Lifecycle Assessment for Transportation Facilities

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Meet Your Instructors

- John Harvey, Ph.D., P.E., M.ASCE
  - Professor, UC Davis
  - Director, University of California Pavement Research Center
  - Chair, ASCE Sustainability sub-committee, Transportation & Development Institute

- Alissa Kendall, Ph.D.
  - Associate Professor, UC Davis
  - Chair, Energy Graduate Group

- Both instructors are part of the contract team for the FHWA Sustainable Pavements Technical Working Group

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Outline

- Brief history of Life Cycle Assessment
- Overview of LCA basics and international standards
- Transportation life cycles
- Applications of LCA for transportation infrastructure projects; for transportation operations, management and policy
- Basics of Environmental Product Declarations
- Current resources and gaps
- How to get started on LCA with few resources
- Integration of LCCA and LCA in decision making
- Summary and expected future developments
- Questions and Answers

Webinar Outcomes

- Learn what LCA is and how it works
- Learn about current standards and guidelines for transportation
- Learn about gaps and future trends
- Review several case studies
- Learn about interaction of life cycle cost analysis (LCCA) and life cycle assessment (LCA)
- Learn how to begin implementing “LCA thinking” into practice with few resources

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Why Care? US Pavement Facts

- Scale: 4 million miles public roads, 2.65 million miles paved (asphalt or concrete) roadways
- Mobility & access: three trillion vehicle miles travelled annually
- Value: Roads carry about 67 percent of all freight in the US (tons and $)
- Employment: 300,000 people employed in roads and bridges
- Cost: $182.1 billion spent on highways
- Owners: State and local governments, private and institutional owners, federal government

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Image sources: Pixbay.com and Microsoft Clip Art

Source: FHWA Pavement Sustainability Reference Document

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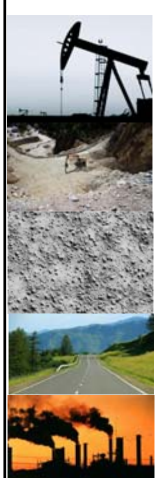
Why Care? US Pavement Facts



- Energy used each year: vehicles moving on pavement burn 169 billion gallons of fuel
- Natural resources used each year: 1,200 crushed stone, 987 sand/gravel, 21 asphalt binder, 72 cement (incl. bridges) million metric tons, all highly recycled
- Emissions from road system: Greenhouse gases (GHGs), air and water pollutants

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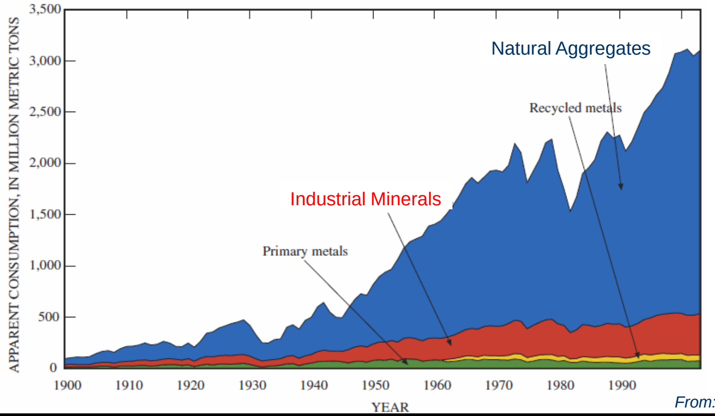
Image sources: Pixbay.com and Microsoft Clip Art

Source: FHWA Pavement Sustainability Reference Document

Why Care? Material Flows

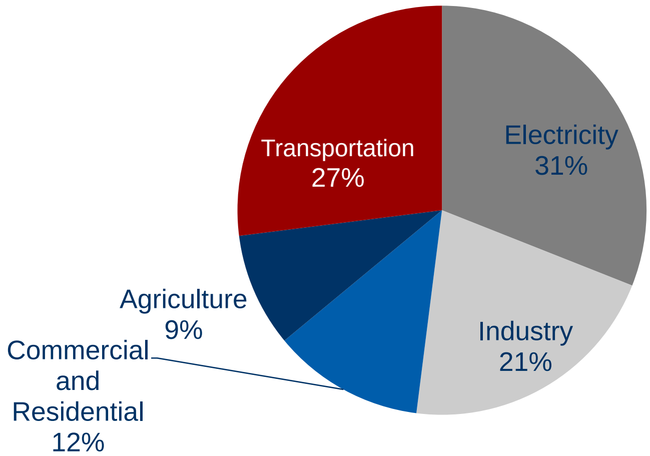
- Natural resource consumption grew with increasing traffic demand and new roads; few new roads being built now
- Aging pavement network requires maintenance, rehabilitation



From: Sullivan, *2006*

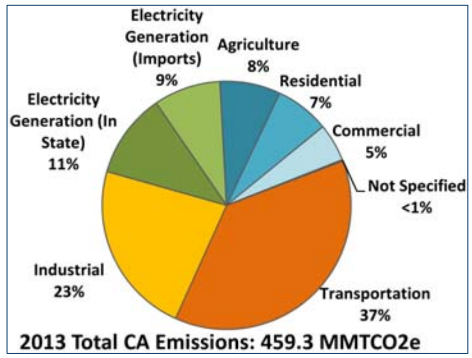
Why Care? Greenhouse Gas Emissions

US Greenhouse Gas (GHG) Inventory 2013, US EPA



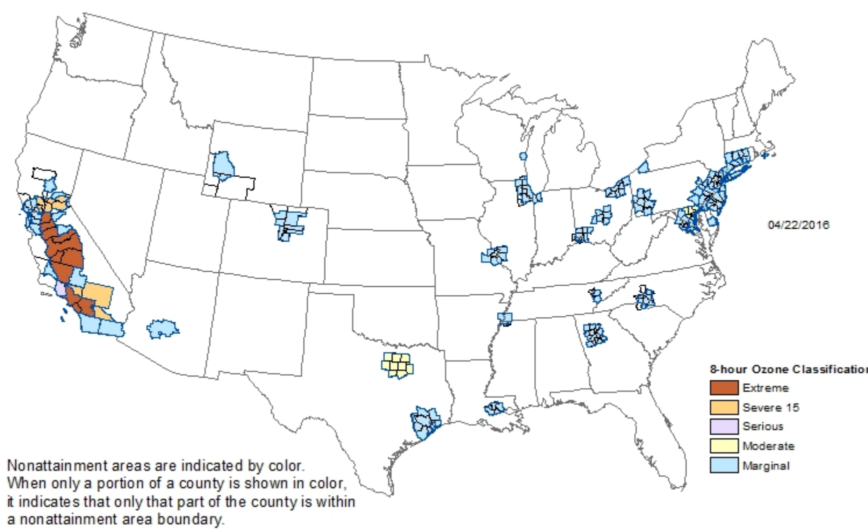
How do Pavements Contribute to GHG Emissions?

- Out of 459 MMT CO2e
  - On road vehicles 155 MMT
    - Pavement roughness and other effects can change vehicle fuel use by about 0 to 4 %
  - Refineries 29 MMT
    - Paving asphalt about 1 % of refinery production
  - Cement plants 7 MMT
    - Paving cement about 5 % of cement plant production
  - Commercial gas use 13 MMT
    - Very small amounts for asphalt mixing plants
  - Mining 0.2 MMT
    - Large portion for aggregate mining



http://www.arb.ca.gov/cc/inventory/data/data.htm

8-hour ozone non-attainment by county



https://www3.epa.gov/airquality/greenbook/map8hr_2008.html

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Master equation for environmental impacts

Environmental impact as function of Gross Domestic Product (national economic output) =

$$\text{Impact} = \text{Population} * \frac{\text{GDP}}{\text{Person}} * \frac{\text{Impact}}{\text{GDP}}$$

Environmental Impact

Increase in wealth and economic activity

Technological efficiency (how to measure?)

Ehrlich and Holdren (1971) Impact of population growth. e.g. via LCA. *Science* 171, 1211-1217. Slide adapted from R. Rosenbaum, Pavement LCA 2014 keynote address

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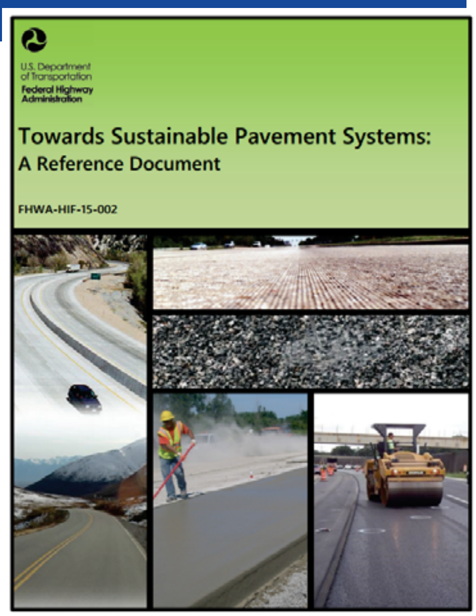
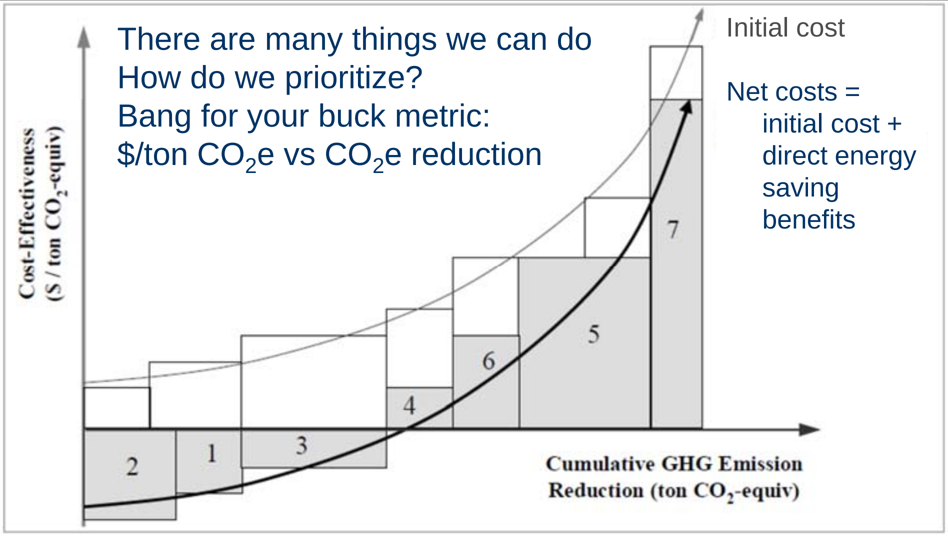
Many things can be done to reduce impacts

- FHWA
  - Reference document February 2015
    - Summary of state-of-the-knowledge for reducing environmental and cost impacts of pavement
    - Covers all pavement life cycle phases
  - Tech briefs and webinars



http://www.fhwa.dot.gov/pavement/sustainability/ref_doc.cfm



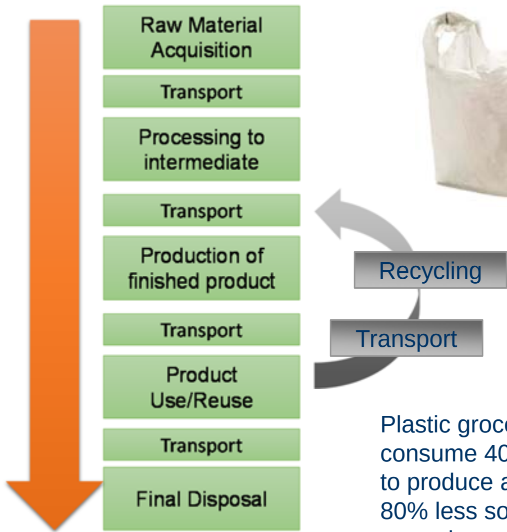
- **Prioritizing Climate Change Mitigation Alternatives: Comparing Transportation Technologies to Options in Other Sectors**
- **Lutsey, N. (2008)**
  Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-15

Life Cycle Assessment (LCA)

- If we are to improve sustainability of pavement, we must be able to measure impacts
- LCA is a method for characterizing and quantifying environmental sustainability using a cradle-to-grave perspective, and considering system-wide impacts for a product, policy, or system
- The purpose of an LCA is typically to compare the performance of alternatives, to anticipate unintended consequences of a decision or technology, or to identify environmental “hot spots” that might be targeted for improvement.

Consider the life cycle of these two products – do you think you could predict the outcome of the LCA?

Research from 2000 shows 20% of paper bags were recycled, while 1% of plastic bags were recycled.



Plastic grocery bags consume 40% less energy to produce and generate 80% less solid waste than paper bags.

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http://techalive.mtu.edu/meec/module14/ReusingBags.htm

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Standardization of LCA methods

- LCA standards were first proposed in the early 90s, first by SETAC and then by ISO
  - SETAC: Society of Environmental Toxicology and Chemistry
  - ISO: International Organization for Standardization
- The most commonly cited standard for LCA is the ISO 14040 series standard
- One challenge for LCAs (and particularly for comparing LCAs) is ensuring that similar methods were applied by different practitioners
  - However standards on their own are insufficient for this task

ISO LCA Standards

- Part of ISO 14000, Environmental Management
  - **14040 Environmental management -- Life cycle assessment -- Requirements and guidelines (2006)**
    - 14041:Goal and Scope Definition and Inventory Analysis
    - 14042: Impact Assessment
    - 14043: Interpretation
  - **14044: Environmental management -- Life cycle assessment -- Requirements and guidelines (2006)**
  - 14047:2003 Environmental management — Life cycle impact assessment — Examples of application of ISO 14042
  - 14048:2002 Environmental management — Life cycle assessment — Data documentation format

SETAC

- *SETAC Guidelines for Life-Cycle Assessment: A "Code of Practice" (1993)*
- Though one of the earliest standards, the ISO 14000 series is more frequently cited and used
- Partnered with the UN to publish some guidance manuals available through: http://www.unep.org/resourceefficiency/

Others LCA and related standards: PAS250, US EPA

- PAS 2050 – specification for life cycle assessment of GHG emissions only – i.e. “Carbon Footprint”

Can be downloaded for free from the British Standards Institute

Note: Carbon (or energy) footprints are a narrow and incomplete form of LCA, where only one kind of environmental impact is tracked and quantified

- The US EPA guidelines are very similar to (and based on) ISO Standards

- The basic steps are:
  (1) Goal Definition and Scope
  (2) Inventory Analysis
  (3) Impact Assessment
  (4) Interpretation

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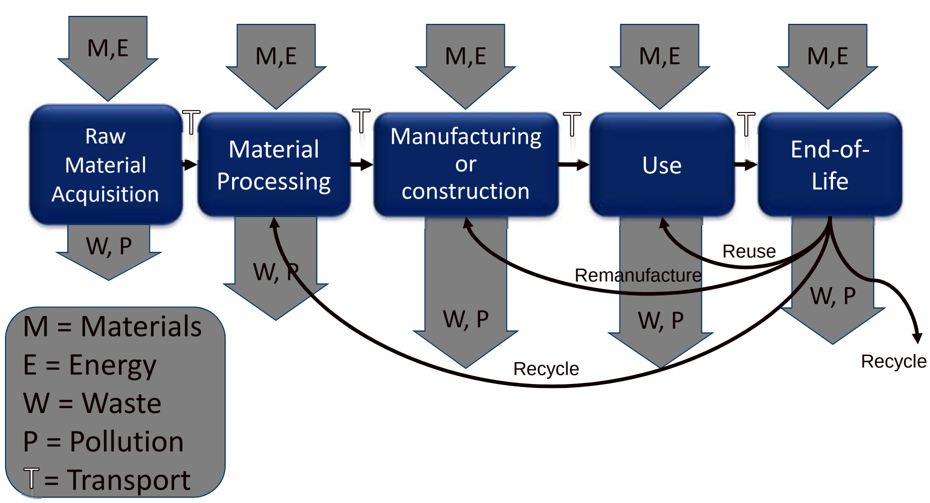
Generic Life Cycle Assessment



Kendall, A., Keoleian, G. A., 2009

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Four Key Steps of Life Cycle Assessment

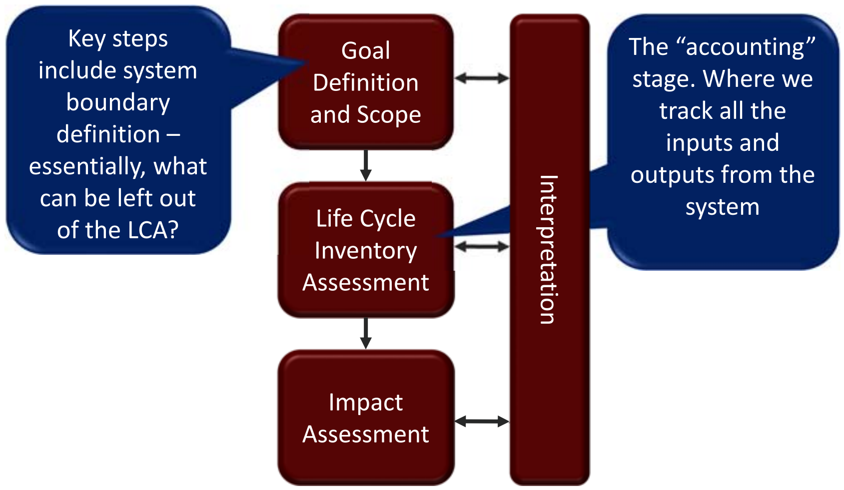

Figure based on ISO 14040

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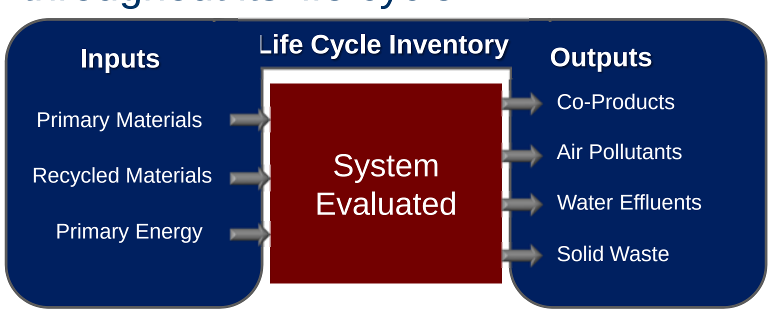
Life Cycle Inventory (LCI)

- The quantification of relevant inputs and outputs for a given product system throughout its life cycle



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Four Key Steps of Life Cycle Assessment

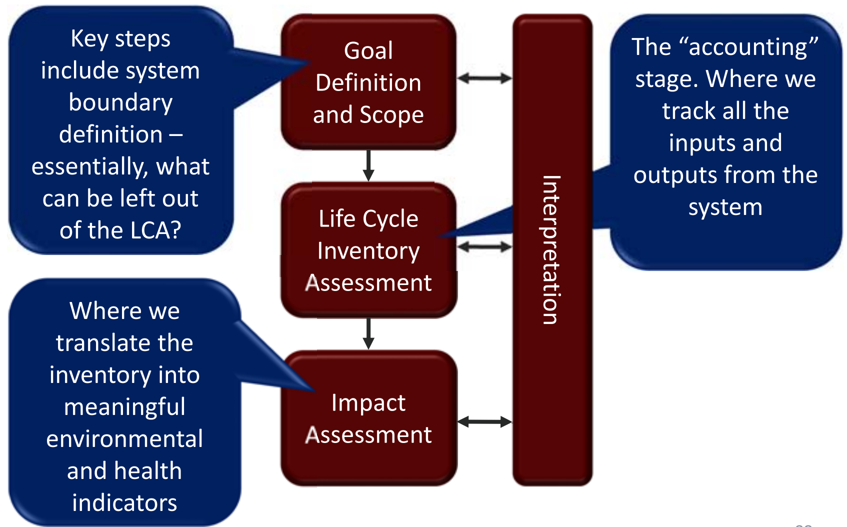

Figure based on ISO 14040

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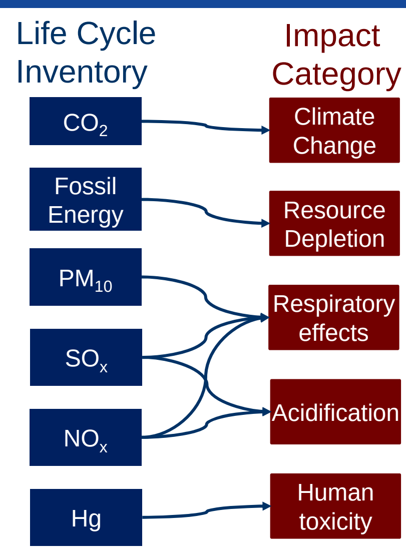
Life cycle impact assessment

- Translate resources consumed or pollutants emitted into effects on humans or the environment.



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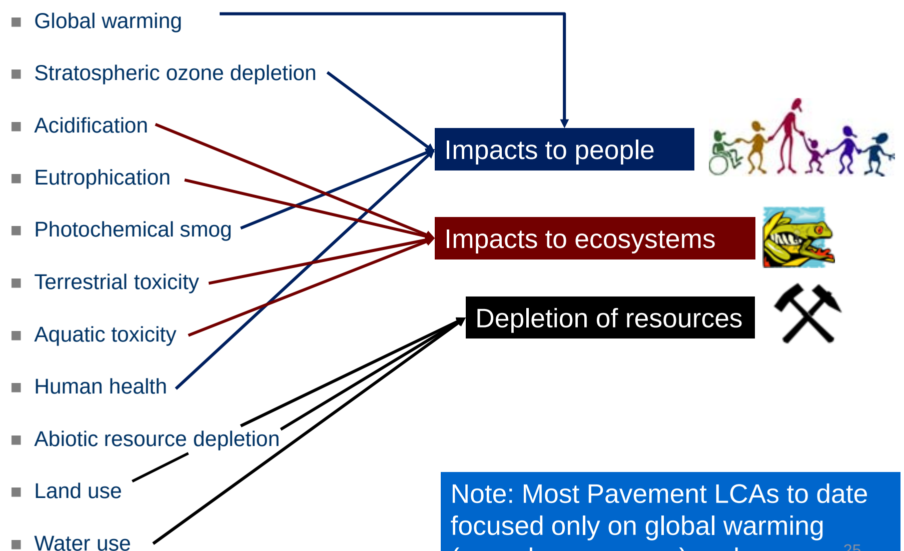
US EPA Impact Assessment Categories (**TRACI – Tool for the Reduction and Assessment of Chemical and other environmental Impacts**)



Note: Most Pavement LCAs to date focused only on global warming (greenhouse gases) and energy use

Image sources: Google

Four Key Steps of Life Cycle Assessment

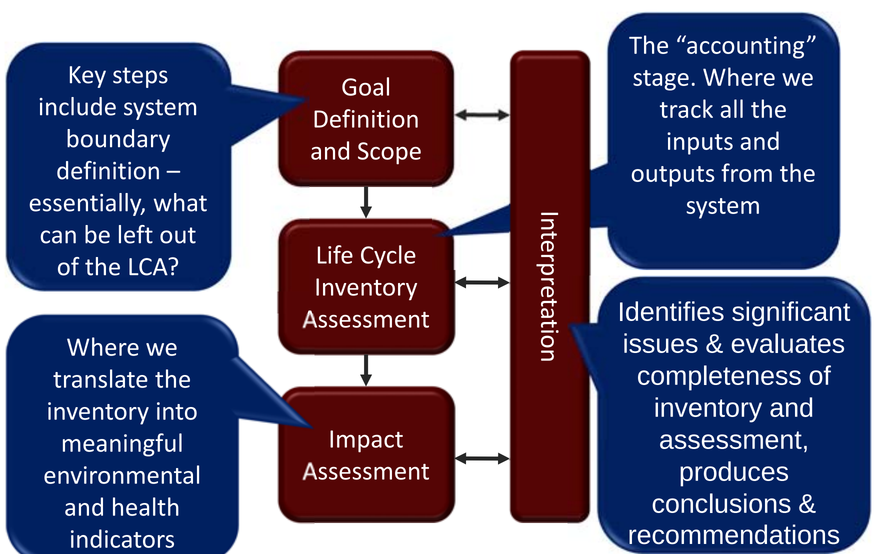


Figure based on ISO 14040

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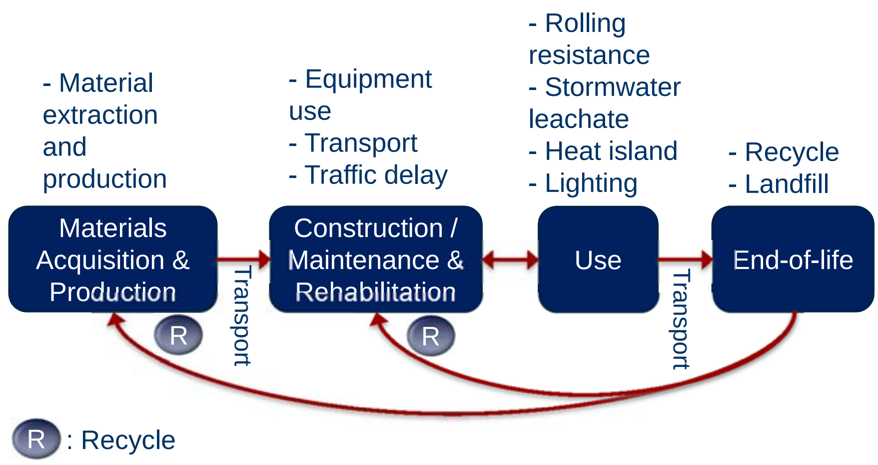
Pavement Life Cycle



From: Kendall et al., *2010*

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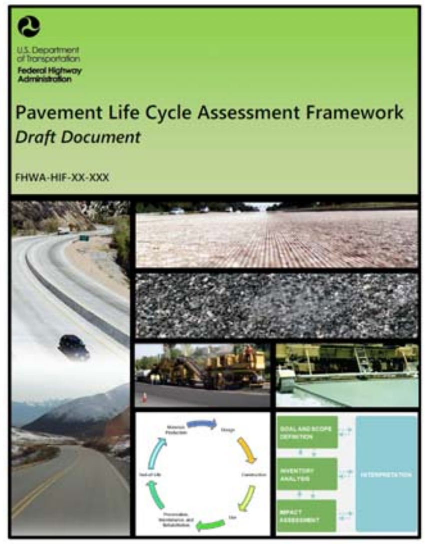
Movement Towards Standardization for Pavement LCA: Symposia

- Recognized need to develop pavement LCA community
- Standardize methods, spread knowledge
- Next: Pavement LCA 2017, Chicago

Movement towards standardization for pavement LCA

- World-wide, ISO standards (14040, 14044, 14049) published 2000-06
  - Applicable to all products
  - Not specific for individual products
- Europe
  - European Standard published in 2012 (EN 15804:2012+A1)
  - Other national standards (Norway, Netherlands, France, UK)
- US
  - University of California Pavement Research Center (UCPRC) guidelines (2010)
  - Federal Highways Administration guidelines (expected summer 2016



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.

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Levels of Complexity: LCA with Limited Scope

- LCA studies with only a few impact indicators and/or which only consider selected phases of the full life cycle
  - Include the development of life cycle inventories (LCI) and life cycle inventory impact assessment (LCIA).
  - May include only a few flows and indicators, such as energy flows and greenhouse gas emissions.
  - May have truncated life cycle, such as materials studies (cradle-to-gate) or materials and construction (cradle-to-laid) for pavements.
  - 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.

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Levels of Complexity: Full LCA

- 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.

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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)

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Most common uses of LCA for Pavements in North America

- Selection of a material or pavement structural design in conjunction with LCCA
- Evaluation of the impacts of potential changes in a policy or specification
- Development of LCA tools for screening and /or detailed LCA for the scoping and/or design of a project
- Evaluation of scenarios for network level decisions and strategies for preservation, maintenance and rehabilitation
- Development of pavement material Environmental Product Declarations (EPD)

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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

Project Level Example

- Project Level Goals: answer these questions:
  - What is effect of construction smoothness on GWP?
  - What is effect of pavement materials on GWP?
  - What is effect of traffic level on GWP?

Models: Materials and construction

- Materials production and plant emissions:
  - Existing databases and studies
- State or regional models, California and US examples:
  - Off-Road equipment
    - *OFFROAD* (California), NONROAD (US)
  - On-Road equipment
    - *EMFAC* (California)*, MOVES* (US)
  - Equipment and hours
    - *CA4PRS:* Caltrans construction schedule analysis tool
  - Road user delay
    - *CA4PRS* (not yet implemented)

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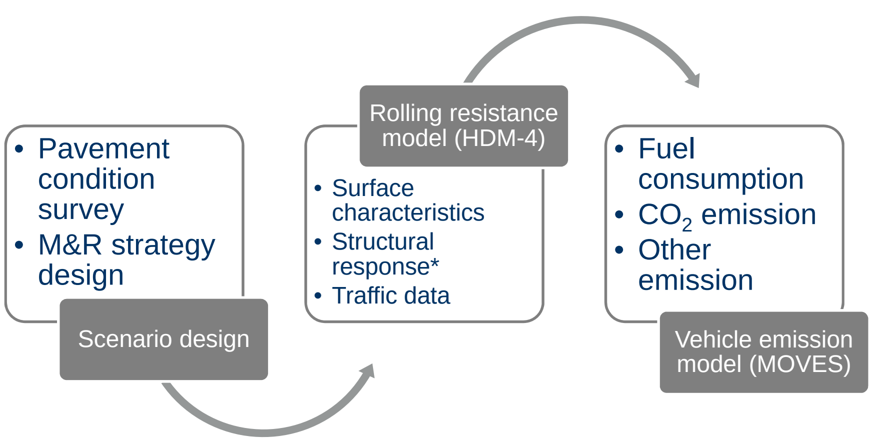
Models: Use Phase



*Models currently being calibrated.

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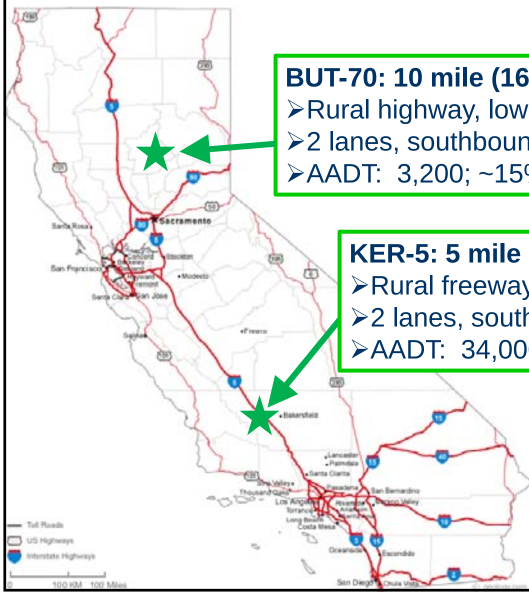
Project-level asphalt case studies



BUT-70: 10 mile (16 km) segment (low traffic)
- ➢Rural highway, low traffic volume
- ➢2 lanes, southbound
- ➢AADT: 3,200; ~15% trucks

KER-5: 5 mile (8 km) segment (high traffic)
- ➢Rural freeway, high traffic volume
- ➢2 lanes, southbound
- ➢AADT: 34,000; ~35% trucks

Comparison:
- *Do Nothing*
- 5 year overlay
  - -HMA, RHMA

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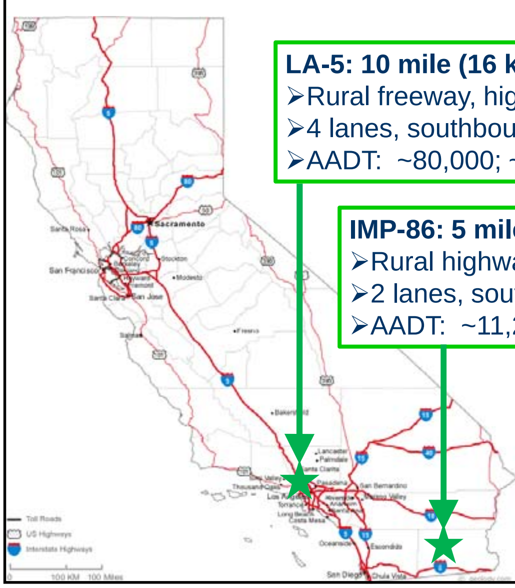
Project-level concrete case studies



LA-5: 10 mile (16 km) segment (high traffic)
- ➢Rural freeway, high traffic volume
- ➢4 lanes, southbound
- ➢AADT: ~80,000; ~25% trucks

IMP-86: 5 mile (16 km) segment (low traffic)
- ➢Rural highway, low traffic volume
- ➢2 lanes, southbound
- ➢AADT: ~11,200; ~29% trucks

Compare:
- *Do Nothing*
- 10 year CPR B
  - -Type III, CSA cement

Case Study 1 (KER-5): Asphalt overlay on rural/flat freeway

10 mile (16 km) segment in need of rehab
- Rural freeway
- 2 lanes, southbound
- AADT: 34,000; ~35% trucks

	Passenger	Trucks
Inner Lane	77%	9%
Outer Lane	23%	91%

Compare:
- Do Nothing
- 10 year rehab (CAPM)
  - HMA, RHMA

Construction Scenarios: KER-5

HMA Type	Design life	Treatment	Cross Section	Smoothness
CAPM, HMA	5 Years	Mill & Overlay	45 mm (0.15') Mill + 75 mm (0.25') HMA with 15% RAP	Smooth Rehab
				Less smooth Rehab
CAPM, RHMA	5 years	Mill & Overlay	30 mm (0.1') Mill + 60 mm (0.20') RHMA	Smooth Rehab
				Less smooth Rehab

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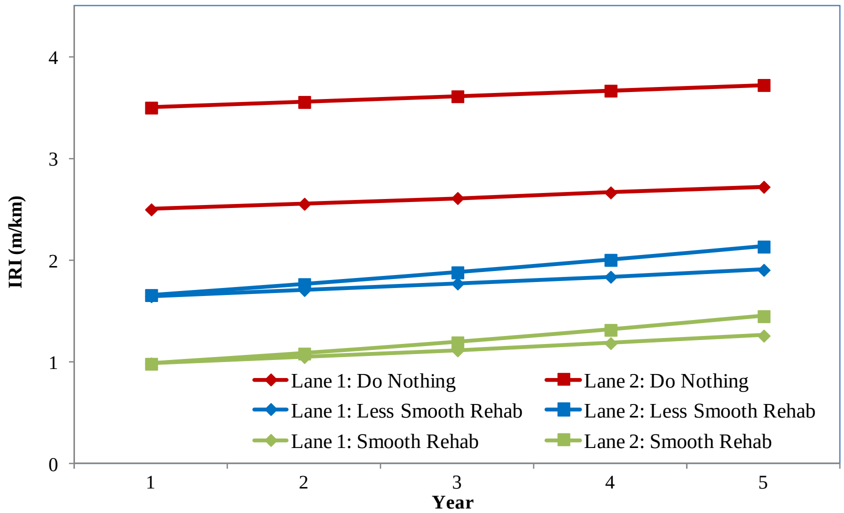
KER-5 IRI Scenarios over 10 years*



* 1st draft from empirical data, needs review and modeling

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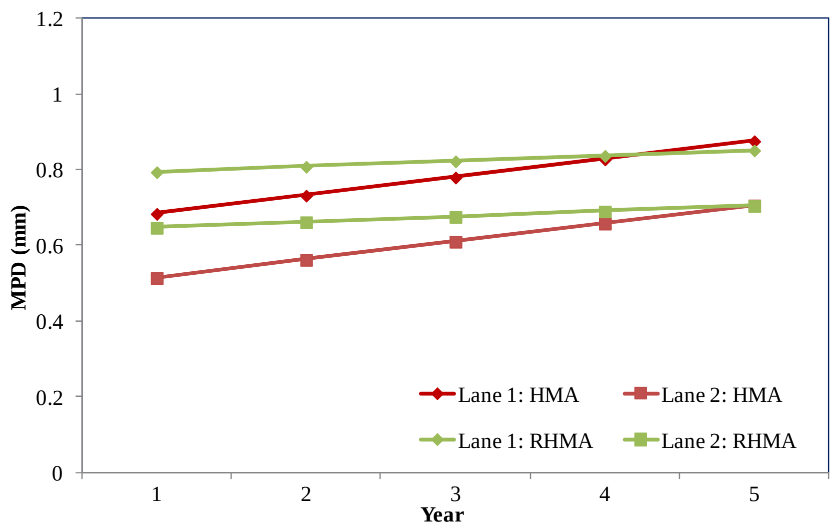
KER-5 MPD Progression from CA data* (For rehabilitated lanes)



* 1st draft from empirical data, needs review and modeling

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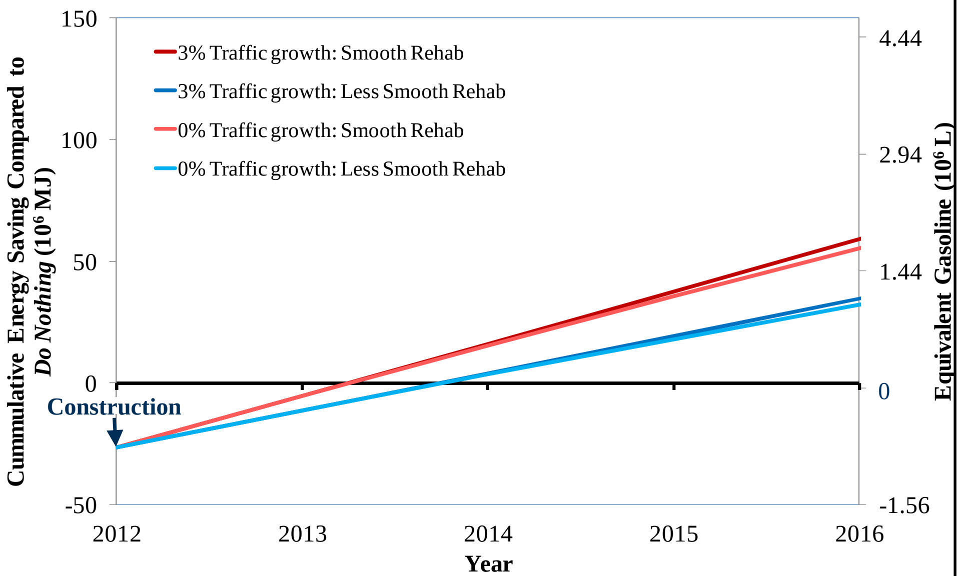
KER-5 (HMA): Cumulative life cycle energy savings compared to *Do Nothing*



Case Study 2 (LA-5): Concrete CPR B on rural/flat freeway

10 mile (16 km) segment in need of rehab
- Rural freeway
- 4 lanes, southbound
- AADT: ~80,000; ~25% trucks

	Cars	Trucks	IRI
Lane 1 (Inner)	38%	0.2%	3
Lane 2	34%	8%	3
Lane 3	16%	42%	3.5
Lane 4 (Outer)	13%	49%	4

Compare:
- Do Nothing
- 10 year CPR B
  - Type III, CSA cement

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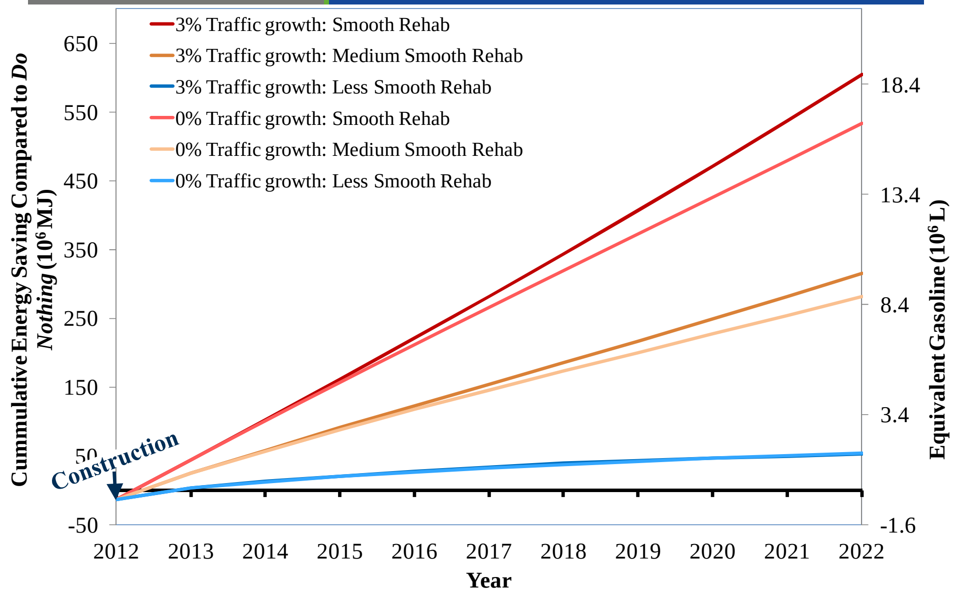
LA-5 (Type III PCC): Cumulative life cycle energy savings compared to *"Do Nothing"*



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Case Study 3 (BUT-70): Asphalt overlay on rural/flat highway

5 mile (8 km) segment in need of rehab

- Rural highway
- 2 lanes, westbound
- AADT: 3,200; ~15% trucks

	Cars	Trucks	IRI
Lane 1 (Inner)	61%	8%	3.8
Lane 2	39%	92%	3

Compare:
- Do Nothing
-5 year rehab (CAPM)
 -HMA, RHMA

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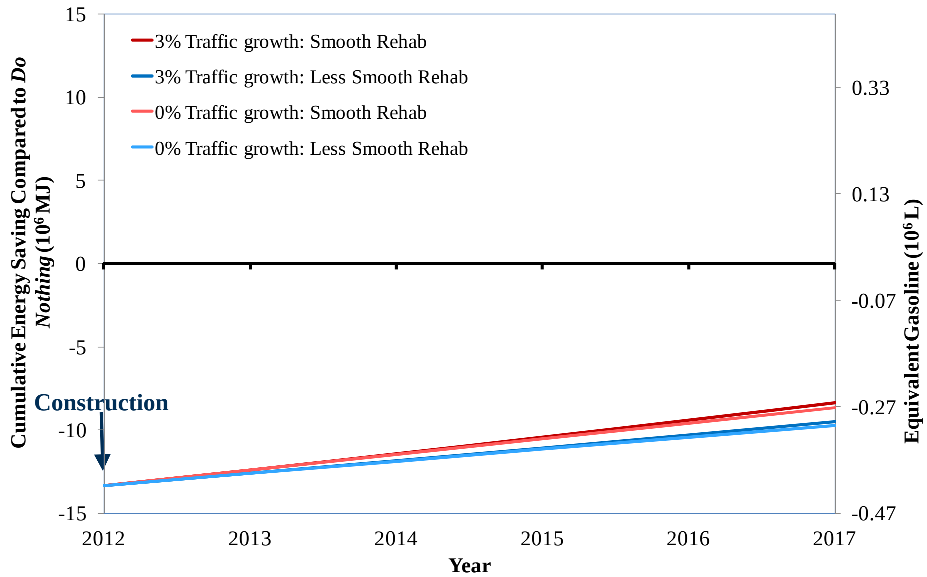
BUT-70 (HMA): Cumulative life cycle energy savings compared to "*Do Nothing*"



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Case Study 4 (IMP-86): Concrete CPR B on rural/flat highway

5 mile (16 km) segment in need of rehab

- Rural highway
- 2 lanes, southbound
- AADT: ~11,200; ~29% trucks

	Cars	Trucks	IRI
Lane 1 (Inner)	76%	8%	2.5
Lane 2	24%	92%	2.7

Compare:
- Do Nothing
- 10 year CPR B
  - Type III, CSA cement

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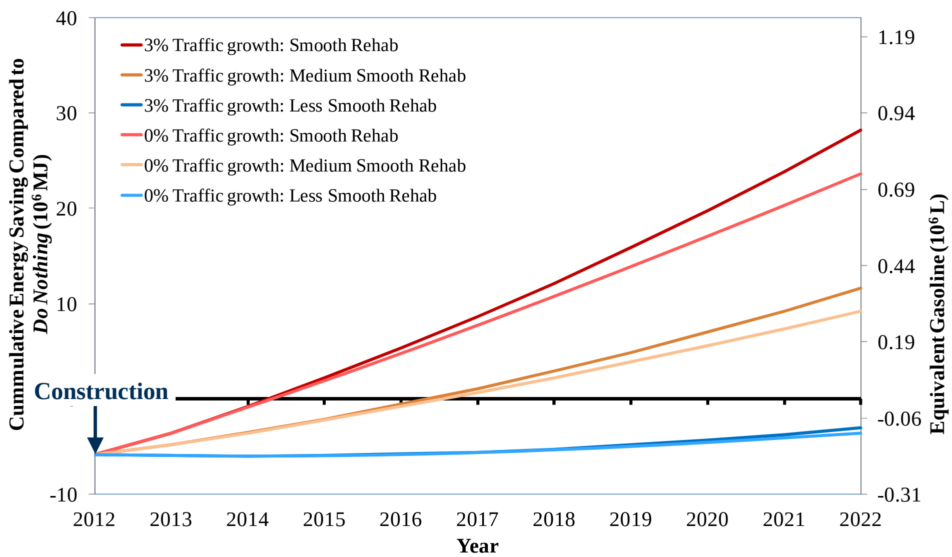
IMP-86 (CSA cement): Cumulative life cycle energy savings compared to "Do Nothing"



Summary of Project Levels Case Studies

- Traffic level determines whether GHG from materials and construction get paid back from smoother pavement
- Good construction smoothness necessary to get fast pay back

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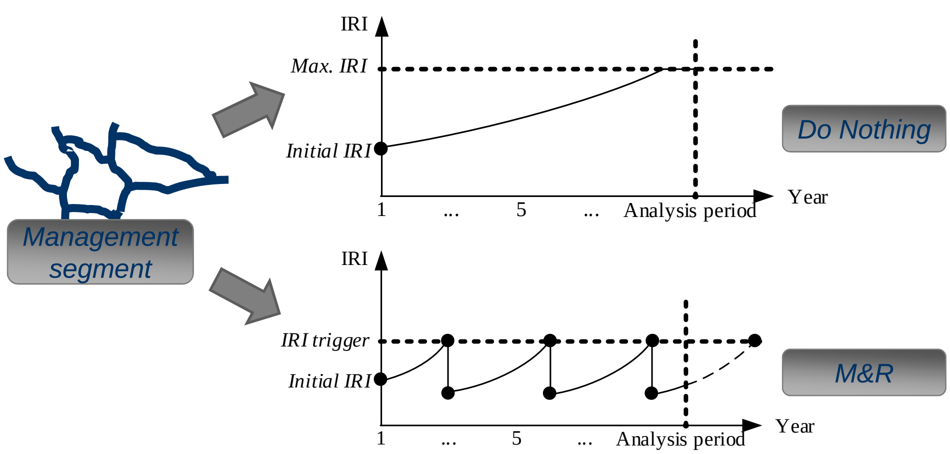
Example Network Level Analysis

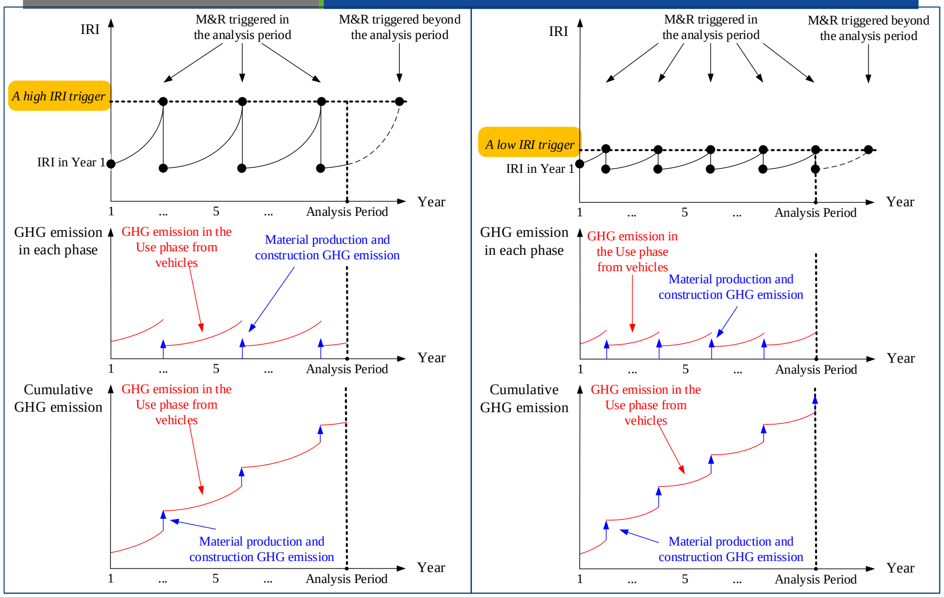
- Network level goals: answer these questions
  - Optimal IRI triggers to minimize the life cycle GHG emission on California highway network.
  - Cost-effectiveness of treatments and IRI trigger for each traffic level.
- Explore the integration with PMS

Modeling: *M&R* and *Do Nothing* scenarios



Analysis period: 10 Years (2012 to 2021)

Different IRI triggers (high vs. low)



Result: Optimal trigger by traffic group

Traffic group	Daily PCE of lane-segments range	Total lane-miles	Percentile of lane-mile	Optimal IRI triggering value (m/km, inch/mile in parentheses)	Annualized CO_2-e reductions (MMT)	Modified total cost-effectiveness ($/t$CO_2$-e)
1	<2,517	12,068	<25	-----	0	N/A
2	2,517 to 11,704	12,068	25~50	2.8 (177)	0.141	1,169
3	11,704 to 19,108	4,827	50~60	2.0 (127)	0.096	857
4	19,108 to 33,908	4,827	60~70	2.0 (127)	0.128	503
5	33,908 to 64,656	4,827	70~80	1.6 (101)	0.264	516
6	64,656 to 95,184	4,827	80~90	1.6 (101)	0.297	259
7	>95,184	4,827	90~100	1.6 (101)	0.45	104
Total					**1.38**	**416**

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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

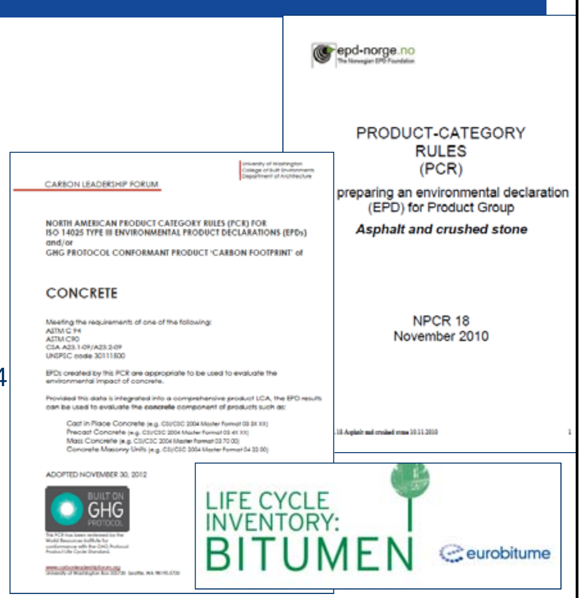
Environmental Product Declaration (EPD)
"Providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information" (ISO 14025)

Adapted from N. Santero

ASCE | KNOWLEDGE & LEARNING

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
- Credits for EPDs in LEED v4
- Pavement PCRS
  - Cement, concrete, lime aggregate in place
  - Asphalt, asphalt mixes under development



Environmental Product Declaration (EPD): Concise, quantitative information

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

Some Life Cycle GHG Tools

- Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE)
  - Inventory and impacts for seven indicators, materials and construction phases
    - (Horvath, 2004)
- Project Emissions Estimator (PE-2)
  - GHG emissions model for construction, maintenance, and use
    - (Mukherjee, Stawowy, and Cass 2013)
- GreenDOT from AASHTO
  - High level CO_2 calculation from the operations, construction, and maintenance activities of state highway agencies, from a single project to an entire state, and ranging from 1 day to several years
    - (Gallivan, Ang-Olson, and Papson 2010)
- Athena Pavement LCA tool from Athena Institute
- Illinois Tollway tool (to be released soon)
  - Pavement, drainage, lighting, landscaping

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Gaps – Technical Issues

- Life Cycle Inventory data for N. America is sparse:
  - Proprietary sources of data that may be high quality, but costly
  - Not regionally applicable, especially for materials production, construction, recycling treatments
  - May not be up to date, especially for warm mix asphalt, concrete additives, and asphalt production
- Use phase modeling gaps:
  - Deflection energy dissipation model validation
  - Urban Heat Island modeling confirmation
- End of Life approach
  - Environmental impact accounting can vary based on allocation approach

Photo: D. Jones

Gaps – Implementation Issues

- Project delivery environment may affect LCA implementation
  - Europe: Design-Build or Design-Build-Maintain
  - US: Design-Bid-Build (low-bid)
- Decisions regarding what LCA should be used for
  - Policy development
  - Guidance
    - Design guidance (project-level)
    - Project management guidance (network-level)
  - Design selection like Life Cycle Cost Analysis (LCCA)
  - Part of procurement (like Netherlands, France)

LCA can be complicated
How to get started 1/2

1. Define question to be answered and specific environmental goals or decision to be made
   - Calculate total impact
   - What if analysis, comparisons
2. Define system boundaries
   - Identify items that are the same and do not need to be considered
3. Define the functional unit and approach
   - specific project variables, cases for impact calculation of comparison, analysis period
4. Model the system
   - specific project variables, cases for impact calculation of comparison, analysis period
   - Identify operations, materials, thicknesses, functional lives, materials production and construction processes, etc.

LCA can be complicated
How to get started 2/2

5. Quantify differences between alternatives over the life cycle

First five steps may be enough to determine whether full LCA needed

6. Identify appropriate environmental data sets (life cycle inventory data) needed and quantify the environmental impacts of differences, complete LCA

Example of Combining LCCA and 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

Santero et al. Environmental Policy for Long-Life Pavements, 2010

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

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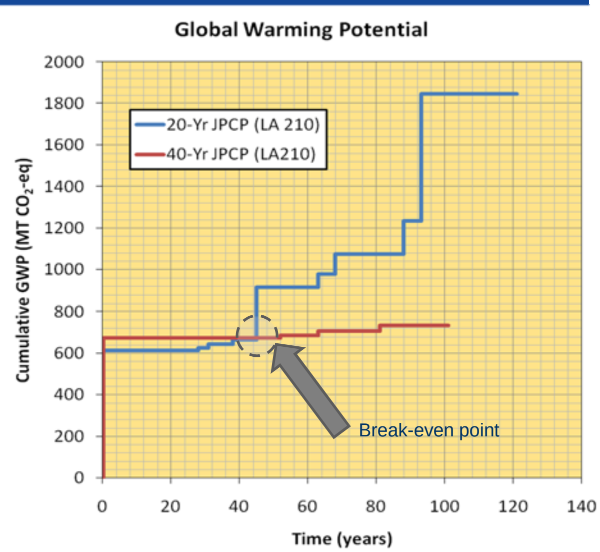
GWP Payback Period

- 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?



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Use of Pavement LCA to date

- Pavement LCA has largely been implemented by researchers in case studies
- Caltrans has implemented GHG and energy LCA calculator in pavement management system
- Illinois Tollway developing tool, for use in design and design, potentially later to select contractors
- Netherlands and France use LCA and cost analysis to select contractors for design/build and design/build/maintain projects

Summary: Why use LCA for evaluating environmental performance?

- Quantifies outcomes:
  - GHG, energy, pollutants, finite resources
- Uses project-specific inputs:
  - materials, transport, construction, traffic levels, re-use
- Requires explicit prioritization of outcomes for decision-making
- Can account for regional and time variability, and other uncertainties in data sets and analysis

Recommendations for the Future

- Use LCA to evaluate benefits and unintended consequences of pavement policy decisions before implementation
- Integrate LCA principles and calculations into pavement design, procurement policies and pavement management systems (PMS)
- Encourage and facilitate an active and comprehensive market for LCA data
  - PCRs and widespread creation of EPDs
  - Support and incentivize use and improvement of public LCI databases
  - Need for an authority and guidelines to resolve conflicts in PCRs between industries
- Current gaps should be addressed to make pavement LCA more useful to decision-makers
  - Improved models for pavement-vehicle interaction
  - Additional tools and data (see EPDs above, and development of other data)
- Develop an approach for incorporating pavement LCA with LCCA into the design-bid-build project delivery process

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Questions?

- Thank you
- We have time for questions