Freight ship fuel: Heavy Oil

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Content

Introduction

Our estimate for energy requirements and emissions from production of heavy oil products is taken from ProBas, a LCA-database developed by the German Ministry for Environmental Affairs together with the German research institute Öko-Institut [1].

In ProBas, international freight ships are assumed to use heavy oil as fuel [2]. The raw oil input mix used to produce the heavy oil is a weighted average of two sources, primary and secondary raw oil from OPEC countries. The raw oil is drilled onshore.

The primary oil input is given a weight of 0,8 while the secondary oil input is given a weight of 0,2. The difference between them is that the secondary onshore oil is more demanding to drill and extract since water injection is used to raise the pressure in the reservoir. Therefore the amount of input materials is considerably higher for secondary oil. Input materials are steel which the drilling pipes are made of as well as cement and concrete which keeps the drilling pipe fastened to the drilling hole [3].

Heavy oil

Figure 1 shows a flow chart for heavy oil. The output at any node in the production chain is labeled with the internal German names from ProBas so that is it easier to look up the estimate for further reviewing. Heavy oil is the left-over material after light oil is produced at the refinery. Light oil are products where 90% of the content has vaporized at a temperature of at most 210^{o} C [4].

In the refinery, oil products are separated from each other by heating the raw oil. Since different products vaporize at different temperatures, different products or fractions are separated at different boiling temperatures. The fractions left over after the light oil products have vaporized are called heavy oil products. The heavy oil fractions are not vaporized since they have a higher boiling point than what is used in a refinery. That is why they are called residues or left over's from the distillation process. Heavy oil products are used as marine fuel or bunker oil [5].

The flow chart shows all input and output associated with the production of 1 TJ of energy from heavy oil. As can be seen from the flow chart, input for production of secondary raw oil in form of process heat and materials is bigger than the corresponding input for primary raw oil.

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[1] http://www.probas.umweltbundesamt.de/php/index.php

[2] The internal German name for the estimate of a ship used in international ship freight in ProBas is "Überseeschiff", see http://www.probas.umweltbundesamt.de/php/themen.php?&prozessid={0E0B2D28-9043-11D3-B2C8-0080C8941B49}&id=13472104448&step=4&search=

[3] http://science.howstuffworks.com/oil-drilling5.htm

[4] http://de.wikipedia.org/wiki/Leicht%C3%B6l

[5] http://de.wikipedia.org/wiki/Schwer%C3%B6l

Figure 1 Flow chart for heavy oil

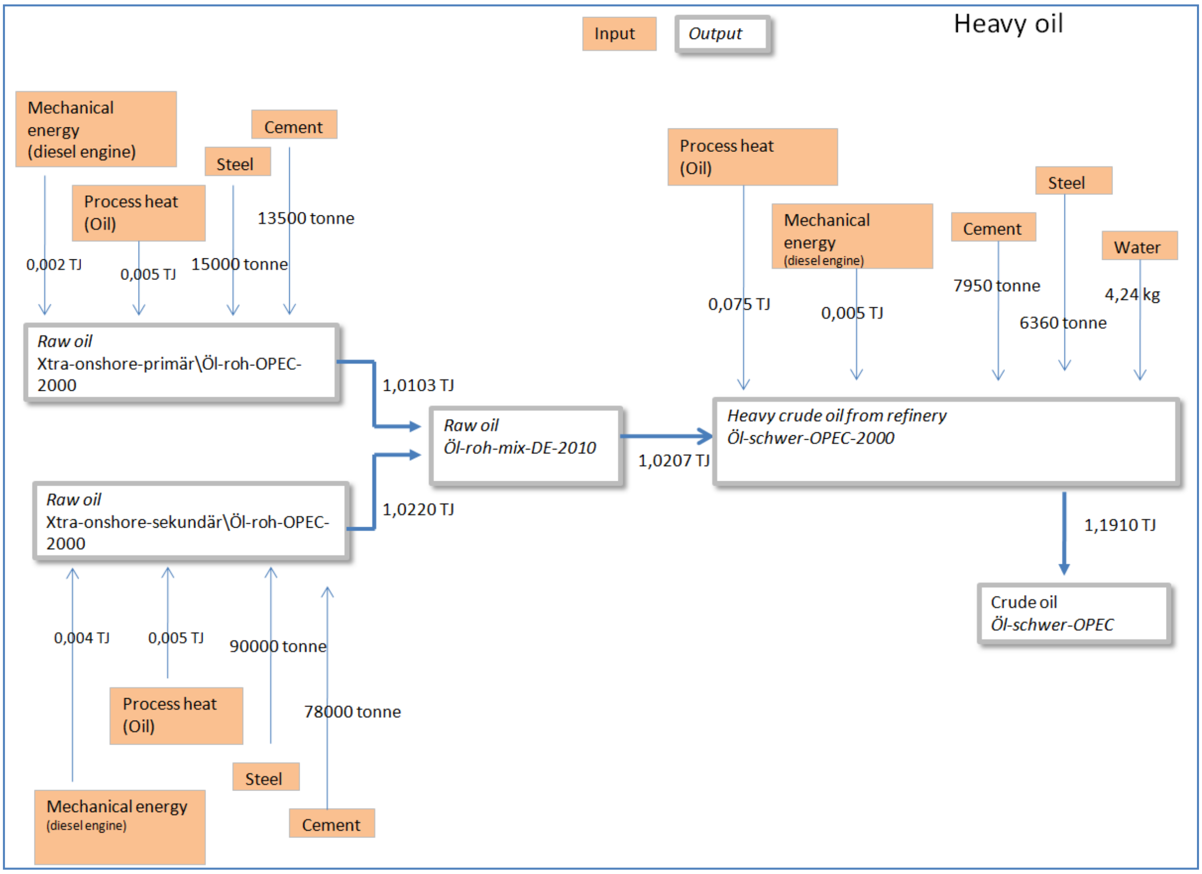

Table 1 shows the input energy required to produce 1 TJ of energy from heavy oil products. The energy content from raw oil is taken into consideration, therefore it is possible to calculate the thermal efficiency of the heavy oil products. In table 1, this thermal efficiency is estimated to be 84%. This yields a loss multiplicator of 1,19. This means that for any amount of energy generated by the combustion of heavy oil, a multiplicator of 1,19 should be used in order to accommodate for the energy required to produce the fuel.

Table 1 Energy input for production of 1 TJ of energy from heavy oil

All numbers (except for CO_2-equiv) in TJ	Heavy oil from refinery Raffinerie\Öl-schwer-OPEC-2000	Raw oil mix Xtra-mix\Öl-roh-OPEC-2000	Primary raw oil Xtra-onshore-primär\Öl-roh-OPEC-2000	Secondary raw oil Xtra-onshore-sekundär\Öl-roh-OPEC-2000
Residual heat	-1,31E-13	0,00E+00	0,00E+00	-2,47E-13
Nuclear power	-3,57E-06	-3,07E-06	-1,47E-06	-9,47E-06
Biomass	6,39E-07	3,96E-07	2,07E-07	1,15E-06
Brown coal (lignite)	4,63E-05	2,86E-05	1,50E-05	8,32E-05
Natural gas	-2,63E-05	-1,78E-05	-9,07E-06	-5,27E-05
Raw oil	1,19	1,02	1,01	1,02
Geothermal	5,20E-10	3,45E-10	1,77E-10	1,02E-09
Waste	-8,67E-07	-7,44E-07	-3,57E-07	-2,29E-06

Secondary raw materials	0,000148	9,90E-05	5,06E-05	0,000293
Solar energy	-1,28E-11	-8,60E-12	-4,38E-12	-2,54E-11
Coal	0,000847	0,000563	0,000288	0,00166
Hydro power	6,22E-06	4,11E-06	2,11E-06	1,21E-05
Wind	-1,89E-07	-1,39E-07	-6,91E-08	-4,17E-07
Sum (TJ)	1,1910	1,0207	1,0103	1,0220
Thermal efficiency (%)	84	98	99	98
CO_2-equiv. (kg)	11 900	2 744	2 592	3 354
Process heat (TJ)	0,075		0,005	0,005
CO_2 (kg)	11 500	2 472	2 325	3 062

As can be seen from table 1, the biggest energy loss relative to the energy content of raw oil appears in the refinery section of the production chain. About 14% of the energy content is lost in the refinery process.

All in all, producing 1 TJ of energy from heavy oil requires 0,085 TJ of process heat which is produced by combustion of oil. All in all, production of 1 TJ of energy from heavy oil leads to emissions of 11,9 tonnes of CO_2-equivalents (of which 11,5 is CO_2 alone). The definition of CO_2-equivalents in ProBas is identical to the one used in the Kyoto protocol.

For raw oil, the following features are considered:

- energy requirement for pumps,
- process heat,
- gas flaring, 1 TJ of energy from raw oil (measured as higher calorific value) is assumed to flare 8 kg CH_4, 5 kg NMVOCand 1,189 kg CO_2,
- diffuse emissions, 1 TJ of energy from raw oil is assumed to have additional emissions of 3 kg CH4 and 2 kg NMVOC,
- exploration requirements, it is assumed that one tonne of raw oil needs 0,003 meter of drilling, which again requires 210 kg steel/meter, 200 kg cement/meter, 200 liter of diesel/meter, emissions of 1,9 kg CH2/meter and finally emissions of 0,65 kg NMVOC /meter.

Heavy oil has an energy density of 37 MJ/liter [6]. 1 TJ of energy from heavy oil thus yields 27027 liter of heavy oil fuel. Consequently, the energy requirement for process heat is 3,145 MJ/liter heavy oil and the total energy requirement over the whole production chain for producing 1 liter of heavy oil is 44,1 MJ. Also, the total emissions of CO_2-equivalents are 0,44 kg pr liter of heavy oil (0,426 kg CO_2).

How should we treat ship freights from other countries than Germany? Should all ship feights be assumed to use the same fuel from the same raw oil input? In ProBas, the estimate for heavy oil products used as marine fuel is a generic estimate. This means that it is an average ship freight which

[6] http://en.wikipedia.org/wiki/Energy_density#Energy_densities_ignoring_external_components

is considered universally valid for all ship freights from all countries. The estimate is not confined to Germany. The estimate will not be accurate for all countries since their oil import mix will differ, and since some countries will have domestic production of raw oil.

Table 2 World oil production and reserves 2008 [7]

Country	Reserve billion barrels	Percent share reserves (barrels)	Production million barrels/day	Percent share production (barrels)	Reserve years
Saudi Arabia #	267	21,5 %	10,2	16,1 %	72
Canada	179	14,4 %	3,3	5,2 %	149
Iran #	138	11,1 %	4,0	6,3 %	95
Iraq #	115	9,3 %	2,1	3,3 %	150
Kuwait *	104	8,4 %	2,6	4,1 %	110
United Arab Emirates #	98	7,9 %	2,9	4,6 %	93
Venezuela #	87	7,0 %	2,7	4,3 %	88
Russia	60	4,8 %	9,9	15,6 %	17
Libya #	41	3,3 %	1,7	2,7 %	66
Nigeria #	36	2,9 %	2,4	3,8 %	41
Kazakhstan	30	2,4 %	1,4	2,2 %	59
United States	21	1,7 %	7,5	11,8 %	8
China	16	1,3 %	3,9	6,1 %	11
Qatar #	15	1,2 %	0,9	1,4 %	46
Algeria #	12	1,0 %	2,2	3,5 %	15
Brazil	12	1,0 %	2,3	3,6 %	14
Mexico	12	1,0 %	3,5	5,5 %	9

OPEC Country

Table 2 shows oil production and oil reserves 2008 by country. All in all, the OPEC countries has about 50% of world production in 2008, while the same countries have 73,5% of world reserves. With almost three quarters of the known reserves, it is reasonable to use OPEC raw oil as the average input for production of marine fuel. In other words, it is a 75% chance that a random ship freighter will run on raw oil input from OPEC countries in the long run.

Specific Chinese estimate

It is also possible to make a specific estimate for a specific country. This can be done by applying the known raw oil mix for this country. This mix is dependant on raw oil import mix for the country as well as domestic oil production when applicable. In this section, we will make such an estimate for China.

China's oil import comes from two major sources. One is the OPEC countries which alone account for 63% of Chinese oil import in the period January-June 2008. The other is Russian oil import which alone stands for 8% of Chinese oil import in the same period. If we consider Sudan, Oman and Yemen

[7] http://en.wikipedia.org/wiki/Oil_reserves#Estimated_reserves_by_country

to have similar conditions for their exploration and production of oil as OPEC countries, the OPEC share rises to 88,1% of Chinese oil import in the period. If we assume Kazakhstan to be similar to Russia in the same way, we can attribute a 10,7% share to Russian oil import [8]. In order to build an estimate for China, we assume 90% share of oil import for OPEC oil and 10% share for Russian.

ProBas has an estimate for raw oil delivered to pipeline for raw oil from OPEC countries and Russia. These estimates include energy requirements and emissions to air for producing 1 TJ of energy from raw oil. The estimates are for year 2000. By weighing these two raw oil inputs together, we can arrive at an estimate for Chinese oil import mix. In addition, we must take into account the domestic Chinese oil production. ProBas has an estimate for Chinese heavy oil products from refinery which is based on domestic production of oil. The estimate is for year 1995. Chinese domestic production is assumed to make up 95% of imported oil [9]. With this number, we can weigh Chinese domestic raw oil with the calculated import mix. To complete the estimate, we assume the same energy requirement relative to raw oil as for Chinese heavy oil products which was exclusively based on domestic oil production.

Figure 2 Process flow chart for raw oil from OPEC countries 2000

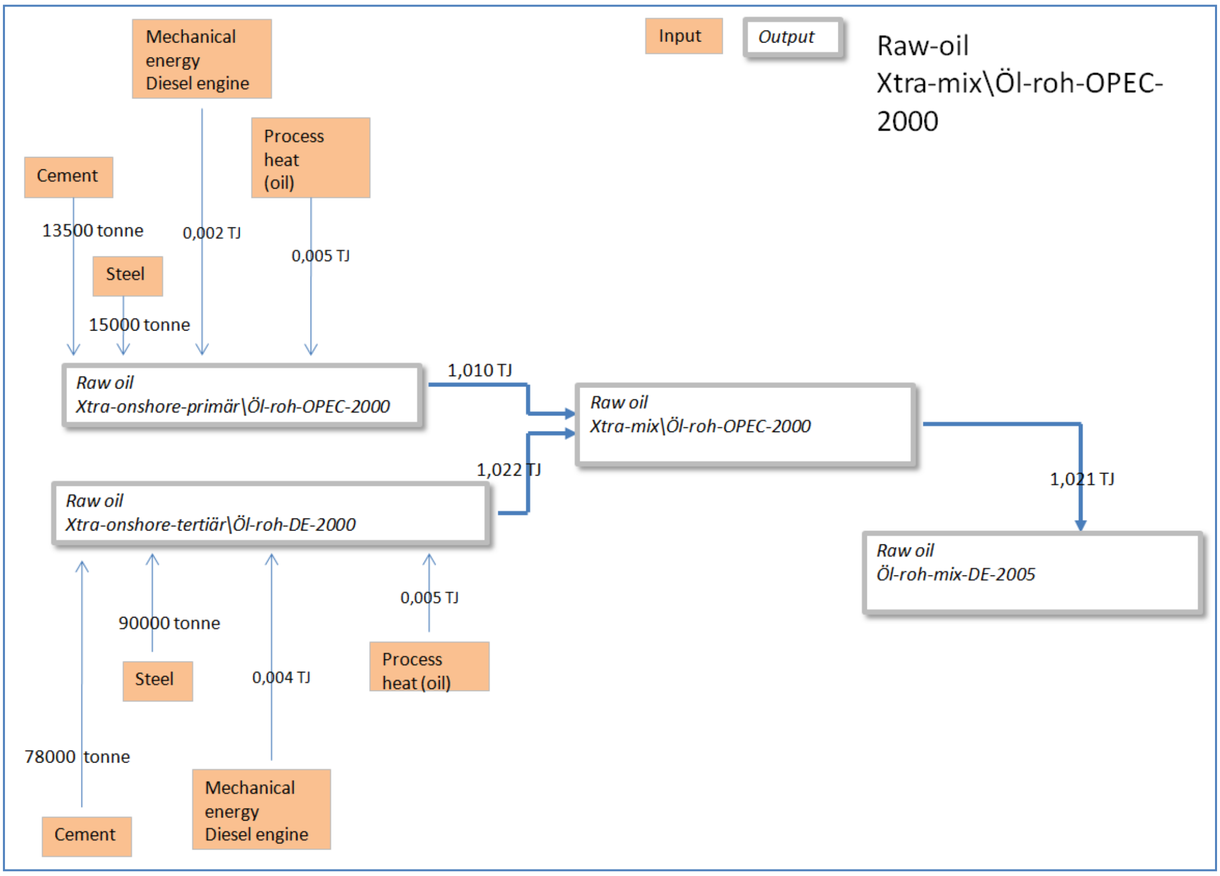

Figure 2 -Figure 4 shows process flow charts for production of raw oil from OPEC, Russia and China. The flow charts show the material and energy requirements for producing 1 TJ of energy from these raw oil sources. As can be seen from the charts, the Chinese domestic oil production is by far the most energy intensive. Primary oil production in the OPEC estimate means that no water injection is

[8] http://www.chinaoilweb.com/UploadFile/docs/Attachment/2009-9-2767140777.pdf
[9] http://www.reuters.com/article/pressRelease/idUS59261+21-Sep-2009+PRN20090921

necessary for retrieving the oil out of the reservoir. With secondary production, water injection is necessary in order to raise the pressure in the reservoir.

Figure 3 Process flow chart for raw oil from Russia 2000

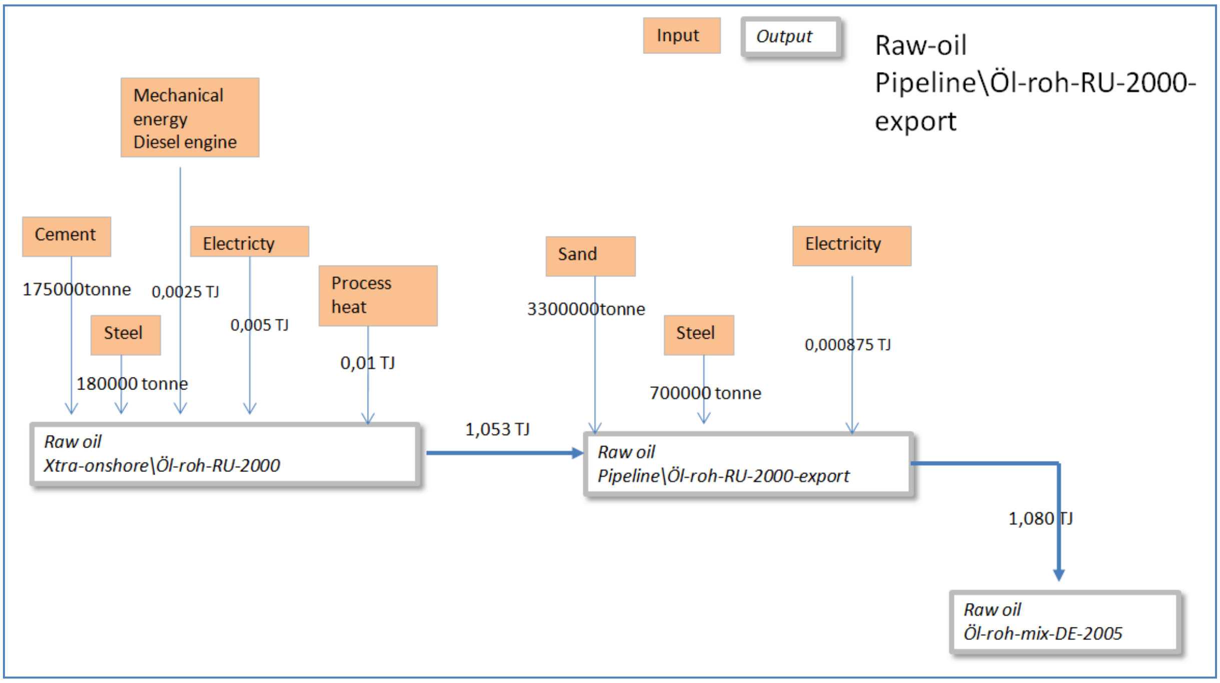

Figure 4 Process flow chart for raw oil from China 1995

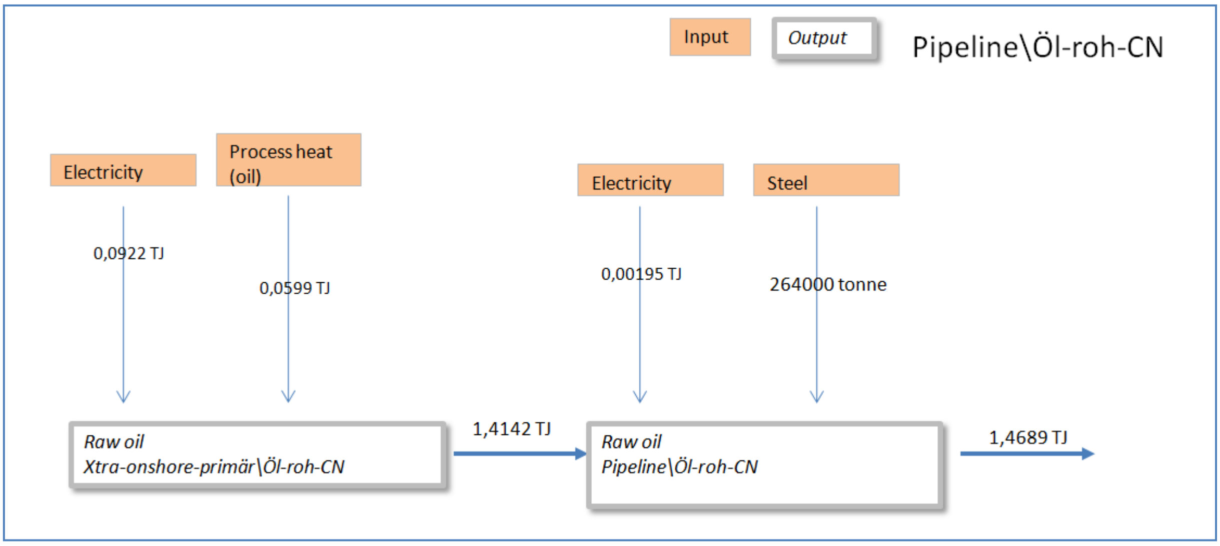

Table 3 shows the input for the calculated Chinese oil mix. We define the combined raw oil input for year 2000. The two imported raw oil inputs have a combined weight of 51,28%. Of this combined weight, 90% is attributed to raw oil input from OPEC and 10% to Russian oil. Table 3 shows that the Chinese domestic oil input has a much higher consumption of coal relative to total energy consumption than the other raw oil inputs. The share of brown coal (lignite) and stone coal in Chinese domestic oil production is 14,3% while the same share for Russian oil is 1,6% and for OPEC 0,1%. The other major energy sources is oil which has a 99,9% share in OPEC raw oil input and a 95,4% share in the Russian. Coal has an energy density of 32,5 MJ/kg while crude oil has a energy density of 46,3 MJ/kg. The relative higher consumption of coal with lower energy density probably explains part of the total higher energy consumption for domestic Chinese raw oil input. Other explanation factors can be the quality of the infrastructure for oil production and exploration in China in 1995 relative to OPEC and Russia in 2000.

Table 3 Raw oil input for heavy oil estimate for China.

	Raw oil OPEC Xtra-mix\Öl-roh-OPEC-2000	Raw oil input Russia Pipeline\Öl-roh-RU-2000-export	Raw oil input China Raffinerie\Öl-Produkte-CN
Residual heat	0	-8,21E-13	-2,25E-13
Nuclear power	-0,000003	0,00673	0,000258
Biomass	3,96E-07	4,36E-06	4,22E-06
Brown coal (lignite)	2,86E-05	0,000312	0,000335
Natural gas	-1,78E-05	0,0226	6,21E-05
Raw oil	1,02	1,03	1,5
Geothermal	3,45E-10	3,35E-09	5,24E-06
Waste	-7,44E-07	-4,13E-06	2,77E-05
Secondary raw materials	9,90E-05	0,000949	0,000147
Solar energy	-8,60E-12	-8,10E-11	1,27E-13
Coal	0,000563	0,0166	0,256
Hydro power	4,11E-06	0,00271	0,0318
Wind	-1,39E-07	-1,10E-06	6,51E-06
Sum	1,021	1,080	1,7886
Thermal efficiency (%)	98	93	56

In Table 3, the table column headers show the internal name for the estimates in ProBas so that the estimates can be easily be reviewed.

Table 3 shows that the thermal efficiency for the different part of the calculated raw oil mix for China vary considerably from 98% for OPEC raw oil input to only 56% for domestic Chinese oil production. For the latter, almost half of the energy content of raw oil is lost during extraction an production of it.

Table 4 shows the energy consumption and emissions to air required to produce 1 TJ of energy from Chinese heavy oil products. The raw oil mix is calculated from table 3 with weights discussed. The energy consumption at refinery relative to raw oil input for each energy source is assumed to be the same as for the ProBas estimate of heavy oil products from China which only considers domestic Chinese raw oil input.

All in all, it requires 1,5084 TJ of energy to produce 1 TJ of energy from heavy oil products in China 2000. This gives an energy efficiency of 66,3%. The total emission of CO_2-equivalents for the same energy amount is estimated to be 32,1 tonnes (30,2 tonnes CO_2). Since there are 27027 liter in 1 TJ of energy from heavy oil products, this gives an energy requirement of 55,8 MJ/liter and emissions of CO2-equivalents in the order of 1,19 kg pr liter (1,12 CO_2). The total amount of process heat is estimated to be 0,08 TJ for 1 TJ of energy from heavy oil products which gives an estimate of 3,14 MJ/liter.

Table 4 Energy requirement and emissions of CO2-equivalents for Chinese heavy oil products 2000

	Raffinerie\Öl-Produkte-CN	Pipeline raw oil mix domestic and import (calculated)	Pipeline raw oil mix for imported oil (calculated)
Residual heat	-1,62E-13	-1,31E-13	-8,21E-14
Nuclear power	0,00056465	0,00044209	0,00067024
Biomass	2,56954E-06	2,03E-06	7,92E-07
Brown coal (lignite)	0,000199997	0,000158804	0,00005694
Natural gas	0,001482551	0,001174581	0,00224398
Raw oil	1,364161649	1,127706964	1,021
Geothermal	2,55E-06	1,98E-06	6,46E-10
Waste	1,27946E-05	1,01E-05	-1,08E-06
Secondary raw materials	0,000191185	0,000150867	0,000184
Solar energy	-1,07E-11	-8,08E-12	-1,58E-11
Coal	0,126136124	0,100022004	0,0021667
Hydropower	0,015672179	0,012419462	0,0002747
Wind	3,02E-06	2,35E-06	-2,35E-07
Sum	1,5084	1,2421	1,02660
Thermal efficiency (%)	66,3	80,5	97,4
CO_2-equivalents kg	32 092	21 093	3 412
CO_2 kg	30 240	19 701	3 072