Life Cycle Assessment of Asphalt Binder, 2019

- Executive Summary -

1. Goal of the Study

More and more frequently, companies from all industry sectors located at different points in their respective value chain are being asked to supply information about the potential environmental impacts of their products. Life cycle assessment (LCA) as governed by the international standards ISO 14040 and 14044 is a science-based method used to quantify these potential impacts occurring throughout the supply chain of a given product. Driven by green building standards (e.g., LEED, Living Building Challenge, IgCC) and other initiatives, the availability of accurate life cycle inventory (LCI) and life cycle impact assessment (LCIA) data have become a market demand for products used in the construction sector, including pavements. Transportation agencies such as the Illinois Toll Road Authority and the California Transportation Department are starting to look at how they can use such information in their project plans and designs (Ozer and Al-Qadi 2017, California Department of Transportation 2018).

With this study, the Asphalt Institute (AI) provides an industry-average LCI dataset on asphalt binders to provide data that are representative of North American industry conditions. Along with aggregate, asphalt binder is the major component of asphalt mixtures. As environmental profiles for asphalt mixture are being developed, AI wants to ensure that the background data for the asphalt binder are as accurate as possible. This is especially relevant as the National Asphalt Pavement Association (NAPA) has completed its Environmental Product Declaration (EPD) program for asphalt mixtures, using the Product Category Rule (PCR) for asphalt mixtures it helped develop (NAPA 2017). The NAPA EPD program is planning to use the datasets produced by this study.

2. Scope of the Study

This study covers several asphalt binders manufactured by AI members in North America:

- Asphalt binder without additives
- Asphalt binder with 3.5% styrene-butadiene-styrene (SBS)
- Asphalt binder with 8% ground tire rubber (GTR) (terminal blend)
- Asphalt binder with 0.5% polyphosphoric acid (PPA)

This industry-average assessment is based on information supplied by twelve AI member refineries (from nine companies) and eleven terminals (from four companies) in the U.S. and Canada. The declared unit of these four products is ***1 kilogram of asphalt binder*.** The scope of this cradle-to-gate study includes raw material sourcing and extraction, transportation to refineries, refining of crude oil into asphalt, transport to the terminal, and final blending of the asphalt binders at the terminal. Only those refinery processes that are associated with asphalt production were included in the assessment.

2.1. Representativeness

The data are intended to represent asphalt production during the 2015 and 2016 calendar years for the four types of asphalt binders as produced by AI members in North America. To assess geographical representativeness the total asphalt and road oil capacity of the five US PADD regions and Canada were compared to the reported asphalt capacity of the participating facilities. The geographical representativeness is considered to be good, per the method described in the full report (Koffler, Shonfield and Vickers 2016).

The representative asphalt data provided accounts for 24% of asphalt capacity in the United States and Canada as of the beginning of 2017 and 27% of annual production for 2016 (EIA 2017b, Government of Canada 2017). Finally, the technological representativeness was evaluated based on facility size, as a proxy for overall efficiency, according to reported asphalt and road oil production capacity. It was also found to be good.

2.2. Allocation

Since asphalt is only one product stream in a complex multi-product system (refinery), it is crucial that the allocation methodology appropriately captures only that share of the total impacts of the system that can be attributed to the asphalt binder. For this study, the main material and energy inputs that needed to be allocated were crude oil input, thermal energy consumption (including associated emissions), and electricity. Mass allocation was selected for the electricity because the density of products is directly related to the electrical demand for pumping the products. Energy content of the co-products (using the net calorific value a.k.a. lower heating value) was selected as the allocation methodology for crude oil input, as it accounts for the fact that the majority of co-products are used as fuels. The thermal energy demand for asphalt production was calculated based on the sensible heat of asphalt in the system, i.e., based on the temperature differential between the crude tank and the asphalt going to storage in combination with the specific heat capacity of the asphalt. Finally, the total direct emissions of thermal energy production were allocated based on the ratio of thermal energy use (excluding recovered heat) calculated for asphalt production and the refinery's total thermal energy consumption during asphalt runs only.

2.3. Crude Oil Slate

The production stage starts with extraction of crude oil and delivery to the refinery. Crude oil is modeled based on thinkstep's proprietary crude oil supply model, which considers the whole supply chain of crude oil (i.e., extraction, production, processing, the long-distance transport and the regional distribution to the refinery) and forms the basis of all refinery product inventories in the GaBi databases (thinkstep 2016). Companies were asked to provide crude name, region of origin, extraction technology, and mode of transportation. In many cases, primary information on the extraction technology was not available, in which case it was selected and modeled based on crude name. When the name alone did not provide enough information to select an extraction technology, it was modeled using the region of origin's average crude slate mix as a proxy.

Table 1: Crude oil extraction method of AI asphalt binder

Category of extraction technology	Percentage (by mass)
Crude from oil sands	44%
Primary extraction	22%
Secondary extraction	16%
Tertiary extraction, steam injection	15%
Tertiary extraction, CO_2 injection	1%
Tertiary extraction, nitrogen injection	1%
Tertiary extraction, natural gas injection	1%
Other (refinery products)	<1%

The resulting average crude oil slate for North American asphalt binder is used for this report and represents a mix of conventional (primary, secondary and tertiary production) and unconventional (oil sands, in-situ) extraction technologies (Table 1).

AI member's asphalt binder products are manufactured in Canada and the United States, with 85% of crude oil sourced from those nations.

2.4. Asphalt Production

Crude oil refinery activities begin with the input of crude oil. Crude is fed to the desalter where it is partially heated and mixed with water to dissolve salts. The water is separated and removed. Next, the crude oil enters the atmospheric distillation unit, where it is heated and distilled. All products lighter than heavy gas oil vaporize and the energy required for vaporization is fully attributable to those lighter products. The residue from the atmospheric distillation is introduced to the vacuum distillation unit. The atmospheric residue is heated and further distilled under a vacuum, vaporizing all gas oils and any remaining diesel, with asphalt remaining as a hot liquid in the bottom of the vacuum distillation tower. The hot asphalt passes through heat exchangers alongside other refinery feeds, mostly in the crude and vacuum distillation units, to return heat to the process, before going to asphalt storage.

While process-specific electricity, thermal energy, water usage, and emissions would have been preferred, these data points were not available. Therefore, refinery-level data were collected for site-wide consumption of electricity, thermal energy, and water as well as direct emissions and allocated to the asphalt product as described in section 2.2.

2.5. Asphalt terminal

The processes within each refinery were vertically aggregated first and then combined into one production-weighted average. This average asphalt production process then provided the input of asphalt to the average terminal process.

At the asphalt terminal, hot liquid asphalt is stored, additives (ground tire rubber, styrene-butadiene-styrene, or polyphosphoric acid) are mixed or milled into the asphalt, and hot liquid asphalt is further distributed. The terminals consume electricity (mainly used for milling) and thermal energy (used for storage). Terminals can be either co-located with the refinery or off-site. For this study, all participating companies were located off-site. Inbound transportation from the refinery to the terminal is a production weighted average of the distances and modes collected from the companies.

3. Results

The reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions (a) followed the underlying impact pathway and (b) met certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach). Results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks. Table 2 presents the total cradle-to-gate environmental impact results for all four products.

Table 2: Impact assessment, per kg (IPCC 2013, EPA 2012)

Impact Category	Unit	Asphalt binder, no additives	Asphalt binder, with 8% GTR	Asphalt binder, with 0.5% PPA	Asphalt binder, with 3.5% SBS
IPCC AR5					
Global warming potential [GWP100]	kg CO_2 eq	**0.637**	**0.621**	**0.654**	**0.765**
Global warming potential [GWP20]	kg CO_2 eq	**0.766**	**0.745**	**0.786**	**0.918**
TRACI 2.1					
Acidification potential (AP)	kg SO_2 eq	**1.78E-03**	**1.69E-03**	**1.96E-03**	**2.12E-03**

Impact Category	Unit	Asphalt binder, no additives	Asphalt binder, with 8% GTR	Asphalt binder, with 0.5% PPA	Asphalt binder, with 3.5% SBS
Eutrophication potential (EP)	kg N eq	1.66E-04	1.57E-04	1.69E-04	1.82E-04
Smog formation potential (SFP)	kg O_3 eq	0.0360	0.0347	0.0365	0.0427
Fossil fuel consumption (FF)	MJ (NCV)	5.32	4.98	5.36	5.66
Total use of non-renewable primary energy resources (PED)	MJ (NCV)	53.2	52.2	53.5	55.2
Use of net fresh water (excl. rain water)	L	1.01	0.92	1.06	1.44
Use of net fresh water (incl. rain water)	L	1.68	1.57	1.76	2.40

Figure 1 presents the relative results of asphalt without additives leaving the terminal, broken down by crude oil extraction and transport, refinery operations, and terminal operations (including transport to the terminal).

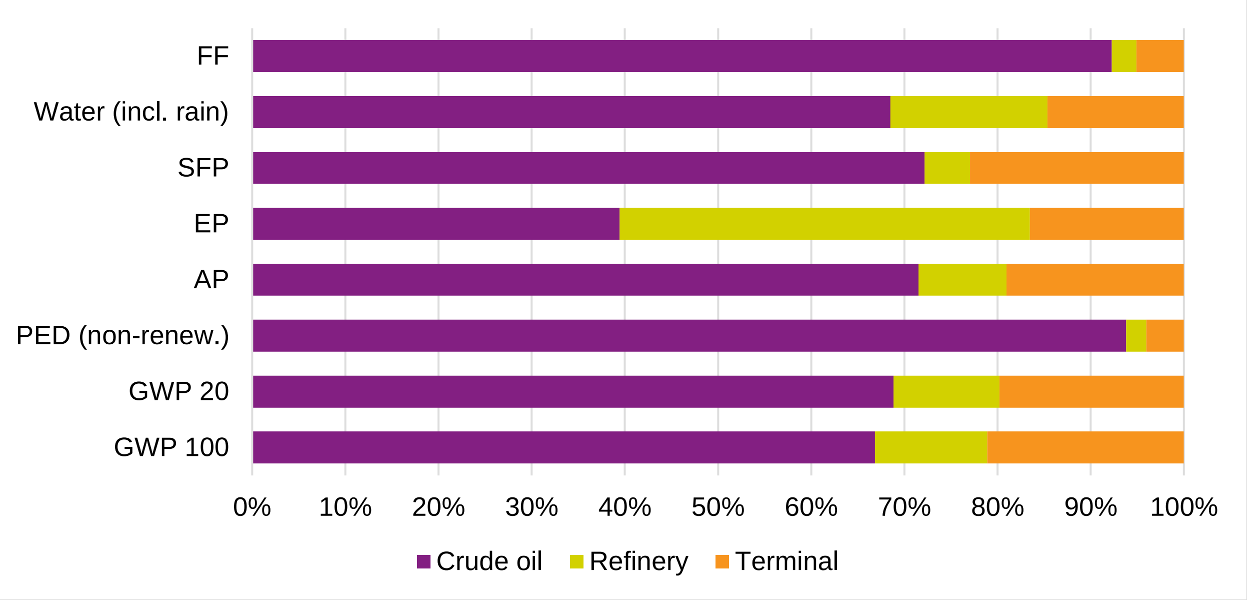

Figure 1: Overall impacts of asphalt binder, no additives [TRACI 2.1, except PED (non-renew.) and Water (incl. rain)]

4. Conclusions

The extraction of the crude oil is the primary driver of all potential environmental impacts, due most significantly to the use of crude oil from oil sands or crudes extracted via a tertiary method. At the refinery itself, electricity is the most significant single driver of impact followed by on-site thermal energy generation and associated direct emissions. Terminal operations can contribute up to 20% of potential environmental impacts without additives, driven primary by thermal energy and inbound transport of the asphalt.

This study achieved its goals in creating an LCI that fairly represents the asphalt binder industry in North America. By combining the primary data collected from participants with the secondary data available through the Gabi database, the Asphalt Institute and thinkstep have created the most accurate and representative LCI data for the region available at the time of the report publication. Updates to these datasets are expected on a periodic basis. Additionally, the methodology has been shared and reviewed by other organizations within the petroleum industry, with the hope that they apply it to future petroleum LCI datasets to ensure consistency across the industry.

5. Critical Review

A critical review of the completed study report was conducted by the following panel members:

- Arpad Horvath – Consultant, Berkeley, California (Chair)
- Mike Southern – Eurobitume
- Amit Kapur – Phillips 66

The review of the report has found that:

- the approach, described in the report, used to carry out the LCA is consistent with the ISO 14040:2006 principles and framework and the ISO 14044:2006 requirements and guidelines,
- the methods used in the LCA are scientifically and technically valid as much as the peer-reviewers were able to determine without having access to the LCA model and the data collection information,
- the interpretations of the results reflect the limitations identified in the goals of the study, and
- the report is transparent concerning the study steps and consistent for the purposes of the stated goals of the study.

6. References

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