# KEROSENE – JET FUEL

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# Content

# Introduction

Kerosene is airplane fuel. This fuel is identical to type Jet A (sold in US) and Jet A1 [1]. The German database ProBas has an estimate for kerosene. The estimate is valid for Germany 2005.

# Crude oil extraction methods

Kerosene is made by refining raw oil. Raw oil is refined by using a distillation process. Raw oil consists of carbon chains with varying length and amount of carbon atoms. When heated up, different fractions of the oil will vaporize at different temperatures, dependent on the properties of the carbon chain. Consequently, different oil products or fractions can be distilled or separated from each other by heating oil since they have different boiling temperatures. Condensing the vapor will give the oil products in liquid form. Light oil products are products where 90% of the content will vaporize at temperatures up to 210° C. Kerosene is a light oil product [2].

The raw oil in the ProBas estimate is assumed to come from four different sources with different weights.

**Table 1 German raw oil mix**

| Raw oil from….. | Proportion % | Energy consumption (TJ/TJ) [3] | Energy efficiency (%) |
|---|---|---|---|
| German domestic production | 3 | 1,046 | 95,6 |
| EU | 30 | 1,027 | 97,4 |
| Russia | 32 | 1,080 | 92,6 |
| OPEC | 35 | 1,021 | 98,0 |
| | | | |
| Sum | 100 | | |

In ProBas, extraction and production of oil can be done by three different methods [4]. The first method is called primary extraction. For primary extraction, it is assumed that only pumping of oil is necessary without any other form of injection in order to raise the pressure in the reservoir. The work done by pumps is dependent on how deep the reservoir is as well as the pressure in the reservoir. The energy expenditure for pumping is estimated to be 0,1% relative to the heat value of the oil.

For secondary extraction, injection of water is necessary in order to raise the pressure in the reservoir so that the oil can be extracted. If the injection pumps are run by diesel engines, an additional energy consumption of 0,2% relative to the heat value of oil is assumed. If the pumps are electrically driven, the additional energy consumption is estimated to be 0,4%.

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[1] http://en.wikipedia.org/wiki/Jet_fuel

[2] http://science.howstuffworks.com/oil-refining1.htm, http://science.howstuffworks.com/oil-refining2.htm and http://de.wikipedia.org/wiki/Leicht%C3%B6l

[3] The energy consumption required to produce 1 TJ of energy from extracted oil

[4] http://www.oeko.de/service/gemis/files/present/2006vorketten_iwo.pdf, page 11

For tertiary extraction, injection of steam or $CO_2$ is assumed. This injection is necessary if the oil has higher viscosity or is embedded in rock with lower pressure.

For German domestic production, both secondary and tertiary *onshore* extraction is assumed. The share of the secondary extraction is et to 80%. The energy consumption of pumps is estimated to be 0,4% relative to the heat value of the oil. For separation of oil, gas and water, an energy consumption of 0,5% relative to the heat value of the oil is assumed. These numbers are valid both for secondary and tertiary extraction.

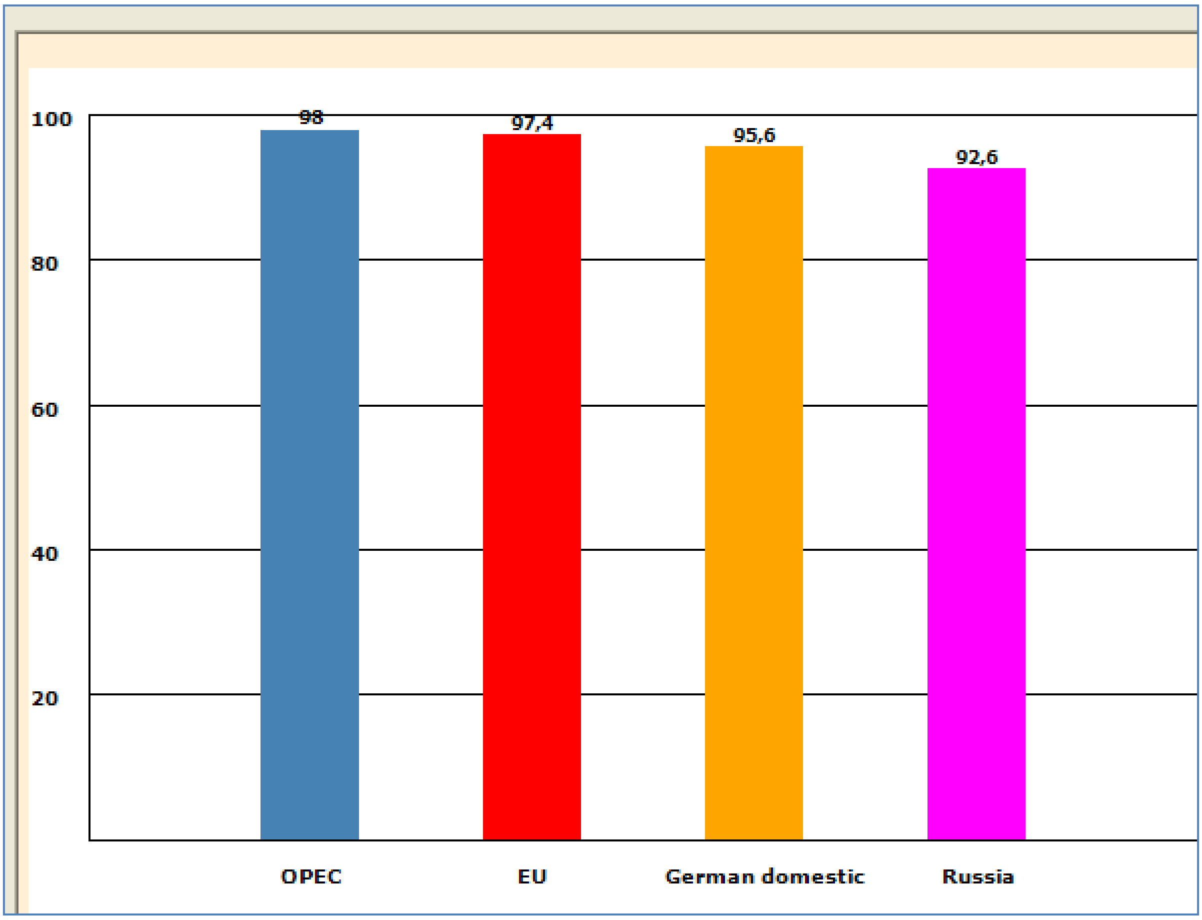
For oil production from EU (inclusive Norwegian oil fields in the North Sea), 50% primary and secondary extraction of *offshore* oil is assumed. The additional energy consumption for secondary extraction is estimated to be 434 MJ pr TJ of energy produced from the oil.

For oil from OPEC, 80% primary onshore extraction and 20% secondary onshore extraction is assumed. The pumps are run by diesel engines with an estimated energy expenditure equal to 0,2% of the heat value of the oil. Process heat necessary to separate oil, gas and water is estimated to be 0,5% of the heat value of the oil. These numbers are valid both for primary and secondary extraction. The secondary extraction needs more pump work, and the additional energy consumption for secondary extraction is assumed to be 11,6 GJ pr TJ of produced energy from the oil.

For the Russian oil, both secondary and tertiary extraction is assumed. The exact split between them is not given. The additional energy consumption for pumps because of inferior infrastructure in Russia is estimated to be 0,1% relative to the heat value of the oil. Pumps are assumed to be driven by diesel engines.

As Table 1 shows, oil from OPEC has the lowest energy requirement for producing 1 TJ of energy from the oil. Consequently, this oil has the highest energy efficiency measured in % of the heat value of the oil as is shown in Figure 1.

**Figure 1 Energy efficiency (%) in German oil mix**




## Production of kerosene

Figure 2 - Figure 5 show process charts for oil produced in different regions. The charts show the amount of primary energy and input materials needed to extract the oil. Cement, steel and mechanical energy is required for drilling. In the North Sea, mechanical energy is produced from gas turbines in addition to diesel engines. Process heat is required for separation of oil, gas and water. Drilling pipes are made of steel and cement is used to fasten the drill pipe to the drilling hole [5]. Different production sites use different amounts of steel, cement, process energy and mechanical energy because of different locations and depth of the oil reservoir as well as differences in the infrastructure.

Figure 2 Process chart for domestic German oil production

[5] http://science.howstuffworks.com/oil-drilling.htm/printable

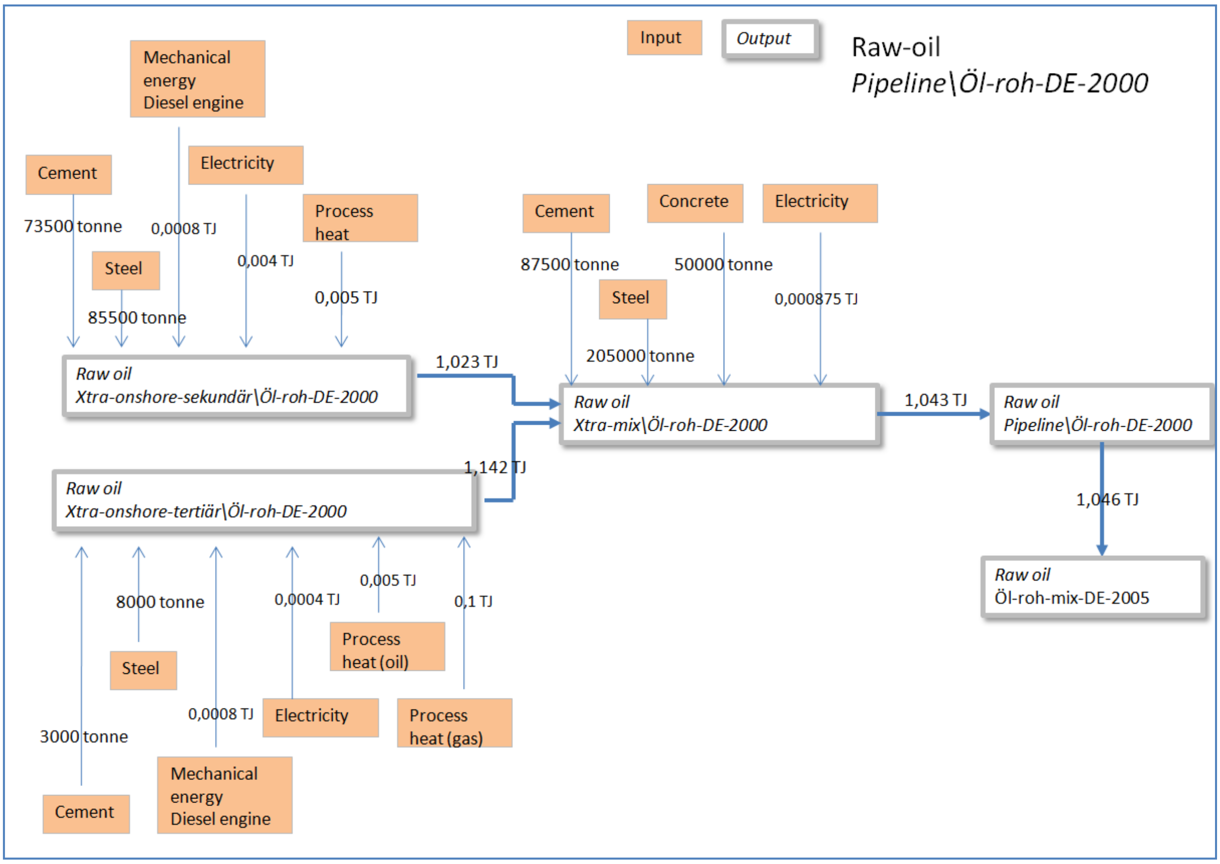
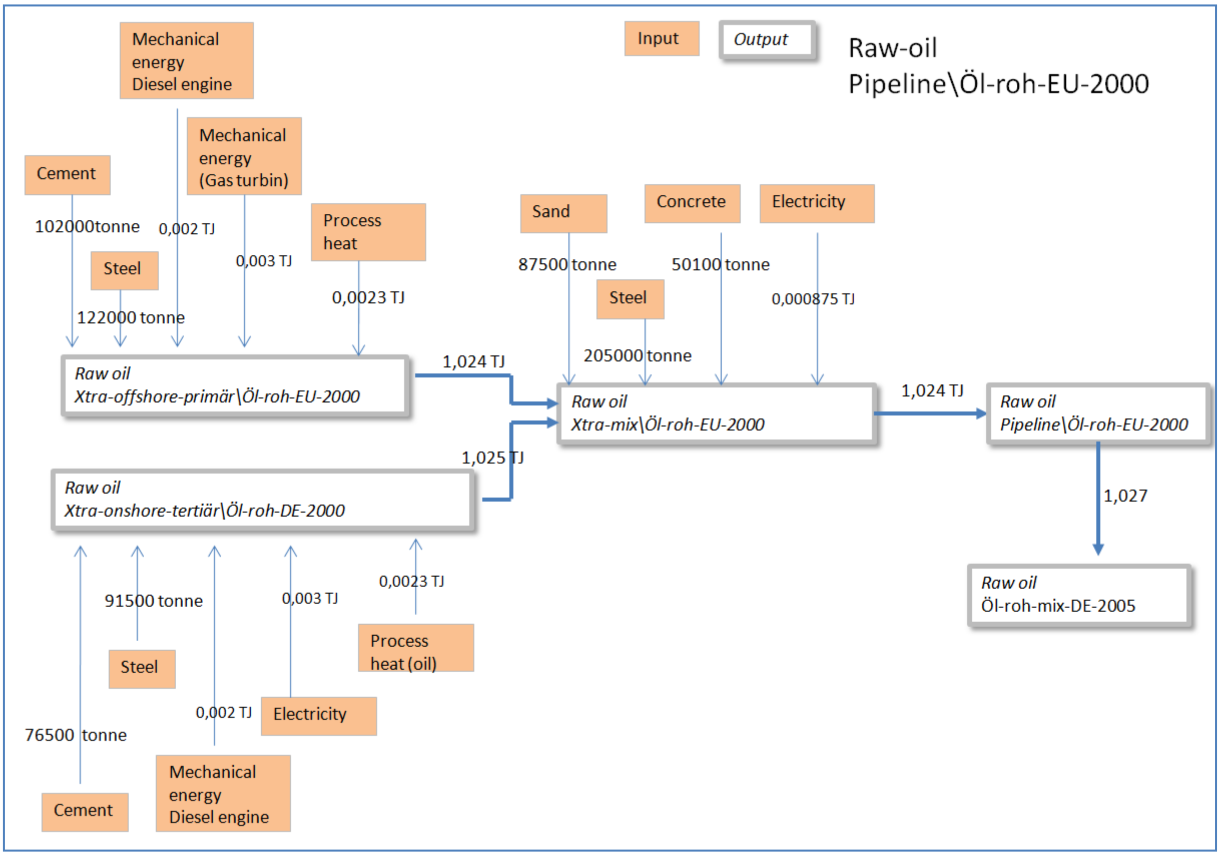



Figure 3 Process chart for oil produced in the North Sea



After oil is extracted, it needs to be refined in order to produce kerosene. Crude oil [6] consists of different types of hydrocarbons. Hydrocarbons are chains of hydrogen- and carbon-atoms linked together. The amount of carbon-atoms present and the length of the chain distinguish the different types of hydrocarbons from each other [7].

In the refinery, crude oil is distilled into different products. The products are separated from the crude oil at different temperatures since the boiling point of the products vary [8]. Products with different boiling points are called fractions. A difference in boiling points will make the products vaporize at different temperatures, and this property can be used in the distillation process. Kerosene has a boiling point of $175^{o}$-$325^{o}$ C while diesel distillate has a boiling point of $250^{o}$-$350^{o}$ C.

[6] We will use crude oil in the same meaning as raw oil or petroleum (rock oil). *Heavy* crude oil has the same meaning as heavy oil or Schweröl in German. Heavy crude oil is a left-over product after oil refining.
[7] http://science.howstuffworks.com/oil-refining1.htm
[8] http://science.howstuffworks.com/oil-refining2.htm

**Figure 4 Process chart for Russian oil production 2000**

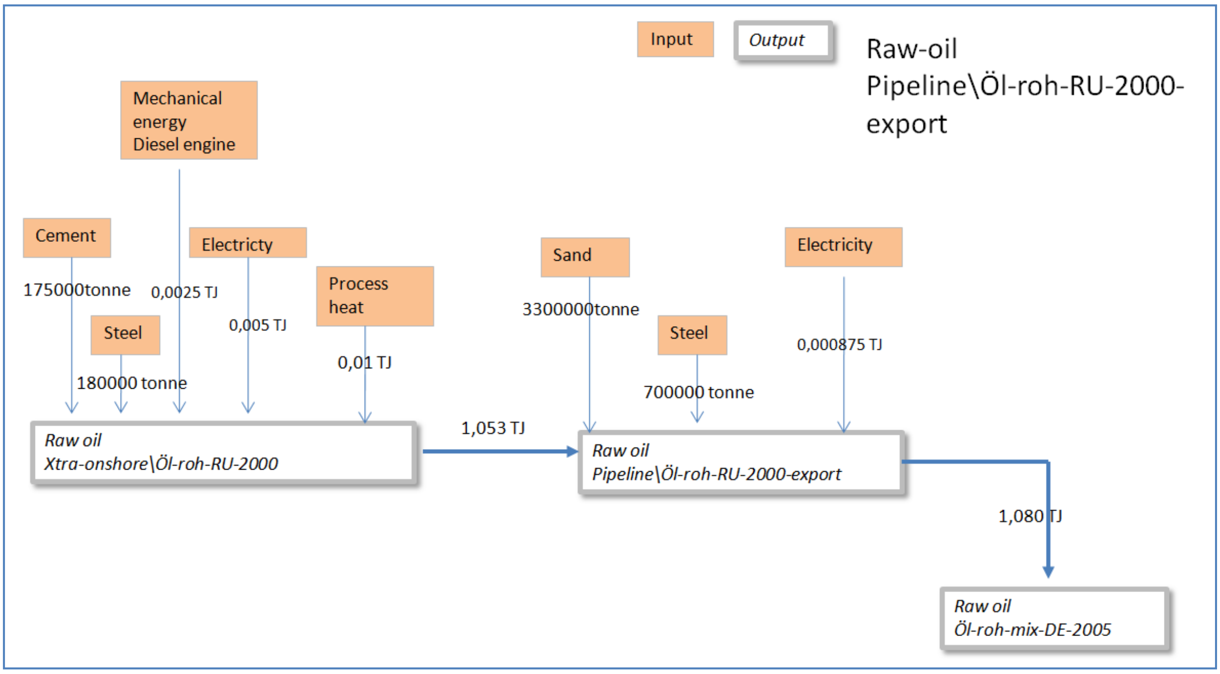



**Figure 5 Process chart for OPEC oil production**

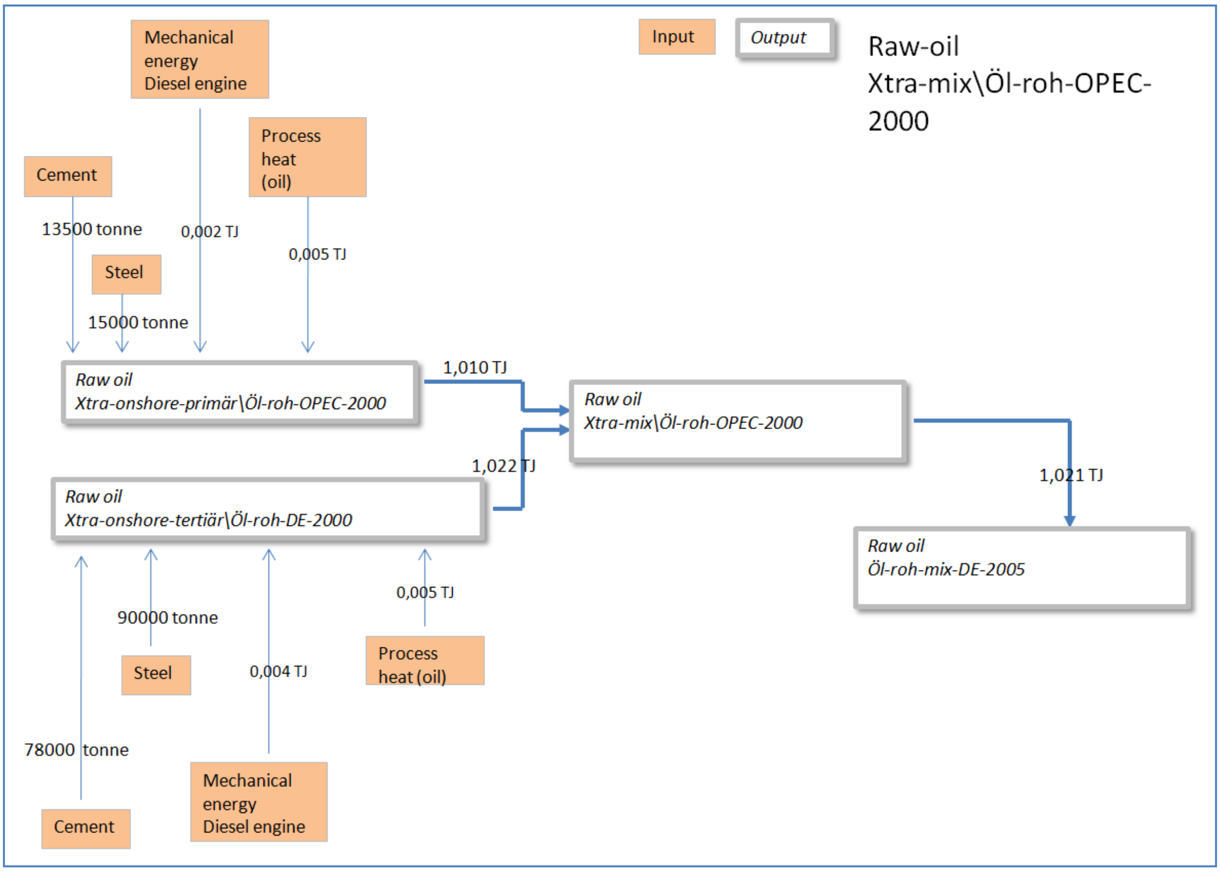
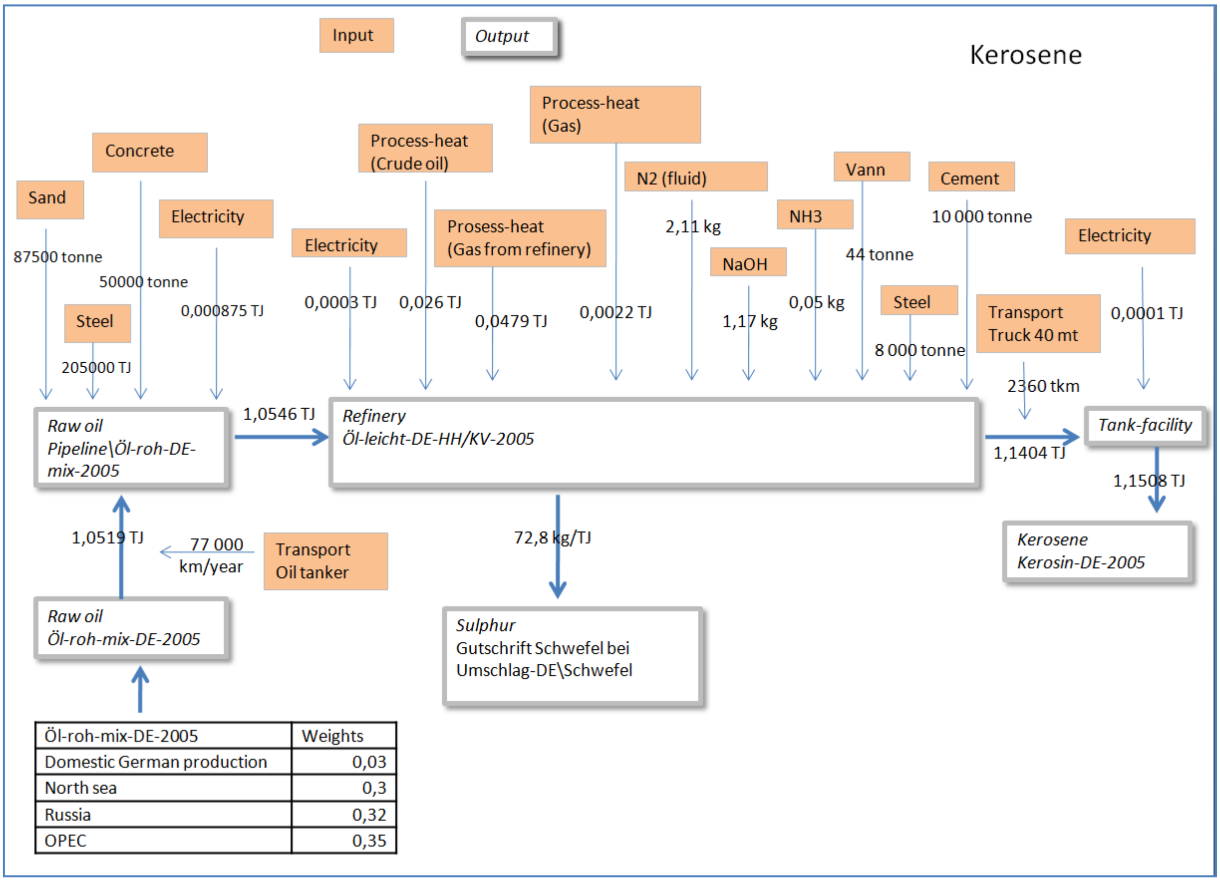


Figure 6 Production chain from pipeline to tank facility for producing 1 TJ of energy from kerosene




| Öl-roh-mix-DE-2005 | Weights |
|---|---|
| Domestic German production | 0,03 |
| North sea | 0,3 |
| Russia | 0,32 |
| OPEC | 0,35 |

Figure 6 shows a process chart for distillation of kerosene. The amount of sand, concrete and steel required for the process is dependent on the mix of the raw oil discussed above. Sulphure is produced as by-product in the process. In the ProBas estimate, the total energy used and the associated emissions are allocated between the main product kerosene and the by-product sulphure, as can be seen in figure 6. In the refinery step, about 7% of the heat value of crude oil is lost through transformation of crude oil to kerosene. The energy efficiency of kerosene delivered at tank facilities in Germany is 86,9%, which means that it takes about 1,151 TJ of energy to deliver 1 TJ of energy from kerosene. During the process, some 11,8 tonnes of CO2-equivalents are emitted into the air (of this is 11,2 tonnes $CO_2$ alone) .

The energy consumption in figure 6 includes loss in extraction of oil and transportation of oil in pipelines to German tank facilities. The estimate does *not* include loss at tanking facility.

Table 2 shows the energy requirement for producing 1 TJ of energy from kerosene. The table shows the energy requirement distributed on energy sources. The column heading includes the internal database name in ProBas so that the estimate can be easily reproduced and re-evaluated by the reader. The fossil energy sources (coal, natural gas, crude oil) account for 99,5% of all energy consumption.

**Table 2 Energy requirement and emissions of $CO_2$-equivalents for producing 1 TJ of energy from kerosene Germany 2005**

| TJ | Kerosene from tank facility<br>Tankstelle\Kerosin-DE-2005 | Kerosene from refinery<br>Raffinerie\Öl-leicht-DE-2005 | German oil mix from pipeline<br>Pipeline\Öl-roh-DE-mix-2005 | German oil mix<br>Öl-roh-mix-DE-2005 |
|---|---|---|---|---|
| Waste heat | -1,1E-09 | -1,1E-09 | -1E-09 | -1E-09 |
| Nuclear power | 0,00394 | 0,00385 | 0,00329 | 0,00259 |
| Bio mass rest material | 0,00015 | 0,000139 | 0,000098 | 1,05E-05 |
| Brown coal (lignite) | 0,00136 | 0,00128 | 0,000935 | 0,000287 |
| Natural gas | 0,0149 | 0,0148 | 0,0112 | 0,011 |
| Crude oil | 1,12 | 1,11 | 1,03 | 1,03 |
| Geothermal | 5,5E-07 | 5,48E-07 | 5,04E-07 | 5,02E-07 |
| Garbage | 0,000278 | 0,000262 | 0,000198 | 7,87E-05 |
| Secondary raw materials | 0,000599 | 0,000594 | 0,000523 | 0,000481 |
| Solar energy | 2,77E-06 | 2,57E-06 | 1,76E-06 | -2,3E-11 |
| Stone coal | 0,00847 | 0,00836 | 0,00735 | 0,00653 |
| Hydro power | 0,00106 | 0,00105 | 0,000955 | 0,000921 |
| Wind power | 0,000064 | 5,95E-05 | 4,17E-05 | 3,99E-06 |
| | | | | |
| Sum | 1,150824 | 1,140398 | 1,054593 | 1,0519 |
| Energy efficiency(%) | 86,9 | 87,7 | 94,8 | 95,1 |
| $CO_2$-equivalents kg | 11 800 | 11 600 | 5 585 | 5 405 |
| $CO_2$-equivalents kg/liter | 0,3894 | 0,3828 | 0,184305 | 0,178365 |
| Energy consumption MJ/liter | 37,9772 | 37,63312 | 34,80157 | 34,71 |
| Process heat MJ/liter | | 2,5113 | | 0,40029 |
| $CO_2$ kg | 11 200 | 11 000 | 5 116 | 4 945 |

Kerosene has an energy content of 33 MJ pr liter [9]. There is consequently 30303 liter in 1 TJ of energy from kerosene. Using this number, we can calculate energy consumption, emissions of $CO_2$-equivalents and process heat requirement pr liter as is shown in table 2.

All in all, production of 1 TJ of kerosene is estimated to require 2 360 tonne-km from refinery to tank facility. This transport is done by a semi-trailer truck with a total weight of 40 tonnes. It's usage rate is assumed to be 50%. The truck weighs 9 200 tonnes, all of it as steel. The transport requires 1,21 MJ of energy for each tonne-km and the estimated emission of $CO_2$-equivalents pr tonne-km is 0,092 kg (0,0905 $CO_2$ alone). All in all, this yields 2,86 GJ of energy for transport of kerosene equal to 1 TJ of energy to tank facility. Similarly, this transport leads to emission of 217 kg of $CO_2$-equivalents (214 kg $CO_2$).

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

In addition, there is an estimated transport requirement of 77 000 km pr year in order to transport crude oil equal to 1 TJ of kerosene from OPEC-countries to Germany by oil tanker. Since this number is given in km and not in tonne-km we have not estimated energy requirements and emissions from this transport.

## Consumption of kerosene in China

Can we use this estimate to make assumptions about the energy requirement for production of kerosene in China? In order to answer this question, we must know the mix of oil import to China.

China's oil supply comes from domestic production and from imports. During the period March to July 2009, the domestic production was on average 95% of the imported amounts of oil [10].

Table 3 shows the Chinese oil import mix from January to July 2009. All in all, countries from OPEC supply China with around 63% of it's oil import in this period of time. Russia alone has a 8% share. Only Norway is represented as a North Sea supplier, and it's import share is totally negligible at 0,1%. Oman, Sudan and Yemen has a total market share of 14,7%. We expect these countries to have an energy requirement for it's oil production quite similar to the one OPEC has. With this assumption, the OPEC import share can be assessed to be 77,4%. Similarly, we expect Kazakhstan to have an energy requirement equal to Russia's. With these assumptions, Russia has a share of 10,7%, and together with OPEC plus similar countries we can account for 88,1% of Chinese oil import in 2009.

Table 3 Chinese oil import January-July 2009 [11]

| OPEC | Country | Jan-July Tons | Proportion |
|---|---|---|---|
| OPEC | Saudi Arabia | 22 847 832 | 20,7 % |
| OPEC | Angola | 15 520 397 | 14,1 % |
| OPEC | Iran | 15 317 937 | 13,9 % |
| | Russia | 8 848 959 | 8,0 % |
| | Oman | 8 188 807 | 7,4 % |
| | Sudan | 6 449 107 | 5,8 % |
| OPEC | Kuwait | 4 665 827 | 4,2 % |
| OPEC | Iraq | 3 555 783 | 3,2 % |
| | Kazakhstan | 2 958 957 | 2,7 % |
| | Congo(b) | 2 776 159 | 2,5 % |
| OPEC | Libya | 2 598 794 | 2,4 % |
| | Indonesia | 1 921 898 | 1,7 % |
| | Brazil | 1 820 242 | 1,6 % |
| | Yemen | 1 582 573 | 1,4 % |
| OPEC | UAE | 1 540 069 | 1,4 % |
| OPEC | Venezuela | 1 498 499 | 1,4 % |
| | Equal Guinea | 1 098 225 | 1,0 % |
| | Malaysia | 1 028 080 | 0,9 % |

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

| | | | |
|---|---|---|---|
| OPEC | Ecuador | 893 951 | 0,8 % |
| | Australia | 824 736 | 0,7 % |
| | Argentina | 682 106 | 0,6 % |
| | Vietnam | 625 907 | 0,6 % |
| | Cameroon | 468 174 | 0,4 % |
| | Thailand | 444 025 | 0,4 % |
| OPEC | Algeria | 407 038 | 0,4 % |
| OPEC | Nigeria | 329 976 | 0,3 % |
| | Colombia | 290 422 | 0,3 % |
| | Mauritania | 267 499 | 0,2 % |
| | Brunei | 161 226 | 0,1 % |
| | Norway | 157 598 | 0,1 % |
| | Canada | 152 659 | 0,1 % |
| | Gabon | 135 987 | 0,1 % |
| | Mongolia | 103 166 | 0,1 % |
| | Azerbaijan | 83 028 | 0,1 % |
| OPEC | Qatar | 59 539 | 0,1 % |
| | Cuba | 49 203 | 0,0 % |
| | Myanmar | 43 133 | 0,0 % |
| | Niger | 1 | 0,0 % |
| | USA | 1 | 0,0 % |
| | Total | 110 397 520 | 100,0 % |

In order to calculate an appropriate oil import mix for China we set OPEC's part of the Chinese oil mix to 90% and Russia's to 10%.

In Figure 4 the energy requirement for 1 TJ of Russian oil delivered to German oil mix is 1,08 TJ. We give this number a weight of 0,1. In figure 5, the similar energy requirement for OPEC-countries is 1,021 TJ. We give this number a weight of 0,9 according to the discussion above. This gives a total energy consumption of 1,02660 TJ for the delivery of 1 TJ from kerosene with our calculated Chinese oil import mix. This is 2,41% lower than the energy requirement for the German oil mix from ProBas.

This is the imported share of Chinese oil products. The domestic production is assumed to make up 95% of the imported oil. Consequently, we give a weight of 0,512 to imported oil and a weight of 0,488 to domestic oil production. Table 4 shows the estimate for weighted Chinese oil delivered at pipeline in 2000. The table shows the imported oil, the domestic production and the weighted average of the two. All in all, the energy requirement for production of 1 TJ of energy from crude oil delivered at pipeline is calculated as 1,2421 TJ in the weighted estimate. The energy efficiency is calculated to be 80,5%. This estimate covers both domestic production and imported oil. The total emissions of CO2-equivalents is estimated to be 21 093 kg (of which 19 701 kg is from $CO_2$ alone).

**Table 4 Estimate of raw oil at pipeline China 2000**

| TJ | Oil delivered at pipeline domestic plus imported (weighted estimate) | Domestic Chinese production at pipeline | Import mix calculated at pipeline |
|---|---|---|---|
| Waste heat | -1,30776E-13 | -1,82E-13 | -8,21E-14 |
| Nuclear power | 0,00044209 | 0,000202 | 0,00067 |
| Bio mass rest material | 2,03371E-06 | 3,34E-06 | 7,92E-07 |
| Brown coal (lignite) | 0,000158804 | 0,000266 | 5,69E-05 |
| Natural gas | 0,001174581 | 4,92E-05 | 0,002244 |
| Crude oil | 1,127706964 | 1,24 | 1,021 |
| Geothermal | 1,98342E-06 | 4,07E-06 | 6,46E-10 |
| Garbage | 1,01156E-05 | 2,19E-05 | -1,08E-06 |
| Secondary raw materials | 0,000150867 | 0,000116 | 0,000184 |
| Solar energy | -8,07539E-12 | 9,57E-14 | -1,58E-11 |
| Stone coal | 0,100022004 | 0,203 | 0,002167 |
| Hydro power | 0,012419462 | 0,0252 | 0,000275 |
| Wind power | 2,34979E-06 | 5,07E-06 | -2,35E-07 |
| | | | |
| Sum | 1,2421 | 1,4689 | 1,0266 |
| Energy efficiency(%) | 80,5 | 68,1 | 97,4 |
| | | | |
| CO2-equivalents kg | 21 093 | 39 700 | 3 412 |
| CO2 kg | 19 701 | 37 200 | 3 072 |

The estimate for domestic crude oil production in China is for 1995. The estimate for crude oil OPEC and Russia is for 2000. We define the estimate above to be valid for 2000.

ProBas has an estimate for refinery of oil products in China in 1995. This estimate uses only Chinese domestic oil production as input. The output from the refinery is heavy oil products which do not include kerosene [12].

ProBas has two estimates for German refineries in 2000. One estimate is for heavy oil products, the other for light oil products. The last group of products include kerosene. Table 5 shows the two estimates. The rightmost column in Table 5 is data for refinery of heavy oil products in China 1995.

Input for both refineries is German raw oil mix delivered to pipeline in 2000. Consequently, they share the same input. Since we can control for the input, the only properties that can cause differences in energy consumption between them must come from the refinery process itself. The point here is that the energy consumption is quite similar in both of them. Refining of light oil products has the highest energy consumption, but is only 0,98% higher than consumption estimate for the heavy oil products. Therefore, substituting refining of light oil products with refining of heavy oil products will not introduce an unacceptable margin of error. This seems a better strategy than

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

assuming the same efficiency in refineries in Germany and China which is obviously wrong when comparing column 1 and 3 in table 5.

**Table 5 Oil products from German refineries 2000**

| TJ | Heavy oil products from German refinery 2000<br>Raffinerie\Öl-schwer-DE-2000 | Light oil products from German refinery 2000<br>Raffinerie\Öl-leicht-DE-2000 | Heavy oil products from Chinese refineries 1995<br>Raffinerie\Öl-Produkte-CN |
|---|---|---|---|
| Waste heat | -1,14E-09 | -1,16E-09 | -2,25E-13 |
| Nuclear power | 0,00382 | 0,00388 | 0,000258 |
| Bio mass rest material | 6,55E-05 | 6,65E-05 | 4,22E-06 |
| Brown coal (lignite) | 0,00121 | 0,00123 | 0,000335 |
| Natural gas | 0,0137 | 0,0145 | 6,21E-05 |
| Crude oil | 1,1 | 1,11 | 1,5 |
| Geothermal | 5,58E-07 | 5,67E-07 | 5,24E-06 |
| Garbage | 0,000374 | 0,00038 | 2,77E-05 |
| Secondary raw materials | 0,00057 | 0,00058 | 0,000147 |
| Solar energy | 8,29E-10 | 1,05E-09 | 1,27E-13 |
| Stone coal | 0,00786 | 0,00799 | 0,256 |
| Hydro power | 0,000994 | 0,00101 | 0,0318 |
| Wind power | 2,62E-05 | 2,66E-05 | 6,51E-06 |
| | | | |
| Sum | 1,12862 | 1,13966 | 1,78865 |
| | | | |
| CO2-equivalents kg | 10 200 | 11 400 | 60 400 |
| CO2 kg | 9 658 | 10 800 | 57 100 |

We will assume that the energy consumption at the refinery relative to the oil input is the same for light oil products and heavy oil products. We will therefore use the estimate for *heavy* oil refining in China to estimate the energy consumption and emissions for *light* oil refining.

In our estimate of light oil products we have accounted for Chinese oil import which is not accounted for in the ProBas estimate of heavy oil products in China. For each energy source, the energy consumption for Chinese heavy oil products is calculated relative to the energy consumption for the same energy source from raw oil. This relative consumption factor for each energy source is used to calculate the expected increase in energy consumption for refining of light oil products in China. For the last node in the production chain, delivery from refinery to tank facility, we assume the same relative increase in energy consumption as in the German estimate for kerosene. This increase is 0,9%.

Table 6 shows the result. The last column in the table is the kerosene estimate for Germany in 2005 presented earlier. This is included in order to make it easier to compare the two kerosene estimates for China and Germany. All in all, producing 1 TJ of energy from kerosene in China requires about 0,37 TJ more energy than production of the corresponding energy in Germany. The energy efficiency for kerosene in Germany is 21,2% higher for the same energy amount. This is because Chinese domestic oil production is much more energy demanding than imported oil in China.

**Table 6 Energy requirement and emissions of $CO_2$-equivalents for producing 1 TJ of energy from kerosene China 2000**

| | Kerosene delivered at tank facility China 2000 | Light oil products delivered from refinery | Oil delivered at pipeline (domestic plus imported, weighted average) | Kerosene delivered at tank facility Germany |
|---|---|---|---|---|
| Waste heat | -1,63E-13 | -1,62E-13 | -1,31E-13 | -1,1E-09 |
| Nuclear power | 0,000569812 | 0,00056465 | 0,00044209 | 0,00394 |
| Bio mass rest material | 2,59303E-06 | 2,5695E-06 | 2,03E-06 | 0,00015 |
| Brown coal (lignite) | 0,000201826 | 0,0002 | 0,0001588 | 0,00136 |
| Natural gas | 0,001496106 | 0,00148255 | 0,00117458 | 0,0149 |
| Crude oil | 1,376634235 | 1,36416165 | 1,12770696 | 1,12 |
| Geothermal | 2,58E-06 | 2,55E-06 | 1,98E-06 | 5,5E-07 |
| Garbage | 1,29116E-05 | 1,2795E-05 | 1,01E-05 | 0,000278 |
| Secondary raw materials | 0,000192933 | 0,00019119 | 0,00015087 | 0,000599 |
| Solar energy | -1,08E-11 | -1,07E-11 | -8,08E-12 | 2,77E-06 |
| Stone coal | 0,127289391 | 0,12613612 | 0,100022 | 0,00847 |
| Hydro power | 0,01581547 | 0,01567218 | 0,01241946 | 0,00106 |
| Wind power | 3,04E-06 | 3,02E-06 | 2,35E-06 | 0,000064 |
| | | | | |
| Sum | 1,5222 | 1,5084 | 1,2421 | 1,150824 |
| Energy efficiency(%) | 0,657 | 0,663 | 80,5 | 86,9 |
| CO2-equivalents kg | 32 645 | 32092 | 21 093 | 11 800 |
| CO2-equivalents kg/liter | 1,08 | 1,06 | 0,70 | 0,3894 |
| CO2 kg | 30 789 | 30 240 | 19 701 | 11 200 |
| CO2 kg/liter | 1,02 | 1,00 | 0,65 | 0,3696 |
| Energy use MJ/liter | 50,23 | 49,78 | 40,99 | 37,9772 |
| Process heat (TJ) | | 0,08 | 0,03 | |
| Process heat MJ pr liter | | 2,80 | 1,13 | |

The total emissions of CO2-equivalents is estimated to be 32 645 kg(30 789 $CO_2$ alone) for 1 TJ of energy from kerosene in China 2000. The estimate for emissions of CO2-equivalents for the same amount of energy from kerosene in Germany 2005 was 11 800 kg (11 200 $CO_2$).