UCPRC Pavement LCA Workshop: Discussion Summary

Pavement Life Cycle Assessment Workshop, Davis, CA, May 2010

Background

The University of California Pavement Research Center (UCPRC, Davis and Berkeley) and the University of California Institute of Transportation Studies (Berkeley and Davis) are working together on establishing common practices for conducting environmental life cycle assessment (LCA) for pavements. Funding for this work is provided by the California Department of Transportation in partnership with the MIRIAM (Models for Rolling Resistance in Road Infrastructure Asset Management Systems, [Link to be added]) pooled fund project which is led by the Danish Road Institute (Ministry of Transportation, Road Directorate). This work is being done in collaboration with the International Society for Asphalt Pavements (Asphalt Pavement and the Environment Technical Committee, ISAP APE) and the International Society for Concrete Pavement (ISCP).

Research products under development as part of this work include:

a. An LCA framework for pavements.

b. A summary of system boundaries and assumptions for the framework, as well as an examination of the pros and cons of alternatives.

c. Assessment of models/data for each phase of the life cycle with regard to project type.

d. Documentation requirements for pavement LCA studies sufficient to permit comparison between studies in terms of completeness, assumptions, system boundaries and data/models.

The desired outcomes of the Pavement LCA Workshop were:

1. Review and discussion of documents prepared by the research team for each of the four items (a, b, c, and d) listed above.

2. Brief presentations and discussion of critical issues for pavement LCA where conflicting practices or gaps in knowledge have been identified.

3. Summary of areas of consensus and disagreement with regard to items a, b, c, and d above and documentation of alternative views.

The UCPRC/ITS research team is using the results of the workshop to improve the LCA framework and recommended documentation requirements. The focus of the framework and documentation will be for studies to be performed in California, and later for the

MIRIAM project; however, they may serve as guidance documents for pavement LCAs performed in any region. A follow-up will likely be required to capture similar information for European studies to be performed as part of the MIRIAM project. The final documents prepared by the research team, after incorporation of the workshop results, were posted for comment and critique by the pavement and LCA communities. The intention of the research team and workshop sponsors is that the results will provide the following benefits:

- Use of appropriate assumptions, system boundaries, models, and data by the research team for the California and MIRIAM studies.
- Better understanding of LCA among pavement LCA practitioners, sponsors, and consumers of pavement LCA information.
- Recommendations for improvement in practice of LCA studies.
- More transparency in the documentation of how pavement LCA studies are performed.

Process Used to Produce this Document

Workshop participants were broken into groups by the workshop organizers. The composition of each group remained constant through all breakout sessions, with each group intended to provide a diversity of background and expertise. Three breakout sessions were held during the second day of the workshop. Each group was given one question in each session. Some of the questions were given to multiple groups to ensure that a wide range of discussions were held.

To help improve the research products and achieve the desired outcomes of the workshop, the discussions held in each of the breakout sessions were captured in notes taken by a designated member of the organizing team. Those notes were then summarized into summary slides and presented by each breakout session group for discussion with all the workshop attendees in a session held on the third day of the workshop. The notes from the breakout sessions were then written up and edited into this document by the workshop organizers.

Purpose and Organization of this Document

The purpose of this document is to present the major elements of the discussions held in each breakout session, followed by the decisions made by the research team regarding the research products in response to those discussions.

This document is organized around the questions that were posed to one or more breakout session groups. For each question, the main points of the discussion are itemized,

followed by the key outcomes. These are followed by a statement by the UCPRC LCA Research Team regarding the actions that will be taken regarding the question.

Disclaimer

The contents of this workshop document reflect the views of the research team and the workshop participants, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California, the Federal Highway Administration, the University of California, the MIRIAM project or its sponsors, the International Society for Concrete Pavements, or the International Society for Asphalt Pavements, or the organizations by whom the workshop participants are employed. This workshop document does not constitute a standard, specification, or regulation.

Question: Critique the Proposed Framework:

- **Goal (focus on scale and purpose)**
- **System Boundary**
- **Functional Unit**
- **Assumptions**
- **Recommended models and data sources**

Main discussion:

Participants, in general, have agreed to the structure of the proposed framework with some recommendations for changes. The importance of having a clear goal and scope was emphasized many times during the discussions. A physical dimension for the functional unit, a key component of the scope, was not agreed upon. Some group members indicated that a unit based on lane-km cannot be generalized to different types of pavements, For example, a lane-km unit works for a highway system, but not necessarily for streets, parking lots, airports, and other pavement applications. A few group members suggested functional units should be defined on a square-meter basis.

Key outcomes:

1. There are two levels of LCA studies (i.e. network level and project level), and the distinction between the two should be clarified.
2. The proposed framework refers to a project level LCA. A guideline for a network level LCA should be developed.
3. The framework should include the site design, not just pavement design (e.g. location of batch plant).
4. Performance requirements / functional design life need to be more clearly defined in the framework.
5. Need to setup the unit for the output.
6. The diagram provided in the framework needs to include an exhaustive list of construction materials and comprehensive list of environmental loads.
7. Need to split maintenance and rehabilitation into separate parts.
8. Equipment manufacturing and capital investments dedicated to the construction process should be included.
9. Consider including transportation of workers and support from service sectors.
10. ISO 12006 has been recommended for review to refine the proposed framework.

UCPRC Actions:

For Numbers 1 and 2 above, the language has been revised to better reflect the difference between these two. Also, this LCA guideline is intended to guide project-level studies; however, the network effects incurred by a project, such as the network effect of work zone-induced traffic, should be included when data and models are available.

For Number 3, general site work is included in the construction phase, such as the location of the batch plant. Also, text has been provided at the beginning of the framework addressing the difference between roadways and pavement. This framework is only intended to guide pavement LCA studies, so site design such as signs or stripping are not included.

For Number 4, we have enhanced the detail and specificity of pavement performance requirements

For Number 5, these concerns are addressed through the functional unit. All outputs of an LCA are based on the functional unit.

For Number 6, this diagram is intended as an example. It is not intended to provide an exhaustive list of pavement materials, in part because the variety of pavement materials is nearly infinite and no list could be truly comprehensive. The *UCPRC Pavement LCA Guideline* requires inclusion of all materials used in the pavement. Similarly the list of environmental loads is dependent on the goals of the LCA study and is likely to change over time. The recommended checklist for documentation of pavement LCA studies we have developed includes suggested environmental impact categories.

For Number 7, we recommend that each construction, maintenance, or rehabilitation event be modeled separately in the study, but in terms of system boundaries, they are essentially the same. For this reason they are considered in the same section in the guideline.

For Number 8, the manufacturing and capital investments attributable to the particular construction event are within the system boundary.

For Number 9, we have excluded this so far because we would need to understand the difference between a worker's typical driving activity and the travel to the specific construction site. Therefore, we have not proposed that the transportation of workers be generally included. However there are cases where transportation of workers seems important; for example if a construction site is in a remote place, or if alternative modes of transport or efficiency actions (e.g. carpooling or busing) of workers are being implemented.

For Number 10, we are currently reviewing the appropriateness of using ISO 12006 for this framework.

Question: Bitumen feedstock energy (*UCPRC Pavement LCA Guideline: LCA Framework and Standard Assumptions*, Title 4.1). The basic questions considered under this topic include:

1. **How could an LCA practitioner interpret bitumen feedstock energy?**
2. **When bitumen is considered as a fuel source, does it need to consider its marginal emissions? If so, how is this incorporated into analysis?**
3. **If the alternative upgrading of bitumen is taken into consideration, is it an important component? How could this component be included?**

Main discussion:

The relevant ISO standard specifically requires that feedstock energy be reported in an LCA. However, questions arise for what feedstock energy really means for bitumen which could never be burnt as a fuel source. Participants with experience in the asphalt industry tend not to treat bitumen as an energy source, arguing that bitumen makes a very poor fuel, and bitumen used in pavements will never be combusted for its energy value. Furthermore, California law prohibits direct combustion of bitumen. If bitumen is to be burned, it needs to be mixed with bunker fuel, and may only be burned at sea. In addition, energy from bitumen is not 100% available for work.

Opponents argued that the "dirtiness" of bitumen is relative. It is actually cleaner than coal[1]. Furthermore, although bitumen is not commonly used as a fuel today, it does not mean it will not be tomorrow. A compromise may be to separate feedstock energy from other types of consumed energy in LCA reporting.

Discussion participants were concerned about the focus on the feedstock energy of bitumen, as opposed to feedstock energy in rubber and polymers, which should be treated the same way[2].

Another question addressed by the groups was marginal emissions related with burning bitumen – essentially a consequential approach to thinking about bitumen feedstock energy. If feedstock energy is ever used for energy purposes, emissions would occur due to upgrading and combustion, so these emissions are prevented as long as bitumen is used for its material, rather than energy purposes. However, some group members argued these emissions should not be included. They asserted it would be double counting to consider the "saved" emissions from not burning bitumen, because "saved" emissions are only "figurative," which reflects the viewpoint of an attributional LCA approach. Therefore, whether these emissions should be included essentially depends on the type of LCA approach - consequential or attributional, which should be clearly stated in the goal of the study.

[1] This reflects the perspective of some discussion attendants and has not been verified yet.
[2] However, to clarify, ISO standards require that feedstock energy be reported for all materials. This discussion likely reflects a participant's misinterpretation of the ISO standard.

Group consensus settled on the following: whenever feedstock energy or marginal emissions are reported, they should be reported separately from the rest of the energy and emissions reported in the LCA.

An alternative option for bitumen is further upgrading. So group members questioned whether the "recoverable" energy be addressed in feedstock energy values. It is suggested that only net energy available after upgrading should be accounted for. The coking factor is the limiting factor for upgrading bitumen, which is very energy intensive.

Furthermore, since more and more of our bitumen comes from asphalt refineries, not integrated refineries, asphalt refineries specialize in producing heavy products. They need more attention in future studies. The group reached a consensus that energy for upgrading should be rolled into raw feedstock energy.

Finally, discussion turned to whether this feedstock energy problem is confined to bitumen. Some group members argued that feedstock energy would not really be considered in decision-making, in part because its meaning is difficult to interpret. There was a suggestion that this question be brought to the ISO standards committee, arguing that the ISO may not have fully addressed the complexity of this issue.

Key outcomes:

1. Feedstock energy is fundamentally different from other forms of life cycle primary energy in that,
    a. It must be reported for a study to be ISO compliant; and
    b. The group recommends that feedstock energy be reported separately.
2. Since the relevance of feedstock energy is not clear, its consideration should be left up to the user.
3. Whether the emissions from potential use as a fuel should be considered depends on the type of LCA approach – consider if it is consequential and not if it is attributional.
4. For future research, net upgrading impacts could be calculated for possible inclusion in LCA in addition to reporting the feedstock energy in its entirety.

UCPRC Actions:

The research team will report bitumen feedstock energy in the *UCPRC Pavement LCA Guideline* documents in order to be compliant with ISO guidelines. Bitumen feedstock energy will be reported separately from other types of energy. It will be recommended that bitumen feedstock energy not be considered in decision-making for LCA studies conducted for California and other locations where use of bitumen as a feedstock energy source is highly unlikely over the time horizon of the LCA study.

Question: Surface Characteristics and Rolling Resistance (*UCPRC Pavement LCA Guideline: LCA Framework and Standard Assumptions*, Title 5.4.1 a):

- **Do we have the right models?**
- **Can we have the information to adequately include the use phase?**
- **Beyond direct fuel use, where should the system boundary be drawn regarding vehicle operating effects?**
- **In the document, is the modeling approach outline adequate for consideration of traffic flow (i.e., congestion, acceleration, deceleration)?**

Main discussion and key outcomes:

Groups addressing this question reached consensus that the HDM-4 is an acceptable model for modeling the effect of surface characteristics on vehicle operating conditions. However, group members recommend that HDM-4 would be improved if more mechanistic features were introduced into the model. This change would result in a more flexible model that could adapt to inevitable changes such as new vehicle technology.

Discussion participants pointed out that pavement related information (i.e. IRI, rut depth and texture depths) is easier to collect than vehicle information. Thus, while we may be able to reliably model the pavement performance, we may not be able to predict future traffic loads and vehicle technology.

With respect to system boundary, one group member felt that expanding beyond the direct effect of surface texture on fuel consumption will complicate the problem and should not be undertaken. However, groups agreed that a broader system boundary should be left as an option in order to support more comprehensive LCA and impact categories (e.g. noise, damage / cost to goods, damage / cost to vehicles).

Group members found consensus regarding inclusion of congestion in the LCA framework.[3]

UCPRC Actions:

The research team will do the following:

- Use the HDM-4 models for initial studies until better models are available, with particular attention to new information from the MIRIAM project.
- Leave construction work zone traffic in the LCA Framework.
- Pay particular attention to the composition of the vehicle fleet and speed distributions for particular LCA studies.

[3] Construction work zone congestion is within the current LCA framework. Its effect on the relationship between surface characteristics and fuel economy has not yet been explored.

- Recommend sensitivity analysis regarding changes in fleet composition, speed distributions, and market penetration of new vehicle technologies and changes in vehicle fleet fuel consumption characteristics.
- Further investigate the effects of congestion stop/start traffic speed distributions on fuel economy, and consider congestion in the use phase.
- Add noise, damage / cost to goods, damage / cost to vehicles as options to the LCA Framework dependent on the goals of the study.

Question: Multi-criteria decision making (incorporating LCA into decision making)

Main discussion:

Generally, the discussion groups agreed that the Pareto Frontier can be a potential approach to reconcile financial and environmental objectives for regional planning. The main points summarized from these groups are as following.

First, if we are currently not at the Pareto optimal frontier, keep pushing the current practice to the frontier, so we maximize environmental savings. This may be an iterative process, and it may be difficult to get it right in the first place.

The second important aspect is that all points on the frontier should be assessed using the same scope, including discount rate, analysis period, system boundary, data, etc. Before using the frontier to make any decision based on financial and environmental objectives, we need to know our baseline which is currently unknown. Group members pointed out that the frontier may not be a smooth curve. It could be any shape, like a straight edge, or sawtooth.

Group members also pointed out some broader, conceptual problems with the Pareto Frontier. For example, decision-makers may not accept this approach to decision-making. LCA outcomes will need to be presented as a single indicator of performance using weighting factors.

A weighting system like the following table was suggested. This table provides for transparent reporting of weighting factors and the outcomes for each criterion. The transparency of this method of reporting was seen by the group to be an advantage of this approach. A sensitivity analysis is also very easy to perform based on this system. However, the group acknowledged that different agencies and stakeholders have different values and thus the table may need to be adaptable. Another potential problem is that this system can be easily manipulated.

	Init Const.	LCCA	Environmental Impact	Recycling	Maintainability	Total
Weighting factor	60%	20%	5%	10%	5%	100%
HMA	total / weighted	total / weighted	total / weighted	total / weighted	total / weighted	Total/ weighted
PCC						
Structural						
Etc.						

Concerning the problems of this weighting system, some people suggested that this weighting system be only considered as a framework, and weighting factors should be created by individuals who are as close to the "front lines" as possible. Therefore, "the

owner agency, rather than an environmentalist, politician, etc.", should make the decision regarding the weighting factors.

Right now Caltrans sets their weighting factors based on their environmental requirements. This is already integrated into the CEQA process, etc. However, how LCA results will fit within this framework is another problem requiring further attention.

Finally, all the groups addressing this question agreed that for all the methods used to incorporate LCA into decision-making, the most important factor is standardization. All the processes need to be standardized to minimize the risk of manipulation.

Key outcomes:

1. All points at the frontier plotting should be consistent in terms of the goal and scope and key assumptions, such as discount rate, system boundary, etc, to make an equal comparison.
2. If a weighting factor is used to produce an LCA-based indicator, other externalities also need to be considered.
3. The LCA working group should provide a list of potential criteria for use in multi-criteria decision-making.
    a. The decision of which criteria to use and the weighting of those criteria should be made by the owner-agency.
    b. Owner-agency committees deciding on the weighting factors should be diverse enough to speak for the competing criteria.

UCPRC Actions:

The research team will continue to explore multi-criteria decision-making through research and interactions with Caltrans for the state network and for local government in ongoing research projects. Multi-criteria decision-making will be considered in the LCA Framework; however, no specific recommendations will be made at this time. It is clear that this is an area that needs a great deal of additional work for the US context.

Question: Time Horizon (*UCPRC Pavement LCA Guideline: LCA Framework and Standard Assumptions*, Title 3):

The analysis period refers to the time horizon during which the inputs and outputs associated with the functional unit for a system or systems are inventoried. The initial construction of each system will have a different functional design life, and may be followed by a series of different maintenance and rehabilitation (M&R) activities to preserve its function. Properly assessing the pavement system over a time horizon presents a major challenge. Some proposed approaches to determine the analysis period include:

- **Using 1.5 times the longest functional design life among all alternatives**
- **Using minimum next major rehabilitation activity**
- **Annualizing/amortizing construction events**

Main discussion and key outcomes:

The group discussed two items. The first item was defining "one" service life of a pavement system; and the second item was the analysis period.

For the first item, the discussion was mainly focused on the "end" of service life. Three options were suggested: (1) it ends before demolition, (2) it ends after demolition, and (3) it ends after major rehabilitation (reconstruction). All of the group members agreed to include demolition in the service life, but did not agree whether to include reconstruction.

The rationale for including reconstruction was that often demolition and major rehabilitation happen at the same time and it is very hard to distinguish them from one another. If reconstruction is excluded from a service life it will be harder to capture savings based on recycling material (leading to an allocation problem). The rationale for not including reconstruction was that reconstruction might be the "cradle" for the new pavement system. However, members against including reconstruction also agreed that allocation of demolition / reconstruction should be properly analyzed.

The analysis period should be properly set up so that the result of the study can be compared with other studies. Once again, the decision of analysis period should be in accordance with the goal and scope of the study. However, the definition of service life affects the selection of an analysis period. Members who favor including reconstruction were more comfortable with setting up an arbitrary analysis period (e.g. 30 years or 40 years). Members who favor not including reconstruction liked the idea of having common denominator across different pavement systems with different service lives. These members are comfortable with the idea of annualizing construction events as well.

UCPRC Actions:

The research team concludes that for most comparisons of alternatives the reconstruction and demolition should be considered in the life cycle because reconstruction and demolition are almost always simultaneous (very few roads are demolished and then abandoned) and the amount of demolition is tied to the reconstruction strategy. When the time to reconstruction or major rehabilitation (partial reconstruction) is extremely long (more than about 70 years) which imparts a great deal of uncertainty to the future reconstruction (analysis period of 85 to 100 years), then it will be recommended to not include reconstruction/demolition.

In general, it is very difficult to find a common denominator between alternatives being compared and an arbitrary analysis period that is at least approximately 1.2 to 1.5 times the length of time to major rehabilitation or reconstruction of the longest lived alternative will be recommended. Once again, the decision of analysis period should be in accordance with the goal and scope of the study. Because of the inherent difficulties and arbitrariness associated with selecting an analysis period, the rationale should be clearly described within the study's documentation and sensitivity and/or scenario analysis should be considered

Question: Recycling Allocation and Material "Down-Cycling" (*UCPRC Pavement LCA Guideline: LCA Framework and Standard Assumptions*, Title 5.5.1):

- **Pavement materials may be recycled on-site or through an off-site recycling system. In either case, allocating the burdens of recycled materials or repurposed to a specific pavement system is challenging. The following methods have been proposed in the LCA literature to address this challenge.**
- **One study considered allocation of recycled materials and assumed that each construction event is responsible for the materials it uses.**
- **a 50/50 method that allocates half the burden of producing and disposing of virgin materials to the first construction event and half to the final construction event, which uses recycled forms of the virgin material.**

Main discussion:

A 50/50 method has been used to allocate the environmental burden of recycled materials. The group indicated that this might be the result of uncertainty of how materials will be treated at their end of life. The following questions were used to address the question of recycled material allocation and its challenges.

1. Q: What materials will be recycled in the future?

A: Materials that have not been recycled in the past may be recycled in the future.

2. Q: How will materials be recycled?

A: Not every material can or will be recycled to the same state; that is, materials may be "down-cycled" to a lower-value material.

3. Q: Where will the materials be recycled?

A: At the project level, pavement materials are recycled in-place, on-site, or off-site. At the network level, it is often uncertain where the materials (virgin or recycled) come from.

Despite the questions that were left unanswered above, all of the participants agreed that the 50/50 method is inappropriate due to its vagueness. Participants made several suggestions for replacing the 50/50 method.

1. Contractors will favor a method that counts recycled materials only when the recycled materials are used or when the recycling process is conducted – this means credits for future recycling or material recyclability is ignored. This method is in accordance with current LCCA practice.

2. Sensitivity analysis should be used to capture uncertainty.

3. Refine allocation due to various products and logistics scenarios while optimized with respect to cost.

4. Conduct case studies and explore how materials are actually recycled. This method will take time, effort, and money; but will provide an excellent foundation for allocation in pavement life cycle assessment studies as the number of case studies builds up.

UCPRC Actions:

The research team will follow all four of the key outcomes and include them in the *UCPRC Pavement LCA Guideline* documents. It will be recommended that the third and fourth outcomes be included in research road maps (note, these are similar to recommendations of the recent NSF/FHWA Workshop on Pavement Sustainability).

Question: How and when should heat island effect be taken into account in pavement LCA? (*UCPRC Pavement LCA Guideline: LCA Framework and Standard Assumptions*, Title 5.4.1 b)

- **How to model the consequences on energy and other emission?**
- **How to validate the result?**

Main discussion[4]:

Pavements contribute to the heat island due to multiple factors including impermeability and albedo. Albedo is a measure of the surface's solar reflectivity. Differences in the pavement albedo lead to different pavement temperatures, which then affect air temperature.

Traditional pavement structures are typically impermeable. Permeable pavement is one pavement technology that can help mitigate the heat island effect. The challenge is maintaining permeability over time. Routine cleaning is required to keep the permeable structure from becoming clogged. In the case of concrete, the porous structure decreases the albedo, thus there is a trade-off in reducing the heat island effect with non-permeable pavement increasing the heat island effect, while high albedo helps to mitigate this effect.

One outcome of the heat island effect is increased energy use by air conditioning in buildings and vehicles. In addition, the increase in temperature may affect pavement performance, such as rutting in asphalt pavement and high temperature gradient for concrete pavement, or changing the rolling resistance and thus impacting the fuel economy of vehicles.

A group member pointed out that heat island effect from pavement could be relatively small compared to other factors. Nonetheless, there is a steep curve between the temperature and energy consumption by air conditioning. This is especially true if the electricity grid is operating at peak capacity, as peaking plants are less energy efficient and may emit more pollution per kilowatt generated than plants operating at base load. Therefore, if the temperature can be reduced by even 1 ^{o}C, there is a significant potential in energy saving.

There are several important aspects related to the heat island effect. The first is that pavement albedo changes over time. Asphalt pavement lightens (increasing its albedo) while PCC darkens during its use (decreasing its albedo). The former is a result of aging asphalt, while the latter depends on the traffic volume on the pavement. The second important aspect is that this effect should only be taken into account for places with air

[4] This discussion only deals with the effect from urban heat island, not including radiative forcing. There was some discussion of radiative forcing but it was generally agreed that the research in that area was far from sufficient to include in a generally applicable pavement LCA at this time.

conditioning[5, 6]. This point emphasizes that the effects of heat island formation are regionally specific. Finally, the heat island effect should only be taken into account on a network or regional level[7], such as a city, because the heat island effect from a single section of pavement is not significant enough to change the temperature and energy use in a city.

With regard to how heat island effect should be included in LCA, one group that addressed this question reached the following consensus: If there is available research and data to describe the relationship between pavement characteristics and the heat island effect, then it definitely should be included. If there is no certain scientific consensus right now, then sensitivity analysis should be adopted. For heat island, there are already some quantifiable relationships but the research is still not mature enough for clear integration in LCA. Therefore, it should be included as sensitivity analysis, and only at regional level.

Key outcomes:

1. Current models are adequate and capable for exploring the heat island effect in LCA study. However, heat island effect should be included as sensitivity analysis at regional level.
2. The importance or unimportance of a heat island effect is place-specific, that its consequences are also regionally-dependent..
3. Changing albedo over time for different pavements or photocatalytic surfacing needs to be considered.

UCPRC Actions:

The research team will recommend the following in the *UCPRC Pavement LCA Guideline* documents:

- Albedo is not the only factor that affects the ambient temperature. Surface impermeability is also an important factor that will be analyzed, and there are other micro-climate related factors that may be as important as or more important than albedo.

[5] The heat island effect could also provide a warming effect during winter months.

[6] While admitting that heat island effect is a regionally specific concern, it should be pointed out that the impact from heat island effect goes beyond energy problem from air conditioning. For example, many apartments do not have air conditioning and many people died when there is a heat wave that is exacerbated by the heat island effect, or storm water run-off may be warmed before entering streams, disrupting the ecosystem, or exacerbated ozone pollution.

[7] Our understanding is that currently there are possible reliable quantification methods, but they still need further research to be applied in a project-level LCA. An LCA study is needed to make sure that the benefit from cooler pavement is not offset by any other additional impacts imposed by cooler pavement itself.

- Include pavement temperature and reflectance effects as an option for pavement LCA in a sensitivity analysis.
- If it is considered, the effects must be specific to the location considered in the study, which must be explicitly defined in the study's documentation.
- The specific effects of pavement temperatures and reflection considered in the study must be documented (energy use by buildings, etc).
- Albedo changes over time, and thus the LCA should consider more than just albedo at initial construction.

Question: Policy Concerns:

- What are the questions faced by policy-makers and what outcomes from LCA are necessary to answer these questions?

Main discussion and key outcomes:

Some group members from agencies emphasized that the decision process will be based on need, constructability, cost, etc.; and therefore LCA should inform decision-makers only regarding which option is not the "worst", rather than which option is the "best."

Participants were also interested in linking cost assessment and LCA results as a mechanism to ensure that pavement designs that achieve environmental goals do not compromise limited budgets (i.e. money and time). However, alternative methods for environmental assessment, such as LEED style point-counting, is not preferable.

Agency participants also indicated that Caltrans has changed their indicator from GHG and CO_2 to equivalent barrels of foreign oil.[8]

UCPRC Actions:

The research team will continue to discuss ideas with Caltrans, local government in California, and others.

The research team will recommend against implementation of a LEED-style rating system unless it is calibrated (and updated) by LCA studies adhering to the *UCPRC Pavement LCA Guideline* documents, and is project/region/process-specific enough to avoid rewarding business as usual or unintended negative environmental consequences.

[8] This comment by a discussant is not correct, and was discussed as a possibility depending on political changes that might occur. Caltrans has not made any decisions regarding criteria of this kind (GHG versus foreign oil), they have simply discussed alternatives.

Question: How would Agencies implement LCA? (e.g. Netherlands procurement policy) Differences between design-build and design-bid-build.

Main discussion:

One possible way to implement LCA is by integrating it with LCCA and evaluating benchmark construction activities, such as a rehabilitation or maintenance activities. As decision-makers attempt to reduce life cycle cost (LCC), they can look at the environmental gains (or losses) associated with this change. Then environmental analysis and cost analysis can be carried out within the same framework, such as a Pareto frontier, or simply by analyzing the ratio between changes in dollar and changes in some environmental attribute derived from a base case (changes in dollar vs. changes in environmental impact).

It was suggested that both LCA and LCCA be required for each alternative so decision makers can see the trade-offs between economic costs (or savings) and GHG emissions, for example.

In a design-bid-build system (lowest initial cost bid), such as used in California for most projects, LCA is best applied at the design stage. However, in a low bid system, contractors may not follow the lowest impact processes in construction. Therefore, the owner needs to specify what kind of process is required in design decisions. This process requires clear definition of environmental goals, such as performance criteria. Nevertheless, it is still difficult to dictate the behaviors of contractors, such as requiring specific equipment for construction, and there is a need to educate the construction industry. An extra scoring system in addition to the low bid is also an option.

One problem for agencies is that they have little to no idea where materials are coming from at the design stage. It is therefore difficult to estimate the inventory accurately. To achieve the green construction objective, some agencies set performance goals, such as local material sourcing, as a starting point.

For a design-build system, since the agencies will not get the final design until the proposal is ready, it is a challenge to verify whether LCA is being performed properly under time constraints. It may be possible to set an environmental goal from the beginning, but this requires the contractor be educated on LCA and be very creative.

Group members pointed out in the discussion that there is a need for the academic world to bridge the gap among agencies, owners and consumers, and educate them on the findings through some program like technology transfer.

Key outcomes:

1. There is need to educate agencies and the construction industry about LCA.

2. Environmental impact and economic cost should be evaluated under the same framework, such as a Pareto Frontier in multi-criteria decision-making, or similar.
3. LCA needs to enter the bidding documents. In this way, it can influence the contractors' bidding behavior and encourage them to be innovative.

UCPRC Actions:

The research team will pursue further educational outreach to state and local government and the pavement industry on the results of this project, once initial results are completed. The research team will continue to investigate and discuss with Caltrans, local government, and the pavement industry ideas for implementation of environmental performance considerations.