the ATHENA™ Sustainable Materials Institute

A LIFE CYCLE INVENTORY FOR ROAD AND ROOFING ASPHALT

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Preface

This report has been prepared as part of a continuing program to extend the knowledge base of the ATHENA™ Sustainable Materials Institute, a not-for-profit organization dedicated to helping the building community meet the environmental challenges of the future. The data developed in this report will be used in ATHENA™, the Institute's systems model for assessing the relative life cycle environmental implications of alternative building or assembly designs.

Institute studies and publications fall into two general categories: investigative or exploratory studies intended to further general understanding of life cycle assessment as it applies to building materials and buildings; and individual life cycle inventory studies which deal with specific industries, product groups or building life cycles stages. All studies in this latter category are firmly grounded on the principles and practices of life cycle assessment (LCA), and follow our published Research Guidelines, which define boundary or scope conditions and ensure equal treatment of all building materials and products in terms of assumptions, research decisions, estimating methods and other aspects of the work.

The integration of all the Institute's life cycle inventory data is a primary function of ATHENA™ itself, and we therefore caution that individual industry life cycle study reports may not be entirely stand-alone documents in the sense that they tell the whole story about an individual set of products. ATHENA™ also generates various composite measures that can be best described as environmental impact indicators, a step toward the ultimate LCA goal of developing true measures of impacts on human and ecosystem health.

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A LIFE CYCLE INVENTORY FOR ROAD AND ROOFING ASPHALT

1.0 Introduction

This report provides supporting documentation for life cycle inventories of asphalt materials used in road and roofing applications. The life cycle inventory modeling was conducted using Franklin Associates' data and SimaPro 5 software (Beta version) from PRé Consultants.

1.1 Materials Analyzed

Asphalt is a high molecular weight hydrocarbon, a coproduct of petroleum refining. It is an excellent natural preservative as well as an outstanding waterproofing and adhesive agent. These properties make it useful in road and roofing applications.

The following specific materials are analyzed in this study:

- road asphalt
- roofing asphalt

The analysis is limited to the primary constituents of each material. Unless specifically noted otherwise, the analysis does not include road aggregate, reinforcing materials, fillers, fire retardants, surface coatings, facings, etc. Furthermore, this analysis does not include application or installation of the asphalt road or roofing product, nor their disposal at end-of-life.

1.2 Report Structure

For each asphalt application analyzed, this report includes the following information:

- a brief description of the material and its production;
- a flow diagram showing all the process steps in the production of the material, beginning with raw material extraction and continuing through production of the material in the form in which it is used in road or roofing applications;
- a cradle-to-production table for each material; and
- a list of references for all processes in the production of the material.

References are listed at the end of the report.

Detailed descriptions and tables for individual processes in petroleum extraction and refining may be found in Apprendix A: **LCI Data for Petroleum Production and Refining, Including Asphalt Production.**

2.0 Road Asphalt

Asphalt used in road applications is an emulsion consisting of three basic ingredients: asphalt, water, and a small amount of an emulsifying agent. The emulsion is a liquid product that can be used in cold processes for road construction and maintenance. Asphalt emulsion does not require a petroleum solvent to make it liquid, and in most cases can be used without additional heat. When asphalt emulsion is mixed with the aggregates used in road construction, the emulsion is destabilized and the droplets of asphalt fuse, forming a bond with the aggregates. The water evaporates and the emulsifiers remain in the asphalt. A flow diagram for the production of road asphalt is shown in Figure 1.

Based on information from the Asphalt Emulsion Manufacturers' Association, emulsions typically contain between 55 and 75% asphalt and 0.1-2% emulsifier; the balance is water.[1] This analysis does not include an emulsifier. Table 1 presents cradle-to-production data for the asphalt portion of the emulsion. In addition to asphalt data, the LCI model also contains data for the production of city (tap) water. With the provided data, the user can model emulsions with varying percentages of asphalt and water.

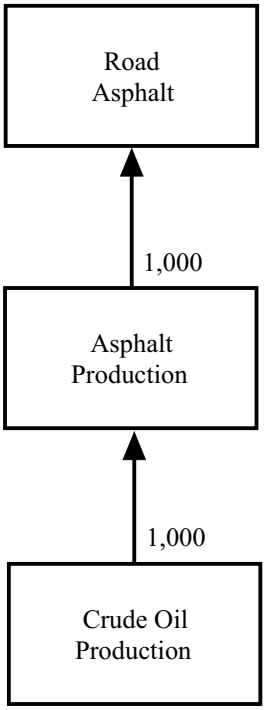

Figure 1: Flow diagram for the manufacture of 1,000 kilograms of Road Asphalt.

[1] Asphalt Emulsion Manufacturers Association website (www.aema.org). March, 2001.

Table 1

Total Cradle to Production Life Cycle Data for 1 Kilogram of Road Asphalt

Raw Materials	**Unit**	**Total**
crude oil (feedstock) FAL	kg	1.03
limestone	g	1.41
Energy Usage (1)	**Unit**	**Total**
coal FAL	MJ LHV	0.646
crude oil FAL	MJ LHV	0.891
energy from hydro power	MJ LHV	0.0336
natural gas FAL	MJ LHV	3.9
uranium FAL	MJ LHV	0.222
wood/wood wastes FAL	MJ LHV	0.000628
Atmospheric Emissions	**Unit**	**Total**
acrolein	ng	836
aldehydes	mg	42.6
ammonia	mg	5.62
As	µg	13
Be	µg	1.02
benzene	µg	1.25
Cd	µg	18.1
Cl2	µg	214
CO	mg	823
CO2 (fossil)	g	307
CO2 (non-fossil)	mg	74.1
cobalt	µg	16
Cr	µg	16.8
dichloromethane	µg	3.56
dioxin (TEQ)	pg	4.58
formaldehyde	µg	2.83
HCl	mg	4.39
HF	µg	582
Hg	µg	4.16
kerosene	µg	21.3
metals	µg	29.6
methane	mg	663
Mn	µg	17
N2O	µg	522
naphthalene	ng	104
Ni	µg	244
n-nitrodimethylamine	ng	177
non methane VOC	g	6.99
NOx	mg	962
organic substances	mg	2.61

(Continued)

particulates	mg	181
Pb	µg	85.6
phenol	µg	3.13
Sb	µg	5.62
Se	µg	11.7
SOx	g	3.95
tetrachloroethene	ng	799
tetrachloromethane	µg	1.44
trichloroethene	ng	790

Waterborne Wastes	**Unit**	**Total**
Acid as H+	µg	1.12
B	mg	4.57
BOD	mg	18.5
Ca	µg	18.3
Cd	µg	201
chromate	µg	14.5
Cl-	mg	201
COD	mg	129
Cr	µg	205
cyanide	ng	301
dissolved solids	g	5.39
Fe	mg	3.74
fluoride ions	µg	84.9
H2SO4	mg	1.14
Hg	ng	15.8
metallic ions	mg	24.5
Mn	mg	1.91
Na	µg	33.7
NH3	mg	1.95
nitrate	µg	8.01
oil	mg	122
other organics	mg	13.5
Pb	µg	2.04
phenol	µg	79.6
phosphate	µg	573
sulphate	mg	168
suspended solids	mg	132
Zn	µg	99.5

Solid Wastes	**Unit**	**Total**
solid waste	g	22.9

Nonmaterial Emissions	**Unit**	**Total**
radioactive substance to air	kBq	1.18

(1) The energy usage for this material utilizes the Franklin Associates fuel data from 1998.

3.0 Roofing Asphalt

Roofing asphalt is the primary adhesion/waterproofing agent used between roofing plies in built up roofing (BUR) applications. Roofing asphalt is oxidized by bubbling air through it, either at the refinery or at the roofing manufacturing plant.[2] Oxidation stiffens the asphalt, making it more resistant to flow in hot conditions. A flow diagram for the production of roofing asphalt is shown in Figure 2.

The asphalt arrives at the job site in solid form, and is then heated and applied as a liquid. Either multiple layers of roofing felts, or membranes and asphalt, may be applied.[3] Surface coatings could include films, gravel, ceramic granules, or other materials. This analysis does not include any felts, membranes, surface coatings, etc. Table 2 provides data for the production of roofing asphalt, including all steps from crude oil extraction through production of oxidized roofing asphalt.

[2] Information provided by Terrence O'Connor and Phil LaDuke of Firestone Building Products Company. March, 2001.
[3] Asphalt Roofing Manufacturers Association website (www.asphaltroofing.org). March, 2001.

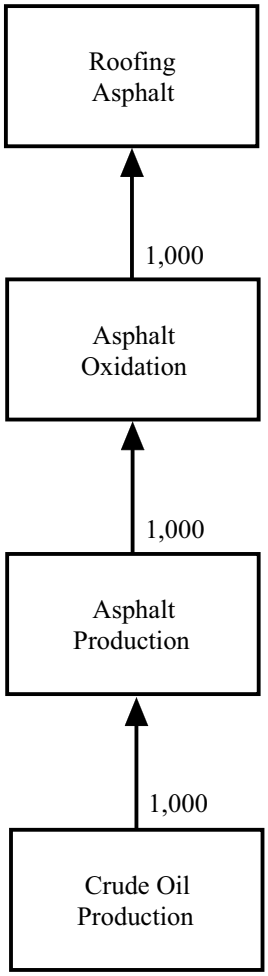

Figure 2: Flow diagram for the manufacture of 1,000 kilograms of Roofing Asphalt.

Table 2

Total Cradle to Production Life Cycle Data for 1 Kilogram of Roofing Asphalt

Raw Materials	**Unit**	**Total**
crude oil (feedstock) FAL	kg	1.03
limestone	g	4.8
Energy Usage (1)	**Unit**	**Total**
coal FAL	MJ LHV	2.2
crude oil FAL	MJ LHV	1.01
energy from hydro power	MJ LHV	0.118
natural gas FAL	MJ LHV	5.99
uranium FAL	MJ LHV	0.754
wood/wood wastes FAL	MJ LHV	0.00117
Atmospheric Emissions	**Unit**	**Total**
acrolein	µg	2.84
aldehydes	mg	43.2
ammonia	mg	6.15
As	µg	20.1
Be	µg	1.84
benzene	µg	4.1
Cd	µg	19.7
Cl2	µg	215
CO	g	1.08
CO2 (fossil)	g	945
CO2 (non-fossil)	mg	143
cobalt	µg	18.7
Cr	µg	28.2
dichloromethane	µg	12.1
dioxin (TEQ)	pg	15.5
formaldehyde	µg	9.53
HCl	mg	14.5
HF	mg	1.98
Hg	µg	8.01
kerosene	µg	72.6
metals	µg	57.4
methane	g	1.23
Mn	µg	39.7
N2O	mg	1.78
naphthalene	ng	230
Ni	µg	271
n-nitrodimethylamine	ng	601
non methane VOC	g	7.43
NOx	g	1.78
organic substances	mg	3.72

(Continued)

particulates	mg	367
Pb	µg	92.3
phenol	µg	8.67
Sb	µg	6.55
Se	µg	26
SOx	g	6.38
tetrachloroethene	µg	2.71
tetrachloromethane	µg	4.6
trichloroethene	µg	2.69

Waterborne Wastes	**Unit**	**Total**
Acid as H+	µg	1.13
B	mg	9.99
BOD	mg	20.9
Ca	µg	62.5
Cd	µg	309
chromate	µg	16
Cl-	mg	310
COD	mg	162
Cr	µg	314
cyanide	ng	463
dissolved solids	g	7.77
Fe	mg	11.7
fluoride ions	µg	289
H2SO4	mg	2.5
Hg	ng	24.3
metallic ions	mg	24.5
Mn	mg	6.52
Na	µg	115
NH3	mg	2.07
nitrate	µg	27.3
oil	mg	164
other organics	mg	21.3
Pb	µg	2.05
phenol	µg	79.8
phosphate	mg	1.25
sulphate	mg	278
suspended solids	mg	265
Zn	µg	137

Solid Wastes	**Unit**	**Total**
solid waste	g	53.4

Nonmaterial Emissions	**Unit**	**Total**
radioactive substance to air	kBq	3.99

(1) The energy usage for this material utilizes the Franklin Associates fuel data from 1998.

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Appendix A

LCI DATA FOR PETROLEUM PRODUCTION AND REFINING, INCLUDING ASPHALT PRODUCTION

Prepared by:
FRANKLIN ASSOCIATES

January, 1999

LCI DATA FOR PETROLEUM PRODUCTION AND REFINING, INCLUDING ASPHALT PRODUCTION

Introduction

The following data and documentation are being delivered in fulfillment of our agreement with The Athena Institute to provide LCI data for asphalt production and for liquid fuel products of a petroleum refinery.

Beginning on page 13 are fourteen tables. Included are data tables and tables showing LCI results for petroleum production and refining into asphalt or general liquid refinery products using U.S. transportation. A set of additional tables were prepared with Canadian transportation data, and a set of basic transportation factor tables are included so that new transportation scenarios can be analyzed.

The petroleum production and refining are based upon typical practice in the U.S., although transportation of oil to the refinery is based upon both average U.S. conditions and a different set of transportation data reflecting conditions in Canada (with data supplied by Jan Consultants). Because the results will be used primarily for Canadian applications, there is a concern about the applicability of U.S. data. However, the technology used in the U.S. and in Canada is very similar. In fact, many of the same multi-national companies own or control many facilities in both countries. Our experience has been that because of the similarity in technology, Canadian and U.S. operations are quite similar in natural resource consumption in the processes, and in total energy. It is interesting to observe that the European data gathered for the highly regarded APME plastics industry database is quite consistent with the U.S. data for petroleum production and refining presented here.

Because environmental laws and regulations are different in the U.S. and Canada, emissions may be more variable. Generally speaking, the LCI data quality and the subsequent quality of LCI results are much higher for natural resource consumption and energy use. Given a large number of facilities in a national population, the site-to-site total range of variation between facilities producing the same product is generally within a range of a factor of two for these measures. However, the range of emissions data from site-to-site may vary by as much as a maximum of a factor of 10. While the variations are typically less than this (especially for criteria pollutants which are strictly controlled), this means that the emissions data quality is quite low at best, and conclusions based upon emissions data need to be made quite carefully. Because of this high level of variability between facilities and the generally low quality of LCI emissions data, the differences between U.S. and Canadian data are likely not greater than the variability already present in the data.

Generally speaking, because of data quality issues, LCI results are most usefully applied when comparing products or processes using a uniform database for all elements being compared. That is, if different products are to be compared, the same refining data should be used consistently for all products. When deciding whether there are significant differences between products, the effects of data quality needs to be included.

Asphalt Production Methodology

Asphalt is a coproduct from petroleum refining, which produces a very large number of chemicals through a complex set of physical and chemical processes. In the

U.S., the dominant products of refineries are fuels, especially gasoline. In recent years, the category of "asphalt and roofing oils" has accounted for less than 3% annually of the output of petroleum refineries. The refining data reported here assumes that the crude oil stream is processed into asphalt by being passed through four subprocesses: desalting, atmospheric and vacuum distillation, and deasphalting of a vacuum distillation output stream.

The methodology of using these four subprocesses to develop data is very important to the issue of U.S. and Canadian data comparability. The crude oil input to Canadian and U.S. refineries may be quite different. Crude oil from different production fields is chemically very different. Because of this, different refineries may have very different overall energy requirements and emissions. For example, refining of a very heavy crude oil may require more energy to be expended on cracking large molecules to achieve the smaller molecules desired for gasoline. Thus, that refinery may require more energy per barrel of output than a refinery receiving a lighter crude oil. However, if we focus only on the asphalt product, the energy to produce a pound of product depends on the energy to distill that particular fraction from the crude. While there will be some energy differences for asphalt produced from different crude oils, focusing on the production of a fixed amount of asphalt using only the specific subprocesses minimizes errors.

Franklin Associates first developed the production and basic refinery data in the early 1970's. Since that time, the data have undergone frequent updating and revision. Along the way, they have been peer-reviewed dozens of times by petroleum and petrochemical experts. We have just recently (1997) undertaken another revision and updating effort on these numbers. While some of the references are more than 10 years old, after our recent investigations, we have not found reason to change them. Production and refining technology is not rapidly changing. In fact, in the U.S., new petroleum refineries have not been initiated for some time. The numbers have been confirmed within the past five years on several occasions by petrochemical firms with extensive exploration and refining operations. We have also compared our numbers to the European Plastics Energy Database (Reference C-24). The petroleum production values are quite close, and the refinery values are also consistent with ours. We have also compared our data with U.S. Department of Energy calculations of petroleum production and refining, and once again find that the values included here are quite consistent with the DoE database (Reference C-27). However, the allocation to subprocesses is not possible without expert input that is absent from published data.

Crude Oil Production

Oil is produced by drilling into porous rock structures generally located several thousand feet underground. Once an oil deposit is located, numerous holes are drilled and lined with steel casing. Some oil is brought to the surface by natural pressure in the rock structure, although most oil requires some energy to drive pumps that lift oil to the surface. Once oil is on the surface, it is separated from water and stored in tanks to await transportation to a refinery. In some cases it is immediately transferred to a pipeline that transports the oil to a larger terminal.

There are two primary sources of waste from crude oil production. The first source is the "oil field brine," or water that is extracted with the oil. The brine goes through a separator at or near the well head in order to remove the oil from the water. These separators are very efficient and leave minimal oil in the water.

According to the American Petroleum Institute (API) it is estimated that 21 billion barrels of brine water were produced from crude oil production in 1985 (Reference C-1). This quantity of water equates to a ratio of 5.4 barrels of water per barrel of oil. The majority of this water (85 percent) is injected into separate wells specifically designed to accept production-related waters. This represents all waters produced by onshore oil production facilities that are not permitted to discharge "oil field brine" to surface waters (Reference C-2). The remainder of the produced water is from offshore oil production facilities and is assumed to be discharged to the ocean. Therefore, the waterborne wastes represent the brine wastes present in this 15 percent of brine water (Reference C-3).

The second source of waste is the gas produced from oil wells. While most of this is recovered for sale, some is not. Atmospheric emissions from crude oil production are primarily hydrocarbons, which are predominately methane, but with dozens of other identified chemical species (Reference C-25). They are attributed to the natural gas produced from combination wells and relate to line or transmission losses and unflared venting.

The transportation data assume a mix of foreign and domestically produced crude oil. According to the Petroleum Supply Annual, June 1994, 49 percent of the crude oil used in the United States is imported.

The energy requirements and environmental emissions for the production of 1,000 pounds of crude oil are given in Table C-1.

Desalting, Distillation, and Deasphalting

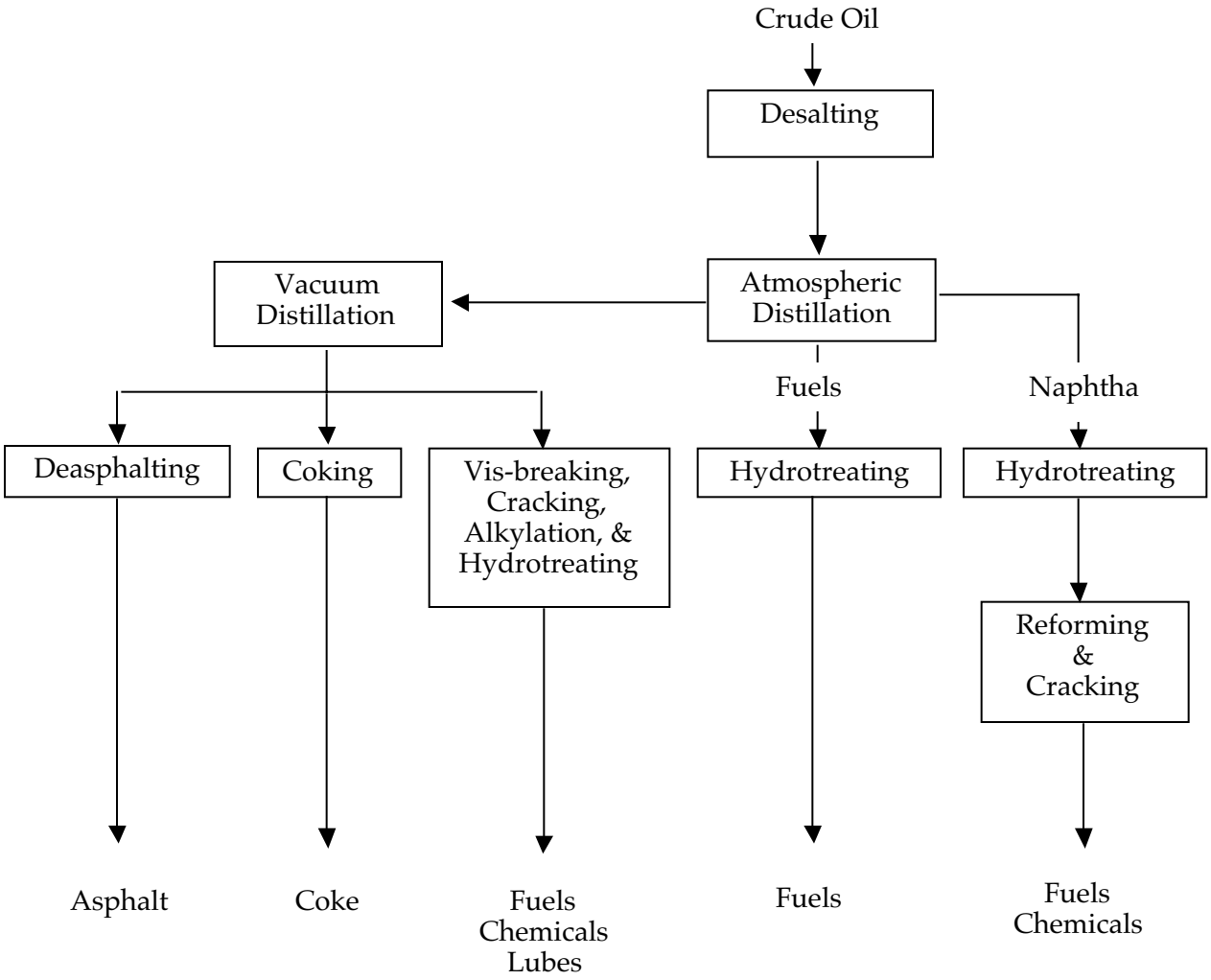
A petroleum refinery is a complex combination of processes that serve to separate and physically and chemically transform the mixture of hydrocarbons found in crude oil into a large number of products. Modern refineries are able to vary the different processing steps through which a charge of crude oil passes in order to maximize the output of higher value products. This variation of processing steps can change according to the make-up of the crude oil as well as the economic value of the products. Because of this variation, it is necessary to identify the specific subsystems within a refinery that are used to produce a specific product.

For this analysis, it is assumed that crude oil used to produce asphalt goes through the following refinery operations: desalting, atmospheric and vacuum distillation, and deasphalting. Due to a lack of facility-specific data, literature sources were used to estimate the energy requirements for these refining steps. A number of literature references were used, most of which showed similar energy inputs (References C-13 through C-17). A greatly simplified flow diagram for a refinery is shown in the figure.

Crude oil desalting is the water washing of crude oil to remove water-soluble minerals and entrained solids (Reference C-18). For this analysis it is assumed that all of the crude that enters a refinery passes through the desalting step (References C-16 and C-18).

Crude oil atmospheric distillation separates the desalted crude oil into fractions with differing boiling ranges. Atmospheric distillation is used to separate the fractions with a boiling point less than 650° F (References C-16, C-17, and C-18). At temperatures greater than 650° F thermal cracking of the hydrocarbons starts. Fuel gas or still gas that is liberated from the crude during distillation is further processed into liquefied petroleum gas or natural gas, depending on the carbon chain length. This gas is

sold or used in the refinery to generate heat. About 52 percent of the non-electrical energy used in a refinery for direct heating or steam production comes from fuel gas (Reference C-19). Coproduct credit is given on a mass basis for the gas fractions not used for energy in the refinery. Fuel gas or still gas used as an energy source in refining is assumed to have the same composition as natural gas and is shown as process energy, not as raw material.



The higher boiling point residues from the atmospheric distillation unit passes to a vacuum distillation unit where separation of the various fractions can be accomplished at lower temperatures than would be required at atmospheric pressure. The residue or bottoms of the vacuum distillation unit is a valuable coproduct that is further processed to make usable products. Coproduct credit is given on a weight basis for this residue. It is assumed that all of the crude passes through atmospheric distillation, while only 46 percent of the initial crude oil charge passes through vacuum distillation (References C-13, C-14, and C-18).

Deasphalting is accomplished by extracting the vacuum residue with liquid hydrocarbon solvent. Asphalt is steam stripped from the solvent, and the solvent is recovered for reuse (Reference C- 17).

Energy requirements for petroleum refineries are usually listed in literature sources as Btu of fuel, pounds of steam, and electricity per 42-gallon barrel of crude processed. For this analysis, a conversion of 3.385 barrels of crude per 1,000 pounds was used. Steam inputs were converted to Btu requirements using a conversion of 1,200 Btu per pound. Btu inputs for steam were added to the Btu inputs listed as fuels, and the total was converted to quantities of fuels using the combustion energy values and the following refinery fuel mix: residual oil and residues (coke), 22 percent; purchased natural gas, 24 percent; LPG, 2 percent; and fuel gas or still gas, 52 percent (Reference C-20). Negligible quantities of coal and distillate oil are also used in the "average" refinery.

The energy requirements and environmental emissions for desalting, distilling, and deasphalting 1,000 pounds of crude oil are presented in Table C-2. Still gas produced in the refinery is combined with purchased natural gas in the table. Raw material inputs are calculated from the average loss due to atmospheric, waterborne, and solid waste emissions per 1,000 pounds of crude processed in a one-year period (Reference C-20). The data in Table C-2 are assumed to be representative of petroleum refineries in 1992.

No data were available that allow the determination of emissions to water, air and land for specific sub-processes within the refinery. The emission data were obtained from total refinery operations, allocating emissions to each product based upon the relative mass of the various products. Table numbers correspond to Franklin spreadsheet numbers and are used here to facilitate cross-referencing by the research team.

Results and Use of the Tables

The following tables are included. They are grouped together at the end of this report, following the references.

- Table C-1 Data for production of crude oil
- Table C-2 Data for the processing of crude oil into asphalt
- Table C-3 LCI results for the production of crude oil (derived from Table C-1)
- Table C-4 LCI results for the processing of crude oil into asphalt (derived from Table C-2)
- Table C-5 LCI results for cradle-to-grave production of asphalt (combination of Tables C-3 and C-4)
- Table C-6 Data for production of average refinery products

- Table C-7 LCI results for cradle-to-grave production of average refinery products (combination of Tables C-3 and C-6)
- Table C-8 Revision of Table C-3 using Canadian transportation
- Table C-9 Revision of Table C-5 using Canadian transportation
- Table C-10 Revision of Table C-7 using Canadian transportation
- Table A-5 Transportation energy requirements
- Table A-7N Electricity factors
- Tables A-28a and 28b Environmental emissions for tractor-trailer trucks
- Table A-32 Environmental emissions for ocean freighters

Tables C-1, C-2 and C-6 were prepared to show actual data in physical units. Tables C-3, C-4, C-5 and C-7 were prepared to show the LCI results of combining the data from the data tables with fuel combustion and electricity generation emissions factors.

Table C-1 will be used as an example of the data tables. The first entry is the natural resource requirement entry, showing that to deliver 1,000 pounds of crude oil to a refinery, 1,035 lb of oil is extracted from the ground. This means that 35 lb of oil is lost from the system as leaks, minor spills or evaporative or waterborne losses.

The next set of entries is for the process energy. The entry of 15.2 kWh of electricity, 542 cu ft of natural gas, etc., are the process energy requirements to produce the 1,000 lb of crude oil. These values are direct process requirements, and do not include "precombustion" energy, such as that required to produce and process the natural gas for use. Following this are the transportation data, listed both as the ton-miles by mode, and the fuels required. The environmental emissions listed in this table are direct process emissions only, and do not include emissions from fuel combustion.

Table C-2 is the data table for converting crude oil into asphalt in a petroleum refinery. The format is the same as for Table C-1. The raw material requirement is 1,005 lb of crude oil to produce 1,000 lb of asphalt. This means that the particular set of subprocesses discussed above result in the loss of 0.5% of the molecules that would have ended up in the asphalt. The methodology used is to take total refinery output and allocate the input to each product. For example, suppose a refinery produces 20,000 lb of products over some period of time. Most of this, perhaps 15,000 lb ends up as fuels (oil and gasoline), 1,000 lb as asphalt 4,000 lb as other products. In our methodology, this would require 20,100 lb of crude oil (20,000 X1.005=20,100), or 15,075 lb for the fuels, 1,005 lb for asphalt and 4,020 lb for the remaining products. However, because we are only interested in the asphalt in table C-2, we show 1,005 lb as the crude oil allocated to the product of interest. As in the case of Table C-1, this table contains the direct process data only. No transportation of the finished product is included.

Table C-3 is an LCI results table. It is linked to the data on Table C-1. The fuels data on Table C-1 have been processed using a comprehensive U.S. average fuels and electricity database to calculate the energy and emissions for the production of crude oil. The combustion energy section in C-3 shows the process energy in physical units and also in million Btu. The next section shows the precombustion energy. It includes the fuels used in the "upstream" energy processes necessary to produce, process and transport fuels. The table also lists the transportation energy, the precombustion transportation energy, as well as the emissions to land, water and air.

Table C-4 is a similar to C-3. It reports the transformation of the data on Table C-2 into the LCI results.

Table C-5 is total system LCI results including both the crude oil production and the refining into asphalt. It is a combination of C-3 and C-4. Because the refinery requires 1,005 lb of crude oil, the results of Table C-3 are multiplied by 1.005, and added to the values on Table C-4. For example, the electricity on C-3 is 15.2 kWh. This multiplied by 1.005 is 15.3 kWh. Adding to this the 13.3 on Table C-4 gives us the 28.6 kWh on Table C-5.

Table C-6 was added to generalize the refinery results. It provides data for the refinery processes of desalting, atmospheric and vacuum distillation and hydrotreating. This more nearly reflects typical refinery products of the U.S., and this process is suitable for use for petrochemical feedstocks and for fuels. While the fuels require cracking of some portion of the crude, and hydrotreating of a different portion, the error incurred by assuming that all of the crude that ends up as fuels is hydrotreated is small.

Table C-7 is the transformation of Table C-6 and Table C-3 into a total system generic refinery product. Comparing Tables C-7 and C-5 for asphalt production, we notice that asphalt requires more energy than average refinery products. This is caused by the energy intensity of extracting the high boiling point components of asphalt from the mixture of hydrocarbons.

Because transportation of crude oil in Canada is very different than for the U.S., Tables C-8, C-9 and C-10 were prepared as revisions of Tables C-3, C-5 and C-7 by substituting a set of Canadian transportation data for the U.S. transportation data. The data submitted was 201,000 cu m/day by pipeline an average distance of 1,500 km, 90,000 cu m/day of crude shipped by ocean tanker a distance of 4,000 miles. For 1,000 lb of crude, this translates into 322 ton-miles by pipeline and 620 ton-miles by ocean tanker.

In order to use other transportation scenarios, a set of Franklin Associates Appendix tables are included. Table A-5 gives our ton-mile factors by mode. It is used to calculate the fuels required and the energy values. Tables A-7N, A-28a, A-28b and A-32 are used to find the emissions from use of electricity and fuels for transportation modes.

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Table A-5

1993 TRANSPORTATION FUEL REQUIREMENTS

		Fuel Consumed per 1,000 Ton-Miles	Energy Consumed (1) (Btu/ton-mile)	DQI
Combination truck (tractor trailer)				
Diesel	gal	9.4	1,465	B
Gasoline	gal	9.4	1,308	B
Single unit truck				
Diesel	gal	26.5	4,129	B
Gasoline	gal	26.5	3,689	B
Rail				
Diesel	gal	2.4	374	B
Barge (2)				
Diesel	gal	2.0	316	C
Residual	gal	0.8	131	C
Total			447	
Ocean freighter (2)				
Diesel	gal	0.1	23	C
Residual	gal	1.8	307	C
Total			330	C
Pipeline - natural gas				
Natural gas	cuft	2,300	2,581	C
Pipeline - petroleum products				
Electricity	kwh	22	241	C
Pipeline - coal slurry				
Electricity	kwh	235	2,578	C

(1) Includes precombustion energy for fuel acquisition.

(2) An average ratio of diesel and residual fuels is used to represent barge and ocean freighter transportation energy.

Source: Franklin Associates, Ltd.

Table A-7N

ENVIRONMENTAL EMISSIONS FOR THE COMBUSTION OF 1 KWH OF ELECTRICTY
(pounds of pollutants per 1 kwh of electricity)

	Precombustion	Combustion	Total
Energy Factors			
Mil. Btu/1 kwh of electricity	0.011	5.3E-04	0.011
Atmospheric Emissions			
Particulates			0.0017
Nitrogen Oxides			0.0057
Hydrocarbons (other than methane)			0.0011
Sulfur Oxides			0.012
Carbon Monoxide			7.5E-04
Fossil Carbon Dioxide			1.53
Non-Fossil Carbon Dioxide			5.2E-04
Formaldehyde			1.0E-07
Other Aldehydes			3.8E-06
Other Organics			5.9E-06
Ammonia			9.0E-06
Lead			6.9E-08
Methane			0.0034
Kerosene			5.1E-07
Chlorine			6.1E-09
Hydrochloric Acid			1.1E-04
Hydrogen Fluoride			1.5E-05
Metals			2.1E-07
Antimony			8.9E-09
Arsenic			4.5E-08
Beryllium			5.3E-09
Cadmium			5.1E-09
Chromium			5.9E-08
Cobalt			2.9E-08
Manganese			1.4E-07
Mercury			3.9E-08
Nickel			2.8E-07
Selenium			1.5E-07
Acreolin			2.1E-08
Nitrous Oxide			1.2E-05
Benzene			1.9E-08
Perchloroethylene			2.0E-08
Trichloroethylene			2.0E-08
Methylene Chloride			9.2E-08
Carbon Tetrachloride			3.6E-08
Phenols			5.6E-08
Naphthalene			1.5E-09
Dioxins			1.2E-13
n-nitrodimethylamine			4.4E-09
Radionuclides (Ci)			4.5E-07

(continued)

Table A-7N (cont)

ENVIRONMENTAL EMISSIONS FOR THE COMBUSTION OF 1 KWH OF ELECTRICTY
(pounds of pollutants per 1 kwh of electricity)

	Precombustion	Combustion	Total
Waterborne Emissions			
Acid			2.3E-11
Metal Ion			4.8E-07
Dissolved Solids			0.0053
Suspended Solids			9.9E-04
BOD			5.5E-06
COD			7.5E-05
Phenol			1.6E-09
Oil			9.4E-05
Sulfuric Acid			1.3E-05
Iron			7.9E-05
Ammonia			9.0E-07
Chromium			2.4E-07
Lead			4.0E-11
Zinc			8.3E-08
Chlorides			2.5E-04
Sodium			8.1E-07
Calcium			4.4E-07
Sulfates			4.4E-04
Manganese			4.6E-05
Fluorides			2.0E-06
Nitrates			1.9E-07
Phosphates			6.7E-06
Boron			5.4E-05
Other Organics			2.6E-05
Chromates			1.8E-08
Cyanide			3.6E-10
Mercury			1.9E-11
Cadmium			2.4E-07
Solid Waste			0.27

Source: Franklin Associates, Ltd.

Table A-28a

ENVIRONMENTAL EMISSIONS FOR 1992 TRACTOR-TRAILER GASOLINE POWERED TRUCKS
(pounds of pollutants per 1,000 gallons of gasoline)

Atmospheric Emissions	Precombustion	Combustion	Total	DQI
Particulates	1.42	43.3	44.7	B
Nitrogen Oxides	7.22	58.3	65.5	B
Hydrocarbons (other than methane)	42.8	20.5	63.3	C
Sulfur Oxides	22.0	4.34	26.3	B
Carbon Monoxide	5.42	380	385	B
Fossil Carbon Dioxide	2,239	18,400	20,639	A
Non-Fossil Carbon Dioxide	5.20		5.20	B
Formaldehyde	1.8E-05		1.8E-05	C
Other Aldehydes	0.40		0.40	C
Other Organics	0.26	117	117	D
Ammonia	0.034		0.034	C
Lead	1.2E-04	0.031	0.031	B
Methane	3.45		3.45	C
Kerosene	8.9E-05		8.9E-05	D
Chlorine	0.0013		0.0013	D
Hydrochloric Acid	0.021		0.021	C
Hydrogen Fluoride	0.0028		0.0028	C
Metals	0.0021		0.0021	D
Antimony	3.2E-05		3.2E-05	E
Arsenic	6.7E-05		6.7E-05	E
Beryllium	4.7E-06		4.7E-06	E
Cadmium	1.0E-04		1.0E-04	E
Chromium	7.6E-05		7.6E-05	E
Cobalt	9.2E-05		9.2E-05	E
Manganese	9.1E-05		9.1E-05	E
Mercury	2.2E-05		2.2E-05	E
Nickel	0.0014		0.0014	E
Selenium	6.2E-05		6.2E-05	E
Acreolin	4.0E-06		4.0E-06	D
Nitrous Oxide	0.0024		0.0024	D
Benzene	1.3E-05		1.3E-05	D
Perchloroethylene	3.9E-06		3.9E-06	D
Trichloroethylene	3.8E-06		3.8E-06	D
Methylene Chloride	1.8E-05		1.8E-05	D
Carbon Tetrachloride	1.6E-05		1.6E-05	D
Phenols	1.0E-04		1.0E-04	D
Naphthalene	6.0E-06		6.0E-06	D
Dioxins	2.2E-11		2.2E-11	D
n-nitrodimethylamine	8.4E-07		8.4E-07	D
Radionuclides (Ci)	7.4E-05		7.4E-05	D

(continued)

Table A-28a (cont)

ENVIRONMENTAL EMISSIONS FOR 1992 TRACTOR-TRAILER GASOLINE POWERED TRUCKS
(pounds of pollutants per 1,000 gallons of gasoline)

Waterborne Emissions	Precombustion (1)	Combustion	Total	DQI
Acid	7.1E-06		7.1E-06	E
Metal Ion	0.15		0.15	E
Dissolved Solids	29.7		29.7	D
Suspended Solids	0.68		0.68	D
BOD	0.11		0.11	D
COD	0.74		0.74	D
Phenol	4.9E-04		4.9E-04	E
Oil	0.69		0.69	E
Sulfuric Acid	0.0059		0.0059	E
Iron	0.016		0.016	E
Ammonia	0.012		0.012	E
Chromium	0.0011		0.0011	E
Lead	1.3E-05		1.3E-05	E
Zinc	5.5E-04		5.5E-04	E
Chlorides	1.09		1.09	E
Sodium	1.4E-04		1.4E-04	E
Calcium	7.6E-05		7.6E-05	E
Sulfates	0.88		0.88	E
Manganese	0.0078		0.0078	E
Fluorides	3.5E-04		3.5E-04	E
Nitrates	3.3E-05		3.3E-05	E
Phosphates	0.0030		0.0030	E
Boron	0.024		0.024	E
Other Organics	0.072		0.072	E
Chromates	8.3E-05		8.3E-05	E
Cyanide	1.6E-06		1.6E-06	E
Mercury	8.4E-08		8.4E-08	E
Cadmium	0.0011		0.0011	E
Solid Waste	113		113	B

Source: Franklin Associates, Ltd.

Table A-28b

ENVIRONMENTAL EMISSIONS FOR 1992 TRACTOR-TRAILER DIESEL POWERED TRUCKS
(pounds of pollutants per 1,000 gallons of diesel fuel)

Atmospheric Emissions	Precombustion (1)	Combustion	Total	DQI
Particulates	1.66	29.8	31.5	B
Nitrogen Oxides	8.47	210	218	B
Hydrocarbons (other than methane)	50.2	37.7	87.9	C
Sulfur Oxides	25.8	36.2	62.0	B
Carbon Monoxide	6.36	209	215	B
Fossil Carbon Dioxide	2,627	22,800	25,427	A
Non-Fossil Carbon Dioxide	6.10		6.10	B
Formaldehyde	2.1E-05		2.1E-05	C
Other Aldehydes	0.47	5.50	5.97	C
Other Organics	0.30	116	116	D
Ammonia	0.040		0.040	C
Lead	1.4E-04		1.4E-04	B
Methane	4.05		4.05	C
Kerosene	1.0E-04		1.0E-04	D
Chlorine	0.0015		0.0015	D
Hydrochloric Acid	0.025		0.025	C
Hydrogen Fluoride	0.0033		0.0033	C
Metals	0.0025		0.0025	D
Antimony	3.8E-05		3.8E-05	E
Arsenic	7.9E-05		7.9E-05	E
Beryllium	5.5E-06		5.5E-06	E
Cadmium	1.2E-04		1.2E-04	E
Chromium	9.0E-05		9.0E-05	E
Cobalt	1.1E-04		1.1E-04	E
Manganese	1.1E-04		1.1E-04	E
Mercury	2.6E-05		2.6E-05	E
Nickel	0.0017		0.0017	E
Selenium	7.2E-05		7.2E-05	E
Acreolin	4.7E-06		4.7E-06	D
Nitrous Oxide	0.0028		0.0028	D
Benzene	1.5E-05		1.5E-05	D
Perchloroethylene	4.6E-06		4.6E-06	D
Trichloroethylene	4.4E-06		4.4E-06	D
Methylene Chloride	2.1E-05		2.1E-05	D
Carbon Tetrachloride	1.9E-05		1.9E-05	D
Phenols	1.2E-04		1.2E-04	D
Naphthalene	7.0E-06		7.0E-06	D
Dioxins	2.5E-11		2.5E-11	D
n-nitrodimethylamine	9.9E-07		9.9E-07	D
Radionuclides (Ci)	8.7E-05		8.7E-05	D

(continued)

Table A-28b (cont)

ENVIRONMENTAL EMISSIONS FOR 1992 TRACTOR-TRAILER DIESEL POWERED TRUCKS
(pounds of pollutants per 1,000 gallons of diesel fuel)

Waterborne Emissions	Precombustion (1)	Combustion	Total	DQI
Acid	8.4E-06		8.4E-06	E
Metal Ion	0.18		0.18	E
Dissolved Solids	34.8		34.8	D
Suspended Solids	0.79		0.79	D
BOD	0.13		0.13	D
COD	0.87		0.87	D
Phenol	5.8E-04		5.8E-04	E
Oil	0.81		0.81	E
Sulfuric Acid	0.0069		0.0069	E
Iron	0.019		0.019	E
Ammonia	0.014		0.014	E
Chromium	0.0013		0.0013	E
Lead	1.5E-05		1.5E-05	E
Zinc	6.5E-04		6.5E-04	E
Chlorides	1.28		1.28	E
Sodium	1.6E-04		1.6E-04	E
Calcium	9.0E-05		9.0E-05	E
Sulfates	1.03		1.03	E
Manganese	0.0092		0.0092	E
Fluorides	4.1E-04		4.1E-04	E
Nitrates	3.9E-05		3.9E-05	E
Phosphates	0.0035		0.0035	E
Boron	0.028		0.028	E
Other Organics	0.085		0.085	E
Chromates	9.8E-05		9.8E-05	E
Cyanide	1.9E-06		1.9E-06	E
Mercury	9.8E-08		9.8E-08	E
Cadmium	0.0013		0.0013	E
Solid Waste	133		133	B

Source: Franklin Associates, Ltd.

Table A-32

ENVIRONMENTAL EMISSIONS FOR OCEAN FREIGHTERS
(pounds of pollutants per 1,000 gallons of fuel)

Atmospheric Emissions	Precombustion	Combustion	Total	DQI
Particulates	1.68	19.5	21.2	B
Nitrogen Oxides	8.54	82.5	91.0	B
Hydrocarbons (other than methane)	50.7	8.80	59.5	C
Sulfur Oxides	26.0	36.2	62.2	B
Carbon Monoxide	6.41	9.02	15.4	B
Fossil Carbon Dioxide	2,650	25,200	27,850	A
Non-Fossil Carbon Dioxide	6.15		6.15	B
Formaldehyde	2.2E-05		2.2E-05	C
Other Aldehydes	0.47	5.50	5.97	C
Other Organics	0.30	7.00	7.30	D
Ammonia	0.041		0.041	C
Lead	1.4E-04		1.4E-04	B
Methane	4.08		4.08	C
Kerosene	1.0E-04		1.0E-04	D
Chlorine	0.0016		0.0016	D
Hydrochloric Acid	0.025		0.025	C
Hydrogen Fluoride	0.0033		0.0033	C
Metals	0.0025		0.0025	D
Antimony	3.8E-05		3.8E-05	E
Arsenic	7.9E-05		7.9E-05	E
Beryllium	5.5E-06		5.5E-06	E
Cadmium	1.2E-04		1.2E-04	E
Chromium	9.1E-05		9.1E-05	E
Cobalt	1.1E-04		1.1E-04	E
Manganese	1.1E-04		1.1E-04	E
Mercury	2.6E-05		2.6E-05	E
Nickel	0.0017		0.0017	E
Selenium	7.3E-05		7.3E-05	E
Acreolin	4.7E-06		4.7E-06	D
Nitrous Oxide	0.0029		0.0029	D
Benzene	1.5E-05		1.5E-05	D
Perchloroethylene	4.7E-06		4.7E-06	D
Trichloroethylene	4.4E-06		4.4E-06	D
Methylene Chloride	2.1E-05		2.1E-05	D
Carbon Tetrachloride	1.9E-05		1.9E-05	D
Phenols	1.2E-04		1.2E-04	D
Naphthalene	7.0E-06		7.0E-06	D
Dioxins	2.6E-11		2.6E-11	D
n-nitrodimethylamine	9.9E-07		9.9E-07	D
Radionuclides (Ci)	8.8E-05		8.8E-05	D

(continued)

Table A-32 (cont)

ENVIRONMENTAL EMISSIONS FOR OCEAN FREIGHTERS
(pounds of pollutants per 1,000 gallons of fuel)

Waterborne Emissions	Precombustion	Combustion	Total	DQI
Acid	8.5E-06		8.5E-06	E
Metal Ion	0.18		0.18	E
Dissolved Solids	35		35	D
Suspended Solids	0.80		0.80	D
BOD	0.13		0.13	D
COD	0.88		0.88	D
Phenol	5.8E-04		5.8E-04	E
Oil	0.82		0.82	E
Sulfuric Acid	0.0070		0.0070	E
Iron	0.019		0.019	E
Ammonia	0.014		0.014	E
Chromium	0.0013		0.0013	E
Lead	1.5E-05		1.5E-05	E
Zinc	6.6E-04		6.6E-04	E
Chlorides	1.29		1.29	E
Sodium	1.7E-04		1.7E-04	E
Calcium	9.0E-05		9.0E-05	E
Sulfates	1.04		1.04	E
Manganese	0.0092		0.0092	E
Fluorides	4.2E-04		4.2E-04	E
Nitrates	3.9E-05		3.9E-05	E
Phosphates	0.0035		0.0035	E
Boron	0.028		0.028	E
Other Organics	0.086		0.086	E
Chromates	9.8E-05		9.8E-05	E
Cyanide	1.9E-06		1.9E-06	E
Mercury	9.9E-08		9.9E-08	E
Cadmium	0.0013		0.0013	E
Solid Waste	135		135	B

Source: Franklin Associates, Ltd.

Table C-1

DATA FOR THE PRODUCTION OF 1,000 POUNDS OF CRUDE OIL

Energy Usage		
Energy of Material Resource		
Petroleum	1,035	lb
Total Resource		
Process Energy		
Electricity	15.2	kwh
Natural gas	542	cu ft
Distillate oil	0.21	gal
Residual oil	0.26	gal
Gasoline	0.094	gal
Total Process		
Transportation Energy		
Combination truck	10.0	ton-miles
Diesel	0.10	gal
Ocean freighter	2,028	ton-miles
Diesel	0.20	gal
Residual	3.65	gal
Pipeline-petroleum products	142	ton-miles
Electricity	3.12	kwh
Total Transportation		
Environmental Emissions		
Atmospheric Emissions		
Methane	3.3	lb
Other Hydrocarbons	1.4	lb
Solid Wastes	0.6	lb
Waterborne Wastes		
Oil	0.043	lb

References: C-4 through C-12, C-25,C-26

Source: Franklin Associates, Ltd.

Table C-2

DATA FOR THE PROCESSING OF OF CRUDE OIL IN A REFINERY TO PRODUCE 1,000 POUNDS OF ASPHALT (INCLUDING DESALTING, DISTALLATION AND DEASPHALTING)

Raw Materials		
Crude oil	1,005	lb
Energy Usage		
Process Energy		
Electricity	13.3	kwh
Natural gas	937	cu ft
LPG	0.27	gal
Residual oil	1.90	gal
Total Process		
Environmental Emissions		
Atmospheric Emissions		
Nonmethane VOC	1.38	lb
Particulates	0.060	lb
Sulfur Oxides	0.20	lb
Aldehydes	0.040	lb
Ammonia	0.0053	lb
Lead	1.4E-06	lb
Chlorine	2.1E-04	lb
Hydrochloric Acid	1.6E-04	lb
Solid Wastes	3.36	lb
Waterborne Wastes		
BOD	0.014	lb
COD	0.066	lb
Suspended solids	0.013	lb
Dissolved solids	0.94	lb
Acid	1.1E-06	lb
Metal ion	0.024	lb
Phenol	7.8E-05	lb
Oil	8.1E-04	lb
Iron	4.2E-04	lb
Ammonia	0.0018	lb
Chromium	4.5E-06	lb
Lead	2.0E-06	lb
Zinc	3.0E-05	lb

References: C-13 through C-23,C-25,C-26
Source: Franklin Associates, Ltd.

Table C-3

LCI RESULTS FOR THE PRODUCTION OF 1,000 POUNDS OF CRUDE OIL

Energy Usage			Energy Million Btu
Energy of Material Resource			
Petroleum	1,035	lb	20.0
Total Resource			20.0
Combustion Process Energy			
Electricity	15.2	kwh	0.16
Natural gas	542	cu ft	0.56
Distillate oil	0.21	gal	0.029
Residual oil	0.26	gal	0.039
Gasoline	0.094	gal	0.012
Total Combustion Process			0.80
Precombustion Process Energy			
Natural gas	65.7	cu ft	0.068
Residual oil	0.037	gal	0.0055
Distillate oil	0.026	gal	0.0036
Gasoline	0.031	gal	0.0039
LPG	8.8E-04	gal	8.4E-05
Coal	0.52	lb	0.0058
Nuclear	2.1E-06	lb U238	0.0021
Hydropower	0.34	thousand Btu	3.4E-04
Other	0.30	thousand Btu	3.0E-04
Total Precombustion Process			0.089
Combustion Transportation Energy			
Combination truck	10.0	ton-miles	
Diesel	0.094	gal	0.013
Ocean freighter	2,028	ton-miles	
Diesel	0.20	gal	0.028
Residual	3.65	gal	0.55
Pipeline-petroleum products	142	ton-miles	
Electricity	3.12	kwh	0.033
Total Combustion Transportation			0.62
Precombustion Transportation Energy			
Natural gas	43.9	cu ft	0.045
Residual oil	0.17	gal	0.025
Distillate oil	0.021	gal	0.0029
Gasoline	0.0058	gal	7.3E-04
LPG	0.0055	gal	5.3E-04
Coal	0.59	lb	0.0066
Nuclear	2.4E-06	lb U238	0.0023
Hydropower	0.38	thousand Btu	3.8E-04
Other	0.34	thousand Btu	3.4E-04
Total Precombustion Transportation			0.084

Environmental Emissions

Atmospheric Emissions-Process		
Hydrocarbons	4.70	lb
Atmospheric Emissions-Fuel-related		
Particulates	0.13	lb
Nitrogen Oxides	0.74	lb
Hydrocarbons	0.61	lb
Sulfur Oxides	1.66	lb
Carbon Monoxide	0.63	lb
Formaldehyde	2.1E-06	lb
Other Aldehydes	0.025	lb
Methane	0.29	lb
Other Organics	0.040	lb
Kerosene	1.0E-05	lb
Ammonia	3.6E-04	lb
Lead	4.5E-06	lb
Chlorine	7.7E-06	lb
Fossil Carbon Dioxide	225	lb
Non-Fossil Carbon Dioxide	0.054	lb
Hydrochloric Acid	0.0021	lb
Hydrogen Fluoride	2.9E-04	lb
Metals	2.2E-05	lb
Antimony	1.1E-06	lb
Arsenic	2.7E-06	lb
Beryllium	2.5E-07	lb
Cadmium	3.3E-06	lb
Chromium	4.0E-06	lb
Cobalt	3.2E-06	lb
Manganese	4.5E-06	lb
Mercury	1.3E-06	lb
Nickel	4.8E-05	lb
Selenium	4.0E-06	lb
Acreolin	4.2E-07	lb
Nitrous Oxide	2.4E-04	lb
Benzene	4.6E-07	lb
Perchloroethylene	4.0E-07	lb
Trichloroethylene	3.9E-07	lb
Methylene Chloride	1.8E-06	lb
Carbon Tetrachloride	8.1E-07	lb
Phenols	1.9E-06	lb
Naphthalene	7.9E-08	lb
Dioxins	2.3E-12	lb
n-Nitrosodimethylamine	8.8E-08	lb
Radionuclides	8.9E-06	lb
Solid Wastes-Process		
Unspecified	0.60	lb
Solid Wastes-Fuel-related		
ash	8.67	lb

Waterborne Wastes-Process		
Oil	0.043	lb
Waterborne Wastes-Fuel-related		
Acid	4.1E-08	lb
Metal Ion	8.7E-04	lb
Dissolved Solids	1.94	lb
Suspended Solids	0.052	lb
BOD	0.0024	lb
COD	0.029	lb
Phenol	2.8E-06	lb
Oil	0.035	lb
Sulfuric Acid	3.7E-04	lb
Iron	0.0016	lb
Ammonia	1.2E-04	lb
Chromium	8.7E-05	lb
Lead	7.3E-08	lb
Zinc	3.1E-05	lb
Chloride	0.087	lb
Sodium	1.6E-05	lb
Calcium	8.7E-06	lb
Sulfates	0.072	lb
Manganese	9.1E-04	lb
Fluorides	4.1E-05	lb
Nitrates	3.8E-06	lb
Phosphates	1.9E-04	lb
Boron	0.0015	lb
Other Organics	0.0057	lb
Chromates	2.8E-06	lb
Cyanide	1.3E-07	lb
Mercury	6.7E-09	lb
Cadmium	8.7E-05	lb

Source: Franklin Associates, Ltd.

Table C-4

LCI RESULTS FOR THE PROCESSING OF CRUDE OIL IN A REFINERY TO PRODUCE 1,000 POUNDS OF ASPHALT (INCLUDING DESALTING, DISTILLATION, AND DEASPHALTING)

Raw Materials			
Crude Oil	1005	lb	
Energy Usage			**Energy Million Btu**
Combustion Process Energy			
Electricity	13.3	kwh	0.14
Natural gas	937	cu ft	0.97
LPG	0.27	gal	0.026
Residual oil	1.90	gal	0.28
Total Combustion Process			1.42
Precombustion Process Energy			
Natural gas	123	cu ft	0.13
Residual oil	0.11	gal	0.017
Distillate oil	0.043	gal	0.0060
Gasoline	0.054	gal	0.0067
LPG	0.0031	gal	2.9E-04
Coal	0.93	lb	0.010
Nuclear	3.8E-06	lb U238	0.0037
Hydropower	0.60	thousand Btu	6.0E-04
Other	0.53	thousand Btu	5.3E-04
Total Precombustion Process			0.17
Environmental Emissions			
Atmospheric Emissions-Process			
Particulates	0.060	lb	
Hydrocarbons	1.38	lb	
Sulfur Oxides	0.20	lb	
Aldehydes	0.040	lb	
Ammonia	0.0053	lb	
Lead	1.4E-06	lb	
Chlorine	2.1E-04	lb	
Hydrochloric Acid	1.6E-04	lb	
Atmospheric Emissions-Fuel-related			
Particulates	0.066	lb	
Nitrogen Oxides	0.60	lb	
Hydrocarbons	0.63	lb	
Sulfur Oxides	2.58	lb	

Carbon Monoxide	0.30	lb
Formaldehyde	1.5E-06	lb
Other Aldehydes	0.0014	lb
Methane	0.42	lb
Other Organics	0.0016	lb
Kerosene	7.5E-06	lb
Ammonia	2.2E-04	lb
Lead	1.8E-05	lb
Chlorine	3.7E-06	lb
Fossil Carbon Dioxide	205	lb
Non-Fossil Carbon Dioxide	0.047	lb
Hydrochloric Acid	0.0016	lb
Hydrogen Fluoride	2.1E-04	lb
Metals	1.9E-05	lb
Antimony	5.5E-06	lb
Arsenic	1.1E-05	lb
Beryllium	7.2E-07	lb
Cadmium	1.7E-05	lb
Chromium	1.2E-05	lb
Cobalt	1.6E-05	lb
Manganese	9.7E-06	lb
Mercury	3.1E-06	lb
Nickel	2.5E-04	lb
Selenium	8.0E-06	lb
Acreolin	3.1E-07	lb
Nitrous Oxide	1.8E-04	lb
Benzene	3.5E-07	lb
Perchloroethylene	2.9E-07	lb
Trichloroethylene	2.9E-07	lb
Methylene Chloride	1.3E-06	lb
Carbon Tetrachloride	6.3E-07	lb
Phenols	1.5E-06	lb
Naphthalene	6.6E-08	lb
Dioxins	1.7E-12	lb
n-Nitrosodimethylamine	6.5E-08	lb
Radionuclides	6.5E-06	lb
Solid Wastes-Process		
Unspecified	3.36	lb
Solid Wastes-Fuel-related		
ash	9.31	lb
Waterborne Wastes-Process		
Acid	1.1E-06	lb
Metal Ion	0.024	lb
Dissolved Solids	0.94	lb
Suspended Solids	0.013	lb

BOD	0.014	lb
COD	0.066	lb
Phenol	7.8E-05	lb
Oil	8.1E-04	lb
Iron	4.2E-04	lb
Chromium	4.5E-06	lb
Lead	2.0E-06	lb
Zinc	3.0E-05	lb
Ammonia	0.0018	lb
Waterborne Wastes-Fuel-related		
Acid	2.0E-08	lb
Metal Ion	4.2E-04	lb
Dissolved Solids	3.04	lb
Suspended Solids	0.070	lb
BOD	0.0032	lb
COD	0.043	lb
Phenol	1.3E-06	lb
Oil	0.054	lb
Sulfuric Acid	7.8E-04	lb
Iron	0.0012	lb
Ammonia	9.9E-05	lb
Chromium	1.4E-04	lb
Lead	3.5E-08	lb
Zinc	4.7E-05	lb
Chloride	0.14	lb
Sodium	1.2E-05	lb
Calcium	6.5E-06	lb
Sulfates	0.11	lb
Manganese	6.7E-04	lb
Fluorides	3.0E-05	lb
Nitrates	2.8E-06	lb
Phosphates	3.9E-04	lb
Boron	0.0031	lb
Other Organics	0.0092	lb
Chromates	1.4E-05	lb
Cyanide	2.0E-07	lb
Mercury	1.1E-08	lb
Cadmium	1.4E-04	lb

Source: Franklin Associates, Ltd.

Table C-5

LCI RESULTS FOR THE CRADLE-TO-GRAVE PRODUCTION OF 1,000 POUNDS OF ASPHALT

(Includes Crude oil production, desalting, distillation, and deasphalting)

Energy Usage			**Energy Million Btu**
Energy of Material Resource			
Petroleum			20.1
Total Resource			20.1
Combustion Process Energy			
Electricity	28.6	kwh	0.31
Natural gas	1,482	cu ft	1.53
LPG	0.27	gal	0.026
Distillate oil	0.21	gal	0.029
Residual oil	2.16	gal	0.32
Gasoline	0.094	gal	0.012
Total Combustion Process			2.22
Precombustion Process Energy			
Natural gas	189	cu ft	0.19
Residual oil	0.15	gal	0.022
Distillate oil	0.069	gal	0.0096
Gasoline	0.085	gal	0.011
LPG	0.0040	gal	3.8E-04
Coal	1.46	lb	0.015
Nuclear	5.9E-06	lb U238	0.0058
Hydropower	0.94	thousand Btu	9.4E-04
Other	0.83	thousand Btu	8.3E-04
Total Precombustion Process			0.26
Combustion Transportation Energy			
Combination truck	10.1	ton-miles	
Diesel	0.094	gal	0.013
Ocean freighter	2,038	ton-miles	
Diesel	0.20	gal	0.028
Residual	3.67	gal	0.55
Pipeline-petroleum products	143	ton-miles	
Electricity	3.14	kwh	0.035
Total Combustion Transportation			0.63
Precombustion Transportation Energy			
Natural gas	44.2	cu ft	0.045
Residual oil	0.17	gal	0.026
Distillate oil	0.021	gal	0.0029
Gasoline	0.0058	gal	7.3E-04
LPG	0.0056	gal	5.3E-04
Coal	0.59	lb	0.0061
Nuclear	2.4E-06	lb U238	0.0024
Hydropower	0.38	thousand Btu	3.8E-04
Other	0.34	thousand Btu	3.4E-04

Total Precombustion Transportation	0.084	

Environmental Emissions

Atmospheric Emissions-Process		
Particulates	0.060	lb
Hydrocarbons	6.10	lb
Sulfur Oxides	0.20	lb
Aldehydes	0.040	lb
Ammonia	0.0053	lb
Lead	1.4E-06	lb
Chlorine	2.1E-04	lb
Hydrochloric Acid	1.6E-04	lb
Atmospheric Emissions-Fuel-related		
Particulates	0.20	lb
Nitrogen Oxides	1.35	lb
Hydrocarbons	1.24	lb
Sulfur Oxides	4.25	lb
Carbon Monoxide	0.93	lb
Formaldehyde	3.6E-06	lb
Other Aldehydes	0.026	lb
Methane	0.71	lb
Other Organics	0.042	lb
Kerosene	1.8E-05	lb
Ammonia	5.8E-04	lb
Lead	2.2E-05	lb
Chlorine	1.1E-05	lb
Fossil Carbon Dioxide	431	lb
Non-Fossil Carbon Dioxide	0.10	lb
Hydrochloric Acid	0.0037	lb
Hydrogen Fluoride	5.1E-04	lb
Metals	4.1E-05	lb
Antimony	6.6E-06	lb
Arsenic	1.4E-05	lb
Beryllium	9.7E-07	lb
Cadmium	2.1E-05	lb
Chromium	1.6E-05	lb
Cobalt	1.9E-05	lb
Manganese	1.4E-05	lb
Mercury	4.4E-06	lb
Nickel	2.9E-04	lb
Selenium	1.2E-05	lb
Acreolin	7.2E-07	lb
Nitrous Oxide	4.2E-04	lb
Benzene	8.2E-07	lb
Perchloroethylene	6.9E-07	lb
Trichloroethylene	6.8E-07	lb
Methylene Chloride	3.2E-06	lb
Carbon Tetrachloride	1.4E-06	lb
Phenols	3.5E-06	lb
Naphthalene	1.4E-07	lb
Dioxins	4.0E-12	lb
n-Nitrosodimethylamine	1.5E-07	lb

Radionuclides	1.5E-05	lb
Solid Wastes-Process		
Unspecified	3.96	lb
Solid Wastes-Fuel-related		
ash	18.0	lb
Waterborne Wastes-Process		
Acid	1.1E-06	lb
Metal Ion	0.024	lb
Dissolved Solids	0.94	lb
Suspended Solids	0.013	lb
BOD	0.014	lb
COD	0.066	lb
Phenol	7.8E-05	lb
Oil	0.044	lb
Iron	4.2E-04	lb
Chromium	4.5E-06	lb
Lead	2.0E-06	lb
Zinc	3.0E-05	lb
Ammonia	0.0018	lb
Waterborne Wastes-Fuel-related		
Acid	6.1E-08	lb
Metal Ion	0.0013	lb
Dissolved Solids	4.99	lb
Suspended Solids	0.12	lb
BOD	0.0056	lb
COD	0.072	lb
Phenol	4.2E-06	lb
Oil	0.089	lb
Sulfuric Acid	0.0012	lb
Iron	0.0028	lb
Ammonia	2.2E-04	lb
Chromium	2.3E-04	lb
Lead	1.1E-07	lb
Zinc	7.8E-05	lb
Chloride	0.23	lb
Sodium	2.8E-05	lb
Calcium	1.5E-05	lb
Sulfates	0.18	lb
Manganese	0.0016	lb
Fluorides	7.1E-05	lb
Nitrates	6.7E-06	lb
Phosphates	5.8E-04	lb
Boron	0.0046	lb
Other Organics	0.015	lb
Chromates	1.7E-05	lb
Cyanide	3.3E-07	lb
Mercury	1.7E-08	lb
Cadmium	2.3E-04	lb

Source: Franklin Associates, Ltd.

Table C-6

DATA FOR THE PRODUCTION OF 1,000 POUNDS OF AVERAGE REFINERY PRODUCTS

Energy Usage		
Process Energy		
Electricity	10.0	kwh
Natural gas	593	cu ft
LPG	0.17	gal
Residual oil	1.19	gal
Total Process		
Environmental Emissions		
Atmospheric Emissions		
Hydrocarbons	1.38	lb
Particulates	0.060	lb
Sulfur Oxides	0.20	lb
Aldehydes	0.040	lb
Ammonia	0.0053	lb
Lead	1.4E-06	lb
Chlorine	2.1E-04	lb
Hydrochloric Acid	1.6E-04	lb
Solid Wastes	3.36	lb
Waterborne Wastes		
BOD	0.014	lb
COD	0.066	lb
Suspended Solids	0.013	lb
Dissolved solids	0.94	lb
Acid	1.1E-06	lb
Metal ion	0.024	lb
Phenol	7.8E-05	lb
Oil	8.1E-04	lb
Iron	4.2E-04	lb
Ammonia	0.0018	lb
Chromium	4.5E-06	lb
Lead	2.0E-06	lb
Zinc	3.0E-05	lb

Source: Franklin Associates, Ltd.

Table C-7

LCI RESULTS FOR THE CRADLE-TO-GRAVE PRODUCTION OF 1,000 POUNDS OF REFINED PETROLEUM

(Includes Crude oil production, desalting, distillation, and hydrotreating)

Energy Usage			**Energy Million Btu**
Energy of Material Resource			
Petroleum			20.1
Total Resource			20.1
Combustion Process Energy			
Electricity	25.3	kwh	0.27
Natural gas	1,138	cu ft	1.17
LPG	0.17	gal	0.016
Distillate oil	0.21	gal	0.029
Residual oil	1.45	gal	0.22
Gasoline	0.094	gal	0.012
Total Combustion Process			1.72
Precombustion Process Energy			
Natural gas	144	cu ft	0.15
Residual oil	0.11	gal	0.016
Distillate oil	0.054	gal	0.0075
Gasoline	0.065	gal	0.0082
LPG	0.0028	gal	2.7E-04
Coal	1.13	lb	0.012
Nuclear	4.6E-06	lb U238	0.0045
Hydropower	0.73	thousand Btu	7.3E-04
Other	0.64	thousand Btu	6.4E-04
Total Precombustion Process			0.20
Combustion Transportation Energy			
Combination truck	10.1	ton-miles	
Diesel	0.094	gal	0.013
Ocean freighter	2,038	ton-miles	
Diesel	0.20	gal	0.028
Residual	3.67	gal	0.55
Pipeline-petroleum products	143	ton-miles	
Electricity	3.14	kwh	0.035
Total Combustion Transportation			0.63
Precombustion Transportation Energy			
Natural gas	44.2	cu ft	0.045
Residual oil	0.17	gal	0.026
Distillate oil	0.021	gal	0.0029
Gasoline	0.0058	gal	7.3E-04
LPG	0.0056	gal	5.3E-04
Coal	0.59	lb	0.0061
Nuclear	2.4E-06	lb U238	0.0024
Hydropower	0.38	thousand Btu	3.8E-04
Other	0.34	thousand Btu	3.4E-04

Total Precombustion Transportation		0.084

Environmental Emissions

Atmospheric Emissions-Process		
Particulates	0.060	lb
Hydrocarbons	6.10	lb
Sulfur Oxides	0.20	lb
Aldehydes	0.040	lb
Ammonia	0.0053	lb
Lead	1.4E-06	lb
Chlorine	2.1E-04	lb
Hydrochloric Acid	1.6E-04	lb
Atmospheric Emissions-Fuel-related		
Particulates	0.18	lb
Nitrogen Oxides	1.14	lb
Hydrocarbons	1.01	lb
Sulfur Oxides	3.32	lb
Carbon Monoxide	0.82	lb
Formaldehyde	3.2E-06	lb
Other Aldehydes	0.026	lb
Methane	0.56	lb
Other Organics	0.041	lb
Kerosene	1.6E-05	lb
Ammonia	5.2E-04	lb
Lead	1.6E-05	lb
Chlorine	1.0E-05	lb
Fossil Carbon Dioxide	358	lb
Non-Fossil Carbon Dioxide	0.085	lb
Hydrochloric Acid	0.0033	lb
Hydrogen Fluoride	4.5E-04	lb
Metals	3.5E-05	lb
Antimony	4.6E-06	lb
Arsenic	9.6E-06	lb
Beryllium	7.1E-07	lb
Cadmium	1.4E-05	lb
Chromium	1.2E-05	lb
Cobalt	1.3E-05	lb
Manganese	1.1E-05	lb
Mercury	3.3E-06	lb
Nickel	2.0E-04	lb
Selenium	9.2E-06	lb
Acreolin	6.4E-07	lb
Nitrous Oxide	3.7E-04	lb
Benzene	7.2E-07	lb
Perchloroethylene	6.2E-07	lb
Trichloroethylene	6.1E-07	lb
Methylene Chloride	2.8E-06	lb
Carbon Tetrachloride	1.3E-06	lb
Phenols	3.0E-06	lb
Naphthalene	1.2E-07	lb
Dioxins	3.6E-12	lb
n-Nitrosodimethylamine	1.4E-07	lb

Radionuclides	1.4E-05	lb
Solid Wastes-Process		
Unspecified	3.96	lb
Solid Wastes-Fuel-related		
ash	15.0	lb
Waterborne Wastes-Process		
Acid	1.1E-06	lb
Metal Ion	0.024	lb
Dissolved Solids	0.94	lb
Suspended Solids	0.013	lb
BOD	0.014	lb
COD	0.066	lb
Phenol	7.8E-05	lb
Oil	0.044	lb
Iron	4.2E-04	lb
Chromium	4.5E-06	lb
Lead	2.0E-06	lb
Zinc	3.0E-05	lb
Ammonia	0.0018	lb
Waterborne Wastes-Fuel-related		
Acid	5.4E-08	lb
Metal Ion	0.0011	lb
Dissolved Solids	3.88	lb
Suspended Solids	0.099	lb
BOD	0.0044	lb
COD	0.056	lb
Phenol	3.7E-06	lb
Oil	0.069	lb
Sulfuric Acid	8.9E-04	lb
Iron	0.0025	lb
Ammonia	1.8E-04	lb
Chromium	1.8E-04	lb
Lead	9.5E-08	lb
Zinc	6.1E-05	lb
Chloride	0.18	lb
Sodium	2.5E-05	lb
Calcium	1.4E-05	lb
Sulfates	0.14	lb
Manganese	0.0014	lb
Fluorides	6.3E-05	lb
Nitrates	5.9E-06	lb
Phosphates	4.4E-04	lb
Boron	0.0035	lb
Other Organics	0.012	lb
Chromates	1.2E-05	lb
Cyanide	2.6E-07	lb
Mercury	1.3E-08	lb
Cadmium	1.8E-04	lb

Source: Franklin Associates, Ltd.

Table C-8

LCI RESULTS FOR THE PRODUCTION OF 1,000 POUNDS OF CRUDE OIL USING CANADIAN TRANSPORTATION

Energy Usage			**Energy Million Btu**
Energy of Material Resource			
Petroleum	1,035	lb	20.0
Total Resource			20.0
Combustion Process Energy			
Electricity	15.2	kwh	0.16
Natural gas	542	cu ft	0.56
Distillate oil	0.21	gal	0.029
Residual oil	0.26	gal	0.039
Gasoline	0.094	gal	0.012
Total Combustion Process			0.80
Precombustion Process Energy			
Natural gas	65.7	cu ft	0.068
Residual oil	0.037	gal	0.0055
Distillate oil	0.026	gal	0.0036
Gasoline	0.031	gal	0.0039
LPG	8.8E-04	gal	8.4E-05
Coal	0.52	lb	0.0058
Nuclear	2.1E-06	lb U238	0.0021
Hydropower	0.34	thousand Btu	3.4E-04
Other	0.30	thousand Btu	3.0E-04
Total Precombustion Process			0.089
Combustion Transportation Energy			
Ocean freighter	620	ton-miles	
Diesel	0.06	gal	0.009
Residual	1.12	gal	0.17
Pipeline-petroleum products	322	ton-miles	
Electricity	7.08	kwh	0.076
Total Combustion Transportation			0.25
Precombustion Transportation Energy			
Natural gas	14.6	cu ft	0.015
Residual oil	0.05	gal	0.008
Distillate oil	0.010	gal	0.0013
Gasoline	0.0024	gal	3.0E-04
LPG	0.0017	gal	1.6E-04
Coal	0.24	lb	0.0027
Nuclear	9.6E-07	lb U238	0.0009
Hydropower	0.15	thousand Btu	1.5E-04
Other	0.14	thousand Btu	1.4E-04
Total Precombustion Transportation			0.029

Environmental Emissions

Atmospheric Emissions-Process		
Hydrocarbons	4.70	lb
Atmospheric Emissions-Fuel-related		
Particulates	0.08	lb
Nitrogen Oxides	0.50	lb
Hydrocarbons	0.43	lb
Sulfur Oxides	1.53	lb
Carbon Monoxide	0.57	lb
Formaldehyde	2.4E-06	lb
Other Aldehydes	0.008	lb
Methane	0.29	lb
Other Organics	0.009	lb
Kerosene	1.2E-05	lb
Ammonia	2.8E-04	lb
Lead	4.3E-06	lb
Chlorine	3.1E-06	lb
Fossil Carbon Dioxide	154	lb
Non-Fossil Carbon Dioxide	0.038	lb
Hydrochloric Acid	0.0025	lb
Hydrogen Fluoride	3.4E-04	lb
Metals	1.6E-05	lb
Antimony	1.0E-06	lb
Arsenic	2.7E-06	lb
Beryllium	2.6E-07	lb
Cadmium	2.9E-06	lb
Chromium	4.0E-06	lb
Cobalt	3.0E-06	lb
Manganese	4.8E-06	lb
Mercury	1.3E-06	lb
Nickel	4.4E-05	lb
Selenium	4.3E-06	lb
Acreolin	4.9E-07	lb
Nitrous Oxide	2.8E-04	lb
Benzene	5.0E-07	lb
Perchloroethylene	4.6E-07	lb
Trichloroethylene	4.6E-07	lb
Methylene Chloride	2.1E-06	lb
Carbon Tetrachloride	9.0E-07	lb
Phenols	1.8E-06	lb
Naphthalene	6.4E-08	lb
Dioxins	2.7E-12	lb
n-Nitrosodimethylamine	1.0E-07	lb
Radionuclides	1.0E-05	lb
Solid Wastes-Process		
Unspecified	0.60	lb
Solid Wastes-Fuel-related		
ash	9.34	lb
Waterborne Wastes-Process		
Oil	0.043	lb

Waterborne Wastes-Fuel-related		
Acid	1.6E-08	lb
Metal Ion	3.5E-04	lb
Dissolved Solids	1.86	lb
Suspended Solids	0.054	lb
BOD	0.0020	lb
COD	0.026	lb
Phenol	1.1E-06	lb
Oil	0.033	lb
Sulfuric Acid	4.0E-04	lb
Iron	0.0018	lb
Ammonia	7.8E-05	lb
Chromium	8.4E-05	lb
Lead	2.9E-08	lb
Zinc	2.9E-05	lb
Chloride	0.084	lb
Sodium	1.9E-05	lb
Calcium	1.0E-05	lb
Sulfates	0.071	lb
Manganese	1.1E-03	lb
Fluorides	4.7E-05	lb
Nitrates	4.5E-06	lb
Phosphates	2.0E-04	lb
Boron	0.0016	lb
Other Organics	0.0056	lb
Chromates	2.6E-06	lb
Cyanide	1.2E-07	lb
Mercury	6.5E-09	lb
Cadmium	8.4E-05	lb

Source: Franklin Associates, Ltd.

Table C-9

LCI RESULTS FOR THE CRADLE-TO-GRAVE PRODUCTION OF 1,000 POUNDS OF ASPHALT USING CANADIAN TRANSPORTATION

(Includes Crude oil production, desalting, distillation, and deasphalting)

Energy Usage			**Energy Million Btu**
Energy of Material Resource			
Petroleum			20.1
Total Resource			20.1
Combustion Process Energy			
Electricity	28.6	kwh	0.31
Natural gas	1,482	cu ft	1.53
LPG	0.27	gal	0.026
Distillate oil	0.21	gal	0.029
Residual oil	2.16	gal	0.32
Gasoline	0.094	gal	0.012
Total Combustion Process			2.22
Precombustion Process Energy			
Natural gas	189	cu ft	0.19
Residual oil	0.15	gal	0.022
Distillate oil	0.069	gal	0.0096
Gasoline	0.085	gal	0.011
LPG	0.0040	gal	3.8E-04
Coal	1.46	lb	0.015
Nuclear	5.9E-06	lb U238	0.0058
Hydropower	0.94	thousand Btu	9.4E-04
Other	0.83	thousand Btu	8.3E-04
Total Precombustion Process			0.26
Combustion Transportation Energy			
Ocean freighter	623	ton-miles	
Diesel	0.062	gal	0.0086
Residual	1.12	gal	0.17
Pipeline-petroleum products	324	ton-miles	
Electricity	7.12	kwh	0.079
Total Combustion Transportation			0.26
Precombustion Transportation Energy			
Natural gas	14.7	cu ft	0.045
Residual oil	0.052	gal	0.0078
Distillate oil	0.0097	gal	0.0013
Gasoline	0.0024	gal	3.0E-04
LPG	0.0017	gal	1.6E-04
Coal	0.24	lb	0.0061
Nuclear	9.7E-07	lb U238	9.5E-04
Hydropower	0.15	thousand Btu	1.5E-04
Other	0.14	thousand Btu	1.4E-04
Total Precombustion Transportation			0.062

Environmental Emissions

Atmospheric Emissions-Process		
Particulates	0.060	lb
Hydrocarbons	6.10	lb
Sulfur Oxides	0.20	lb
Aldehydes	0.040	lb
Ammonia	0.0053	lb
Lead	1.4E-06	lb
Chlorine	2.1E-04	lb
Hydrochloric Acid	1.6E-04	lb
Atmospheric Emissions-Fuel-related		
Particulates	0.14	lb
Nitrogen Oxides	1.11	lb
Hydrocarbons	1.07	lb
Sulfur Oxides	4.12	lb
Carbon Monoxide	0.87	lb
Formaldehyde	3.9E-06	lb
Other Aldehydes	0.0095	lb
Methane	0.71	lb
Other Organics	0.011	lb
Kerosene	1.9E-05	lb
Ammonia	5.0E-04	lb
Lead	2.2E-05	lb
Chlorine	6.8E-06	lb
Fossil Carbon Dioxide	359	lb
Non-Fossil Carbon Dioxide	0.085	lb
Hydrochloric Acid	0.0040	lb
Hydrogen Fluoride	5.5E-04	lb
Metals	3.5E-05	lb
Antimony	6.5E-06	lb
Arsenic	1.4E-05	lb
Beryllium	9.8E-07	lb
Cadmium	2.0E-05	lb
Chromium	1.6E-05	lb
Cobalt	1.9E-05	lb
Manganese	1.4E-05	lb
Mercury	4.5E-06	lb
Nickel	2.9E-04	lb
Selenium	1.2E-05	lb
Acreolin	7.9E-07	lb
Nitrous Oxide	4.5E-04	lb
Benzene	8.5E-07	lb
Perchloroethylene	7.6E-07	lb
Trichloroethylene	7.5E-07	lb
Methylene Chloride	3.5E-06	lb
Carbon Tetrachloride	1.5E-06	lb
Phenols	3.3E-06	lb
Naphthalene	1.3E-07	lb
Dioxins	4.4E-12	lb
n-Nitrosodimethylamine	1.7E-07	lb
Radionuclides	1.7E-05	lb

Solid Wastes-Process		
Unspecified	3.96	lb
Solid Wastes-Fuel-related		
ash	18.7	lb
Waterborne Wastes-Process		
Acid	1.1E-06	lb
Metal Ion	0.024	lb
Dissolved Solids	0.94	lb
Suspended Solids	0.013	lb
BOD	0.014	lb
COD	0.066	lb
Phenol	7.8E-05	lb
Oil	0.044	lb
Iron	4.2E-04	lb
Chromium	4.5E-06	lb
Lead	2.0E-06	lb
Zinc	3.0E-05	lb
Ammonia	0.0018	lb
Waterborne Wastes-Fuel-related		
Acid	3.6E-08	lb
Metal Ion	7.6E-04	lb
Dissolved Solids	4.90	lb
Suspended Solids	0.12	lb
BOD	0.0052	lb
COD	0.070	lb
Phenol	2.5E-06	lb
Oil	0.087	lb
Sulfuric Acid	0.0012	lb
Iron	0.0030	lb
Ammonia	1.8E-04	lb
Chromium	2.2E-04	lb
Lead	6.4E-08	lb
Zinc	7.6E-05	lb
Chloride	0.22	lb
Sodium	3.1E-05	lb
Calcium	1.7E-05	lb
Sulfates	0.18	lb
Manganese	0.0017	lb
Fluorides	7.8E-05	lb
Nitrates	7.3E-06	lb
Phosphates	6.0E-04	lb
Boron	0.0048	lb
Other Organics	0.015	lb
Chromates	1.7E-05	lb
Cyanide	3.3E-07	lb
Mercury	1.7E-08	lb
Cadmium	2.2E-04	lb

Source: Franklin Associates, Ltd.

Table C-10

LCI RESULTS FOR THE CRADLE-TO-GRAVE PRODUCTION OF 1,000 POUNDS OF REFINED PETROLEUM USING CANADIAN TRANSPORTATION

(Includes Crude oil production, desalting, distillation, and hydrotreating)

Energy Usage			Energy Million Btu
Energy of Material Resource			
Petroleum			20.1
Total Resource			20.1
Combustion Process Energy			
Electricity	25.3	kwh	0.27
Natural gas	1,138	cu ft	1.17
LPG	0.17	gal	0.016
Distillate oil	0.21	gal	0.029
Residual oil	1.45	gal	0.22
Gasoline	0.094	gal	0.012
Total Combustion Process			1.72
Precombustion Process Energy			
Natural gas	144	cu ft	0.15
Residual oil	0.11	gal	0.016
Distillate oil	0.054	gal	0.0075
Gasoline	0.065	gal	0.0082
LPG	0.0028	gal	2.7E-04
Coal	1.13	lb	0.012
Nuclear	4.6E-06	lb U238	0.0045
Hydropower	0.73	thousand Btu	7.3E-04
Other	0.64	thousand Btu	6.4E-04
Total Precombustion Process			0.20
Combustion Transportation Energy			
Ocean freighter	623	ton-miles	
Diesel	0.062	gal	0.0086
Residual	1.12	gal	0.17
Pipeline-petroleum products	324	ton-miles	
Electricity	7.12	kwh	0.079
Total Combustion Transportation			0.26
Precombustion Transportation Energy			
Natural gas	14.7	cu ft	0.045
Residual oil	0.052	gal	0.0078
Distillate oil	0.0097	gal	0.0013
Gasoline	0.0024	gal	3.0E-04
LPG	0.0017	gal	1.6E-04
Coal	0.24	lb	0.0061
Nuclear	9.7E-07	lb U238	9.5E-04
Hydropower	0.15	thousand Btu	1.5E-04
Other	0.14	thousand Btu	1.4E-04
Total Precombustion Transportation			0.062

Environmental Emissions

Atmospheric Emissions-Process		
Particulates	0.060	lb
Hydrocarbons	6.10	lb
Sulfur Oxides	0.20	lb
Aldehydes	0.040	lb
Ammonia	0.0053	lb
Lead	1.4E-06	lb
Chlorine	2.1E-04	lb
Hydrochloric Acid	1.6E-04	lb
Atmospheric Emissions-Fuel-related		
Particulates	0.14	lb
Nitrogen Oxides	1.11	lb
Hydrocarbons	1.07	lb
Sulfur Oxides	4.12	lb
Carbon Monoxide	0.87	lb
Formaldehyde	3.9E-06	lb
Other Aldehydes	0.0095	lb
Methane	0.71	lb
Other Organics	0.011	lb
Kerosene	1.9E-05	lb
Ammonia	5.0E-04	lb
Lead	2.2E-05	lb
Chlorine	6.8E-06	lb
Fossil Carbon Dioxide	359	lb
Non-Fossil Carbon Dioxide	0.085	lb
Hydrochloric Acid	0.0040	lb
Hydrogen Fluoride	5.5E-04	lb
Metals	3.5E-05	lb
Antimony	6.5E-06	lb
Arsenic	1.4E-05	lb
Beryllium	9.8E-07	lb
Cadmium	2.0E-05	lb
Chromium	1.6E-05	lb
Cobalt	1.9E-05	lb
Manganese	1.4E-05	lb
Mercury	4.5E-06	lb
Nickel	2.9E-04	lb
Selenium	1.2E-05	lb
Acreolin	7.9E-07	lb
Nitrous Oxide	4.5E-04	lb
Benzene	8.5E-07	lb
Perchloroethylene	7.6E-07	lb
Trichloroethylene	7.5E-07	lb
Methylene Chloride	3.5E-06	lb
Carbon Tetrachloride	1.5E-06	lb
Phenols	3.3E-06	lb
Naphthalene	1.3E-07	lb
Dioxins	4.4E-12	lb
n-Nitrosodimethylamine	1.7E-07	lb
Radionuclides	1.7E-05	lb

Solid Wastes-Process		
Unspecified	3.96	lb
Solid Wastes-Fuel-related		
ash	18.7	lb
Waterborne Wastes-Process		
Acid	1.1E-06	lb
Metal Ion	0.024	lb
Dissolved Solids	0.94	lb
Suspended Solids	0.013	lb
BOD	0.014	lb
COD	0.066	lb
Phenol	7.8E-05	lb
Oil	0.044	lb
Iron	4.2E-04	lb
Chromium	4.5E-06	lb
Lead	2.0E-06	lb
Zinc	3.0E-05	lb
Ammonia	0.0018	lb
Waterborne Wastes-Fuel-related		
Acid	3.6E-08	lb
Metal Ion	7.6E-04	lb
Dissolved Solids	4.90	lb
Suspended Solids	0.12	lb
BOD	0.0052	lb
COD	0.070	lb
Phenol	2.5E-06	lb
Oil	0.087	lb
Sulfuric Acid	0.0012	lb
Iron	0.0030	lb
Ammonia	1.8E-04	lb
Chromium	2.2E-04	lb
Lead	6.4E-08	lb
Zinc	7.6E-05	lb
Chloride	0.22	lb
Sodium	3.1E-05	lb
Calcium	1.7E-05	lb
Sulfates	0.18	lb
Manganese	0.0017	lb
Fluorides	7.8E-05	lb
Nitrates	7.3E-06	lb
Phosphates	6.0E-04	lb
Boron	0.0048	lb
Other Organics	0.015	lb
Chromates	1.7E-05	lb
Cyanide	3.3E-07	lb
Mercury	1.7E-08	lb
Cadmium	2.2E-04	lb

Source: Franklin Associates, Ltd.