LIFECYCLE ASSESSMENT

GOAL

Create new lifecycle assessment information for roads.

CREDIT REQUIREMENTS

Conduct a detailed process-based lifecycle assessment (ISO-LCA) or hybrid economic input-output lifecycle assessment (Hybrid-EIO) according to the ISO14040 standard frameworks for the final roadway design alternative. Include all items on the project bid list in the initial scope of the study before any streamlining of the scope is done. Use primary data for all processes where possible. Where no primary data exists, use the best available data and justify the substitution. Choose at least three impact categories to report for the lifecycle impact assessment (LCIA) from the Environmental Protection Agency (EPA) Framework for Responsible Environmental Decision-Making (FRED: 2000). Use equivalency factors for the impact assessment based on the most current version of the indicator model referenced. FRED is available from the American Center for Life Cycle Assessment here: http://www.lcacenter.org/library/pdf/fred.pdf. Note that some equivalency factors in this document are outdated. See the following MR-1 Research section for more details.

Details

The LCA may be streamlined according to the streamlining process recommendations from the 1999 Society of Environmental Toxicology and Chemistry (SETAC) report "Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup" (Weitz et al., 1999).

Social impact assessment is not required for this credit, but may be completed if social metrics or indices are appropriate or relevant for the project.

DOCUMENTATION

Copy of the completed LCA. This document should include, at minimum, the following specific information.

- Name and contact information of person(s) who conducted the LCA. Be sure to list any LCA Certified Professionals (LCACP) involved in the project.
- A list of all data sources used, and the input data used. If data is proprietary, list the owner and contact information, and identify all processes included in the proprietary data sets.
- List any material inputs not listed in PR-3 but included in the LCA (these will be non-pavement items).
- Detailed results of the life cycle inventory (LCI).
- Life cycle impact assessment (LCIA) results showing a minimum of three impact categories (i.e. global warming potential, acidification, photochemical smog, human health, etc.) from FRED. List sources of equivalency factors used.
- The data quality score of the final alternative (see MR-1 Research section.)
- A list of the top three contributing processes to the impact categories (based on normalized results, such as annual energy use per American household, etc.)
- A list of all limitations of the study scope and data used.

MR-1

2 POINTS

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ PR-3 Lifecycle Inventory
- ✓ PR-6 Waste Management Plan
- ✓ EW-4 Stormwater Cost Analysis
- ✓ CA-3 Site Recycling Plan
- ✓ CA-7 Water Use Tracking

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Extent
- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Improves Accountability
- ✓ Increases Awareness
- ✓ Creates New Information

APPROACHES & STRATEGIES

- Create a spreadsheet to capture all of the processes for production of the roadway project and complete an LCA in accordance with the referenced ISO standards.
- Hire a professional third-party consultant if possible to review the project and produce a final LCA report. The benefits: sometimes they have access to some proprietary data and software that is more recent or higher quality than publicly available sources.
- Use an open source software program for LCA. These are becoming more common and are publically available for free via a number of LCA organizations.
- Consider using a hybrid EIO model that incorporates both economic sector data and process-based data.
- Collect primary emissions data wherever possible.
- Use data that is current, local or otherwise project specific to improve data quality for the project LCA model.

Example: Comprehensive Process-Based LCA Approach (Stripple, 2001)

While not a complete LCA because the impact assessment and interpretation steps were not completed, Stripple (2001) provides the best available example to date of what should be considered in a comprehensive roadway lifecycle inventory analysis and impact assessment based on an ISO-LCA model (from SETAC Europe). The lifecycle phases studied were construction, operation, maintenance and associated transportation activities. Extraction activities and traffic were included, but disposal of waste and production of capital equipment were not considered. In a truly comprehensive study, waste generation and recycling activities for most pavements will have a large role in the overall assessment of the roadway. Capital equipment production may also be included but it is not unusual for it to be excluded via the streamlining process.

Following is a list of unit processes (and equipment) that were considered for the inventory analysis within his defined Goal, Scope, and system boundaries (slightly adapted for clarity). (Stripple, 2001)

Table MR-1.1: Example unit processes in Stripple (2001)

- Aggregate production (blasting, crushing)
- Aluminium [sic] production
- Bitumen production
- Cement production
- Cement stabilization of base course in concrete road construction
- Land clearing of right-of-way
- Clearing snow
- Cold-mix asphalt production
- Concrete production (mixing)
- Concrete texturing
- Driving diesel maintenance vehicles
- Electricity production
- Erection and removal of snow posts
- Extraction of quarry gravel and sand
- Extraction of salt for winter road maintenance
- Felling (trees)
- Foundation reinforcement using cement/lime columns
- Foundation reinforcement using concrete piles
- Freight transportation by sea
- Hot-mix asphalt production
- Laying of concrete wearing course in concrete road construction
- Laying of road markings
- Minor operational activities (minor repairs, other)
- Mowing of right-of-way
- Operating asphalt pavers
- Operating asphalt rollers
- Operating dump trucks
- Operating excavators
- Operating the tack coat truck
- Operating wheel loaders
- Polyethylene plastic production
- Quicklime production
- Road marking, sign, lighting, traffic light, other railing and fence production
- Salt gritting of road in winter road maintenance
- Sand gritting of road in winter road maintenance
- Saw cutting joints in concrete
- Sealing concrete joints
- Steel production
- Surface milling of concrete and asphalt paving
- Synthetic rubber (EPDM) production
- Trench digging in road maintenance
- Truck transportation
- Washing of road signs
- Washing of roadside posts
- Wildlife fences
- Zinc production

The functional units in the study were:

- The construction, maintenance and operation over a 40 year period of 1 lane-km of road, 13 meters in width, with 0.5m surface course and 1m base course paved with **hot-mix asphalt** and using vehicles for construction and maintenance with low emission diesel engines.
- The construction, maintenance and operation over a 40 year period of 1 lane-km of road, 13 meters in width, with 0.5m surface course and 1m base course paved with **cold-mix asphalt** and using vehicles for construction and maintenance with low emission diesel engines.
- The construction, maintenance and operation over a 40 year period of 1 lane-km of road, 13 meters in width, with 0.5m surface course and 1m base course paved with **concrete** and using vehicles for construction and maintenance with low emission diesel engines.

The results of the inventory analysis for energy use are shown in Figure MR-1.1 below.

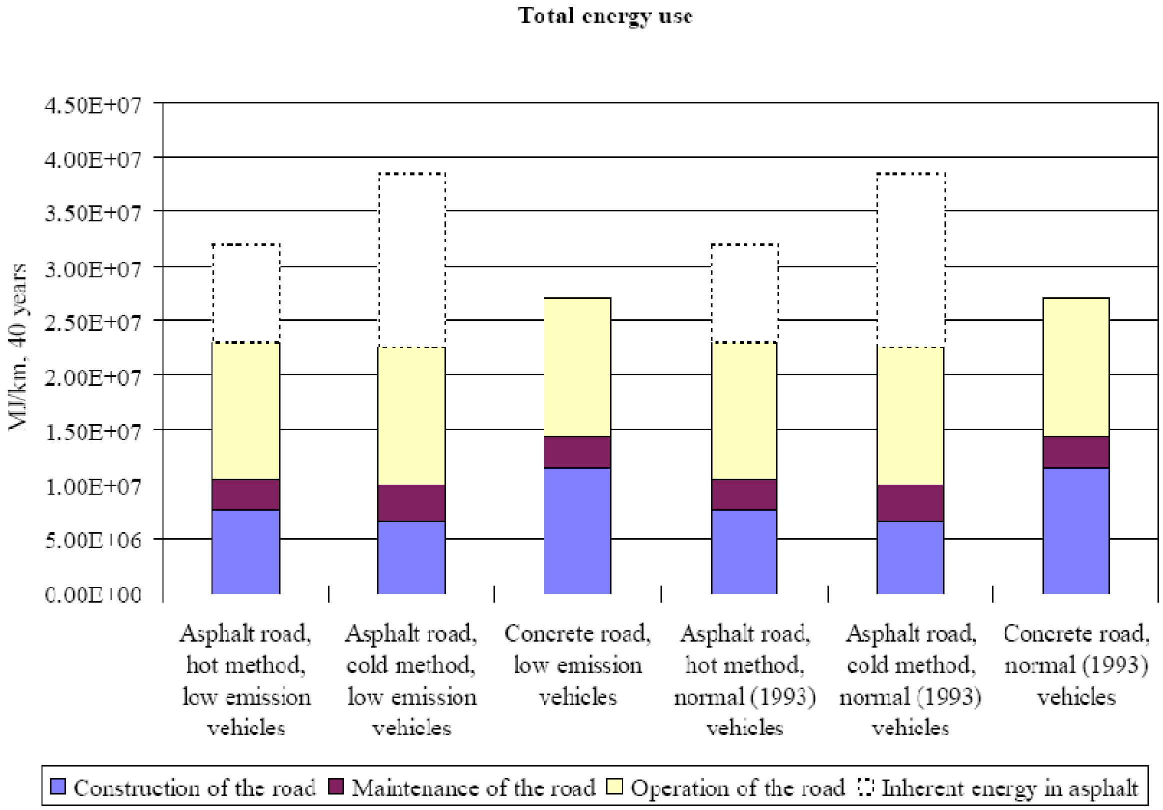


Figure MR-1.1: Results of life cycle inventory analysis for energy of three types of roadways. Dotted lines represent stored energy in asphalt. (Stripple, 2001)

The full report (2nd edition) is available from the IVL Swedish Environmental Research Institute, Ltd. here: http://www3.ivl.se/rapporter/pdf/B1210E.pdf

Example: Impact Assessment for HMA Overlay Using FRED (EPA, 2000; Schenck, 2000)

In their documentation for the FRED tool, the EPA provides a perfectly relevant example of an impact assessment for a roadway product, asphalt cement. The following is taken from Appendix C: Asphalt Coating Case Study and Schenck (2000). The article by Schenck (2000) provides further explanation of how LCA, especially the impact assessment step, can be used to make procurement decisions for road maintenance activities for the Department of Defense.

Goal & Scope of Study

The study modeled a 1.5 inch thick overlay applied with a frequency of 7-9 years over a 20 year time period and estimated the temperature of application at or above 165°F. For purposes of this Example, the inventory and impact assessment results for the water based asphalt emulsion alternative, GSB 88 (gilsonite), are omitted to minimize confusion with the LCIA process that is required for this credit. Note that in general, this was a very simplified life cycle assessment model due to the simplicity of the product itself (EPA, 2000). Explicit data criteria limits ensured that Input and output data was not collected if it represented less than one percent of the total mass, energy, or expected toxicity score contribution (human health and ecosystem health indicators). Table MR-1.2 below shows the processes and material data, sources and types of data collected for the model.

Table MR-1.2: Data Sources for LCA Study (Schenck, 2000; EPA, 2000)

Process or Material Data	Type	Source
Asphalt	Industry Average	Industry Association
Aggregate	Primary	Manufacturer
Diesel (HMA Production)	Primary: surrogate	Applier
Diesel (Construction Vehicle Fuels)	Industry Average	Published Data
Sand	Primary	Manufacturer
Gilsonite	Primary	Manufacturer
Hydrochloric acid (HCl)	Primary	Manufacturer
Water	Primary	Manufacturer
NP-40 (Detergent)	Primary	Manufacturer
Surfactant	Industry Average	Published Data
Light Cycle Oil	Primary	Manufacturer
Land Use (Road, m^2)	Calculated	This study
Land Use (Manufacturing, m^2)	Mixed	Manufacturer, Engr. Estimate

Inventory Analysis

Table MR-1.3 presents the results of the lifecycle inventory analysis for the HMA application only. A zero indicates that a particular raw material was used to make the “Thin Layer of HMA” product.

Table MR-1.3: Summary of HMA Inventory

System Description (Raw Materials)	Thin Layer of HMA (2 Applications) lb/lane-mi/20 yr
Asphalt	122,621
Aggegate	2,181,960
Diesel (Construction Vehicle Fuels)	3,063
Diesel (HMA Production)	884
Sand	0
Gilsonite	0
Hydrochloric acid (HCl)	32
Water	4,779
NP-40 (Detergent)	0
Surfactant	156
Light Cycle Oil	0
Land Use (Road, m^2)	5888
Land Use (Manufacturing, m^2)	<10

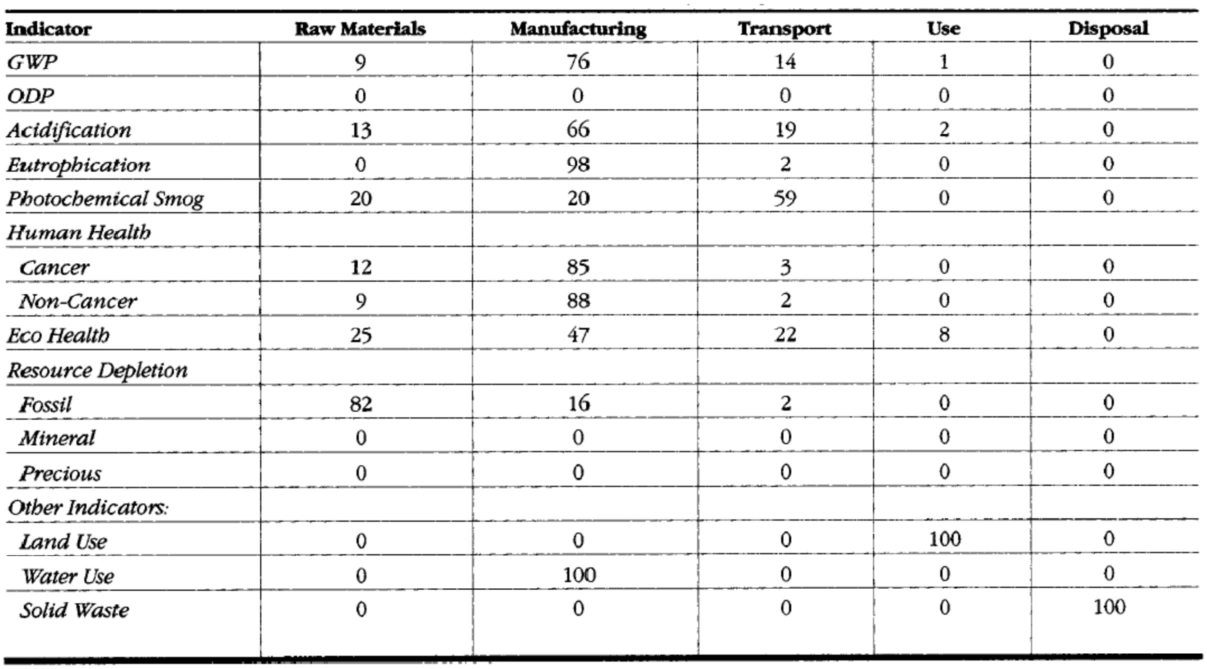
Impact Assessment

Table MR-1.4 presents the results of the lifecycle impact assessment for the HMA application only. Notably, the values in Table MR-1.3 above translate through to Table MR-1.4: a zero indicates that a particular value in the inventory analysis was also zero. This is because the MR-1.3 values are multiplied by equivalency factors as defined in the FRED. (Technically, it could also mean that: 1. the equivalency factor assigned to a particular impact was zero though generally an impact with zero equivalency would not be reported (i.e. not studied), or 2. the result could be considered negligible and reported as zero.)

Table MR-1.4: LCIA Results

Impact	**Thin Layer of HMA (2 Applications) lb/lane-mi/20 yr**
Indicator	*LCIA Results*
Global Warming Potential (kg CO2e)	40,000
Ozone Depletion (kg CFC-11e)	0
Acidification (kg SO2e)	300
Eutrophication (kg PO4e)	0.02
Photochemical Smog (kg O3e)	80
Human Toxicity	
Cancer	0.2
Non-Cancer	5
Ecotoxicity (dimensionless)	2000
Resource Depletion	
Fossil (tons oil equivalent)	90000
Mineral (equivalent tons)	0
Precious metals (equivalent tons)	0
Other Indicators	
Land Use (ha)	0.6
Water Use (m3)	2
Solid Waste (ton)	800

Figure MR-1.2 shows an example of a contribution analysis, where the relative contributions (on a scale of 100 percent) are shown as assigned to each lifecycle stage. A contribution analysis may also be done with the LCIA results to show which processes contribute most to certain impacts.



Indicator	**Raw Materials**	**Manufacturing**	**Transport**	**Use**	**Disposal**
GWP	9	76	14	1	0
ODP	0	0	0	0	0
Acidification	13	66	19	2	0
Eutrophication	0	98	2	0	0
Photochemical Smog	20	20	59	0	0
Human Health					
Cancer	12	85	3	0	0
Non-Cancer	9	88	2	0	0
Eco Health	25	47	22	8	0
Resource Depletion					
Fossil	82	16	2	0	0
Mineral	0	0	0	0	0
Precious	0	0	0	0	0
Other Indicators:					
Land Use	0	0	0	100	0
Water Use	0	100	0	0	0
Solid Waste	0	0	0	0	100

Figure MR-1.2: Example contribution analysis for LCIA of asphalt cement. (Schenck, 2000)

Some Notes on Results (Interpretation)

This Example only shows half the picture, but the full LCA was actually completed on both types of maintenance techniques and is explained in Schenck (2000) and the FRED documentation. However, evaluating these two alternatives by comparing the impacts of the two products must take into account the relative data quality available. A few brief examples of notes that might be useful to a reader of an LCA report for the interpretation step follow:

- In Table MR-1.2, secondary data (average data) for asphalt production was used and may not be representative of the actual product studied. Information from the manufacturer for the GSB 88 was from primary sources and may be more representative. If primary data were available for the asphalt, the results may be different than those produced by the model. This is true for many different parts of the data used.
- Close scrutiny of the data in the inventory analysis shows that many of the data values were not available or not reported for either product, as denoted by “NA” in the FRED case study.
- If the FRED case study is compared to the published results of the LCIA, it is clear that there is very high uncertainty in the results because the computed results report up to five significant digits. The amount, for example, of GWP that was computed was 44,368 kg CO2e. That computed level of precision is not reasonable, and the value reported only reflects one significant digit (40,000 kg CO2e).
- It is unclear why the inventory amount reported for “Resource Depletion - Minerals” is 0. This should probably have been documented somewhere.
- It is unclear what the assumed transportation distance was for either product (both in Schenck and the FRED documentation).

Further discussion and the full lifecycle inventory, impact assessment, and interpretation for this EPA case study are available in the FRED guidance document available at: http://www.lcacenter.org/library/pdf/fred.pdf. The reader is referred to that resource to make his/her own interpretations of the case studies provided.

POTENTIAL ISSUES

1. Missing or otherwise unavailable data (such as from proprietary sources). Wherever possible, data should be collected for the project. This includes (but is not limited to) emissions and energy use such as emissions data gathered from at the hot-mix asphalt (HMA) batch plant, amounts of water used in concrete mixes, fuel types, tipping fee receipts, cut/fill volumes, etc. In general, secondary data choices should be based on realistic project-based information.
2. Professional lifecycle assessment may incur an added cost to the project. Projects should budget for this additional cost where possible when planning to attempt this credit.
3. Data management in process-based LCAs can require much manpower, be time consuming, and also high cost.
4. There is no such thing as a simple product. All products and processes are more complicated than humans could ever conceive. LCAs still only present a simplified model of the actual lifecycle. The goal is that the LCA model is realistic and representative, not exact.
5. Stakeholders involved in LCA tend to set system boundaries and conditions to their credit. This can skew or discredit results in some cases. Transparency is a key issue in part, for this reason.
6. Professional lifecycle assessment infers that final results may be proprietary. Verify rights to share this information prior to submitting documentation for this credit. Where possible, use data sources or LCA software that does not incorporate proprietary data unless, adequately referenced and documented for the project. Using OpenSource LCA programs may be able to help avoid such issues.
7. Any uncertainties or assumptions made in the LCA must be clearly specified or documented (per the ISO standards). Additionally, any substitutions or generic data used must be explicitly stated.
8. Allocation procedures used for estimations or assumptions should be transparent and supporting documentation (including references) should be provided (where publishing and proprietary rights permit).
9. Comprehensive lifecycle assessments require detailed attention to data quality.

RESEARCH

This particular credit is available as a supplement to the three related Project Requirements: PR-1 Environmental Review Process, PR-2 Lifecycle Cost Analysis, and PR-3 Lifecycle Inventory. This credit represents both an added step (impact assessment) to the basic process involved in these three credits and an expanded roadway system scope for the inventory analysis step completed for PR-3. PR-2 and PR-3 provide decision-making information about cost and baseline environmental performance (specifically energy use and carbon dioxide emissions) for the roadway pavement section. Similarly, social impact classification and characterization is part of the environmental review process (see PR-1) for many roadway projects, but generally this process will not require or specify the use of any particular social metric (e.g. birth and death rates, obesity rates, productivity rates, etc.) for measurement of these impacts. This credit requires an expanded scope of these three Project Requirements that includes the entire roadway project system as well as an impact assessment step for the project.

Note that an introduction to LCA, its basic framework components, and variety of LCA methods is provided in the Research section of PR-3. This research discussion is supplemental.

Existing Literature

Most existing literature for roadway lifecycle assessments focus on the initial construction and maintenance of pavement sections alone. To our knowledge no studies have completed a full system-wide LCA for a roadway project. However, one study completed by Stripple et al. (2001), has completed a full life cycle inventory (LCI) that incorporates all aspects of a roadway, from production processes of several kinds of pavement all the way to the components of the roadway such as electric utilities and wildlife fencing. This study followed the recommendations for the LCA process by the Society of Environmental Toxicology and Chemistry (SETAC Europe), but is considered an incomplete LCA because the impact assessment and interpretation steps were not done. However, the paper serves as a great example of the first two steps in LCA, but note that the applicability and utility of the primarily European data set is questionable for applications in the United States (i.e. it is difficult to justify substitution of Stripple's inventory data into a non-European LCA study without close scrutiny of his data). However, because SETAC references the same methodology for LCA, namely the International Standards Organization (ISO) 14040 and 14044 standards, this paper is a great example of the framework and approach for this credit. See the first Example in the previous section for more details.

LCA Methodology Steps

A lifecycle is defined as "consecutive and interlinked stages of a product [or project] system, from raw material acquisition or generation from natural resources to final disposal or [end-of life: EOL]" (International Standards Organization: ISO, 2006a). Generally, there are four basic steps to any type of lifecycle assessment. A different interpretation of these steps than that shown in Figure PR-3.2 is shown in Figure MR-1.3 from SETAC. Definition of the goal and scope (the boundaries and extent of the study) will always take place for every LCA project, and the variation in methodology will result from the initial choices made in this initial. Inventory Analysis, the second step, will take place as one of three general types as noted in PR-3. These are briefly:

- Process-Based LCA (also ISO-LCA)
- Economic Input-Output LCA (EIO-LCA)
- Hybrid LCA (also Hybrid EIO-LCA)

Each of these approaches will produce different results for the inventory analysis and in general cannot be compared cross-platform because the processes considered and system boundaries will vary widely.

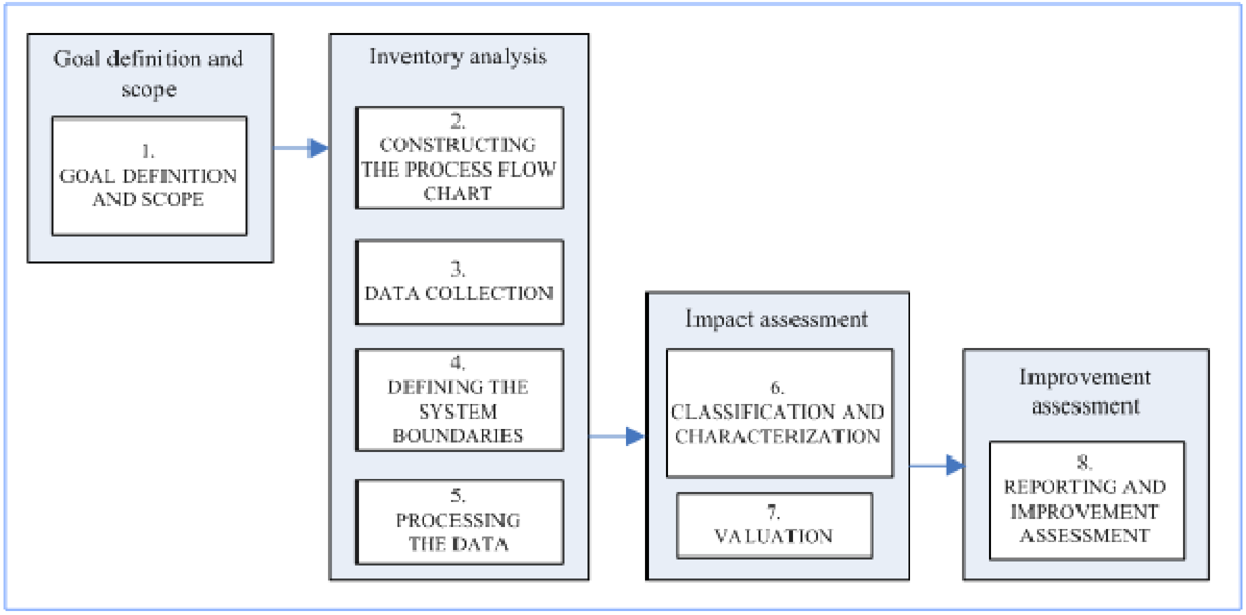


Figure MR-1.3: The framework for Life Cycle Assessment (Consoli, 1993)

The final two steps of the LCA are the impact assessment and interpretation of the results. The impact assessment step involves an assignment or application of subjective values, wherein particular indicators or metrics are chosen to weigh the results of the inventory analysis according to those subjective values. These values also need to be explicitly defined in the goal and scope in order to produce a meaningful result for interpretation. Due to the iterative nature of LCAs, however, it is more practical to state that the interpretation step really happens throughout the entire LCA process, and often results in refining the scope when data is collected and analyzed in the inventory analysis.

Choosing the LCA Model

A **process-based lifecycle assessment** is one that is conducted (usually) according to the standards set by the International Standards Organization (ISO) lifecycle assessment standards, ISO14040 and ISO14044 (2006a, 2006b). The ISO clearly outlines the steps and iterative process behind a technical LCA in both of those standards. The basic idea of a process-based LCA is that everything is made of a sum of different parts. Those parts are also results of different processes. Fundamentally, every part and process needs materials and energy (e.g. “makes”) in order to fit together into a whole (e.g. “takes”).

For a simple example, making one ton of the product called “hot mix asphalt” (“HMA”) is actually the result of taking two materials, “asphalt binder” and “aggregate”, through a process that makes HMA, “mixing.” So the processes that that the HMA product actually takes are: asphalt binder production (material), aggregate production (material), and HMA mixing (a process).

These three processes could be further broken down into even more specific processes, called “unit processes.” For example, “HMA mixing” is composed of “heating,” “drum plant operating,” and “fuel combustion for heating,” etc. The model, and also the data collection requirement, expands as the processes get more specific. Similarly, each of these processes “take” more than just asphalt and aggregate to make HMA: they also require energy from electricity, capital equipment and workers, who also need food and housing, healthcare, a car to drive to work, and so on. If the process-based model were continued and scaled up to include such information, it would become incredibly complex and difficult. Clearly, the scope, system boundaries and purpose of the LCA are key issues.

This scoping issue is somewhat alleviated by **Economic Input-Output LCA** (EIOLCA) models. EIOLCA uses a basis of economic input-output (EIO) analysis to model how sector-based national industries interact and how products are intertwined. LCA was easily combined with EIO data because the computational structure was similar to the EIO approach. EIOLCA uses only publicly available information to determine economy-wide, system-level results instead of process-specific results (Hendrickson et al., 1998). This means that EIOLCA aggregates sector-level of data to quantify the environmental impact contributed directly or indirectly by each sector of the economy. It is typically based on monetary inputs instead of dimensions or mass and outputs a handful of common environmental impacts, depending on the index selected. **This method will not earn Greenroads credit.**

Hybrid LCA is a combination of process-based and EIO-based LCA (Bilec et al., 2006), effectively eliminating most of the disadvantages of either model aside from built-in uncertainties in data. EIO data are usually used for common products or processes, while others are described by the process-based method. Hybrid LCA can be further categorized into following types: tiered hybrid analysis, input-output based hybrid analysis, integrated hybrid analysis, and augmented process-based hybrid analysis (Suh, 2004; Bilec et al., 2006). These types differ in technical details such as how data is allocated or aggregated, where the specific boundaries are drawn between process and EIO analysis, and general data processing techniques.

Streamlined LCA is a proposed method of minimizing data collection efforts at the start of a LCA project by scoping out particular processes through educated assumptions (most of the time). This inevitably leads to a technically non-ISO conformant framework, because valuation is applied at the start, before data has been collected and analyzed. Curran et al. (1996) note that streamlining is really part of a continuum that falls somewhere between the level of detail for an ISO-LCA and an EIO-LCA, and also technically all LCAs are streamlined to some extent due to their iterative nature.

A comparison of the advantages and disadvantages of the common types of LCA are shown in Table MR-1.5. Ultimately it is up to the project team to determine which method will be most appropriate.

Table MR-1.5: Process-Based LCA and EIO-LCA (Expanded from Hendrickson, Lave & Matthews, 2006)

LCA Method	Advantages	Disadvantages
Process-Based LCA (ISO-LCA) *(ISO, 2006a; ISO 2006b)*	• Detailed, process-specific results • Allows for specific product comparisons • Identifies areas in supply chain for improvement (weakest links, or lack of data) • Provides a basis for process-specific information that may be used for other development processes and assessments • Can be done with publicly available data	• System boundaries are subjective (or project-specific) • May be high cost and time intensive • Hard to use when initially developing a process or product • Often use proprietary data • Cannot be replicated if confidential data is used • Uncertainty in data or missing data
EIO-LCA *(Hendrickson et al, 1998; Hendrickson, Matthews & Lave, 2006)* **NOTE: METHOD WILL NOT EARN THIS CREDIT. DO NOT USE.**	• Results are economy-wide, comprehensive assessments • Allows for systems-level comparisons • Provides information on every commodity in the economy • Provides a basis for information that may be used for other future development of products and processes and assessments • Can be done with publicly available data	• Product assessments contain aggregate data (such as food that feeds workers and the wood that makes their housing) • Process assessments are difficult • Must link monetary values with physical units • Economic imports are treated as products created within economic (region, state or country) boundaries • Lack of complete data for environmental effects • Difficult to apply to an open economy (with substantial non-comparable imports) • Uncertainty in data

LCA Method	Advantages	Disadvantages
Tiered Hybrid LCA *(Suh & Huppes, 2005)*	• Combines process and EIO data to produce more representative result • Facilitates inventory analysis • Reduces data collection time • Incorporates advantages from both ISO and EIO models	• Double-counting errors may be present in results • May omit important processes • Does not always model interaction between process and I-O data appropriately • Incorporates some disadvantages from both ISO and EIO models
Hybrid EIO *(Treloar, 1997; Joshi, 2000; Crawford, 2008)*	• Combines process and EIO data to produce more representative result • Disaggregates I-O key sectors and substitutes detailed economic information • Incorporates advantages from both ISO and EIO models • Use and disposal phases are addressed manually instead of by sector • Fills process data gaps where previously no information existed	• Requires iteration • Incorporates some disadvantages from both ISO and EIO models • Substitution of IO data for missing processes may reduce model reliability
Integrated Hybrid *(Suh, 2004; Bilec et al., 2006)*	• Combines process and EIO data to produce more representative result • Incorporates advantages from both ISO and EIO models • Connects process and EIO models in matrix • Eliminates need for tiered analysis • Addresses interactions between sector and process data • Consistent computational framework • No double counting	• Incorporates some disadvantages from both ISO and EIO models • Computationally complex • Difficult to learn • Data intensive • Time intensive
Augmented Process-Based Hybrid *(Guggemos, 2003; Guggemos & Horvath, 2005)*	• Starts with process data and system and scales up • Uses economy as ultimate system boundary • Uses mostly process data	• Incorporates some disadvantages from both ISO and EIO models
Streamlined LCA *(Curran et al., 1996; Weitz et al., 1999)*	• May save money • May save time • Requires reasonable data management efforts • Processes assigned significance early in scoping and align with goals of study • Provides focused assessment	• Excludes upstream and/or downstream processes • Limits raw material input considerations • Results may be more subjective due to weighting assigned early (by scoping out processes or data requirements) • May ignore important impacts unintentionally • May result in reporting incomplete results to public

Additional Notes on LCIA: FRED Framework

Equivalency factors for impact classification and characterization for this Greenroads credit are provided by the Environmental Protection Agency's (EPA) Framework for Responsible Environmental Decision-Making (FRED) (EPA, 2000). The factors are subdivided into eight categories and three general types of flows are investigated: (1) emissions to air, (2) emissions to water, and (3) resource depletion (includes raw materials, fuels, water and land). We recognize that there are a number of metrics, indicators and indices available for use; the FRED framework is flexible, broadly applicable, comprehensive, and documented respectably. Currently this is the most transparent and flexible tool that is publicly available for impact assessment.

FRED is based on a variety of different indicator tools or metrics that have been developed by different institutions, and reflect global averages or indicators. However, documentation for some of the indicators used in the tool has not been updated, likely due to lack of funding. The user may consult those individual sources in order to check for updates, determine applicability, or substitute regional and local indicator values where appropriate (EPA, 2000). “The designers of FRED consider impact model selection to be an iterative process. As the science and the data supporting the science [develop], newer, more environmentally relevant models will gradually replace the current models” (EPA, 2000). Some other limitations of the FRED tool are provided explicitly in the documentation. Notably, any data uncertainties in the established equivalency factors that are used within the tool itself are inherent issues. Also, FRED does not include any social or economic impacts.

Greenroads has provided some suggested resources to use in place of those listed in the FRED documentation. Either may be used in support of this credit (the process is what we are looking for here), but references for the selected indicator must be cited to earn this credit. Table MR-1.6 (next page) lists the FRED impact categories with some typical examples that would be found in an LCI and used in the impact assessment. Note that this is only a sample, and that the FRED documentation provides a number of chemical compounds to track.

Note that ideally FRED is designed to compare two or more products that have the same functional unit. The utility of completing an impact assessment for just one single project is that there is not necessarily any established industry average in terms of environmental performance that can be used for comparison of pavements. This credit aims to help develop this information in a systematic way by using the framework provided for impact assessment by the EPA’s FRED tool. Results of the impact assessment may therefore not be suitable for evaluative purposes (EPA, 2000), however, this does not mean that two different design alternatives should not be compared using LCA. For reporting purposes in this Greenroads credit, we just want to know about the final design alternative.

Other LCIA Tools

- Another EPA tool, the Tools for Reduction and Assessment of Chemical and Other Releases (TRACI), is no longer available from the EPA. As of this writing, we understand that this tool is currently being updated. (EPA, 2008).
- Commonly used proprietary software tools may have built-in impact assessment indicators, such as GaBi and SimaPro. These tools often report a single value for all impacts (an index) that does not necessarily disaggregate contributions to that index from each impact or process, and may not be appropriate for use in this credit because the weighting can lack transparency.
- Other tools for impact assessment are available through the National Institute of Science and Technology (NIST), such as the BEES (Building or Environmental and Economic Sustainability) tool. The caveat with BEES is that it is mostly used in the building industry, so valuation and weighting systems used by NIST impact assessment tools may not be adequate for weighting impacts of pavement or infrastructure projects without further adjustment and review. Also, this software tool generates only one index as a “score” instead of reporting disaggregated impacts.

Table MR-1.6: FRED Impact Categories and Indicator Models for the FRED LCA System (EPA, 2000)

Impact Category	Impact Indicator Model/Source	Indicator*	Example LCI Data Needed for Model	Greenroads Comment
Global Warming Potential	Intergovernmental Panel on Climate Change (IPCC)	CO_2e (kg)	Carbon dioxide (CO_2) Nitrous oxide (N_2O) Methane (CH_4) Halons	Recommend using updated equivalency factors from IPCC 2007 FAR (Solomon et. al.), especially for CH_4, N_2O. Others are less prevalent in roads/paving.
Stratospheric Ozone Depletion	World Meterological Organization (WMO)	CFC-11e	Methyl bromide Chlorofluorocarbons (CFCs) Hydrofluorocarbons (HCFCs)	Recommend using updated indicator for equivalency factors: Effective Equivalent Stratospheric Chlorine concentration (EECl, EESC). See EPA's 2006 *Air Quality Criteria for Ozone and Other Photochemical Oxidants*
Acidification	Chemical Equivalents	Acidification Potential (AP)	Ammonia Nitric oxide Nitrogen dioxide Sulfur dioxide	
Photochemical Smog	Empirical Kinetic Modeling Approach (EKMA)	Maximum Incremental Reactivity (MIR)	Acetone Carbon Monoxide Formaldehyde Alkanes Aromatics (VOCs) Napthalenes	Recommend using a box or Eulerian model and MIR values from Carter (2009) with binned reactivities based upon n-alkane, iso-alkane, cyclo-alkane, aromatics and napthalenes. See also Leuken and Mebust (2008).
Eutrophication	Redfield Ratio	PO_4e (kg)	Phosphates Nitric oxide Nitrates Ammonia	
Human Health	University of California, Berkeley (UCB) TEPs	Benzene TEP (cancer) Toulene TEP (non-cancer)	Toxic chemicals	Recommend using current data from the Environmental Defense Fund (EDF) Scorecard and UCB TEPs as shown in FRED documentation. See also McKone and Hertwich (2001) and Hertwich et al. (2006)
Ecological Toxicity	Research Triangle Institute (RTI) LCIA Expert (Version 1)	N/A	Toxic chemicals	Recommend RTI model and data from EPA's ECOTOX database to determine specific weighting as shown in FRED documentation (EPA, 2000; 2010)
Resource Depletion	Life Cycle Stressor Environmental Assessment (LCSEA) Model by Scientific Certification Systems	Mass, volume (water) or land area	Various	Recommend using computed "resource depletion" equivalency factors using updated SCS -002-2008 (Draft) as shown in FRED document (EPA, 2000; SCS, 2008)

Data Quality

The most important step in the interpretation phase of the LCA is the identification of the data quality and statement of uncertainties. Quality of data used in an LCA can be evaluated during the interpretation stage of the LCA using data quality scores. For this credit, each piece of data should be rated with numbers 1 to 5 and scored according to the criteria set forward by the University of Washington Design for Environment Lab (College of

Engineering, Department of Mechanical Engineering, under the direction of Dr. Joyce Cooper), based on ISO14040:2006 requirements. The scoring is shown in Table MR-1.7.

Table MR-1.7: Data quality scores (DQS) by the University of Washington Department Of Mechanical Engineering Design for Environment Lab (Cooper et al., n.d.)

Score ID	ISO14040 Data Quality Indicators	Supporting Information	Scoring Method
DQS1	Time-Related Coverage Data (i.e. data age)	Start date of valid time span End date of valid time span	Deviation from intended period (difference in years to year of study) 1. Less than 3 years 2. Less than 6 years 3. Less than 10 years 4. Less than 15 years 5. Age of data unknown or more than 15 years
DQS2	Geographical Coverage	Area and country names	Deviation from intended area 1. Data from study area 2. Average data from larger area which includes study area 3. Data from area under similar production conditions 4. Data from area with slightly similar production conditions 5. Data from unknown area or area with different production conditions
DQS3	Technology Coverage	Technology description Included processes Extrapolations	Deviation from intended technology 1. Data from enterprises, processes and materials under study 2. Data from processes and materials under study but different enterprises 3. Data from processes and materials under study but different technology 4. Data on related process and materials but same technology 5. Data on related process and materials but different technology
DQS4	Precision, completeness, and representativeness of the data	Sampling procedure Number of samples Absolute sample volume Relative sample volume Extrapolations Uncertainty adjustments	Representativeness for intended process 1. Very high (data represent all aspects of system under study) 2. High (data represent a majority subset of the system under study) 3. Moderate (data represent a minority subset of the system under study) 4. Low (data represent an example of the system under study) 5. Very low or unknown (the extent to which the data represents the study is unknown)

Score ID	ISO14040 Data Quality Indicators	Supporting Information	Scoring Method
DQS5	Consistency and reproducibility of the methods used throughout the LCA	Description of method for data collection and data treatment	1. Very high (data are based on direct measurements using a widely accepted test method or on sound engineering models representing the current technology and have been extensively peer reviewed. Also, the source provides a transparent account of the assumptions made.) 2. High (although the data are based on a generally sound test method or model and the source provides a transparent account of the assumptions made, the data are dated or lack enough detail for adequate validation or have not been extensively peer reviewed) 3. Moderate (data are based on an unproven or new methodology or are lacking a significant amount of background information) 4. Low (data are based on a generally unacceptable method, but the method may provide an order-of-magnitude flow) 5. Very low or unknown (data are based on an unknown method, but the method may provide an order-of-magnitude value of the flow)
DQS6	Sources and their representativeness	References used for data collection and data treatment	Type of reference 1. Data from reviewed source 2. Data from public written source (not reviewed) 3. Data from closed written source (not reviewed) 4. Other sources 5. Unknown source
DQS7	Uncertainty of the information	Mean value Standard deviation Uncertainty type Description of strengths and weaknesses (e.g. occurrence of data gaps)	Coefficient of variance 1. Below 10% 2. 10-25% 3. 25-50% 4. 50-100% 5. Over 100% or unknown

GLOSSARY

CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent emission
-e	Equivalent
EIO	Economic Input-Output
EIO-LCA	Economic Input-Output for Life Cycle Assessment
EOL	End-of-life
Functional unit	The quantified performance of a product system for use as a reference unit (ISO, 2006a)
Hybrid LCA	A type of LCA that combines both process-based and economic input-output models
ISO	International Standards Organization

ISO-LCA	Process-based LCA
LCA	Lifecycle assessment
LCCA	Lifecycle cost analysis
LCI	Lifecycle inventory analysis
LCIA	Lifecycle impact assessment
Lifecycle	consecutive and interlinked stages of a product [or project] system, from raw material acquisition or generation from natural resources to final disposal or [end-of life: EOL] (ISO, 2006a)
Lifecycle assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifecycle (ISO, 2006a)
Process-based LCA	An LCA conducted according to ISO Standard 14040
Reference flow	The measure of the outputs from processes in a given product system required to fulfil [sic] the function expressed by the functional unit (ISO, 2006a)
SETAC	Society of Enviornmental Toxicology and Chemistry
Streamlined LCA	Identification of elements of an LCA that can be omitted or where surrogate or generic data can be used without significantly affecting the accuracy of the results (Weitz et al., 1999)
System boundary	Set of criteria defining which unit processes are part of a system (ISO, 2006a)
Unit process	Smallest unit considered in the lifecycle inventory analysis for which input and output data are quantified (ISO, 2006a)

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