Uses of LCA for pavement

John Harvey

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UC PRC
UNIVERSITY of CALIFORNIA
Davis • Berkeley
PAVEMENT RESEARCH CENTER

Outline

- Transportation uses
- Overview of pavement uses
  - Project level
  - Network level
  - Policy evaluation
- Levels of complexity
- Overview of Product Category Rules and Environmental Product Declarations

LCA Uses in Transportation

- LCA topics have included:
  - Payback time for global warming potential for high speed rail vs air and road transportation
    - Impact of building high speed rail
    - How many people are diverted from air and road and the reduction in GWP that occurs from mode change
  - Evaluation of low carbon fuel standards for on-road vehicles
    - Gasoline, ethanol, biodiesel, electricity
    - Including critiques of LCA when not done properly (functional units not comparable, poorly defined system boundaries)

Pavement Uses Organized per ISO

ISO Use Case	Example
1. Identifying opportunities to improve the environmental performance of products at various points in their life cycle.	a. Pavement material or structural design selection (in conjunction with LCCA) b. Pavement material procurement optimization c. Evaluation of the potential benefits of the use of higher recycled content or on-site recycling of pavement materials

ISO Use Case	Example
2. Informing and guiding decision makers in industry, government, and non-governmental organizations for a number of purposes, including strategic planning, priority setting, product or process design selection, and redesign.	d. Identify the effects of potential changes in a project. Typically comparisons of alternatives for pavement material types and sources, pavement structural designs, pavement type, design lives, future maintenance and rehabilitation scenarios or other types of project-specific plans and specifications. Project can be for a new pavement, rehabilitation or maintenance for a single project. Typically done by or for a project designer or planner who is comparing alternative strategies for treatment of a pavement or a new pavement. An example would be the effects of an improvement in the materials or construction thereby extending the pavement lifespan, or improving smoothness.

ISO Use Case	Example
2. Informing and guiding decision makers in industry, government, and non-governmental organizations for a number of purposes, including strategic planning, priority setting, product or process design selection, and redesign.	e. Identify the effects of potential changes in a policy. Studies used for policy assessment usually consider changes in specifications, design methods, standards, or project or network level goals that will be applied across all projects and all scenarios for network management. Usually evaluate by doing LCA study on a set of example cases selected to sufficiently characterize all expected applications of the change to projects and/or the network for the purposes of deciding whether or not to make the change. Typically done by a pavement engineer or planner to answer questions posed by internal or external stakeholders before moving ahead with changes.

ISO Use Case	Example
2. Informing and guiding decision makers in industry, government, and non-governmental organizations for a number of purposes, including strategic planning, priority setting, product or process design selection, and redesign.	f. External communication of improvements in pavement life cycle design and use by comparing environmental performance over time (current project vs projects from before) g. LCA based environmental performance as part of the procurement purposes in the design-bid-build (low-bid) project delivery system, being used in some European countries. h. Development and application of LCA tools for screening and /or detailed project level LCA

ISO Use Case	Example
3. Selecting relevant indicators of environmental performance from a system-wide perspective.	i. Identification of relevant and significant indicators that an Agency has control over from a network level LCA approach. This type of study focuses on decisions or scenarios regarding timing and types of preservation, maintenance, rehabilitation and reconstruction treatments for a set of pavements that are managed as a network. Typically performed by or for pavement management staff in order to answer questions posed to the pavement management unit regarding the entire network or subsets within the pavement network. j. Prioritize LCI database development, either state (regional) or national

ISO Use Case	Example
4. Quantifying information on the environmental performance of a product or system (e.g., to implement an eco-labeling scheme, make an environmental claim, or produce an environmental product declaration statement).	k. The development of an Environmental Product Declaration (EPD) following the Product Category Rules (PCR) for the product that is the subject of the EPD. l. While some pavement materials that are used in pavement LCA are in the process of or have published Environmental Product Declarations (EPD) there are currently no programs available in the US market for environmental claims on a pavement structure level. It is generally expected that pavement structures will not be subject to EPD in North America because pavement structures are generally individually designed for unique conditions for each project. They are also often designed by the owner rather than the producer without knowing the precise source of material, and therefore cannot be assessed generically with an EPD.

Most common uses of LCA in North America using the categorization from previous table

- Selection of a material or pavement structural design in conjunction with LCCA (1.a)
- Evaluation of the impacts of potential changes in a policy or specification (2.e.)
- Development of LCA tools for screening and /or detailed LCA for the scoping and/or design of a project (2.h)
- Evaluation of scenarios for network level decisions and strategies for preservation, maintenance and rehabilitation (3.i)
- Development of pavement material EPDs (4.k)

Levels of Complexity

- Benchmarking studies
  - Intended to provide initial results for comparison of alternative decisions
  - Often limited to goal and system definition, determination of flows of materials and resources into the system and products, wastes and pollutants out of the system, and quantitative comparison of those results.
  - This type of study can also be limited to only focus on the changes between the different alternatives.
  - May not include impact assessment and only include inventory data such as energy, emissions and waste.
  - Not considered a full LCA, but begins the process of applying LCA methodology to decisions.

Levels of Complexity

- LCA studies with only a few impact indicators and/or which only consider selected phases of the full life cycle
  - Usually cover all of the phases of LCA
  - Include the development of life cycle inventories (LCI) and life cycle inventory impact assessment (LCIA).
  - Current pavement LCA tends to fall in this category looking mostly at energy flows and greenhouse gas emissions.
  - The interpretation phase may also include less detail than is called for in a more comprehensive LCA, however it should include sensitivity assessment and complete documentation of its limitations for transparency reasons.

Levels of Complexity

- LCA studies that include LCI, LCIA for a larger set of impact indicators and interpretation, and consider the complete pavement life cycle.
  - This can be referred to as full LCA.
  - A full LCA is generally required for EPDs as called for in PCRs except that the life cycle stages only go from cradle to producer's gate.
  - As data and knowledge become more available, expect to see more complete LCA studies in North America.

Example: Procurement of Contractor in Design/Build/Maintain Project

- In Netherlands and France contractor is picked based on combination of cost and environmental impact of pavement
  - Cost: life cycle cost analysis
  - Environmental impact: life cycle assessment
- Standardized software approved by committees used for LCA
- In Netherlands LCA results are converted into cost and added to find total cost
- In France LCA and LCCA results are used combined in a score
- Sweden, UK and Chicago (USA) moving towards this process
- Incentives designers, materials producers and contractors to reduce environmental impact in all phases of producing pavement

Example Pavement Scenarios That Can Be Analyzed with LCA

- Project level:
  - Selection and design of pavement structures, recycling strategies, pavement and rehabilitation design lives, materials sourcing and transport alternatives
- Network level:
  - Timing of maintenance and rehabilitation treatments, funding levels, policies for network application
- Policy level:
  - Evaluation of new materials, structures, specifications, construction approaches for current pavements
  - Estimation of use phase effects and changes in practice: smoothness, reflectivity, permeable pavement
- In all cases, often a comparison of alternatives

Example of LCA for Pavement: Comparison of Concrete Design Lives for GWP and Cost

- Goal: Determine the economic and environmental impact of alternative pavement designs.
  - Life Cycle Cost Analysis: agency costs (Caltrans LCCA-RealCost)
  - Looked at energy, global warming potential, and other environmental effects
  - Same materials for each design
  - Different design lives
  - Different structural thicknesses
- Focuses on differences in material volumes rather than material types
  - Does not address whether concrete or asphalt is a environmentally superior pavement choice

Scenarios

- Scenario designs created for three locations
  - 20- and 40-yr design lives compared
  - Designs created using the Mechanistic Empirical Pavement Design Guide (MEPDG)
  - Maintenance schedules based on the MEPDG simulations and the data from the Caltrans LCCA Manual

Location	Design	Project Length (ln-mi)	PCC Surface (in)	AC Base (in)	Granular Subbase (in)	Volume (yd^3)	Steel (# of dowels)
LA 210	20-yr JPCP	1	8	6	6	1695	4224
	40-yr JPCP		10			2119	4224
Merced 99	20-yr JPCP	4.8	8	6	6	8214	20472
	40-yr JPCP		12			12321	20472
SLO 49	20-yr JPCP	6.4	8	6	6	10847	27034
	40-yr JPCP		12			16271	27034

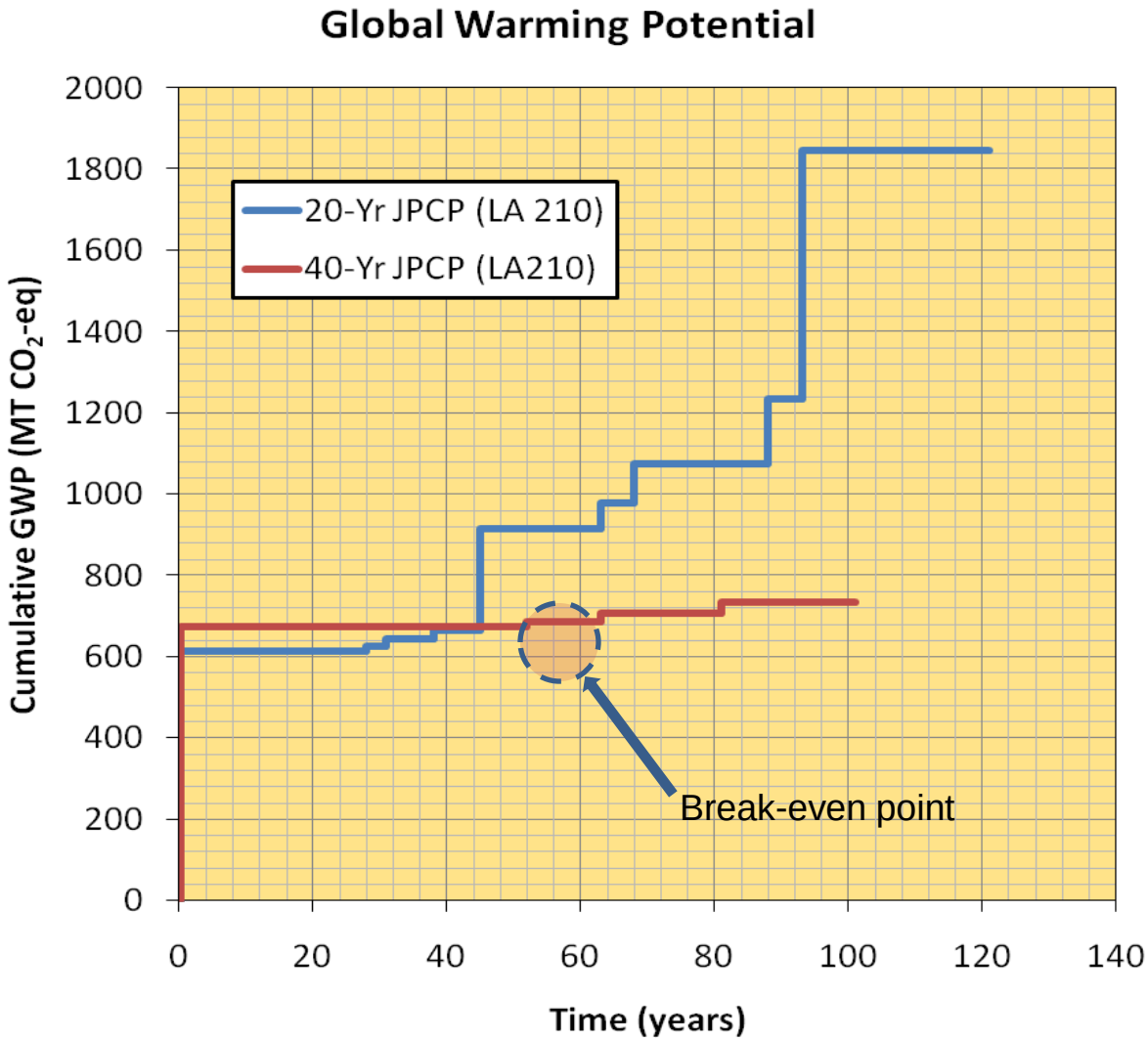
Initial Results

	40-Year Designs, relative to 20-Year Designs
Initial Construction	•10-20% more CO_2 and other greenhouse gases emissions •5-10% more expensive
100-Yr Analysis Period	•200-300% less CO_2 and other greenhouse gases emissions •3-11% less expensive (NPV)

- 40-yr design shows promise from both financial and environmental perspectives
  - Consistent across all three scenario locations
  - Results are dependent upon the analysis period
- Other environmental metrics (e.g. energy consumption) follow this trend

GWP Payback Period

- Savings are not immediately realized
  - Payback ~30-45 years in the future
- Future is highly uncertain
  - Technological advancements
  - Uncertain demand
- What's the right analysis period?



Pavement Materials PCRs

- Specific to a material
- Typically cradle-to-gate (i.e., excludes use and/or end-of-life)
- PCRs (and EPDs) are available for many basic materials
- Becoming more prevalent
- Pavement PCRs
  - Cement, concrete, lime aggregate in place
  - Asphalt, asphalt mixes under development

epd-norge.no
The Norwegian EPD Foundation

PRODUCT-CATEGORY RULES (PCR)

For preparing an environmental declaration (EPD) for Product Group

Asphalt and crushed stone

NPCR 18
November 2010

rushed stone 10.11.2010 1

University of Washington
College of Built Environments
Department of Architecture

CARBON LEADERSHIP FORUM

NORTH AMERICAN PRODUCT CATEGORY RULES (PCR) FOR
ISO 14025 TYPE III ENVIRONMENTAL PRODUCT DECLARATIONS (EPDs)
and/or
GHG PROTOCOL CONFORMANT PRODUCT 'CARBON FOOTPRINT' of

CONCRETE

Meeting the requirements of one of the following:
ASTM C 94
ASTM C90
CSA A23.1-09/A23.2-09
UNSPSC code 30111500

EPDs created by this PCR are appropriate to be used to evaluate the environmental impact of concrete.

Provided this data is integrated into a comprehensive product LCA, the EPD results can be used to evaluate the **concrete** component of products such as:

Cast in Place Concrete (e.g. CSI/CSC 2004 Master Format 03 3X XX)
Precast Concrete (e.g. CSI/CSC 2004 Master Format 03 4X XX)
Mass Concrete (e.g. CSI/CSC 2004 Master Format 03 70 00)
Concrete Masonry Units (e.g. CSI/CSC 2004 Master Format 04 22 00)

ADOPTED NOVEMBER 30, 2012

BUILT ON GHG PROTOCOL

This PCR has been reviewed by the World Resources Institute for conformance with the GHG Protocol Product Life Cycle Standard.

www.carbonleadershipforum.org
University of Washington Box 355720 Seattle, WA 98195-57

LIFE CYCLE INVENTORY: BITUMEN

eurobitume

Example of LCA for Pavment:

Environmental Product Declaration:

Concise, quantitative information

Increasingly important in pavement product competition

Environmental Facts

Functional unit: 1 metric ton of asphalt concrete

Primary Energy Demand [MJ]	4.0×10^3
Non-renewable [MJ]	*3.9×10^3*
Renewable [MJ]	*3.5×10^2*
Global Warming Potential [kg CO_2-eq]	79
Acidification Potential [kg SO_2-eq]	0.23
Eutrophication Potential [kg N-eq]	0.012
Ozone Depletion Potential [kg CFC-11-eq]	7.3×10^{-9}
Smog Potential [kg O_3-eq]	4.4

Boundaries: Cradle-to-Gate
Company: XYZ Asphalt
RAP: 10%

Example LCA results

Adapted from N. Santero

Definitions and Relationships

PCRs, LCAs, and EPDs

PCR: the framework

Product Category Rule (PCR)

"Set of specific rules, requirements, and guidelines for developing Type III environmental product declarations for one or more product categories" (ISO 14025)

LCA: the analysis

Life Cycle Assessment (LCA)

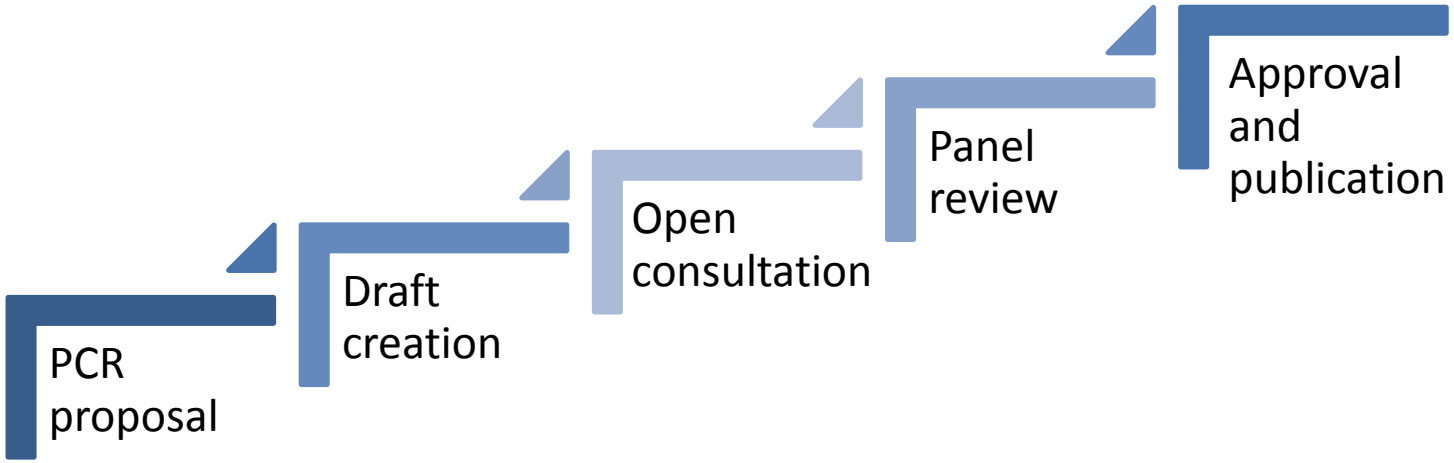
"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040)

EPD: the declaration

Environmental Product Declaration (EPD)

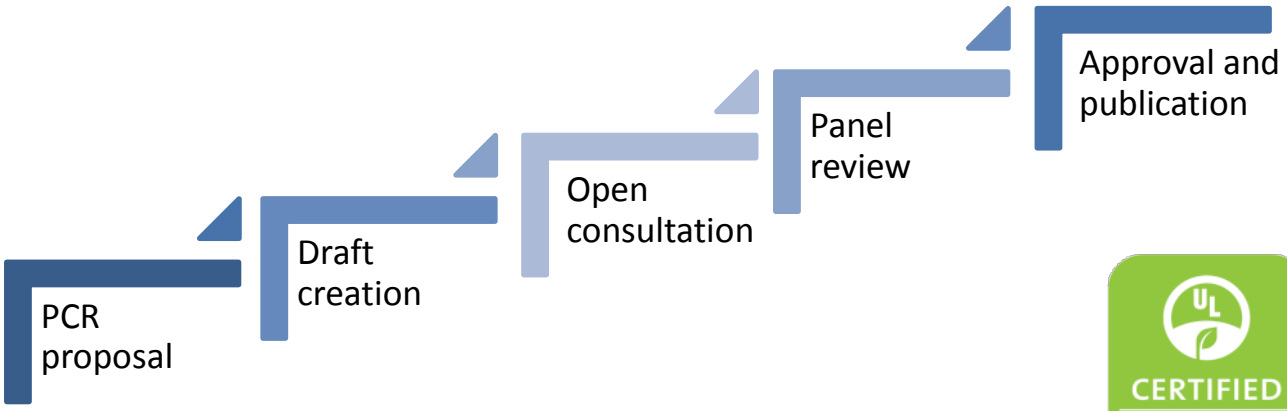
"Providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information" (ISO 14025)

PCR Development Steps



- Stakeholder engagement
  - Industry associations (e.g., ACPA, NAPA, IGGA, ISSA)
  - Manufacturers (e.g., companies)
  - LCA practitioners (e.g., LCA consultants)
  - Government agencies (e.g., FHWA, state DOTs)
  - NGOs
- Subject to critical review, relative to ISO and other standards of importance to customers

PCR Development Steps



- Facilitated by a program operator
  - Hosts the PCR
  - Verifies EPDs
  - Registers EPDs
- Currently some chaos in US for PCRs
- In Europe generally reviewed by government coordinating committees

Example North American program operators →

Environmental Product Declaration:

Concise, quantitative information

Increasingly important in pavement product competition

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Example LCA results

Adapted from N. Santero

Example of Pavement LCA: World-wide Benchmarking

- Goal: Compare two inventory data sets on same pavements
- Benchmarking of LCA should lead to better understanding of practice and results
  - assumptions, life cycle inventory (LCI) process models, differences in inventory results for individual materials
- Benchmarking should also help increase the transparency of LCA
  - Reduce the tendency to treat LCI results as "golden black boxes"
  - Many inventories have been used extensively and are widely accepted, but have not been subjected to recent critical review

World-wide Benchmarking of Pavement Design Practice

- Goal: compare environmental impacts of structures designed by four national methods
- Pavement design methods follow same principles world-wide, but vary in local calibration
  - Soils
  - Traffic
  - Climate
- Pavement types vary around the world
- We can learn how to reduce environmental impact of pavement construction, maintenance and rehabilitation by benchmarking our structures

Scope of Comparisons of Pavement Design and LCI

Inventory/Design	California R-value design	France LCPC catalog design	South Africa standard design	China national catalog design
ECORCE	X	X	X	X
UCPRC[1]	X	X	X	X
ECORCE adjusted to local country conditions[2]	X	-	X	X
UCPRC adjusted to local country conditions[2]	-	X	X	X

Pavement Types

- Same traffic, soil for all pavements
- Different design methods, climates
- California and France:
  - Thick asphalt on granular base
  - Very similar designs
- China: Thick asphalt on cement treated base
- South Africa: Thin asphalt on cement treated and granular base

Electricity Mix in California, US, France, South Africa and China

Type	California	France	South Africa	China
Coal	7.7%	4.5%	85.6%	66.0%
Natural Gas	41.9%	4.1%	5.5%	3.3%
Hydro	10.8%	12.5%	1.4%	21.7%
Nuclear	13.9%	78.0%	4.3%	1.1%
Oil (Pumped Storage)	0.02%	-	3.2%	-
Wind (Renewable)	13.7%	Included in the Hydro percentage	0.01%	5.3%
Solar (Renewable)	-	Included in the Hydro percentage	-	0.3%
Other	12.0%	0.9%	-	< 2%

Benchmarking of LCA: GWP with French and Californian Inventory and Assumptions

Table 5 Energy results in MJ (ECORCE) with French Electrical Energy and HMA Plant Fuel

	French case	Californian case	South African case	China case
Bitumen	1.93E+06	1,898, 689	3.68E+05	1.66E+06
Stabilisation plant	-	-	8.41E+05	6.12E+05
Hot-mix asphalt plant using gas	3.85E+06	3.56E+06	-	-
Hot-mix asphalt plant using fuel oil	-	-	7.71E+05	3.86E+06
EN 197-1 Portland slag cement CEM/II A-S 81	-	-	4.00E+6	3.79E+06
Gravel soil extraction	-	-	8.32E+04	-
SBS Elastomer	-	-	-	6.95E+05
Emulsion plant	4.97E+03	9.93E+03	-	9.93E+03
Aggregates	1.98E+06	2.36E+06	1,068 625	1.84E+03
Road transport	9.83E+05	1.15E+06	6.30E+05	1.03E+06
Gravel soil transport by dumper	-	-	1.66E+05	-
Total	8.74E+06	8.98E+06	7.93E+06	1.35E+07

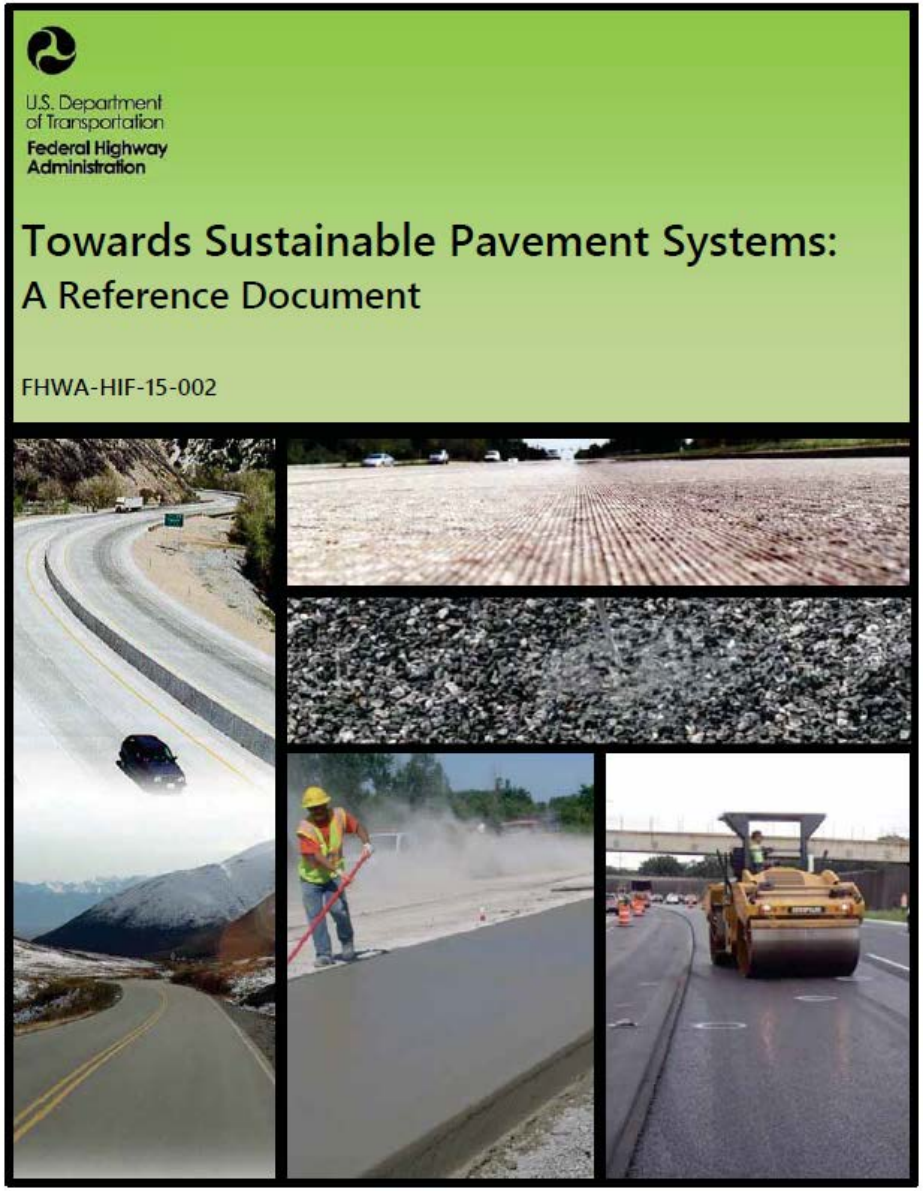
Table 6 Energy results in MJ (UCPRC) with California Energy and HMA Plant Fuel

	France	California	South Africa	China
Hot Mix asphalt surface	6.32E+06	1.52E+07	3.16E+06	3.38E+07
Coarse Aggregate	1.82E+06	1.57E+06	2.28E+06	1.24E+06
Fine Aggregate	4.89E+05	7.60E+05	6.48E+05	4.84E+05
Asphalt (not in HMA)	4.90E+06			
Cement (Type I/II portland cement)			5.70E+06	5.32E+06
Transportation (Asphalt+Cement)	8.52E+04	8.41E+04	1.28E+05	1.79E+05
Transportation (Aggregate)	1.17E+06	1.41E+06	1.38E+06	8.59E+05
Total Material Production	1.35E+07	1.75E+07	1.18E+07	4.09E+07
Total Transportation	1.25E+06	1.49E+06	1.51E+06	1.04E+06
Total	1.48E+07	1.90E+07	1.33E+07	4.19E+07

Harvey et al. Pavement LCA 2014 paper

Other questions that can be addressed

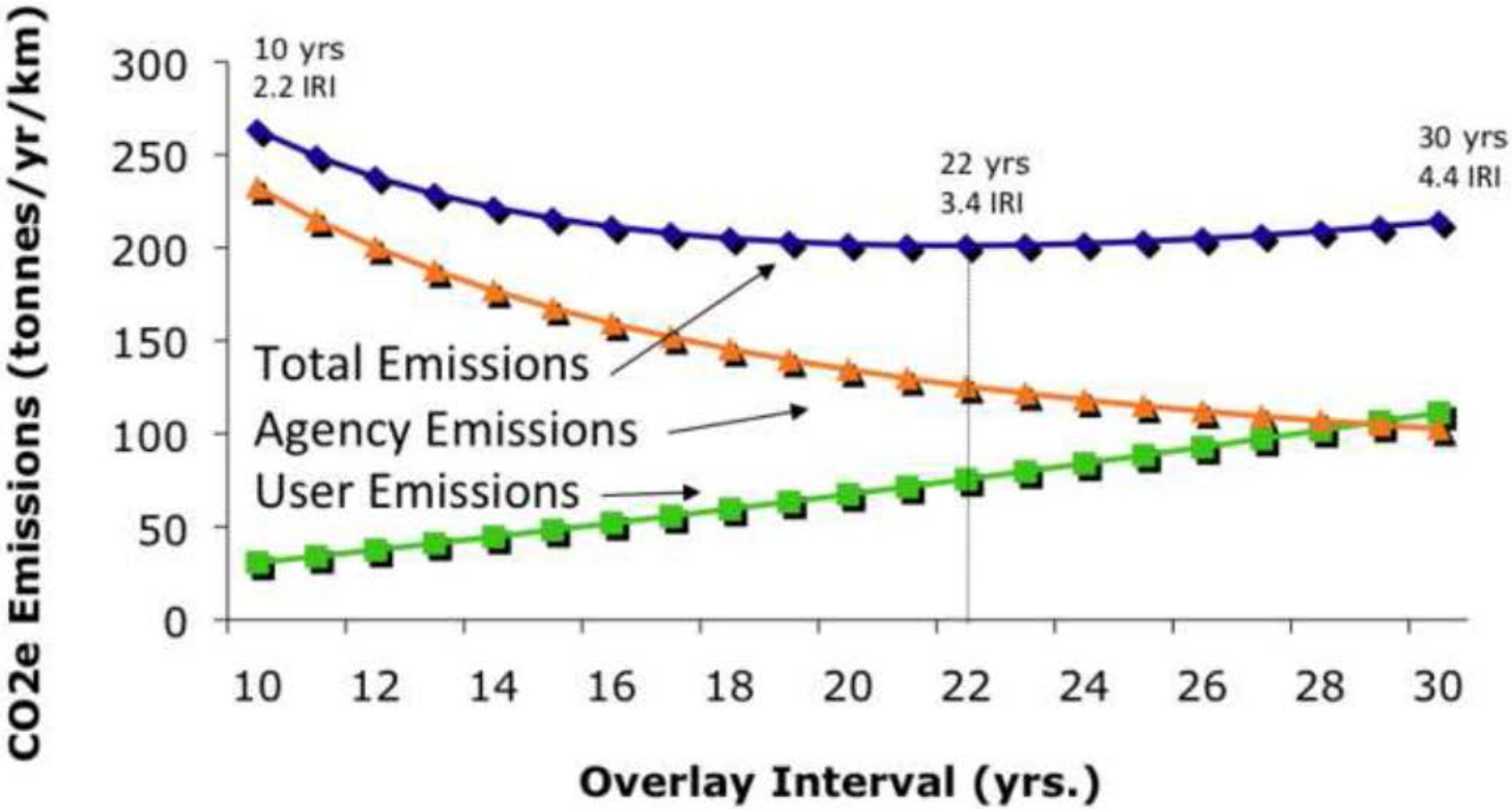
- See tables in FHWA Reference Document: Towards More Sustainable Pavement
- http://www.fhwa.dot.gov/pavement/sustainability/ref_doc.cfm
- Recommendations for improving sustainability across entire pavement life
- Can be evaluated with pavement LCA



Asphalt materials questions

Asphalt Materials Objective	Sustainability Improving Approach	Economic Impact	Environmental Impact
Reduce Virgin Binder Content in Asphalt Concrete	Use greater quantities of RAP if same or better performance can be realized.	Reduces cost of asphalt concrete if RAP available.	Dependent on performance, energy costs of mixing, transportation.
	Use rubberized asphalt for asphalt concrete.	Some increase in initial cost, impact of mixture design higher, potential payback in less material for thin overlays, increased life.	Reduces impacts by decreasing amount of materials needed over time horizon.
	Use RAS as partial replacement for asphalt binder if same or better performance can be realized.	Reduces cost of asphalt concrete if RAS available.	
	Use bio-binders.	Impacts and trade-offs unknown.	Impacts and trade-offs unknown.
	Use sulfur-modified asphalt.	Not well quantified.	Potential difficulty in future recycling.

Network level question: GWP tradeoffs of keeping pavement smooth



Lidicker ASCE J. Infr. Sys.

Summary

- Different types of studies can be performed
  - Can address almost any question regarding pavement environmental impact
- Different levels of complexity
  - Use relevant to goal of study and ability to collect data

Discussion Questions

- What are some of the environmental goals in China?
- What are some of the potential questions to be addressed in China?
  - Project level
  - Network level
  - Policy level
  - Production of EPDs
  - Levels of detail possible with current data availability

Questions?

John Harvey, jtharvey@ucdavis.edu
Hui Li, hili@ucdavis.edu; hli@tongji.edu.cn