 6 water injection/process platforms to support the secondary recovery. The crude and natural gas is transported from the well platforms to 28 process platforms. For this purpose 2,240 km of infield sub-sea pipelines and 875 km of trunk pipelines are used. On the process platforms the well fluid is separated into oil, gas and water (PETROTECH-ABSTRACTS 1995:249; ONGC 1995/01).

Energy Use and Flaring

Energy is used for the following facilities:

- Steam and electricity generators
- Pump engines for oil, water and gas
- Gas compressors driven by diesel engines or electricity
- Fuel oil heaters used to reduce the viscosity of fuel oil in tanks
- Hot and cold flaring of natural gas
- Burning of natural gas to evaporate effluents in evaporation pits

The energy demand is met mainly by burning fossil fuels for power and steam generation. A small share of the energy needs is also met by other sources, for example solar panels. The combustion devices are fired with crude oil, fuel oil, diesel oil, natural gas or fuel gas. OIL meets 95% of the energy demand for its activities with natural gas. The rest is delivered by other petroleum products like diesel oil and petrol (AGNIHORTI ET AL. 1992; JAGGI 1995; ONGC 1994/12).

There are different types of flaring[10]. At the beginning of the production gas from a well is flared due to the lack of using facilities. This is called technical flaring. During the production period, there should be no flaring. The gas can be delivered to users. Because of variation in demand or stoppages, there are short flaring periods of surplus natural gas. Gas with a low natural pressure, which is difficult to transport, is always flared (ONGC 1994/12).

The energy needs for the offshore fields are met by three power units, installed on processing platforms, with a capacity of 4 to 5 MW each. The plants have dual fuel burners for both gas and fuel oil, but they use gas most of the time. One of the units lies idle as a reserve. At present two working units possess an energy over-capacity, so there is no incentive to adopt energy savings. The offshore platforms use 7.8% of the natural gas for their requirements. HSD is also used offshore in the production facilities (ONGC 1994/12; PETROTECH 1995). The next table shows the amount of different energy carriers used for the production facilities and for the drilling activities. This energy is used for different combustion devices.

Table: Total quantity of energy carriers used for the oil and gas production including the exploration activities during one year

	Offshore	***Onshore***
Flared gas	899 Mm³	955 Mm³
Fuel gas	532 Mm³	488 Mm³
HSD	91,200 t	60,700 t

Onshore Use of Water and Discharge of Effluents

Onshore sites, there is a need for injection water. A large part of this demand is met by purified water from the crude oil production. In smaller amount, **water** is used for other purposes such as cleaning of equipment or sanitary water. The amount of used ground and surface water is calculated at 40% of the treated effluent with 4.71E+12 g. This value is in the same range as the data available for the production of OIL (JAGGI 1995).

Effluents are produced mainly from the GGS during the separation of crude oil, associated gases and the so-called **formation water**. The water contains dissolved mineral salts and in small concentrations dissolved petroleum products. The quantity of formation water involved varies from well to well according to the water content of the crude. It can range from almost zero to 90%. The older the well, the more formation water will be in the crude oil. Due to the water injection, the crude in the formation is mixed with the injected water (JAGGI

[10] The burning of gas is called *hot flaring*. It can be done by releasing the gas through a burner. Steam is injected to the flame to prevent the development of smoke and to lower the temperature of the flame. Gas is discharged also through submerged vents placed in pits that are filled up with effluent. Due to this, the effluent evaporates. Sometimes the gas is released unburned through 90 to 120 m high pipes into the atmosphere. For 30 to 90 days the *cold flaring* leads to direct emissions of methane that has a high greenhouse gas potential (SHARMA 1992; JAGGI 1995).

1995; PETROTECH 1995; TERI 1993/01). Effluents are produced also by other production activities, for example by the cleaning of equipment. With rainfalls there is increased amounts of effluents (OIL 1995).

The ratio between crude oil and the total amount of treated water ranges among 0.23 and 1.1 at different sites. The average ratio for the *specific water production* in India is assumed at 1.05. The estimation was necessary because overall data for India was not available. FRISCHKNECHT ET AL (1995) estimated the value to be 1 for the situation in Europe. The total amount of treated water is calculated at 11.8 million tones per annum (OIL 1995; ONGC 1995/03; PETROTECH 1995).

Producers of oil and gas have several options for the disposal of the produced water:

- The treated water can be disposed into deep horizons of the formation through specially drilled **disposal wells**
- Thermal **evaporation** in pits. The heat required is delivered by burning natural gas. Another possibility is surface evaporation
- **Discharge** of the treated water into rivers or the sea
- The water can be used instead of tube well water for the secondary recovery. It is pumped into the oil bearing reservoirs through **deep injection wells**. An advantage of this method is that the possibility of subsidence is reduced
- **Recycling** of the water for use in the production facilities
- Use of the water for **irrigation**

About 60% of the wastewater from the production sites of OIL is re-injected, 20% is evaporated and 20% is discharged into rivers. The water balances of both ONGC (western region) and of OIL are shown in the next table. The last column gives the estimated split of the disposed treated water in percentages (JAGGI 1995; PETROTECH 1995; WSN 1994).

Table: Water Balances for the western region of ONGC and for the production of OIL and estimates for the inventory

	Western Region ONGC		**Oil India Ltd.**		**Estimation for the LCI**
Total water	**7,020 t/a**	**100.0%**	**3.86 Mtpa**	**100.0%**	**11.8 Mtpa**
Formation water	*n.a.*	*n.a.*	1.93 Mtpa	50.0%	**60%**
Well water	*n.a.*	*n.a.*	1.93 Mtpa	50.0%	**40%**
Disposal in wells	1,860 t/a	26.6%	1.11 Mtpa	28.8%	**16%**
Injection water	3,540 t/a	50.4%	1.58 Mtpa	40.9%	**50%**
Evaporated	1,620 t/a	23.0%	0.584 Mtpa	15.1%	**18%**
Discharged	*n.a.*	*n.a.*	0.584 Mtpa	15.1%	**16%**
ETP capacity	*n.a.*	*n.a.*	2.92 Mtpa	75.6%	**-**

n.a. - not available

Sources: *ONGC 1995/03; JAGGI 1995*

Offshore Use of Water and Discharge of Effluents

Today there are 164 injectors at 35 different well platforms. The **water** requirement is met by three water-processing platforms with a total capacity of 180 thousand m³ per day (= 65.4 Mtpa). Sea water is lifted up and purified by adding chemicals like hypochloride for disinfection, coagulants and defoamers. The high pressure injection water is distributed through a network of pipelines (PETROTECH-ABSTRACTS 1995).

A share of the wastewater from offshore platforms is discharged after treatment directly into the sea. The remaining effluents are treated onshore at the processing terminals of Uran and Hazira (PETROTECH 1995). The total amount of effluents discharged from onshore production is estimated at 5.13 Mtpa. This average is based on the assumptions of NEERI (1990/03) and RANA (1992).

Emission of Water Pollutants with the Effluents

The discharge of the effluents is regulated by the State Pollution Control Board. Normally the standards of the CPCB (Central Pollution Control Board) are prescribed. A new guideline for the quality of the effluents from drilling sites is expected to be issued in the next future. Additional limits now set values for seven heavy-metals will be prescribed (HAWK 1995). The planned standards for onshore drilling sites and the general standards for effluents are given in the next table.

Table: Tolerance limits according to IS 2490-1981 for the discharge of effluents into different environments (mg/l) and planned Indian standard for onshore and offshore drilling as presented by HAWK (1995)

	Onland Surface	Public Sewer	Onland Irrigation	Onshore Drilling	Offshore Drilling	Coastal area
BOD	30	350	100	30	-	100
COD	250	-	-	-	-	250
TDS	2,100	2,100	2,100	-	-	-
TSS	100	600	200	100	-	100
Oil & grease	10	20	10	10	100	20
Phenol	1	5	-	-	-	5

The next table shows the range of measured values for water pollutants in the effluents. The available information was not sufficient to calculate average concentrations describing the situation in India. The available data (CBWP 1985/12; ONGC 1994/04:44; PAUL 1995; SHARMA/CHAUDHARI 1992; SURRENDER ET AL. 1992) and the limits shown above were used to give estimates of the emissions of water pollutants originating from drilling and production sites effluents.

Table: Minimum and maximum concentrations of water pollutants in the effluents of drilling and production sites and estimates for the LCI (mg/l)

	Minimum	*Maximum*	*Offshore estimation*	*Onshore estimation*
BOD	20	70	**50**	**30**
COD	46	200	**200**	**70**
TDS	400	10,000	**1,500**	**1,200**
TSS	nil	4,000	**100**	**90**
Oil & grease	nil	1,000	**20**	**10**
Phenol	n.a.	n.a.	**0**	**0**

On- and Offshore Wastes

The chemical and biological treatment of effluents produces sludge. Normally this sludge is dumped at landfills or it is burnt (ONGC 1994/12). The ratio between sludge and treated water is assumed to be 0.1%. This reflects the data found for refineries (0.03%) and the information given by SURRENDER ET AL. (1992) and CHAND (1992), 5% and 0.11% respectively. Thus the total amount of sludge is 12.8 Mtpa onshore and 5.23 Mtpa offshore.

Dismantling and Reclaiming of the Production Facilities

The environmental impacts of production do not end with the extraction of the crude oil and natural gas. The production facilities must be dismantled after the plant ceases production. For offshore production this creates big problems as was demonstrated by the North Sea platform „*Brent Spar*" in June 1995. Some experts claimed that the most environmentally friendly solution was to send the platform to the bottom of the sea. This would result in tones of hazardous wastes, stored on the platform, being dumped into the north sea. Bringing the platform onshore for dismantling is claimed to be too expensive by the owners *SHELL*. Protests initiated by *GREENPEACE* finally prevented the dumping of the platform. Other companies plan to blow up their facilities. A future problem is what to do with the pipelines laid in the North Sea once production in the North Sea ceases (TAZ 1995). These problems need to be addressed in India soon because platforms and onshore production facilities are reaching the end off their 20 years production life span. Information regarding these problems could not be found.

Accidents

A **Blow-Out** is another form of accident associated with the production of crude and natural gas, and occurs once in every few years in the country. The last one started at January 8, 1995 during the drilling of an oil well in Andhra Pradesh, because insufficient drilling mud was used to neutralize the formation pressure. The flames of the fire were 100 to 200 m high and could be seen at a distance of 40 km. The fire consumed 1 to 1.3 million cubic meters of gas per day and caused a financial loss of 1.7 million Rupees per day. More than 5,000 villagers in the surrounding area were evacuated. After one month the well started spilling out a shower of crude oil affecting an area of 5 km². Thick black smoke accompanied the flames (BLOW-OUT 1995).

Several attempts were made to control the fire with plastic explosives. These actions were executed in co-operation with foreign fire fighting experts. Their high financial demands and the lack of planning on the part of ONGC led to several differences and delays. It took 61 days to finally put the fire out. It was reported as the biggest blaze in the history of the Indian petroleum industry. The costs to date are 411 million Rupees (US$ 13.3 million) for fire-control expenses and damage to equipment. A few years prior a blow out occurred in the western region of ONGC (BLOW-OUT 1995; ONGC 1995/03).

Allocation of the Investigated Impacts on the two Resources

The allocation of environmental burdens to different outputs in a multi-output system is a problem often met in the practice of LCA. The environmental burdens investigated in the previous chapter for the gas and oil production must be related to an amount of product. This makes it necessary to allocate the impacts between oil and gas. Both are products of the same processes. Sometimes the necessary steps are different for both resources, but it was not possible to investigate these differences in the limited time available. Possible **general** criteria for the allocation are:

- Energy content
- Mass of the outputs
- Economic value of the products
- Volume of the outputs
- Molar content of the outputs
- Exergy content[11]

FEYTER (1994) compared a few methods for the petroleum sector and showed that there are relative small differences. He compared the ratio of natural gas to crude oil if different units are used to express the amount. The allocation ratio between crude and gas varies from 31:69 (by mass), 35:65 (by heating value) to 37:63 (by prices). The impacts in this study are allocated by the energy content of the products. This makes it possible to use processes in TEMIS with the same specifications for both resources.

KNOEPFEL (1994) compared the *general allocation* and a more specific combination of general and *direct allocation* for the case of North Sea offshore production. He investigated the specific differences in the production of natural gas and crude oil. Therefore basic engineering knowledge of the system is necessary to determine if impacts of single processes can be allocated directly to one of the products. The environmental burdens of gas treatment are for example directly allocated to the gas exploitation.

KNOEPFEL (1994) showed that, for the indicator *oil emissions into water,* the general allocation leads to higher values for the gas and lower values for the oil production than a combined allocation that considers different ways of production. The share allocated to the production of oil increased from 87% to 98%.

The impacts of crude oil and natural gas production were allocated in this study by the higher heating value of the products. This assumes for both products the same impacts. It is likely that a more specific allocation could change some of the results for the LCI. The gas production is linked with fewer impacts in the case of water pollutants than assumed in the LCI for India because some gas is explored as free gas. This causes smaller quantities of effluents. For the exploitation of free gas less auxiliary energy is necessary because the efforts for pressure maintenance are smaller (KNOEPFEL 1994). The impacts of crude oil exploitation might turn to be higher in a more specified inventory of the Indian situation. BUWAL (1995) found on the other side higher values in the case of gas exploitation for some indicators. The reasons for the differences are not quoted. FRISCHKNECHT ET AL. (1995) used also a general allocation with the LHV for a comparable study about the petroleum sector in Europe.

Final Inventory for the Petroleum Exploitation

The next table shows the final life cycle inventory for the supply of natural gas and crude oil in India for **all quantitative indicators**. To estimate the environmental impacts of the drilling activities, the impacts of one

[11]The exergy concept takes into account both the quality and the quantity of energy carriers. It uses the work content instead of the heat content of a fuel (ENGELENBURG/NIEUWLAAR 1994).

year are related to the amount of natural gas and crude oil produced in this year. Normally these impacts should be spread over the life time of the constructed production facility. For a broad estimation, the chosen way seems to be reliable because the activities of drilling and the production of crude and gas has not changed essentially in the last years. The burdens of the production were investigated in the previous chapter. They are related to the amount of **total products** (gas and crude) in one year expressed in MJ or TJ. The specific values (MJ/MJ, g/MJ or kg/TJ) are shown in the next table.

The data estimates for the exploitation of imported crude oil are shown in the next table. These data are used also for crude oil throughput to *international* refineries and to calculate the impacts of crude oil imports to India. It was not possible to make an inventory for the world-wide crude oil exploitation and the specific throughput to the Indian market.

The two last columns in the table show data as investigated by FRISCHKNECHT ET AL. (1995), BUWAL (1995) and ÖKO (1994/12). The values of FRISCHKNECHT ET AL. are calculated for an average import of crude oil to Europe with a share of 50:50 for on- and offshore exploitation.

Data for the import of crude oil are estimated using these three sources and the Indian values. To avoid a bias in the calculation, values for the import are chosen in a way that they do not differ strongly from the values investigated for India. This does not totally reflect the true values but otherwise the results of the LCI would be influenced mainly by the different share of imports for the two fuels LPG and kerosene. The values for kerosene are influenced more by the estimation for imports than the results for LPG.

The Indian data for the **energy use** are in the range of the values found by the Öko-Institute and FRISCHKNECHT ET AL. The specific values in MJ/MJ consider the efficiency of the combustion devices. The ÖKO values do not consider the flaring of natural gas. The Indian values might turn out to be higher in a more specific inventory where more uses of energy were investigated. Energy use will rise in the future due to greater efforts for secondary and tertiary recovery. Flaring consumes about 3 to 6 per cent of the produced energy carriers. The necessary energy use for the extraction is 2 to 3 per cent. Additional emissions of sulfur dioxide from non-combustion sources are not investigated in the ÖKO study. The investigated emission of hydrocarbons is also in the range of the values as investigated by BUWAL and ÖKO. The values found by FRISCHKNECHT ET AL. are higher than the values found for India but they consider emissions due to the flaring that are not shown directly for the Indian situation. These emissions are considered in the combustion process.

The use of **water** investigated by BUWAL and FRISCHKNECHT ET AL. is considerably smaller than that found for India. Different definitions of water use make an explanation difficult. About 4,500 liters of **effluents** are discharged in India for the production of 1 TJ crude oil or natural gas. FRISCHKNECHT ET AL. found a higher value for the discharge of effluents. One reason might be that re-injection of water is not considered in this value. The values found by BUWAL for the emission of **water pollutants** are approximately in the range of the values investigated for India. Even with the higher amount of effluents FRISCHKNECHT ET AL. found smaller values for some water pollutants.

Table: Data for India in the EM, data for international extraction and comparison with the range of values found by other authors

	Unit	Offshore (India)	Onshore (India)	Import (international)	Imports to Europe [a]	Imports to Europe [b]
Capacity	MW	2,000	2,000	2,000	1,000	1,000
Product crude	t/a	1.57E+07	1.12E+07	-	-	7.12E+05
Crude	MJ/a	6.63E+11	4.72E+11	-	2.84E+10	2.83E+10
Natural gas	m³/a	1.34E+10	4.62E+09	-	-	3.92E+06
Natural gas	MJ/a	6.05E+11	2.09E+11	-	-	1.61E+08
Total products	MJ/a	1.27E+12	6.81E+11	-	2.84E+10	2.84E+10
Supplied gas	MJ/a	5.64E+11	1.66E+11	-	-	-
Flared gas	m³/a	8.99E+08	9.55E+08	-	-	3.16E+07
Flared gas	MJ/MJ	0.0321	0.0635	0.046	-	0.046
Fuel gas	m³/a	5.32E+08	4.88E+08	-	-	-
Process heat (Fuel gas)	MJ/MJ	0.0161	0.0276	-	0.001 to 0.01	-
HSD use	kg	9.12E+07	6.07E+07	-	-	-
Mechanical power (HSD)	MJ/MJ	0.00101	0.00102	0.005	0.003 to 0.78	0.018
SO_2	kg/TJ	0.00	18.27	-	-	-
CH_4	kg/TJ	2.58	40.51	28	2 to 137 (40/46)	51
NMVOC	kg/TJ	0.42	6.66	9.4	0 to 36	166
Chemicals	g/a	2.03E+10	7.26E+10	-	-	-
Chemicals	g/MJ	1.63E-02	1.08E-01	0.113	-	0.12
Steel	kg/MW	11,400	25,000	12,000	25,000	2,240
Cement	kg/MW	4,190	46,600	5,000	8,000	2,140
Raw water	g/a	6.54E+13	5.30E+12	-	-	-
Raw water	g/MJ	52.5	7.9	9.4	0.67/?	0.98
Effluent total	kg	5.23E+09	1.28E+10	-	-	-
Effluent discharged	kg	5.23E+09	2.93E+09	-	-	-
Effluent evaporated	kg	0.00E+00	2.12E+09	-	-	-
Effluent discharged	kg/TJ	4,200	4,354	4,230	-	13,000
BOD	mg/l	50.00	30.00	-	-	-
BOD	kg/TJ	0.210	0.131	0.13	< 0.10/ < 0.09	0.0049
COD	mg/l	200.00	70.00	-	-	-
COD	kg/TJ	0.840	0.305	0.30	< 0.10/ < 0.09	0.0489
TDS	mg/l	1500.00	1200.00	-	-	-
TDS	kg/TJ	6.3	5.2	5.3	< 0.10/1.29	-
TSS	mg/l	100.00	90.00	-	-	-
TSS	kg/TJ	0.420	0.392	0.39	1.56/1.48	-
Oil & grease	mg/l	20.00	10.00	-	-	-
Oil & grease	kg/TJ	0.084	0.044	1.4	0.67/1.56	3.12
Cuttings	kg/a	1.71E+08	4.05E+08	-	-	-
Cuttings	kg/TJ	137	602	442	-	472
Waste	kg/a	5.23E+06	1.28E+07	-	-	-
Waste	kg/TJ	13	75	38	32.7/88.2	20
BSM (only for crude)	kg/TJ	4.75E-02	4.73E-02	-	-	
Load	h/a	8,000	8,000	8,000	7,900	7,900
Life time	a	10	15	20	25	25
Land use	m²/MW	13	126	20	200	1.70E+06

Sources: *ASTHA 1995; CPWB 1985/12, GOEL 1995; JAGGI 1995; ONGC 1994/12, 1995; OIL 1995; PAUL 1995; PETROTECH 1995; SUYAN 1994/12, SHARMA/SHARMA 1994/04; TERI 1992/07; VELCHAMY/SINGH/NEGI 1992; WSN 1994*

[a] *Values for petroleum extraction for OPEC, Northern Europe, North Sea and CIS as investigated by ÖKO (1994/12). The data for water use, water pollutants, HC emissions and wastes in this column were investigated by BUWAL (1995) for the situation of crude oil and natural gas exploitation (oil/gas) for the demand in Europe.*

[b] *The last column shows the values as investigated by FRISCHKNECHT ET AL. (1995) for the import of crude oil to Europe (1:1 - onshore/offshore).*

Hardcoal extraction in India

The next table shows the estimated data for open-cast and underground mining in India. Data for the share for the two types of mining and the electricity use are based on information in TEDDY (1994). The environmental impacts are calculated with information given by EM - DATABASE (1995) and BUWAL (1991) based on the European situation.

Table: Data for hardcoal extraction in India

	Unit	Open-cast mining	Underground mining
Share		69.5%	30.5%
Capacity	MW	10,000	10,000
Auxiliary energy electricity	MJ/MJ	0.00126	0.00378
Mechanical power	MJ/MJ	0.0015	0.00075
Waste-coal-mining	kg/TJ	13,000	48,000
Methane	kg/TJ	106	660
Load	h/a	7,000	7,000
Life time	a	25	25
Land use	m²/MW	220	50
Steel	kg/MW	2,000	7,000
Cement	kg/MW	0	7,000

Sources: *BUWAL 1991; EM 1995; ÖKO 1994/12 and TEDDY 1994*

Processes in downstream fuel cycles

The Petroleum Downstream Sector in India

In refineries, the crude oil is processed to LPG, kerosene and other products. The first plant for the production of LPG was set up in Delhi in 1960. During the 1970s, LPG was obtained solely from refinery flue gases. As LPG is a clean fuel that can be used for domestic cooking, the government made plans to considerably increase the supply. The commissioning of LPG extraction plants in Bombay in 1981 and Duliajan in Assam (OIL) in 1982 allowed LPG to be extracted from natural gas. The lean gas is fed to fertilizer plants or is used for other purposes. All eight plants in India are situated near the point of exploitation or along the pipelines (ARORA 1994; SHAMSUNDAR 1995).

The amount and share of refinery products are centrally controlled by the governmental Oil Co-ordination Committee (OCC). The committee members are employees of the companies running the refineries or ministry officials. The Committee also controls the crude oil allocation and any expansion plans for the refineries. The retail prices for the products are fixed by this committee. This includes a cross subsidy system. (BUSINESS INDIA 1994, OCC 1995).

Production in the refineries and fractionating plants is not sufficient to meet the demand in India. First priority has the production of diesel oil, because of its importance in the transportation sector as a fuel for trains and trucks. Kerosene is similar to diesel oil so that, if the priority would change, the ratio between kerosene and diesel oil could be varied by a margin of 30%. At present, apart from being used for cooking and lighting by poor people, kerosene is not important for the Indian economy. Five to six times more diesel oil is produced than petrol, the world-wide average is two to three times. For the production of LPG in the refinery, there are no competing products, except the lean gas used for the refinery's own energy demand (IOC 1994/12).

The refinery production has increased from 17 million tones in 1970/71 to over 48 million tones in 1990/91. In 1993/94 the Indian refineries had a crude throughput of 54.3 million tones. Final production amounted to 53.8 million tones. The net production excluding internal demand by the refineries amounted to 51.3 million tones (CFHT 1995; TERI 1993/01).

The refinery output-mix in recent years was 20% light distillates (LPG, petrol, motor gasoline), 54% middle distillates (diesel oil, kerosene, aviation turbine fuel) and 26% heavy ends (fuel oils, lube oils, bitumen, coke). This represents a recent shift in output mix away from heavy ends to light and middle distillates (TEDDY 1994; TERI 1993/01).

LPG and kerosene are also imported into the country. LPG is bought from companies in USA, Japan, Greece and a few Middle-East countries. The structure of the Indian market is shown in the next table (MODAK 1995; SHARMA 1995; TEDDY 1994).

Table: Origin of LPG and kerosene in India in 1992/93 (TEDDY 1994)

	LPG	Kerosene
Import	11%	40%
Production Refineries	44%	60%
Production Gas Processing	45%	-
Availability (thousand tones)	2,940	8,750
Sales (thousand tones)	2,870	3,580

The LPG is filled into cylinders at a **bottling plant**. In India there are at present 83 existing LPG bottling plants. LPG is filled into cylinders at 11 out of 12 existing refineries. Likewise in the 8 fractionating plants for natural gas, most of which are located near the gas fields or pipelines (ARORA 1994; MODAK 1995).

Energy Pricing Policy in India

Energy prices in India are administered with the goal of pursuing certain social objectives. They do not reflect the production costs. A **key concern** of this policy is the provision of cheap fuels in the domestic sector, for poorer sections of society and for fertilizer plants. The subsidy on kerosene is ostensibly to make a relatively clean and efficient fuel available to low income urban and rural households. The primary reason for the subsidy is to make lighting available the majority of the population (BHANDARI/THUKRAL 1994).

The next table illustrates the costs of production and the selling prices for energy in India. The subsidization for LPG and kerosene is 90 Rs and 70 Rs per GJ of energy content respectively. A rational energy pricing policy is very important for the purposes of long-term energy planning. The petroleum products are divided into two main categories: the *price administered* products and *free trade* products. The major products (for example kerosene, diesel oil, LPG and naphtha) belong to the price-administered category. The government fixes the ex-storage point prices for them. These prices are beneath the level of the world market. About 90% of the total volume of petroleum products sold and 95% of the petroleum products refined fall under the price-administered category (TEDDY 1994; WSC 1994).

Table: Costs of production and selling prices for energy in 1993/94 (INDIA TODAY 1995)

	LPG	Kerosene	Domestic electricity	Irrigation electricity
Unit	*Rs per 14.5 kg cylinder*	*Rs per liter*	*Rs per kWh*	*Rs per kWh*
Costs of production	142.30	5.03	1.48	1.36
Selling price	83.20	2.4	0.79	0.15
Total annual subsidies (million Rs)	9,260	24,010	27,660	81,980

The comparative costs of cooking fuels are shown in the next table. The prices are related to the useful energy of the different fuels. This takes into account the efficiency of the cookstove. Cooking food with LPG costs less than one-tenth the price of cooking with firewood and half that of kerosene. LPG is used mostly by the urban middle class and the rich. In the poor rural areas it is not available and under these circumstances the subsidizing policy is not compatible with its stated objects (DOWN TO EARTH 1995/02).

Table: Comparative costs of cooking fuels (CFSAE 1985; DOWN TO EARTH 1995/02)

Energy source	Unit	Unit price (Rs)		Cost of useful energy (Rs/GJ)		Ratio of fuel cost to LPG	
	Year	*84/85*	*93/94*	*84/85*	*93/94*	*84/85*	*93/94*
Firewood	1 kg	0.65	2.00	498	1,533	6.03	11.34
Kerosene (PDS[a])	1 liter	1.90	2.70	100	126	1.19	0.92
Kerosene (open market)	1 liter	4.00	6.00	209	278	2.50	2.03
LPG	1 kg	3.60	6.50	82	134	1.00	1.00

[a] *PDS - Public distribution system (subsidized products)*

Production of Petroleum Products in Refineries

The incoming crude oil is processed in different refinery units. The processes adopted in Indian refineries can broadly be classified as follows (CBWP 1982):

- **Fractionation and stabilization** are the basic refining processes for forming intermediate fractions of specified boiling point ranges.
- **Reforming** is a process in which low octane naphtha, heavy gasoline and naphthalene rich stocks are converted to high octane gasoline blending stocks, aromatics and isobutane.
- **Thermal and catalytic cracking** are processes in which heavy oil fractions are broken down into lower molecular weight fractions. The cracking can be done with the help of heat or by using catalysts. The catalytic cracking is the key process in the production of large volumes of high octane gasoline stocks, furnace oil and other useful middle molecular weight distillates. In the Indian refineries there is a total FCC (Fluid Catalytic Cracking) capacity of 1 million tones per day. These units consume 1,000 tones of catalysts per day. The production of coke in this process amounts to 0.7% to 0.9% of the throughput. To regenerate the catalyst, this coke is also burnt in furnaces (IOC 1995; PETROTECH 1995).
- **Hydrocracker** units produce cleaner fuels, and can upgrade heavier fractions of crude oil into more valuable middle distillates. In the hydrocracker process C-C bonds are broken down and simultaneously hydrogenated in the presence of catalysts.
- **Desulfurization** is necessary to minimize the sulfur content of the products. Sulfur is by far the most predominant impurity in crude oil. It exists in the form of sulfides, polysulfides and thiophenes. Crude oil varies significantly in sulfur content and therefore the processing scheme must be able to handle the crude oil of the maximum sulfur content that can occur (TERI 1993/01).
- **Hydrofinishing** is the process that removes sulfur and nitrogen compounds, odour, color and gum-forming materials as well as saturates olefins by catalytic actions.
- **Coking** is an operation to produce coke with the help of thermal cracking from heavy residuals of the fuel oil distilled (FRISCHKNECHT ET AL. 1995).
- **Utility** functions are for example the supply of steam, heat, electricity and cooling water.

These processes are connected in different ways in the refinery. The process flow depends on the type of crude, the age of the refinery and the palette of products. A process flow diagram for a newly planned refinery in Numaligarh, Assam, is shown in the next figure.

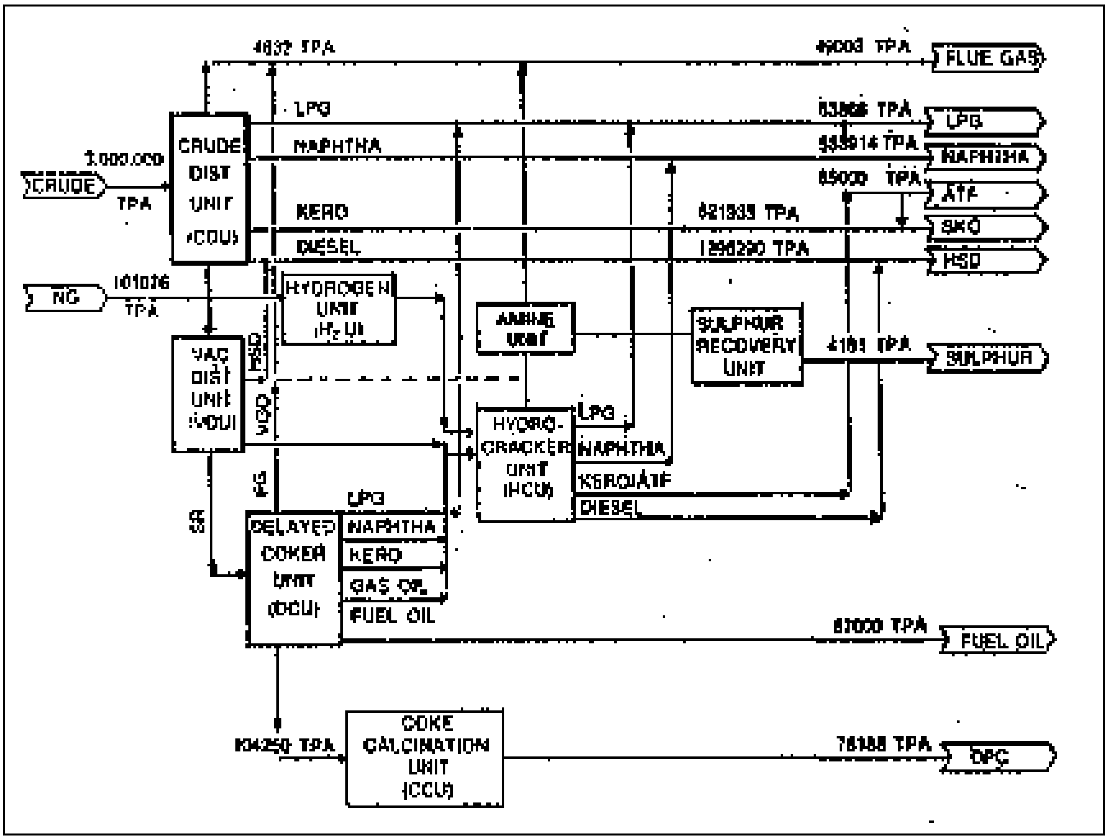


Figure: Simplified process flow diagram for the Numaligarh refinery (NRL 1994)

Energy Use

The energy intensity depends upon crude oil characteristics, adopted processes and the finished product mix. For 1993/94, the fuel consumption ranges from 4.08% to 12.11% with an average of 5.1% of the output (CFHT 1995; OCC 1995; IOC 1994/12, 1995; TERI 1993/01).

Data for the energy use was available for the twelve running units. The average consumption of electricity, fuel oil, fuel gas and coke was calculated with these data. The data for the energy use are shown in the next table. The refineries used fuels with a variety of lower heating values. These are standardized for the inventory. A few refineries sell electricity of their co-generation plants to the state electricity boards. These quantities are subtracted from the total amount. The fuels are burnt in different combustion devices.

Table: Use of auxiliary energy and flaring in the 12 running Indian refineries and the average use of energy in 1993/94 (CFHT 1995)

		Sum of Indian refineries	Average of all refineries	Total (TJ)	Share
Electricity	**(MWh)**	123,241	10,270	444	0.38%
Fuel gas	**(m^3)**	664,497	55,375	34,200	26.87%
Fuel oil	**(t)**	1,623,517	135,293	72,500	58.43%
Coke	**(t)**	262,905	21,909	11,500	9.02%
Flaring of gas (m^3)		130,878	10,907	6,700	5.29%
Total		-	-	125,344	100.00%

The difference between input and output in Indian refineries in 1993/94 reached from 0.61% to 1.29% of the output. The average of these **losses** for 1993/94 in India was 0.95% (OCC 1995; IOC 1994/12). The share of flaring in these losses is not clear. For this study the share of flaring in the total losses is estimated to be 30%. The hydrocarbon emissions are calculated as the loss of the refinery less the estimated flaring, the emissions of hydrocarbons with the wastewater and the discharged wastes. The emission of methane is estimated to be 1/11 of the total hydrocarbon emissions. The rest is assumed as NMVOC.

Water Use and Discharge of Effluents

The use of water in a refinery depends on the type of cooling system. In India refineries have *once through* or *re-circulation* systems. The two refineries in Madras and Vizag (Vishakhapatnam) use sea water; other refineries use treated effluents or river water for cooling. Other requirements for water comprise of steam generation, service water (cleaning, etc.), sanitary and fire water (ACHARYA/DAS 1995, CBWP 1982; NEERI 1995).

The calculated water balance for the Indian refineries is shown in the next table. The **water use** includes water for cooling, processes and sanitary use. The given value is the average of 12 refineries. The theoretical amount of *discharged water* is shown in the second row. This takes into consideration data about the water use and the capacity of the ETP. This value is used for the indicator **effluents**. The last row shows the estimated quantity of effluents discharged after treatment containing the later investigated water pollutants. Neither cooling water nor reused water are considered in this calculation. The value of **effluent with pollutants** is used to calculate the amount of discharged water pollutants.

Table: Water balance for the Indian refineries (kg)

	Total	***Number of data***
Water use	4.38E+11	12
Effluent and cooling water	4.10E+11	12
Effluent with pollutants	2.19E+10	10

Sources: *Own calculation with ACHARYA/DAS 1995; BPCL 1995; CBWP 1982; CPCB 1994/01; HPCL 1995/02; IOC 1995; NEERI 1990/09, 1991/04, 1995; PETROTECH 1995*

The MINAS for refineries prescribes maximum permissible concentrations of pollutants in the effluents. The standard is based on a wastewater generation of 700 liters per tone of processed crude oil (CBWP 1982). The next table shows the minimum, maximum and mean of the values for the investigated refineries. The emission of water pollutants with the effluents was calculated as a weighted mean. In the first step the total emissions of the pollutants were calculated with consideration to the amount of *effluent with pollutants*. These values were added and the average concentration in the total discharged wastewater was calculated. This average concentration is used in the second step to calculate the product specific emissions for the LCI. One refinery in Bombay did not meet the normal CPCB standard. The prescribed limits for this refinery are higher. This is the reason that the value for BOD is higher than the standard. The emission of water pollutants is calculated with the mean values for the concentration and the value for discharged *effluents with pollutants*.

The table shows also the range of comparable values for refineries in Europe and the GUS found by FRISCHKNECHT ET AL. (1995). The given value for the discharge of effluents is higher because it considers the additional discharges of cooling water. The found concentrations of water pollutants are smaller than the Indian values. The total emissions are of a comparable figure if it is considered that the concentrations must be multiplied with the amount of effluents.

Table: Average concentration of water pollutants in the effluents (excluding. cooling water) of Indian refineries

	Number of data	Minimum	Maximum	Mean (used for the LCI)	Indian standard	Inter-national
Effluent (kg/TJ)	*9*	6,348	28,726	**9,660**	16,922	98,000
BOD (mg/l)	*11*	3.6	50	**17**	15	1-1.1
COD (mg/l)	*6*	27	231	**98**	250	30-33
TSS (mg/l)	*9*	8	30	**17**	20	1-10
Phenol (mg/l)	*10*	nil	1.10	**0.46**	1.0	0.04-0.2
Oil & Grease (mg/l)	*11*	0.7	20.4	**9.6**	10	0.25-0.6

Sources: *Own calculation with ACHARYA/DAS 1995; BPCL 1995; CBWP 1982; CPCB 1994/01; CFHT 1995; HPCL 1995; IOC 1995; NEERI 1990/09, 1991/04, 1995; PETROTECH 1995; TEDDY 1994; Range of data for international refineries by FRISCHKNECHT ET AL. 1995 (Data for effluents include cooling water)*

Solid Wastes

Solid wastes generated during refinery operations consists mainly of oily sludge from storage tank bottoms or oil separators and the chemical or biological sludge from ETP facilities. Tarry material is generated during acid refining of some products. Oily sludge is treated in melting pits for the recovery of oil. Left over sediments and dry sludge are disposed off by land filling within the site of the refinery. Chemical and biological sludge are disposed off by land filling after neutralization or natural degradation in drying beds (PETROTECH 1995; IOC 1994/12a; IOC 1995).

The average waste produced by a refinery can be estimated to be around 1,000 to 4,000 tones per year. The oil from this sludge is recovered and between 75 to 700 tones treated sludge is disposed of per year. The total amount of disposed waste is calculated to be 10,800 tones per year for all the refineries in total (ACHARYA/DAS 1995; CBWP 1982;CPCB 1994/01; NEERI 1990/09, 1991/04, 1995; IOC 1994/12A; IOC 1995).

Allocation of the Impacts

With regard to the life cycle inventory, the production of the following fuels (Product Data) in refineries is investigated:

- Liquefied petroleum gas (LPG)
- Kerosene (SKO)
- High speed diesel (HSD) and light diesel oil (LDO)
- Fuel Oil (HPS and LSHS)
- Fuel gas
- Petrol
- Coke

It was not possible to investigate the different production stages separately for all Indian refineries. The entire process was taken as a black box and all indicators were investigated for this system. In a second step the investigated environmental loads for the indicators are allocated by general **allocation criteria**. The possible allocation criteria are described for the upstream processes.

Economic value of the products is not useful as an allocation criteria in India because prices do not reflect the true market value because the subsidy system. The allocation criteria *lower heating value* would be the easiest way, but various authors have shown that this does not reflect the existing differences regarding the production of the refinery products (FRISCHKNECHT 1994; FRISCHKNECHT ET AL. 1995; ÖKO 1994/12; RØNNING 1994).

ÖKO (1994/12) deducted **allocation coefficients** to calculate the energy use for different refinery outputs. The average value for an **indicator** (e.g. energy use in the refinery) under a specific *allocation criteria* (e.g. LHV) is multiplied with the allocation coefficient to calculate the product specific use or emission for this indicator.

FRISCHKNECHT (1994) has shown that allocation coefficients are related to the types of refineries, the composition of products and the investigated indicator. The specific energy use for a product depends also on the production unit. The direct production of LPG from crude oil, for example, is less energy consuming than the secondary production in the FCC (IIP 1994/12).

Allocation coefficients are investigated by different authors and given in the next table. The coefficients investigated by ÖKO (1994/12) describe the situation in German, Swiss and US-American refineries. The comparison of LHV and mass in the second column indicates that the difference between these two allocation criteria is small.

The last column of the table gives the estimates for the allocation of energy use and emissions of air pollutants in the life cycle inventory. The estimation considers the shown investigated coefficients and the refinery production in India. The *allocation coefficient* for the light distillates and heavy ends is estimated to be 1.5 and 1 respectively. The coefficient for middle distillates (HSD, SKO) is chosen in a way that the overall balance for the emissions of Indian refineries is met. Kerosene is treated in the same way as diesel oil because it is a similar product. In a first step the environmental load of the refinery is allocated to all products similarly by the lower heating value. In a second step these burdens are multiplied by the allocation coefficients to consider the differences in the production. The emissions of water pollutants are allocated in a more specific way because they vary for every product and every indicator.

Table: Allocation coefficients investigated for different allocation criteria, indicators and refinery products and the estimation for the LCI

Indicator	*Energy use*	*LHV*	*Catalyst use*	*Thermal energy*	*Electricity use*	*Emissions to water*	*Air pollutants*	*Energy use*	***Energy use, air pollutants***
Allocation criteria	LHV	Mass	Mass	Mass	Mass	Mass	Mass	Mass	**LHV**
Gas oil	*n.a.*	1.01	0.4	0.5	0.5	1.0 - 1.2	*n.a.*	*n.a.*	**0.813**
Fuel oil	1.0	0.95	1.1	1.0	1.0	0.3 - 1.7	*n.a.*	*n.a.*	**1.0**
Petrol	2.0	1.02	2.1	2.0	1.5	0.9 - 1.2	*n.a.*	*n.a.*	**1.5**
Diesel oil	0.5	1.01	*n.a.*	0.5	0.5	0.9 - 1.2	0.4 - 0.58	0.42	**0.813**
Kerosene	*n.a.*	1.02	*n.a.*	0.5	0.5	0.6 - 1.1	*n.a.*	*n.a.*	**0.813**
Propane/ Butane (LPG)	1.5	1.08	*n.a.*	1.5	1.5	0.9 - 1.2	*n.a.*	*n.a.*	**1.5**
Fuel gas	1.0	1.14	*n.a.*	1.0	1.0	0.9 - 1.2	*n.a.*	*n.a.*	**1.0**
Coke	*n.a.*	0.95	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	**1.0**
Source:	ÖKO 1994/12	FRISCHKNECHT 1994 FRISCHKNECHT ET AL. 1995					RØNNING 1994		**Estimation for the LCI**

The allocation for the water pollutants is more complicated. FRISCHKNECHT ET AL (1995) investigated detailed allocation coefficients for a list of water pollutants. These coefficients are calculated for an allocation by mass. The values are multiplied for this study with the factor for mass to LHV allocation as shown in the previous table. The next table shows the used values for a list of water pollutants. Other water pollutants, the water use, the discharge of effluents, wastes, the use of land and materials are all calculated with a coefficient of 1. This follows the proposals made by FRISCHKNECHT ET AL (1995).

Table: Allocation coefficients for the emissions of water pollutants (FRISCHKNECHT ET AL. 1995)

Indicator	***BOD***	***COD***	***Phenol***	***Oil & Grease***
Allocation criteria	LHV	LHV	LHV	LHV
Fuel Oil (HPS)	0.5	0.3	1.8	0.3
Petrol	1.1	1.2	0.9	1.2
Diesel oil	1.2	1.1	0.9	1.2
Kerosene	1.0	1.0	0.6	1.1
Propane/ Butane (LPG)	1.0	1.1	0.8	1.1
Fuel Gas	1.0	1.1	0.8	1.1
Coke	1.0	1.0	1.0	1.0

Final Inventory for Refineries

The next table shows the **final data** of the LCI for refineries in India. The differences caused by using different allocation coefficients are calculated. All investigated qualitative indicators are comprehended in this table. This data will be used for the further calculation of environmental impacts. The table gives also the data for *international* refineries to calculate the impacts of imports. The last column of the table gives a comparison with the values for the production of LPG in European refineries as investigated by FRISCHKNECHT ET AL. (1995). All the information in the previous sections concerning quantitative indicators is related to the products quantified in MJ (TJ). *Eta* describes the percentage output of throughput. Fuels used in the refinery are calculated first as products. The mass of steel and cement is calculated with data given by EM - DATABASE (1995).

The data for the specific energy use consider the efficiency of the combustion devices used. The data for the international refinery are estimated, using the data of FRISCHKNECHT ET AL. (1995), ÖKO (1994/12) and BUWAL (1995). Again big differences between the Indian and the international refineries are avoided to hinder a bias in the analysis for LPG and kerosene. GEMIS 2.0 gives an eta of 95% for the OPEC refineries in comparison to 99.5% of German refineries. The energy use of the OPEC refineries is given a value of only 2%. Thus the overall energy efficiency is nearly the same. BUWAL found 9.35% for the energy use in refineries. The reason for the high energy use in comparison to the Indian refineries might be higher complexity of the plants. FRISCHKNECHT ET AL. found a value of 4.8% for the production of LPG. The energy use for the international refinery delivered by fuel gas and fuel oil combustion is estimated to be about 5%.

BUWAL gives the hydrocarbon emissions at 160 kg/TJ. This is within the range of values found for India (153 kg/TJ) and much more than investigated by ÖKO (10 kg/TJ) and FRISCHKNECHT ET AL. (9 kg/TJ). The additional emissions of sulfur found for Europe are in the range of the Indian values (6 kg/TJ).

The amount of used water investigated by FRISCHKNECHT ET AL. (85 kg/TJ) is smaller than the value found for India (195 kg/TJ). A possible reason is the different use of cooling water in the refineries. The value for the effluents in Europe (84 t/TJ) lies between the Indian values for total water discharge and the discharge of polluted effluents (183 t/TJ and 10 t/TJ). The value for oil investigated by BUWAL is much higher (3.9 kg/TJ) than the Indian value (0.07 kg/TJ). Values for water pollutants were also investigated by FRISCHKNECHT ET AL. for refineries which deliver their products to Europe. The values for BOD and TSS are on the same level. The values for COD, oil & grease and phenol are higher than the values found for India. The production of waste is calculated by BUWAL and FRISCHKNECHT ET AL. with higher values than in this study (37 kg/TJ and 17 kg/TJ). But the Indian value of 5 kg/TJ seems to be reliable because adequate information was available.

Table: Refinery data in India, data for the international refinery and a comparison with values for an European refinery producing LPG

	Unit	Indian refineries	International	Europe
Allocation coefficient		1	1	LPG
Capacity	MW	2,000	2000	1000
eta (products/crude)		99.06%	99.00%	-
Electricity use	MJ/MJ	0.000197	-	0.00436
Fuel gas use	MJ/MJ	0.0129	0.0132	0.00683
Fuel oil use	MJ/MJ	0.0275	0.0301	0.03650
Coke use	MJ/MJ	0.0040	-	-
Flaring	MJ/MJ	0.0030	-	0.04830
Auxiliary energy (excluding electricity)	MJ/MJ	0.0474	0.0432	-
CH4	kg/TJ	13.9	13.9	0.94000
NMVOC	kg/TJ	139	139	8
SO2	kg/TJ	6.3	6.3	11
Water use	g/MJ	195	141	85
Effluent discharge	kg/TJ	182,641	178,600	84,600
BOD	kg/TJ	0.162	0.132	0.094
COD	kg/TJ	0.959	1.13	3.10
TSS	kg/TJ	0.217	0.188	0.094
Phenol	kg/TJ	0.003	0.005	0.015
Oil & grease	kg/TJ	0.069	0.282	0.282
Waste	kg/TJ	4.8	14	16.9
Load	h/a	8,000	8,000	8,280
Life time	a	20	20	20
Land use	m²/MW	250	250	73,000
Steel	kg/MW	4,000	4,000	55,000
Cement	kg/MW	5,000	5,000	12,000

Sources: *Own calculation for India with ACHARYA/DAS 1995; BPCL 1995; CBWP 1982;CPCB 1994/01; CFHT 1995; HPCL 1995; IOC 1994/12A, 1995; NEERI 1990/09, 1991/04, 1995; PETROTECH 1995; TEDDY 1994, estimation for an international refinery with ÖKO 1994/12, BUWAL 1995, FRISCHKNECHT ET AL. 1995 and the Indian values and comparison with the data investigated by FRISCHKNECHT ET AL. 1995 for the production of LPG in Europe*

Production of LPG in Gas Processing Plants

The gas processing stages in fractionating plants can be classified into two main groups. The process scheme for the fractionating plant in Hazira is shown in the next figure. The first is the conditioning of gas. Different contaminants are removed from the gas. In the second stage the valuable products are extracted from the gas. The possible products are liquefied ethane/propane mixture (C2/C3), propane, LPG, natural gasoline, liquefied natural gas (NGL) and sulfur. The gaseous residual after all stages of extraction, the fuel gas or lean natural gas (LNG), can also be used as a fuel (TIWARI 1995).

Due to the contaminants H_2S, CO_2, water and liquid hydrocarbons, the natural gas cannot be used immediately. In the first conditioning stage, the *sweetening*, the gaseous contaminants H_2S and CO_2 are removed by passing the gas through an absorber. The solutions used for the absorber are mostly regenerative. At the plant in Hazira, 48 tones of sulfur are produced per year. The second is the removal of water vapour from the natural gas. The dehydration of gas is mainly carried out by means of liquid and solid desiccants such as triethylene glycol (TEG), activated alumna, molecular sieves, etc. These desiccants are of a regenerative type. In the last step, liquid hydrocarbons are removed by passing the gas through a gas-liquid separator (TIWARI 1995).

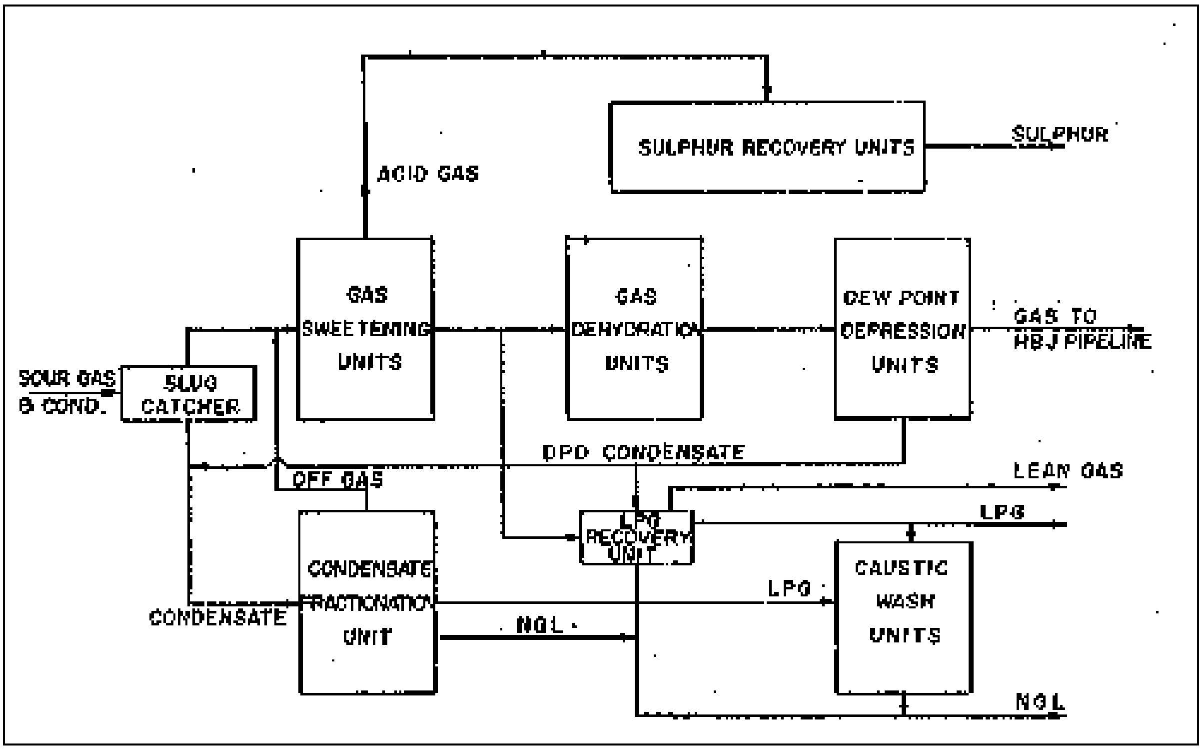


Figure: Overall process flow chart for Hazira gas terminal (BATRA 1995)

The extraction of valuable products is effected by the cryogenic process or the lean oil extraction process. In India the cryogenic process is widely used because it is economically attractive and environmentally friendly. In this process the sweet natural gas is chilled using either a refrigeration system, turbo expander process or a combination of both. With the help of external refrigeration, the gas is cooled down to minus 40°C. The condensed hydrocarbons are separated in separators and fractionated in fractionating columns to obtain the desired valuable products. LPG and NGL are recovered in the first unit. C2/C3 is recovered in the following unit (TIWARI 1995). The share of the different products can be regulated according to demand. Cooling water is normally held in closed systems. Specific effluents are produced only in small amounts from dehydrogenation. For these effluents, the same standards are prescribed as for refineries (PETROTECH 1995; SHAMSUNDAR 1995).

Energy Demand

The demand for energy results mainly from the cooling processes. The demand is met by a co-generator that produces electricity and steam. This generator uses fuel gas. To avoid problems in case of shut downs, provisions is made for flaring of surplus natural gas. For safety reasons, it is necessary that a small flaring fire is fed at all times. In case of difficulties in the downstream sector, the surplus natural gas can be burnt by means of it. The fuel gas is burnt in a combustion device (PETROTECH 1995; SHAMSUNDAR 1995).

Inventory for Gas Processing Plants

The life cycle inventory is shown in the next table. Information about the energy intensity to produce different types of gases was not available. The environmental impacts are allocated by the higher heating value of the products. The emission of air pollutants due to flaring is calculated with the same device as described for the extraction.

Table: Estimates for an Indian gas processing plant (EM 1995; OIL 1995; NEERI 1995; PETROTECH 1995)

	Unit	Estimation
eta		99.90%
Capacity	MW	2,000
Flaring	MJ/MJ	0.001
Auxiliary energy LNG	MJ/MJ	0.0157
Load	h/a	8,000
Life time	a	20
Land use	m²/MW	170
Steel	kg/MW	30,000
Cement	kg/MW	60,000

Bottling Plants for LPG

An installation for LPG bottling normally consists of the following basic facilities:

- Storage tanks for bulk LPG and filling facilities
- LPG cylinder storage and filling facilities
- Process units
- Utilities and effluent disposal

The operations for the LPG bottling are as follows:

- Receipt of LPG cylinders and of LPG delivered in bulk
- Storage of the bulk LPG in tanks
- Cleaning and inspection of the cylinders
- Filling of LPG cylinders
- Handling & storage of LPG cylinders
- Auxiliary operations

The aggregate estimated data for all the Indian bottling plants and the specific data for one plant of OIL are shown in the next table. **Energy** is needed to run gas compressors and auxiliary equipment. The energy needed for bottling plants lies in the range of 18 to 34 kWh electricity per tone LPG. The **land use** for a small plant is about 50,000 m² with a green belt of 30 m. For large plants, comparable values are 500,000 m² and 80 m (BHARAT PETROLEUM 1995; OCC 1995; PETROTECH 1995).

During all stages of the LPG life cycle gas is emitted when connections or disconnections are made between pipes, stores, cylinders, etc.. The losses should be less than 0.1% at the bottling plants and less than 0.5% for the transportation activities. From production or importation to the delivery into the household the actual total loss amounts to 0.3%. The total emissions of NMVOC are taken into account in the bottling stage (OCC 1995). The use of **steel** for cylinders is included in the material data of the bottling plant.

Table: Aggregated average data for an Indian bottling plant

	Unit	**Estimation for the LCI**
eta		**99.70%**
Capacity	MW	**150**
Auxiliary electric energy	MJ/MJ	**0.00185**
NMVOC	kg/TJ	**61.1**
Load	h/a	**3,450**
Life time	a	**15**
Land use	m²/MW	**528**
Steel (incl. cylinder)	kg/MW	**30,000**
Cement	kg/MW	**880**

Sources*: Own calculation with* B*HARAT* P*ETROLEUM 1995; OCC 1995; PETROTECH 1995*

Electricity Generation in North India

The next table shows the LCI for the power generation in North India[12]. About 1.8% of the electricity was produced by nuclear power plants. This is calculated with the generic EM data. Data about the efficiency of coal power plants can be found in TEDDY (1994). The emissions of the combustion devices are estimated to be within the range of values given by EM - DATABASE (1995) under consideration of the Indian standard for particulate matter from coal power plants. The standard prescribes for new plants (since 1979) a limit of 150 mg/Nm³. Old plants in non-protected areas can have emissions of 600 mg/Nm³. The transmission and distribution losses in the Indian electricity grid are very high at 22.8%. The losses are assumed to be this quantity for the LCI. It is possible that the true losses for large scale consumers will be lower because not so many transformation stages are necessary and the amount of pilferage and un-metered supply is lower.

Table: Data for power generation in North India

	Unit	**Coal**	**Gas**	**Hydro**
Share		59.9%	7.8%	30.5%
Capacity	MW	300	150	50
eta		28.2%	37.5%	100%
NO_X	mg/Nm³	1,200	500	0
PM	mg/Nm³	200	10	0
CO	mg/Nm³	200	150	0
Methane	mg/Nm³	6	18	0
NMVOC	mg/Nm³	6	18	0
N_2O	mg/Nm³	10	4	0
Load	h/a	5,000	5,000	5,000
Life time	a	30	30	50
Land use	m²/MW	25	20	25,000
Steel	kg/MW	100,000	50,000	250,000
Cement	kg/MW	250,000	150,000	5.0E+6

Sources: *BUWAL 1991; EM 1995 and TEDDY 1994*

Marketing of LPG and Kerosene

Marketing and Distribution of LPG in India

LPG is obtainable on the parallel market and through the public distribution system (PDS). The public distribution of the cylinders is managed by an agent of the oil company. LPG and other petroleum products have been de-canalized and *parallel marketing* was introduced in 1993. Sales by private entrepreneurs at market determined prices should augment the domestic supply of the products. Today only a small amount is sold on the free market, but the amount should increase in the future (TERI 1989/03; WSC 1994).

[12]North India: Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Rajasthan and Uttar Pradesh

Today LPG is supplied only to towns above 20,000 population and on an exceptional basis to smaller towns. Presently 27% of the urban population and barely 1% of the rural people have access to LPG (ARORA 1994; HINDUSTAN TIMES 1994; MODAK 1995; OCC 1995).

Full cylinders are brought by trucks from the bottling plant to the *godown* (warehouse) of the retailer. The same truck takes the empty bottles back for filling. In the godown the cylinders are stored. The LPG cylinders are delivered by the retailer to the house of the customer in exchange for an empty cylinder. In the end of 1994 the price for a full cylinder was 93.07 Rs. The retail price for the cylinder itself was 500 Rs. The next table shows data for an agent and godown in New Delhi. The office of the agent and the godown for storing the LPG cylinders are located at different places (BHANDARI/THUKRAL 1994; TERI 1989/03).

Table: Data for an godown in New Delhi that distributes LPG

Customers	**8,000**	
Sold cylinder per year approximately	**63,000**	
Capacity	**1.31**	**MW**
Delivery within a radius of	**3**	**km**
Price	**0.13**	**Rs/MJ**
Land use	**770**	**m²**
Life time	**20**	**a**
Cement	**3,820**	**kg/MW**
Load	**3,000**	**h/a**

Marketing and Distribution of Kerosene in India

Kerosene is sold through the public distribution system (PDS) in **fair price shops**. In these shops the kerosene is sold at a fixed, highly subsidized price. On a ration card everyone in India gets 2 liters per months. Recently the Ministry for Petroleum and Natural Gas has allowed the import and marketing of kerosene by private parties. This scheme of Parallel Marketing shall ensure increased availability of the product in the country (WSN 1994:84).

The next table shows the selling prices for kerosene in different cities for PDS and parallel marketing. Data for Dhanawas was not available. The State price for kerosene lies between 2.25 and 4 Rs/l. The price on the parallel private market lies between 4 and 6.50 Rs/l. The price on the world market is $200 per tone or 5.20 Rs/l (OCC 1995). The average price for fair price shops and free marketing is estimated to be 0.066 Rs/MJ and 0.13 Rs/MJ respectively.

Table: Costs of kerosene in different cities for both types of retailers

City	*Type of retailer*	*Rs/l*	*Rs/MJ*
Vododara	Fair price shop	2.25	0.060
Rishikesh	Fair price shop	4.00	0.107
Wardha	Free market	4.00	0.107
Delhi	Fair price shop	2.00	0.054
Delhi	Free market	6.00	0.161

Kerosene is transported with tank trucks from the refinery to the wholesaler. UBA (1993) estimates total retail losses of diesel of 0.175%. For this calculation the loss during wholesaling and retailing is estimated to be 0.1% and 0.5% respectively (TERI 1989/3). The next table shows the estimation for a wholesaler and a retailer of kerosene that is used for the calculation with EM. The next figure shows a retail shop for kerosene.

Table: Data for wholesaling and retailing of kerosene in India

	Wholesaler		*Retailer*	
Capacity	1,000	MW	460	kW
Load	3,000	h/a	3,000	h/a
Life time	15	a	10	a
NMVOC	21.4	kg/TJ	109	kg/TJ
Land use	100	m²/MW	55	m²/MW
Cement	100	kg/MW	2,170	kg/MW
Steel	500	kg/MW	430	kg/MW

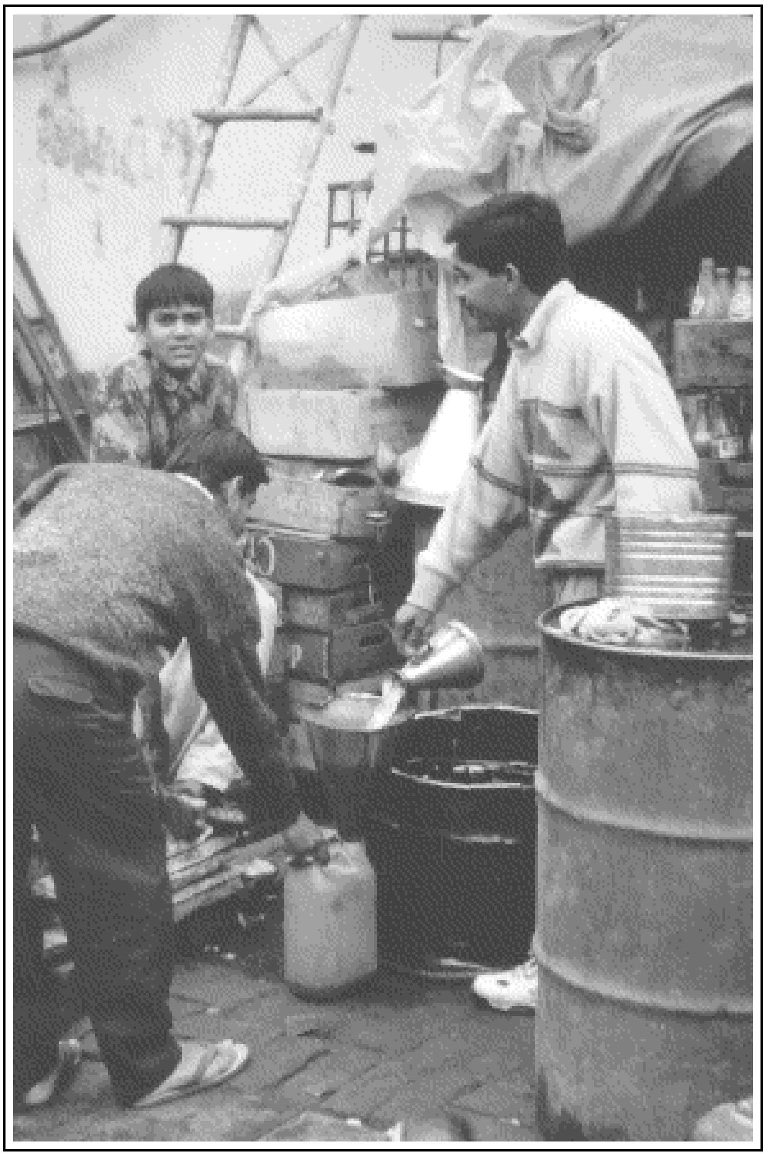


Figure: Photo of a retail shop for kerosene in New Delhi

Processes using fossil fuels

Emission of Air Pollutants from Combustion Devices for Extraction Processes

The next table shows the data for the combustion devices for extraction processes. The values for the flue gas concentrations of pollutants are estimated with the help of the data given by EM - DATABASE (1995); ÖKO (1994/12), FRISCHKNECHT ET AL. (1994) and the available emission data for India.

Data about the flares used in India was not available. The type of flares operated has a considerable influence on the combustion conditions. FRISCHKNECHT ET AL. (1994) assumed the efficiency of flares in different regions of the world to be 94% to 99%. The efficiency is estimated for India to be about 96%. The unburned rest of the natural gas is released as methane and NMVOC. The value for NO_X emissions is estimated with the data given by FRISCHKNECHT ET AL. (1994). For flaring, there is no standard prescribed, and no quantitative limit on glare and smoke has been specified. It is assumed that on average 4% of onshore and 0.5% of offshore flaring is cold flaring (OIL 1995).

Table: Combustion devices for diesel oil and gas. Analysis of the literature values, data from Hazira and estimation for the inventory (mg/Nm³)

	eta	NO_X	PM	CO	CH_4	NMVOC	N_2O
HSD minimum		175	5	100	0	21	0.0
HSD maximum		3,500	500	1,000	10	250	5.0
HSD mean		1,568	209	409	2	126	1.2
HSD†		4,800	530	2,000	84	220	18.6
Dieselmotor	**25%**	**4,000**	**500**	**1,500**	**40**	**200**	**5.0**
Gas minimum		143	0.5	80	5	10	0.1
Gas maximum		500	10.0	322	100	50	5.0
Gas mean		273	3.0	165	16	31	1.3
Gas boiler	**85%**	**300**	**4.0**	**250**	**15**	**30**	**1.0**
Flaring †		1,200	-	-	3,000	450	-
Hazira flaring ‡		133	44	9	-	-	-
Gas flaring estimation	**100%**	**1,200**	**40**	**80**	**3,000**	**450**	**4.0**

***Sources**: † FRISCHKNECHT ET AL. 1995 ‡ SHARMA 1992 All others ÖKO 1994/12*

Emission of Air Pollutants from Refinery Boilers

Due to the very few prescribed standards, measurements of air pollutants are rare. Data when available is only from single measurements and it is unclear how far they give a representative picture. Not all Indian refineries meet the air quality guidelines for the air pollutants SO_2 and particulate matter (IOC 1995; PETROTECH 1995).

The next table shows averages of emission values for some refineries in 1994. They are based on single time stack measurements. Only for Haldia and Guwahati was there enough data available to calculate a weighted mean. The table also shows the average emission values for a German refinery and the prescribed standards for gas and oil furnaces in Germany. The low values for NO_X and CO in the Indian refineries seem to be particularly unreliable. It is possible that the Indian values were not standardized to a certain oxygen content in the flue gases and were not standardized on a temperature. This might be a reason for the great differences.

Table: Average emission values from different stacks in 1994 for Indian refineries and the prescribed standard. Emissions of a German refinery and the standards for gas and oil furnaces in German refineries (mg/m³)

	SO_2	NO_X	PM	CO
Haldia	3,470	131	271	2.8
Guwahati	103	7.4	61	*n.a.*
Barauni	440	49	219	*n.a.*
Vizag	759	526	381	*n.a.*
Digboi	11	1.3	*n.a.*	*n.a.*
Gujarat	68	2.6	*n.a.*	*n.a.*
German refinery	75	260	4	16
Indian Standard for refineries	**1,200**	**-**	**150**	**-**
German standard for gas furnace	**35**	**350**	**5**	**50**
German standard for oil furnace	**1,700**	**450**	**50**	**175**

n.a. - not available

***Sources:** HOLBORN 1995; IOC 1995; NEERI 1990/08, 1995*

A comparison with the values given by ÖKO (1994/12) for boilers used in refineries also indicates recorded values are too low in the given emission data. The estimation considers the shown stack measurements, the Indian standards and the values given by ÖKO (1994/12) and EM - DATABASE (1995). The data for the estimated combustion devices are also shown in the next table. The emissions due to flaring are estimated with the same combustion device as for the petroleum exploitation.

Table: Emission values for calculations in (ÖKO 1994/12) and estimates for the combustion devices in Indian refineries (mg/Nm³)

	eta	NO_X	PM	CO	CH_4	NMVOC	N_2O
Oil boiler (clean gas)		400	50	150	1	25	5
Oil boiler (CIS)(clean gas)		500	150	250	0.50	50	0.50
Fuel oil boiler	**85%**	**500**	**150**	**200**	**1**	**25**	**2**
Gas boiler (clean gas)		150	0.50	100	10	16.25	0.65
Gas boiler (CIS)(clean gas)		400	5	250	25	50	1
Fuel gas boiler	**85%**	**300**	**4**	**150**	**15**	**30**	**1**
Coke boiler (clean gas)		400	4,000	75	0	25	25
Coke boiler	**80%**	**400**	**500**	**200**	**0.1**	**20**	**25**

Emission of Air Pollutants in Gas Processing Plants

The measurements of total emissions from stacks in the processing unit in Hazira are shown in the next table. The estimated values of the gas combustion for co-generation are shown in this table. The ratio of emissions of different pollutants as given and information about gas combustion and their estimates as described for the extraction were used for the estimates.

Table: Emission of air pollutants at the gas processing unit in Hazira from 8 to 10 stacks in 1992/93 and estimates for LNG combustion in the LCI (PETROTECH 1995)

	Minimum (kg/h)	Maximum (kg/h)	Gas boiler (mg/Nm³)
SO_2	3	61	**-**
NO_X	3	700	**250**
PM	5	300	**100**
CO	0,5	250	**90**
HC	3	130	**CH_4: 15** **NMVOC: 30**

Processes for end-uses

Cookstoves for the Use with Kerosene

For the use with Kerosene, different types of cookstoves are marketed in India. They can be broadly classified as being of the "**pressurized**" or the "**wick**" type. Most of the kerosene stoves on the market are pressurized. In the early pressurized stoves, the fuel tank was directly below the burner. The new offset burner stove is safer because the fuel tank is not directly attached to the burner (ISI 1982/05, 1986/05).

The next figure shows a typical **pressurized cookstove** of the offset burner type. The kerosene is delivered to the burner by an over-pressure in the fuel tank. The pressure is built up by a manual air pump. The fuel evaporates through an injector and is mixed with ambient air. This mixture is burnt and the form of the flame is determined by the design of the burner. Some of the heat is used to warm up the incoming kerosene. It is necessary to preheat the burner in the beginning phase of cooking. A little bit of kerosene or sprit is burnt in the spirit cup under the burner. The power of the stove is regulated with a valve in the fuel pipe or by the pressure in the fuel tank. The flame is extinguished by closing the valve or by reducing the pressure on the fuel tank. Normally pressurized cookstoves work quite loudly (LAUTERBACH/SCHNAITER 1995).

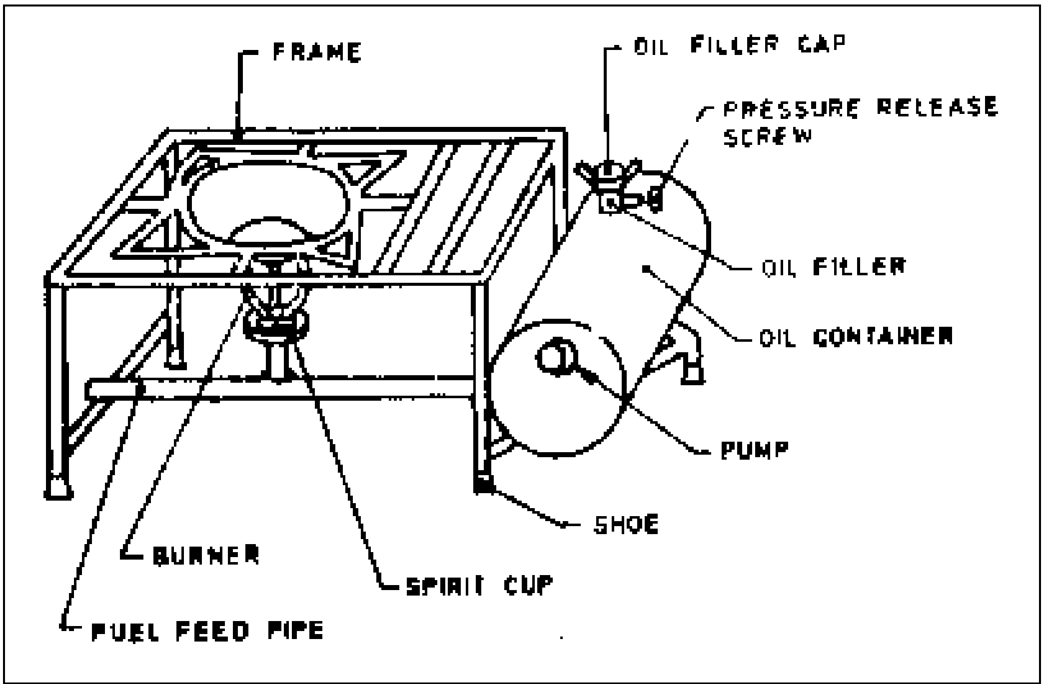


Figure: Typical oil pressure stove of the offset burner type (ISI 1982/05)

The pressurized cookstoves are obtainable in different sizes and qualities on the Indian market. The prices range from Rs 70 up to Rs 125 and Rs 415 for big, "professional" stoves. The IIP (Indian Institute of Petroleum in Dehradun) has worked on an improved SKO pressure stove with an efficiency[13] of 60%. Due to the preheating emissions of some air pollutants and production of noise in the starting phase are probably higher (IIP 1994/12).

The principle of a capillary-fed **wick stove** is shown in the next figure. A ring of wicks is set up over the fuel tank. They are fixed in a construction that makes it possible to adjust their height with a wick winder knob or a handle. The burning room consists of two perforated sleeves. The kerosene from the fuel tank is carried up by capillary power and evaporates at the surface of the wicks into the room between the two sleeves. The fuel is burnt with the ambient air that reaches the burning chamber through the holes in the sleeves. An outer burner casing is around the two perforated sleeves. It serves as an isolation and a shield against wind (IOC n.d.; ISI 1979/11; LAUTERBACH/SCHNAITER 1995).

New improved wick stoves were designed by the IIP. One is the *Mini-Nutan*[14] with an efficiency of 54%. This price (Rs 50) is low enough to make it affordable for low income classes. The Mini-Nutan has a weight of 1.3 kg. The other type is the normal (bigger) *Nutan* for Rs 135 with an efficiency of over 60% (IIP 1994/12).

[13]The efficiency of cookstoves is normally related to the lower heating content of the fuel. For the application in the Environmental Manual all efficiency values are related to the higher heating value.
[14]Nutan is a Hindi word meaning "new".

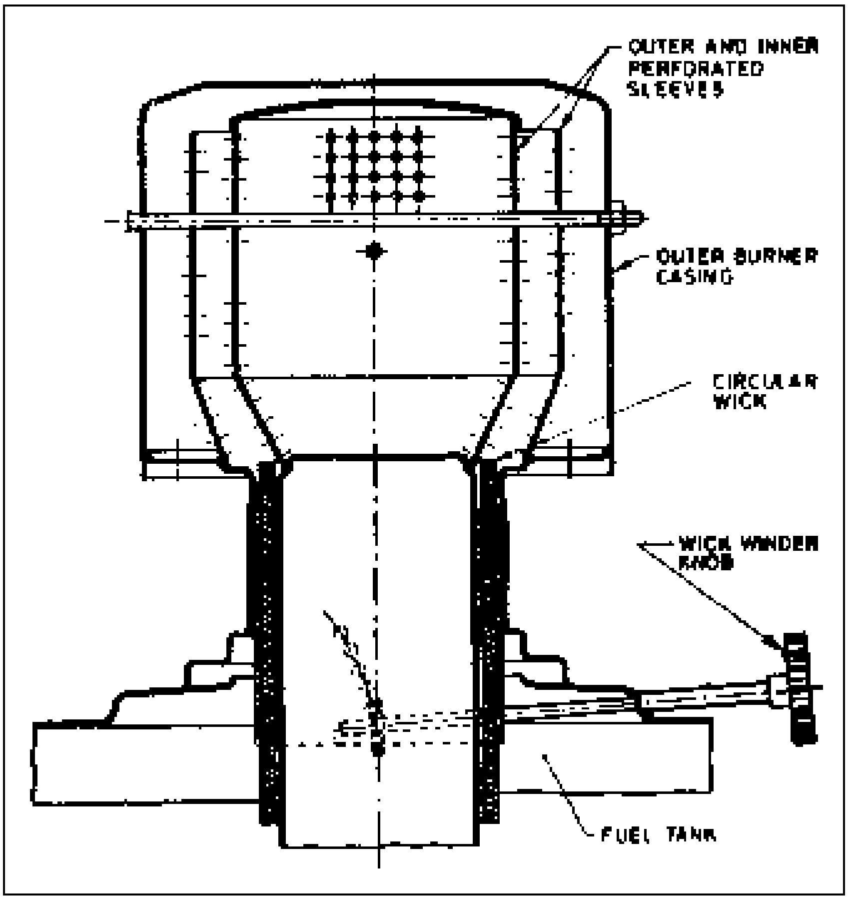


Figure: Functional principle of a capillary-fed wick stove (ISI 1979/11)

Cookstoves for the Use with LPG

The use of LPG is possible with different types of cookstoves. The various parts of a gas installation are shown in the next figure. A pressure regulator is connected to the cylinder valve. It supplies the gas at a constant pressure to the stove. This pressure regulator is connected to the stove by a rubber tube. The gas is mixed with ambient air in a specially designed mixing tube. The air-fuel mixture burns through a burner. After putting the filled vessel on the burner, the taps of the burner is opened to light the flame with a match. The flame should be blue in color to optimize the use of the gas. The use of LPG allows a good control of the fire in comparison to other types of cooking (BPCL n.d.).

LPG cookstoves are sold on the free market in different sizes and types. The price ranges from Rs 450 to about Rs 2,000. The stoves are made mainly of steel, and the weight ranges from 700 g to 2,000 g. The capacity for one flame is normally about 2,300 watt.

Specifications for the cookstoves used in India, are given by the Indian Standards Institution. The thermal efficiency[15] for "ISI" marked LPG stoves ranges from 55% to 62%. After the new standards of 1992, it has to be above 59% to fulfill the ISI specifications. The IIP has developed a new LPG stove with an efficiency of 66%. Previous improvements for LPG stoves have not always been welcomed by the user. Some cooks think that the heat of the flame is not spread uniformly enough for a sufficient cooking of chapatis, a type of bread baked in a pan. The carbon monoxide/carbon dioxide ratio of the exhaust gases under different working conditions must not exceed 2 per cent (BPCL n.d.; ISI 1984/06; TERI 1989/03; PCRA 1993/11).

[15] The efficiency of cookstoves is normally related to the lower heating content of the fuel. For the application in the Environmental Manual all efficiency values are related to the higher heating value.

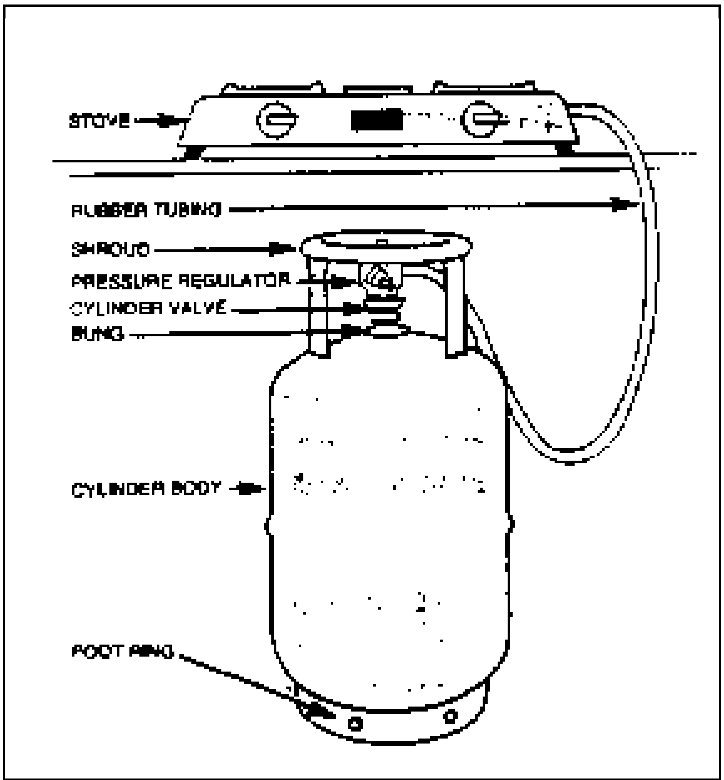


Figure: Parts of an LPG installation (BPCL n.d.)

Efficiency of Indian Cookstoves

In general the fabrication of stoves in India is reserved for small-scale industries, which have neither the technical expertise nor the other resources necessary to produce high-efficiency stoves at the required power ranges. Further improvements for LPG and SKO stoves appear to be difficult to achieve given the increased production costs. The average efficiency of cooking fuels is given in the next table. The efficiency is dependent on the type of cookstove used and on the cooking practices. Savings of up to up to 30% of LPG or kerosene are possible by implementing a few simple fuel-saving-tips (BHANDARI/THUKRAL 1994; PCRA 1993/11; TEDDY 1994).

Table: Average efficiency of cookstoves using commercial fuels in India and the prescribed standards

	Average	*Standard*	*Optimum*
Kerosene (in pressure stoves)	52%†	51% to 54%	60%
Kerosene (in wick stoves)	39%†	56%	> 60%
LPG	58%	57%	66%

Sources: *TEDDY 1994; ISI 1979/11, 1984/07, 1986/05*

† *BHANDARI/THUKRAL (1994) assumed the average efficiency for kerosene stoves in India to be 38%*

Inventory for Cooking with Kerosene

A difficult question in the estimation of the emissions of pressurized kerosene stoves is whether the emissions in the heating phase should be included or not. The emissions during this phase are very high. LAUTERBACH/SCHNAITER (1995) found that the emissions in the first 3 minutes for some pollutants are much higher than during cooking. The next table shows the ratios of the pollutant concentration during the starting time and while using the stove. The total emission of particles, for example in the first 3 minutes, is as high as the subsequent emissions in the following 5 hours of cooking.

In a survey, TERI (1987/02) found out that for any given fuel, the more efficient a stove, the higher the emission factors. In half of the studied cases, the increases in efficiency were greater than the increases in emission factors, so that total emissions per task were lower. This fact was also found by LAUTERBACH/SCHNAITER (1995) for some pollutants. The change of the flue gas concentration, if the kerosene stove is used with a higher power, is given in the next table.

Table: Ratio for the concentration of pollutants in the flue gases between the starting time and the normal cooking session. Changes to the pollutant concentration with a higher power kerosene stove (LAUTERBACH/SCHNAITER 1995)

	Ratio	Change
CO	10	>=
NO_2	0.05 - 0.3	=
PM	100	=
Aldehyde and ketone	10 - 50	>=
PAH [a]	50 - 10,000	>=

[a] PAH - Polycyclic aromatic hydrocarbons

Emission data for kerosene cookstoves, as investigated by different authors, are shown in the next table. The oxygen content is standardized at 3 per cent. The data for some pollutants vary with the ratio of 1 to 100. The surveys may have taken different assumptions for the inclusion of emissions during starting time. In some cases the range of the measured values is also given.

Table: Emission data for various kerosene cookstoves (mg/Nm³) and range of investigated values in brackets

	Nutan [d]	Space heaters [i]	KR-Kerosette [d]	SKO stoves [b]	SKO stoves [e,f]	Primas 101 [c]	MSR-X-GK [c]	Stove [a]	Stove g, h
eta	56%	-	53%	-	-	58% (53%-61%)	43% (35%-59%)	-	42%
Capacity	1.23 kW	-	1.01 kW	-	-	2.50 kW (1.70-2.90)	2.80 kW (0.90-3.17)	4.3 kW	2 kW
NO_X	-	20-160	-	-	209 [e]	289 (257-332)	331 (274-380)	[8]	-
PM	268 (98-431)	0.14-1.1	431 (163-691)	-	-	2.8 (1.5-3.8)	5.9 (5.2-7.2)	[8.5]	19 h
CO	5,122 (2,683-7,560)	32-490	8,373 (4,390-12,276)	3,089	2,000 [f] (500-60,000)	574 (320-810)	275 (162-393)	[50]	500 g
Methane	-	-	-	81	-	-	-	-	5 h
NMVOC	-	-	-	894 [†]	-	-	-	-	94 h
N_2O	-	-	-	4.1	-	-	-	-	7 g

Sources: *[a] DAVE 1987 (The measured values are likely not standardized on a oxygen content of the flue gases) [b] EPA 1992; [c] LAUTERBACH/SCHNAITER 1995 (only cooking); [d] TERI 1987/02; [e] YAMANAKA ET AL 1978 (for a kerosene heater); [f] SCHWENNINGER/SCHULTE 1995 (own estimation for 3 minutes preheating and 60 minutes cooking); g EM 1995; h BPPT/KFA 1992; TRAYNOR ET AL. 1983*

[†] - Total non-methane organic compounds (TNMOC)

It was rather difficult to establish average values for the Environmental Manual. Preliminary calculations indicate that the efficiency and the emissions of the cookstoves determine the results of the scenarios considerably. All environmental impacts of the upper life cycle are lower if the efficiency is greater. The direct emissions from the cookstove are largely responsible for air pollutants. Only the ratio of CO to CO_2 is regulated by the Indian standards for cookstoves. It must not exceed 0.02 for all types of stoves. This equals concentrations in the flue gases of 3,250 mg/Nm³ and 2,900 mg/Nm³ for kerosene and LPG stoves respectively, if the oxygen content of the flue gases is estimated to be 3%.

The LCI scenario should give the emission figures over a period of one hour cooking with a prior heating time of 3 minutes. To estimate the range of possible emissions from cooking with kerosene three estimates are made. They are shown in the next table. The *worst case* considers the upper range of the above given values. The *mean* process stands for a possible, „normal“ average, and the *optimum* process shows values for an optimized cookstove. The life expectancy is estimated at 4 years. The data is estimated as follows.

Table: Estimates for three kerosene cookstoves in the LCI (mg/Nm³)

	Kerosene worst case	Kerosene mean	Kerosene optimum
eta	39%	50%	60%
Capacity	1.50 kW	1.50 kW	1.50 kW
NO_X	300	250	150
PM	400	30	15
CO	8,000	2,000	500
Methane	80	40	0
NMVOC	900	500	100
N_2O	7	3	1

Inventory for Cooking with LPG

Emission data for LPG cookstoves were available from different sources. These data are shown in the next table. The concentration of pollutants in the flue gases is calculated with an oxygen content of 3 per cent. Again the data cover a large range. The reason for the great differences is not clear. For the LCI, three scenarios are considered. A *worst case* scenario to estimate a cookstove with high emissions, a *mean* scenario that equals with an estimated „normal" use of LPG cookstoves and a third scenario with an *optimized* use of LPG stoves. The values are estimated as far as possible to be in the range of the results of EPA (1992), EM - DATABASE (1995), BPPT/KFA (1992) and ÖKO (1994/12). The low NO_X value of YAMANAKA ET AL. does not seem to be reliable. The estimates for CO consider the Indian standards. The investment costs for the stove and a cylinder are estimated to be about 2,000 Rs. The life time of an LPG stove is estimated to be 7 years.

Table: Emission data for LPG cookstoves, space heaters and estimates for the LCI

	Unit	Propane-gas [a]	LPG [b]	Space heater [f]	LPG	LPG worst case	LPG mean	LPG optimum
eta		60%	-	-	51% [a]	**55%**	**59%**	**66%**
Capacity	kW	1.0	-	-	2.0 [a]	**2.3**	**2.3**	**2.3**
NO_X	mg/Nm³	200	-	3.5-140	7 [c]	**200**	**150**	**100**
PM	mg/Nm³	0.5	-	0.2-2.3	0.0 [e]	**1**	**0.5**	**0.0**
CO	mg/Nm³	250	1,868	2-170	700 [g]	**2,900**	**1,800**	**250**
Methane	mg/Nm³	0	3	-	-	**5**	**3**	**0**
NMVOC	mg/Nm³	50	233	-	90 [e]	**250**	**200**	**50**
N_2O	mg/Nm³	2.5	2	-	4 [d]	**4**	**2**	**1**
Load	h/a	500	1,000	-	500 [d]	**1,000**	**1,000**	**1,000**
Weight	g	-	700		2,000 [c]	**1,500**	**1,500**	**1,500**
Life time	a	15	7	-	5 [d]	**7**	**7**	**7**
Costs	Rs					**2,000**	**2,000**	**2,000**

Sources: *[a] ÖKO (1994/12); [b] EPA (1992); [c] YAMANAKA ET AL. (1978); [d] EM - DATABASE (1995); [e] BPPT/KFA (1992); [f] APTE/TRAYNOR (1993); [g] TRAYNOR ET AL (1982) for space heaters*

Transport processes

Description of the Necessary Transports and Scenarios for the Life Cycle

The scenarios for the transportation of crude oil, kerosene and LPG are given in the next tables. The scenarios investigate the distance covered and the mode of transport between all the stages of the life cycle. These scenarios can be adapted to a special region of India by changing the transport distance. The tables show the data for a scenario that is adapted to the use of LPG and kerosene in Dhanawas.

The national demand for Crude Oil, LPG and Kerosene is higher than the amount produced in India. Due to this situation, imports (mainly by tankers) are necessary. The next table gives the details of crude oil import. The vast majority of the crude oil arrives from OPEC countries in the gulf region (SENGUPTA 1994).

Table: Transport of crude oil to India

Crude Oil	Import to India
Single distance (km)	3,000
Tanker	100%

The next table shows the scenario for the import of LPG and its transport to the bottling plants. LPG is bought from companies in the USA, Japan, Greece and a few Middle-Eastern countries. Handling of LPG imports is at present possible only at Bombay and Vizag. Bombay lies on the west coast of India, Vizag on the east coast. Given that the demand for LPG in other regions is higher than the respective production, it is obvious that LPG will have to be transported across the country (MODAK 1995; TERI 1989/03). The distances for the bulk movement of LPG and SKO in India can be in excess of 2,000 km (e.g. Bombay to Calcutta 2,173 km). The LPG can be delivered by rail or road from the storage facilities to the bottling plant. For long distance transport from a harbor rail transport can be assumed (BHANDARI/THUKRAL 1994; TERI 1989/03).

Table: Transport of LPG in India

LPG	Import to India	Harbor (Bombay, Vizag) or Refinery (Mathura) to Bottling Plant (Ghaziabad)
Single distance (km)	9,000	900
Tanker	100%	-
Train	-	80%
Truck	-	20%

The next table shows the transport picture for the distribution of LPG in India. The LPG cylinders are transported normally by trucks from the bottling plant to the distributors. From there they are brought by bike or LCV (Light Commercial Vehicle) to the customer. For large bottling plants the delivery distance can go up to as much as 400 km whereas the distance for the smaller plants is normally in the range of 10 km. To calculate the transports of cylinders with a truck in EM, the simple distance must be multiplied by 2 to consider also the tare weight of the cylinders (TERI 1993/01).

Table: Transport data for LPG distribution in India

LPG	Bottling Plant (Ghaziabad) to Retailer (Gurgaon)	Retailer (Gurgaon) to Customer (Dhanawas)
Single distance (km)	45	15
Distance total (km)	90	30
Truck	100%	-
LCV	-	50%
Bike	-	50%

The data for the transport of kerosene are given in the next table. The tankers bringing SKO imports may be received at any of the existing ports in the country. Kerosene is delivered from the storage points to the wholesalers. The ratio of rail to road is assumed to have the same value as for LPG (TERI 1989/03). The wholesaler delivers the SKO to authorized dealers or sub-agents (retailers) by tank trucks. The customers bring the kerosene from the shop to their house.

Table: Transport of kerosene in India

Kerosene	Import to India	Harbor (Bombay, Vizag) or Refinery (Mathura) to Wholesaler (New Delhi)	Wholesaler (New Delhi) to Retailer (Faruknagar)
Single distance (km)	9,000	900	30
Tankers	100%	-	-
Train	-	80%	-
Truck	-	20%	100%

The average distance LPG and kerosene are carried (across India) is estimated at 960 km and 930 km respectively. These values appear high, but they consider that a part of the fuels is imported and the distance from the harbor to Dhanawas is 1,400 km. LPG processed from offshore gas is transported over the same distance.

Transport of other fuels, e.g. HSD for the upstream sector, is estimated with a total transport of **300 km**. The fuels are transported half and half by train and truck. Hardcoal for power plants and trains is transported 80:20 with trains and trucks. The distance is estimated to be **800 km**. This considers the data given by TEDDY (1994) for average transport distances.

Freight Transport with Tankers

The majority of the imported petroleum products are brought by tankers from the Gulf Region. Data on the energy intensity of cargo haulage for India was not available (IPNGS 1992; TEDDY 1994). Thus the calculations for the energy use and the environmental impacts of the transportation are estimated under consideration of values investigated by different authors. The estimation is made assuming an average load of 50%, because the ships are empty on their return journey. The next table shows the estimated values and data for tankers found by BUWAL (1991), FRISCHKNECHT ET AL. (1995) and ÖKO (1994/12).

OCC (1995) estimates the ocean loss of imported kerosene to be 4.5%. This value appears very high. UBA (1993) estimated the total loss to be about 0.008% of the transported crude oil amount. FRISCHKNECHT ET AL. (1995) found a value of 0.08% for the world wide crude oil transports using tankers. This value includes the spillage in smaller accidents. The loss of imports is estimated for the LCI at 0.001% per 100 km for crude oil imports and 0.0004% per 100 km for imports of petroleum products. This sums up to total losses of 0.03% and 0.036% for the two assumed import scenarios. The losses are considered as emissions of oil & grease (in the case of crude or kerosene imports) in an amount of 0.1/0.04 g/tkm or as NMVOC emissions (for LPG) in an amount of 0.04 g/tkm.

Table: Data for tankers and estimates (with a 50% load occupancy rate)

		Tanker		Estimation	Unit
Steel	n.a.	100	n.a.	**20,000**	t
Driven distance	n.a.	80,000	n.a.	**80,000**	km/a
Lifetime	n.a.	16	n.a.	**16**	a
Fuel oil consumption	0.12	0.11	0.08	**0.215**	MJ/tkm
Tonnage	40,000	1	n.a.	**100,000**	t
NOx	0.008	0.10	0.034	**0.20**	g/tkm
PM	0.005	0.01	0.004	**0.01**	g/tkm
CO	0.001	0.016	0.0044	**0.02**	g/tkm
CH_4	n.a.	0.0003	0.0006	**0.001**	g/tkm
NMVOC	0.001	0.003	0.0009	**0.002**	g/tkm
N_2O	n.a.	0.00003	n.a.	**0.00005**	g/tkm
Waste			0.01	**0.02**	g/tkm
Source	BUWAL 1991	ÖKO 1994/12	FRISCHKNECHT ET AL. 1995		

[a] *tkm - per tone and kilometer*

Freight Transport with Trains

The next table shows the share of different moods of traction. Data of the share in net km was available only for 1989/90. The estimation for the used dispatcher of net tone km considers the rising share of electric traction. The table shows also the distance driven by the different types of trains and an estimation of the land use for the railways. This estimation is based on a calculation of land, covered by tracks.

Table: Ratios for the use of energy carriers (net and gross tone per km) in different years and estimates for the land use of rail transports

	Share of net freight	Share of gross tone km	Estimation for the share of net freight	Driven distance (km/a)	Land use (m^2)
Year	1989/90 [a]	1992/93 [b]		1992/93 [b]	1992/93
Steam traction	0.45%	3.5%	**0.4%**	**2.58E+10**	**1.15E+7**
Diesel traction	59.49%	52.3%	**54.0%**	**3.86E+11**	**1.70E+8**
Electric traction	40.06%	44.2%	**45.6%**	**3.25E+11**	**1.44E+8**

Sources: *[a] RAILWAY (1992) statistics for 1989/91* *[b] TEDDY (1994)*

Full data on the environmental impacts of rail transport are not available. Only estimations of energy consumption per tone and kilometer are possible. The next table shows different calculations for the energy use of trains. The values are compared with the data found by FRISCHKNECHT ET AL (1995) for the situation in Europe. Values for gross-tone km also take the weight of wagons and locomotives into account. The use of energy for other purposes in the railway system is not represented. The shown values take the load of the system into account. The values found for Europe are a little bit higher because the ratio of gross to net tone km is greater. For the calculation of the environmental impacts the use of total MJ per transported tone of freight is decisive. This estimation is made in the last row.

Table: Energy use per tone km in the Indian railway system and estimation for the LCI

	Diesel oil	**Electricity**	**Steam**
MJ/gross-tkm [a]	0.14	0.03	2.45
MJ/gross-tkm [b]	0.24	0.07	4.04
MJ/gross-tkm [c]	0.29	0.09	4.14
MJ/gross-tkm [f]	0.22	0.08	n.a.
MJ/net-tkm [a]	0.27	0.07	5.91
MJ/net-tkm [d]	0.37	0.12	9.25
MJ/net-tkm [b]	0.66	0.18	11.68
MJ/net-tkm [f]	0.50	0.18	n.a.
Estimation (MJ/net-tkm)	0.43	0.12	7.69

Sources: *[a] RAILWAY (1992) statistics for 1989/91* *[b] TEDDY (1994) for different years*
[c] DAS (1994) *[d] Karnik (1989) for 1980/81* *[f] FRISCHKNECHT ET AL. 1995 (for Europe)*

The data for steam trains is based on data given by ÖKO (1994/12) for combustion devices. The values are shown in the next table. The emissions of diesel trains are estimated with emission data investigated by FRISCHKNECHT ET AL (1995) and ÖKO (1994/12). The trains are estimated to have a capacity for 100 t freight. The life time is estimated to be 15 years. The use of steel is estimated to be 3 t per ton of transport capacity. The land use is estimated to be 100 m² for a train driving 200,000 km/a.

Table: Estimation for emission data for steam trains and a diesel oil driven train

		NO_X	**PM**	**CO**	**CH_4**	**NMVOC**	**N_2O**
Hardcoal combustion	**(g/km)**	**126**	**2,510**	**62,9**	**1,26**	**12,6**	**1,26**
Diesel train [a]	(g/km)	42	1.1	10	0.2	4	0. 08
Diesel train [b]	(g/km)	50	4	15	1	14	0.005
Estimation Diesel train	**(g/km)**	**50**	**3**	**15**	**0.5**	**10**	**0.05**

Sources: *[a] FRISCHKNECHT ET AL. 1995* *[b] ÖKO 1994/12*

Freight Transport with Trucks and Light Commercial Vehicles

The LCI distinguishes between light commercial vehicle (LCV) and trucks. Trucks have a total gross weight of more than 3 tones. LCVs are not as heavy as trucks. Data about the emissions of air pollutants from Indian diesel vehicles is available as gram per kg of burnt diesel oil. The calculation is based on the studies of vehicle emissions by the Indian Institute of Petroleum (IIP 1985,1995/09). This data is compared in the next table with values found by FRISCHKNECHT ET AL (1995) for European diesel trucks.

Table: Emission data for diesel vehicles and energy use in India and Europe

	Unit	***Europe***	***India***	***Estimation***
NOx	g/kg	62	44	**60**
PM	g/kg	1.2	2.9	**2.9**
CO	g/kg	19	23	**23**
Methane	g/kg	0.2	n.a.	**0.2**
Hydrocarbons	g/kg	14	10	**14**
N2O	g/kg	0.08	n.a.	**0.1**
Energy use	l/100 km	16t: 26	LCV: 12	**12**
Energy use	l/100 km	40t: 38	Truck: 23	**28**

Sources: *TERI 1993/5; GOI 1991; IIP 1985, 1994/09; FRISCHKNECHT ET AL. 1995*

The data for the LCI are shown in the next table. The values for India are calculated with the factors for fuel emissions as shown in above. The values are multiplied by 2 to consider the assumed average load of 50% for the truck transport. The estimation for the load in the data investigated in Europe is not clear. The estimation for the land use considers the data found by FRISCHKNECHT ET AL. (1995) who estimated this indicator to be 0.0097 m²/tkm. The same source was used to estimate the demand for cement as a construction material to be about 3 t for the truck.

Table: Emission data for Indian transport vehicles with an average load of 50% and a comparison with data for Europe

	Unit	***Light Commercial Vehicle***	***Truck India***	***Small Truck Germany***	***Truck Germany***	***Truck Europe***
Fuel consumption	l/100 km	12	28	45	121	38
Tonnage	t	**0.8**	**10**	10	20	16
Fuel consumption	MJ/tkm	**11**	**2.1**	1.7	2.3	0.9
NOx	g/tkm	**15**	**3**	1.5	0.8	0.995
PM	g/tkm	**0.75**	**0.14**	0.1	0.0575	0.080
CO	g/tkm	**6**	**1**	0.5	0.1225	0.398
CH_4	g/tkm	**0.05**	**0.01**	0.04	0.01	-
NMVOC	g/tkm	**3.5**	**0.6**	0.4	0.0875	0.199
N_2O	g/tkm	**0.025**	**0.005**	0.0001	5.0E-05	-
Material Steel	t	**0.8**	**10**	10	10	-
Material Cement	t	**0.25**	**3**			
Distance per year	km	**30,000**	**30,000**	40,000	40,000	-
Land use	m²	**180**	**1,000**	10	10	-
Life time	a	**10**	**10**	10	10	-

Sources: *Own calculation with TERI 1993/5; GOI 1991; IIP 1985, 1994/09. Data for European trucks as given by BUWAL 1991 (Europe) and ÖKO 1994/12 (Germany)*

A major problem for all users of Indian roads are the frequent **accidents**. Every year many people lose their lives on Indian streets or damage their health. A serious accident happened on 12 March 1995 near Madras. A Public Transport Corporation bus, a tanker carrying benzene and a tractor trailer collided. In the accident 75 people died when the vehicles burst into flames. In another accident six people were killed and four suffered severe burns when an LPG tanker collided with a truck and caught fire. The accident took place near Nashik on the 25th of March (INDIAN EXPRESS 1995; THE TIMES OF INDIA 1995).

Transport of Goods with Bicycle

Bikes are used to deliver the LPG cylinders to the customer. One bike carries 3 cylinders (90.2 kg). The data for the use of bikes as transport vehicles are shown in the next table. The next figure shows a photo of a bike that is used for the transport of LPG cylinders. Sometimes bikes are also used to transport kerosene in cities. A standard oil barrel fits onto a 3-wheeler bicycle. The kerosene is refilled from this barrel into the customers' container. In this case nearly 200 kg of kerosene is transported on the street. This transport mode of transport seems highly dangerous.

Table: Data for the use of bikes as freight transport vehicles

Load factor	3,000 h/a
Tonnage	90 kg
Steel	15 kg
Driven distance	15,000 km/a
Life time	5 a
Land use	5 m²

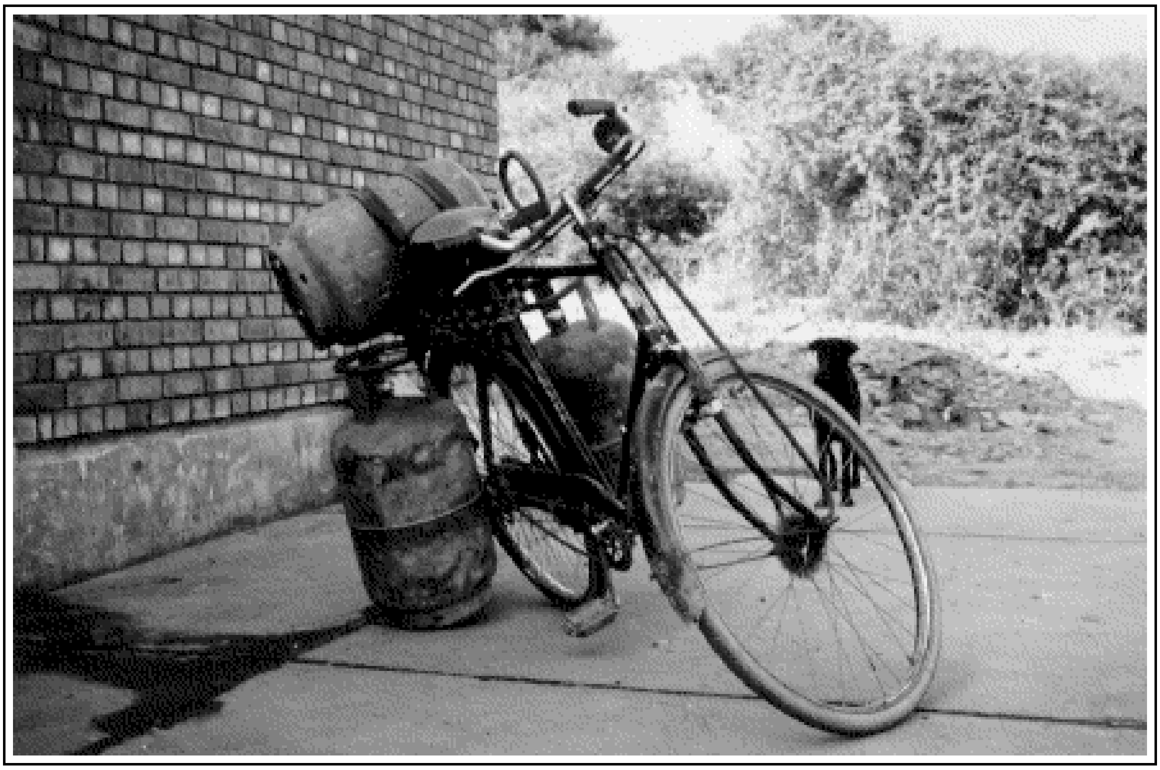


Figure: Transport of LPG cylinders with a bicycle

Scenarios in the EM India Database

Supply of Different Fuels

The „Supply of fuels“ scenario investigates the environmental impacts for the supply of different fuels to the end consumer for a demand of 1 GJ higher heating value of the product. It compares also different types of production for one kind of fuel to evaluate the most environmentally friendly way for an increase in the availability. The scenario is calculated using ***help*** processes to convert the product into process heat, because this is the necessary output to define the scenarios.

Analysis of the Impacts for LPG and Kerosene

JUNGBLUTH (1995) investigated three sections of the **direct** life cycle for LPG and kerosene with similar data as in the EM. The **upstream** sector includes the exploitation of the resources crude oil and natural gas. The second section shows the **downstream** sector with refineries, fractionating and bottling plants. The third sector looks on the **transport and distribution** of LPG and kerosene. This includes the import of crude oil and other products with tankers, the transport of LPG and kerosene from the producer to the consumer and the impacts of their distribution. Each sector includes the production of the used energy carriers and the necessary efforts to transport the fuels to the place of consumption. The bar charts show the percentage origin for different indicators in the three stages of the life cycle. The upper bar stands for kerosene, the lower one for LPG. The next figure shows the share for the environmental impacts in different sections of the life cycle.

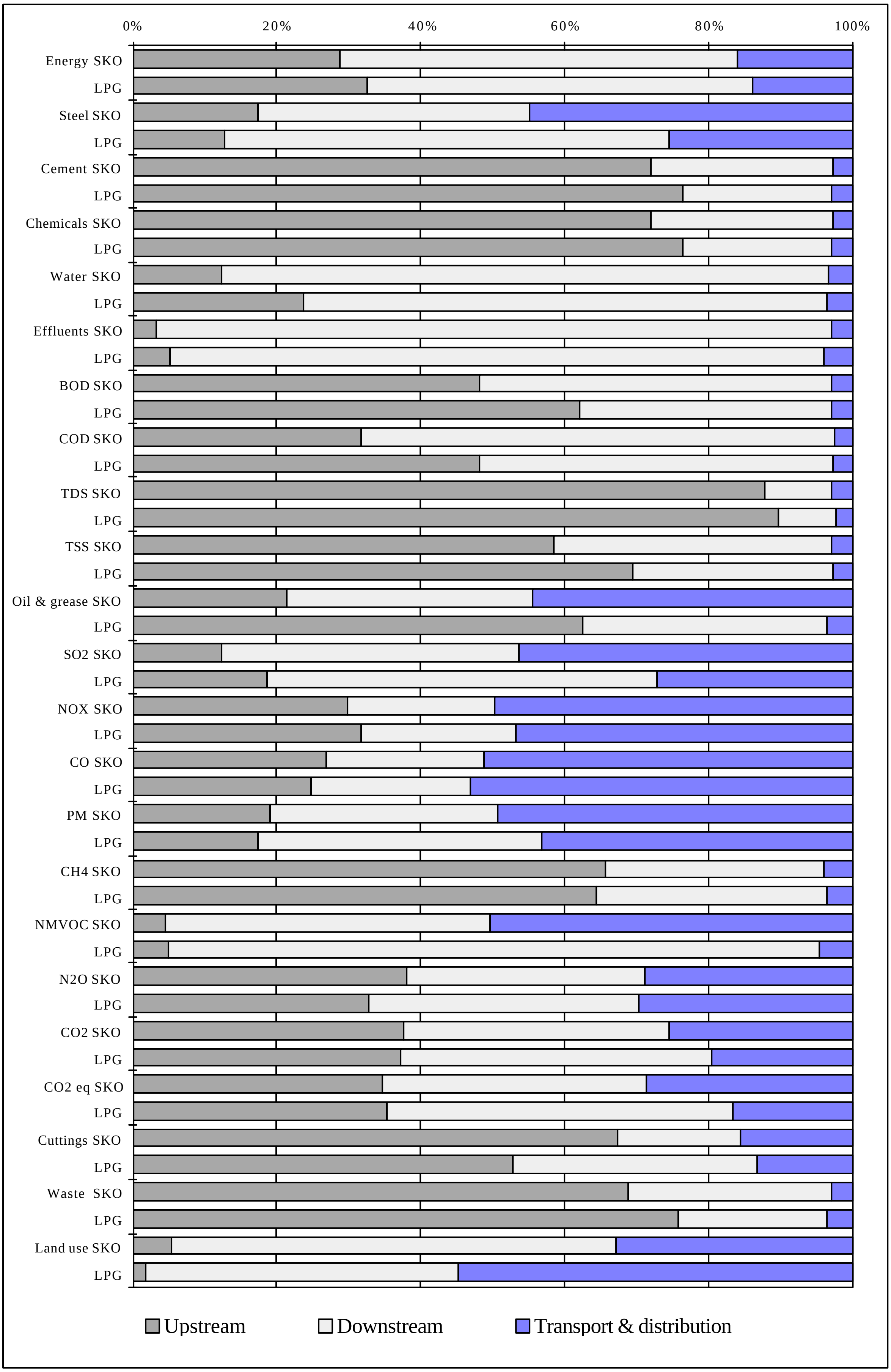


Figure: Environmental impacts in different sections of the life cycle

In comparison the energy use for LPG in the downstream sector has a lower proportion than that for kerosene because of the less energy consuming gas processing plants. The share for transport is higher in the case of kerosene due to the greater demand for imports using tankers. More steel is used in transportation of kerosene. In the LPG scenario it is mainly used for cylinders, needed to transport the LPG. The upstream sector is the main consumer of cement and chemicals, which are necessary for drilling the wells. The other sectors also have a share for this indicator due to the burden of the used fuels.

Water is mainly used as cooling water in refineries. Thus effluent is also discharged mainly from the downstream section. But in some cases the share for water pollutants is nearly the same for downstream and upstream sector. The exception to this is the emissions of TDS which was not investigated for the refineries. Oil & grease are emitted in large amounts by tankers and through the discharge of the cuttings into the sea. Waste and cuttings also have a high share in the first part of the life cycle.

The analysis regarding air pollutants shows a heterogeneous picture. Sulfur dioxide is emitted in a great extent due to imports by tankers because they use fuel oil with high sulfur content. Refineries are also a significant source. The transport devices cause a great share of the NO_X, CO and particle emissions. NMVOC are emitted in a high share with losses during the distribution stage. This is considered in the LPG scenario in the downstream stage of bottling. Methane is emitted on equally high volume during extraction with the flaring. Carbon dioxide and CO_2 equivalents are emitted by all three sectors in the same degree.

The transportation of the products takes a surprisingly high proportion of the environmental burdens of LPG and kerosene. Trucks and LCV are the main single source of NO_X and CO. Flaring of natural gas is important for the emissions of CO_2, methane and CO_2 equivalents. NMVOC are emitted mainly due to the losses during the life cycle and are considered in the process of refining, distribution and bottling. The high volume of particles is due to the small proportion of transportation by steam trains. Exploitation and processing in refineries are the main polluting processes in case of waste, effluent and water pollutant indicators. The environmental impacts of transportation are largely in a direct and immediate relationship to distance journeyed. Further research work needs to investigate the true impacts of transportation in more detail.

The main fuels used as energy carriers in the life cycle are natural gas (flaring) and fuel oil (transports and auxiliary energy). Fuel oil is used in a higher degree for the kerosene scenario because of greater reliance on imports, resulting in its use as a fuel for tankers. The next important energy carrier is HSD as an energy carrier for transports. The use of natural gas marks one important possibility for environmental improvements. The reduction of flaring could lead to a considerable reduction in energy use and emission of air pollutants. Other energy carriers used in a smaller degree are fuel gas, hardcoal and coke. Fuel gas and hardcoal have a higher share in the LPG scenario because of their use as energy carriers in fractionating plants and for power plants (JUNGBLUTH 1995).

Comparison of the Profiles

The direct comparison of the profiles for LPG and kerosene shows an **advantage** to **LPG** in most of the investigated indicators. The energy used in the production of LPG is a little higher than this for kerosene due to the different allocation used for the products in the refining step and the higher energy use for the extraction of natural gas. Water pollutants are released in higher quantity during the production of kerosene. This is because negligible emissions of effluents are associated with the production of LPG in fractionating plants. Release of oil & grease and SO_2 occurs in the main during transportation by tankers. Accordingly the volumes are higher in the kerosene scenario. The use of chemicals and the higher emissions of NMVOC in the SKO profile are linked with the greater pollution due to crude exploitation onshore. Waste is produced in a higher amount accompanying crude oil processing due to the development of BSM.

The comparison of different types of origin shows for LPG, that the most environmentally way of production is the fractionating plant followed by LPG from Indian refineries. Imported LPG causes more negative effects due to the high emissions of the tanker transports. The effect of high emissions due to tanker transports can also be seen at the example of crude oil import and the mix in India or different types of origin for kerosene.

A detailed LCA must compare advantages and disadvantages for different indicators in a more specific way. Several mechanisms are available for the **weighting** of the different forms of impact. One alternative is the detailed discussion of environmental impacts leading to an evaluation. The impact, for example of a specific emission of BOD, is described and the author attempts to evaluate this impact against another one, for example the emission of particulates.

Cooking with Different Types of Stoves in Dhanawas

The environmental profile for cooking scenarios in Dhanawas can be calculated with the „**Cooking in Dhanawas**" scenario. The annual use of cooking energy for one household is difficult to estimate. It depends on many variables. For example (NEERAJA/VENKATA 1991):

- Number of persons
- Cooking and food habits
- Age group of the homemakers
- Regional availability
- Prices and family income
- Convenience of the fuels
- Efficiency of the used cookstove

The figures found by different authors vary in a wide range according to the above factors. The average residential consumption of LPG was 3.2 kg per head in 1993/94. If the LPG consumption is related to the registered consuming families, the average is calculated to be 141 kg per family (5 persons) and year (MODAK 1995). The average Indian person consumed 8.2 kg of kerosene in 1991/92 if the availability is divided through the inhabitants (TEDDY 1994).

The scenario for the EM is calculated on the basis of a requirement for **useful energy** of 1,000 MJ. The value of 1,000 MJ is a little bit more than the annual requirement of one person. This estimation also reflects the fact that it is not possible to give an average energy using requirement for all households. The *mean* processes for LPG and kerosene shows a possible normal scenario for cooking. The two processes *optimum* and *worst-case* cover the range of possible results due to the great uncertainties in the LCI for the cooking. Other cooking possibilities are cooking with electricity and biomass stoves. The latter were taken over from the Generic EM database. The emission values for the gas stoves were copied from the mean LPG stove.

The efficiency of electric stoves is standardized (DIN 44547) in Germany at not less than 43% or 53% depending on whether the cooking starts with a cold or a warm plate[16]. The type of vessels used and other parameters have a big influence on the test results. The efficiency of new stoves in this test is normally ranges from 60% to 70%. The electric stove in the Indian scenario is estimated to have an efficiency of 65% (DIN 1979, 1990; KIEL 1995).

Share of Cooking in the Total Results

JUNGBLUTH (1995) compared the share of direct air pollutant emissions released during cooking as a percentage of the total emissions during the life cycle of LPG and kerosene. About 40% of NO_X are emitted during the cooking. Particulates and SO_2 are emitted in only a negligible share of the total emissions for the LPG life cycle. But kerosene cooking, depending on the different cookstove estimates, produces at this stage about half of its total emissions. The emission of SO_2 is affected only by the sulfur content of the fuel. Thus there are no differences for the different scenarios of cooking with one fuel.

[16] The efficiency describes the energy use for heating up water from 20ºC to 100ºC.

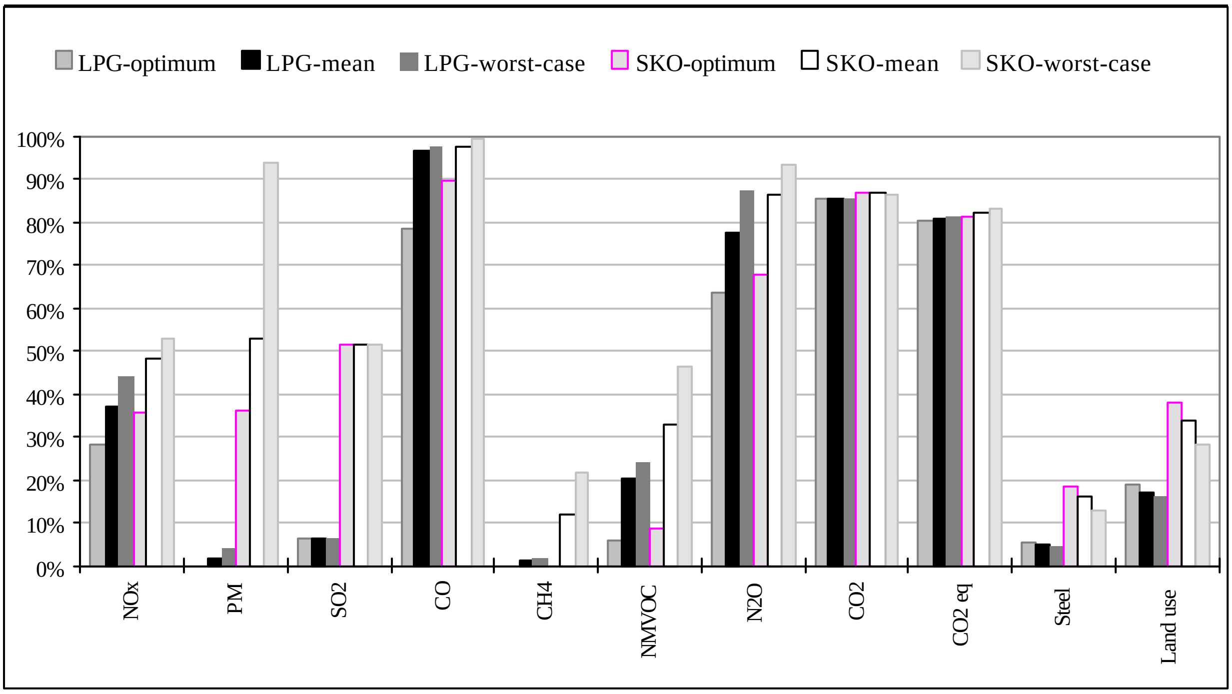


Figure: Share of cookstove emissions and other impacts among the total impacts during the life cycle (JUNGBLUTH 1995)

Emissions of methane are significant in the upper part of the life cycle. Only 20% to 30% of the total NMVOC's emitted by both LPG and kerosene over their product life cycle is released during cooking. For emissions of CO, CO_2, N_2O and CO_2 equivalents, cooking is the critical stage in the life cycle. But as much as 20% of greenhouse gas equivalents are caused by the production of the fuels. The use of steel and land is determined by the results until the delivery to the household. For all other indicators (e.g. water pollutants) the emissions are prior to delivery to the household (and therefore the cooking stage).

Comparison of the Quantifiable Impacts for Cooking in Dhanawas

The results for the LPG and kerosene scenarios can be compared as follows. Cooking with LPG is better than this with kerosene with regard to many indicators even if the worst-case scenario is compared with optimum use of kerosene. These indicators are: Water use, chemicals, effluents, SO_2, PM, CH_4, NMVOC, CO_2, wastes, and all water pollutants except TDS.

The other results depend on the different cooking scenarios. In these cases the advantage of one possibility when comparing the mean scenarios might alternate to a disadvantage if the worst case is compared with the optimum use of the other option. Cooking with kerosene consumes less steel and cement if the mean scenarios are compared. Comparing the remaining indicators results in advantages for the LPG mean scenario in comparison to the mean kerosene scenario. But this result is reversed if an optimized use of kerosene is compared with the worst case LPG scenario.

The cooking with electricity causes the highest emissions for many of the air pollutants. This is due to the high losses in the distribution system and accordingly a low overall efficiency. The emission of water pollutants was not investigated for all steps of the life cycle. Cooking with biomass fuels causes lower emissions of water pollutants (also not investigated for the whole life cycle) and greenhouse gases but higher emissions of some other air pollutants.

Comparison of the Costs

The costs for cooking with LPG and kerosene can be compared as follows. They depend mainly on the efficiency of the used cookstove. For cooking with kerosene two possibilities are thinkable. The kerosene was bought at a fair price shop at a subsidized price or it was bought on the free market. Cooking with kerosene bought on ration cards through the PDS is the cheapest possibility for the consumers. It is less than half the price of the two alternatives. For the mean scenarios cooking with LPG and kerosene bought on the free market the costs are virtually identical. Using the more efficient cookstoves makes LPG cheaper. Cooking with the least efficient kerosene cookstoves makes this possibility the most expensive one. The costs for other cooking possibilities were not evaluated for the Indian market. They are based on world market conditions.

Horizontal Analysis for Qualitative Indicators

JUNGBLUTH (1995) compared different qualitative indicators for the use of the two cooking fuels LPG and kerosene. Qualitative indicators can not be aggregated over the life cycle. It is only possible to point out the main aspects for both fuels. The social and the economic impacts are of the same form of order because the production stages are either identical or very similar. The main aspects can be described and compared as follows:

- *Flora and fauna*: Potentially impacts can occur in all stages of the life cycle. The main impacts are caused however by the exploitation of the petroleum resources, a result of the large areas of land and sea involved. The discharge of residuals during the production also makes an impact.
- *Noise*: It is emitted during all stages of the upper life cycle (this includes all stages except for cooking). The main effects on the public appear to occur with the transportation by trucks through they have the biggest influence on populated areas. There are higher emissions of noise when cooking with kerosene.
- *Temperature*: Main impacts are caused by flaring and discharge of cooling water.
- *Health risks*: All stages of the life cycle provide potential health risks for employees with the regular duties at the work place and with accidents. The public are affected with the emission of air and water pollutants. But cooking is the most important stage because considerable emissions take place near to the possible acceptor. The health risk depends on the ventilation of the kitchen. Cooking with kerosene is eventually connected with higher risks due to the higher emissions of the cookstove. Another important step is the transport because of the high rate of accidents and the direct contribution to emissions in living areas.
- *Gender specific shares*: The main aspect for this point is the cooking. But both types of cooking share the same characteristics in this respect.
- *Time budget*: Cooking is the critical stage. Using LPG takes less time to cook due to the better performance and the fuel supply to the household's door.
- *Product use*: Cooking with LPG is connected with several advantages in comparison to cooking with kerosene. The LPG distribution seems to be easier than that of the liquid fuel, because it is stored in cylinders. Kerosene requires several refills before it can be used. A disadvantage of the transport cylinders is their heavy weight, this disadvantage falls on the employees of the distributor. The use of cylinders also involves additional transport with the return of the bottles to the plant.
- *Cultural plurality*: Both types of cooking are incompatible with some traditional ways of preparing a meal, but there do not seem to be specific differences between them.
- *Accidents*: Accidents can happen during all stages of the life cycle. Transport seems to be the most hazardous step. Accidents during exploitation, for example blow-outs, are connected with hazards for the environment and economic losses. For both types of cooking, accidents are possible. A main problem for cooking with LPG are leaks in the installation that may lead to a gas explosion. Kerosene can be spilled during cooking and thus catch fire. This may lead to injuries of the cook. To point out the more hazardous variant is impossible.
- *Costs*: Individual costs are compared in chapter 9.2.4. Both types of cooking are connected with high costs for the Indian society due to the necessity of imports and the subsidy system.
- *Subsidies*: Both types of fuel are subsidized. But for many Indian people the access to the subsidized fuels is limited due to several constrictions. The amount of kerosene purchasable on a ration card is not sufficient to meet the average demand of a family. Poor people can not afford the initial investment costs involved. And for the poorest the access is further restricted, if they cannot provide proof of legal residence. Access to subsidized LPG is exceptionally difficult. It is only delivered to larger cities. The investment costs are even higher, and the waiting time for an LPG connection is very long. Rich people can shorten the time by connections or corruption. The subsidy of LPG is greater than that of kerosene.
- *International co-operation and dependence*: The indigenous petroleum production does not meet the Indian demand. Thus imports are necessary. This relies to international co-operation and dependence. The dependence will increase in the future due to the opening of the Indian market to foreign investors. Kerosene is imported in a higher amount than LPG.
- *Market concentration*: The Indian market was until recently state controlled. This leads to a high market concentration with only a few companies. These companies do not compete on the market.

This will change in the future due to opening of the market for private enterprises. This opening might be more difficult in the case of LPG because of the higher initial efforts necessary to start an independent distribution system.

- *Couple products*: Natural gas and crude oil are couple products during the exploitation. A variation of the ratio is possible only in small boundaries. The production in refineries and fractionating plants is a mix of several couple products. Kerosene stands in concurrence to the more important HSD, thus the amount produced is influenced by the demand for this fuel. A rising demand could lead to a shortage of HSD. LPG does not have such an important couple product.

It is difficult to evaluate and outweigh the different types of qualitative indicators. The next table shows a subjective evaluation of the positive and negative effects for both fuels. It points out the indicators connected with an advantage for one of the two types of cooking. Indicators not shown in this table are assumed to have nearly the same positive and negative effects. As described before, many impacts are nearly on the same level. Thus the results of the table shall not be misinterpreted as a clear preference for LPG.

Table: Main advantages in the comparison of qualitative indicators for the two fuels (JUNGBLUTH 1995)

Advantage of cooking with kerosene	*Advantage of cooking with LPG*
Lower subsidies	Lower health risks
Lower market concentration	Less noise
	Better time budget
	Easier product use
	No concurrence couple products

Total Environmental Burden of Cooking with LPG and Kerosene in India

The total environmental burden caused by cooking with LPG and kerosene in Indian households can be calculated with „**Total cooking in India**“ scenario. The impacts are calculated with a mix of cooking scenarios (mainly the mean scenario) and the data for the availability of kerosene and LPG in 1992/93. It is assumed that the available fuels are consumed wholly for cooking. The environmental impacts are not restricted to India. Some of the impacts (due to imports) occur in foreign countries. The scenario shows that kerosene is responsible for the main share of impacts due to cooking with fossil fuels because the amount of used kerosene is higher.

The next table compares the emission of greenhouse gases emitted by the cooking with the total emissions in India. The compared figures were not calculated for the same balance room. The figures for cooking with fossil fuels include emissions of greenhouse gases outside India (import of fuels). The total emissions shown above are calculated for India. Thus the values for cooking do not stand for a share on the total emissions. But the values can be compared to classify the environmental burden caused by the cooking with LPG and kerosene.

The emissions of carbon dioxide due to cooking are as high as 3.8% of the total emissions. The comparison for other gases shows 1%, 0.4% and 0.7% for CO, methane and N_2O respectively. The share of LPG and kerosene of the total energy consumption in India amounts to 3%. Thus the found values are reliable considering that other energy carriers are also burnt in the life cycle (General Data; TEDDY 1994).

Table: Comparison of greenhouse gas emissions due to cooking with total emissions in India (TEDDY 1994)

	Unit	*Cooking with fossil fuels*	*Total emissions in India*	*Comparison of cooking with the total emissions*
CO	t	358,000	35,200,000	**1.0%**
CH_4	t	60,000	15,700,000	**0.4%**
N_20	t	575	80,000	**0.7%**
CO_2	MT	46	1,191	**3.8%**

Data for the assessment of EM results

Air-emissions standards for sulfur dioxide and particulate matter (PM) have been evolved by the Central Pollution Control Board (CPCB). The standards for sulfur dioxide emissions from refineries are provided in the next table (TERI 1993/01).

Table: Air pollution emission standards for SO_2 from oil refineries in India (CBWP 1985/07)

Process	SO_2 Emission Limits	
Distillation	0.25	kg per tone of feed
Catalytic cracker	2.5	kg per tone of feed
Sulfur recovery unit	120	kg per tone of sulfur in the feed

Ambient air quality criteria are prescribed for different categories of usage. They are shown in the next table (IOC 1995; TERI 1993/01).

Table: Ambient air quality criteria (µg/m³) (TERI 1993/01; TREND 1995)

Category	SO_2	NO_2	CO	SPM
General: Annual Average	80	100	-	200
General: 24 h Average	130	200	-	400
General: 1 h Average	655	470	-	-
Sensitive: Annual Average	30	30	1,000	100
Sensitive: 24 h Average	30	30	-	200
Industrial/mixed	120	120	5,000	500
Residential/rural	80	80	2,000	200

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Abbreviations

a	per annum
APM	Government administered pricing mechanism
ATF	Aviation turbine fuel
Aux.	Auxiliary
billion	Thousand million
Bm^3	Billion cubic meter
BOD	Biochemical oxygen demand
BPCL	Bharat Petroleum Corporation Ltd.
BRPL	Bongaigaon Refineries and Petrochemicals Ltd.
BSW	Bottom-sediment and water sludge
c. i. f.	Cost, insurance and freight
C2/C3	Liquefied ethane-propane mixture
CIS	Commonwealth of Independent States
CNG	Compressed natural gas
CO	Carbon oxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CPCB	Central Pollution Control Board
CRL	Cochin Refinery Ltd.
DIN	Deutsches Institut für Normung (German Institute for Standardization)
DPD	Dew point depression
EM	Environmental Manual (computer program)
en.	Energy
EOR	Enhanced oil recovery
ESP	Electrostatic precipitator
eta	Thermal efficiency of a process (used in the computer program TEMIS)
ETP	Effluent treatment plant
FCC	Fluid catalytic cracking
FO	Fuel (furnace) oil
FTP	File transfer protocol
g	gram
GAIL	Gas Authority of India Ltd.
GEMIS	Gesamt-Emissions-Modell Integrierter Systeme
GER	Germany
GGS	Group gathering station
GJ	Giga joule = 10^9 joule
GNP	Gross national product
GOI	Government of India
h	per hour
HC	Hydrocarbons

HFO	Heavy fuel oil
HHV	Higher heating value
HPLC	Hindustan Petroleum Corporation Ltd.
HPS	Heavy petroleum stock
HSD	High speed diesel
IIP	Indian Institute of Petroleum
In	India
int	international
IOC	Indian Oil Corporation
IS	Indian standard
ISI	Indian Standards Institution
kgoe	Kilograms of oil equivalent
LCA	Life cycle assessment / analysis
LCI	Life cycle inventory
LCV	Light commercial vehicle
LDC	Low / Less / Least developed country
LDO	Light diesel oil
LHV	Lower heating value
LNG	Lean natural gas
LPG	Liquefied petroleum gas
LSHS	Low sulfur heavy stock
MINAS	Minimal national (Indian water) standards
MJ	Mega joule = 10^6 joule
Mm^3	Million metric cubic meters
MMSCMD	Million metric square cubic meters per day
MRL	Madras Refinery Ltd.
MT	Million tones (in some publications also for metric tones!)
Mtcr	Million tones of coal replacement
Mtoe	Million tones of oil equivalent
Mtpa	Million tones per annum
MW	Mega watt
n.a.	Not available
n.d.	No date
NEERI	National Environmental Engineering Research Institute
NGL	Natural gas liquid
Nm^3	Norm cubic meter
NMVOC	Non-methane volatile organic compounds
NO_X	Nitrogen oxides
O&M	Operating & maintaining
OCC	Oil Coordination Committee
OIL	Oil India Ltd.
ONGC	Oil & Natural Gas Corporation Ltd. (erstwhile Commission)
OPEC	Organization of Oil Exporting Countries
pa	per annum
PAH	Polycyclic aromatic hydrocarbons
PDS	Public distribution system
PM	Particulate matter

POL	Petroleum, oil & lubricants
PP	Power plant
R&D	Research & development
Rs	Indian Rupees[17] (Currency)
SETAC	Society of Environmental Toxicology and Chemistry
SI	Système International (International system of units of measurement)
SKO	Superior kerosene oil
SO_2	Sulfur dioxide
SPM	Suspended particulate matter
SRU	Sulfur recovery unit
t	Metric tones (= 10^6 g)
TDS	Total dissolved solids
TEG	Triethylene glycol
TEMIS	Total Emission Model for Integrated Systems
TERI	TATA Energy Research Institute
TJ	Tera Joule = 10^{12} Joule
tkm	per tone and kilometer
TNMOC	Total non-methane organic compounds
toe	Tones of oil equivalent
tpa	Tones per annum
TSP	Total suspended particulates
TSS	Total suspended solids
UBA	Umweltbundesamt (Environmental Protection Agency in Germany)
vol%	Volume percent
wt%	Weight percent

[17]31 Rs = US$ 1 (January 1995)