Improving the Sustainability of State and Local Government Pavement: A Process and Some Practical Results

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University of California Pavement Research Center

Sustainable Asphalt Pavements Workshop
Phoenix, AZ
22 March 2017

Outline

- What is the UCPRC?
- Measurement of sustainability
- Where and how sustainability can be improved
  - Cost
  - Quality of life
  - Environmental impact
- Future work
- Summary

What is the University of California Pavement Research Center?

Dedicated to providing knowledge, the UCPRC uses innovative research and sound engineering principles to improve pavement structures, materials, and technologies

- UCPRC begun in 1995
- City & County Pavement Improvement Center in 2017

Some Recent UCPRC Work

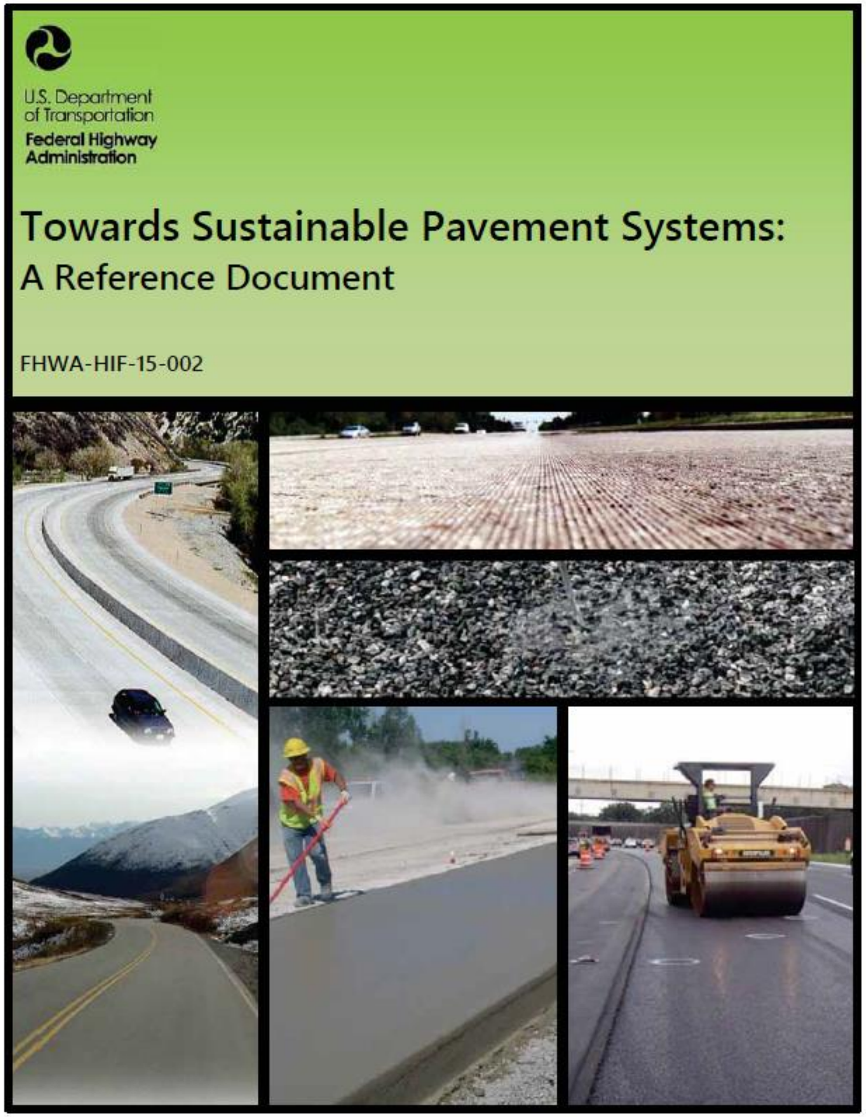
- Caltrans
  - Life Cycle Cost Analysis (LCCA)
  - Environmental Life Cycle Assessment (LCA)Mechanistic-Empirical design methods
    - CalME Caltrans asphalt surface design program
    - Calibration of MEPDG for jointed concrete
    - Long life rehabilitation, concrete and asphalt
  - Construction quality effects on performance
  - Rapid Rehabilitation construction/work zone traffic
  - New Caltrans pavement management system
  - Recycling (asphalt, rubber, concrete, etc)
  - Noise, smoothness
  - Freight logistics decisions and pavement condition

Some Recent UCPRC Work

- California Air Resources Board
  - Urban heat island life cycle assessment
- CalRecycle
  - Rubber asphalt mix development and specifications
- Federal Highway Administration
  - Sustainability of pavement
  - Full-depth reclamation
- Federal Aviation Administration
  - Asphalt recycling
  - Mechanistic-empirical design methods
  - Airfield environmental life cycle assessment
- Caltrans and Interlocking Concrete Pave Institute
  - Permeable pavements for storm water infiltration
- Caltrans and National Center for Sustainable Transportation
  - LCA impacts of complete streets

FHWA Pavement Sustainability Reference Document

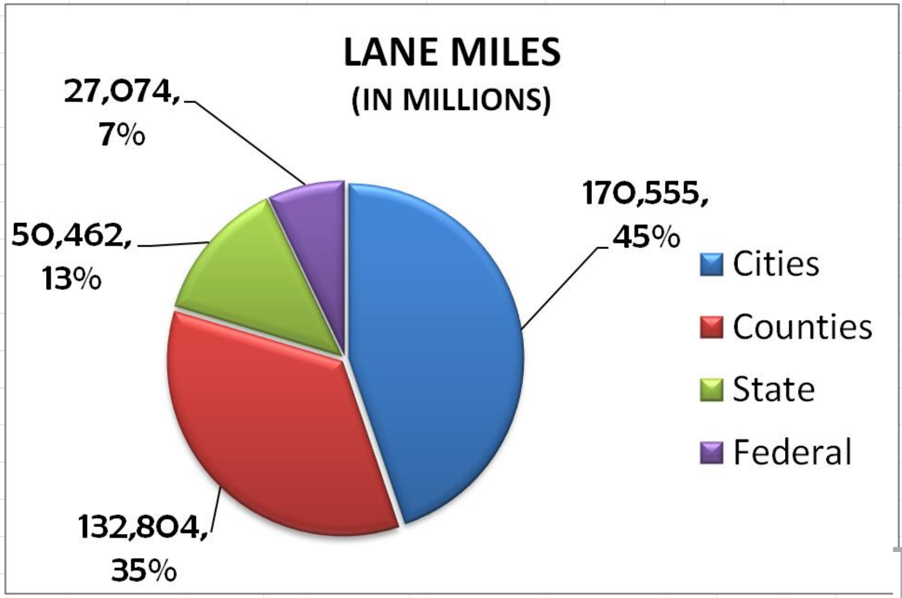
- State of the knowledge on improving pavement sustainability
- Search on “FHWA pavement sustainability”
- Recommendations for improving sustainability across entire pavement life
- Organized around Life Cycle Assessment (LCA) framework
- Other information available at same web site
  - Tech briefs
  - Literature database

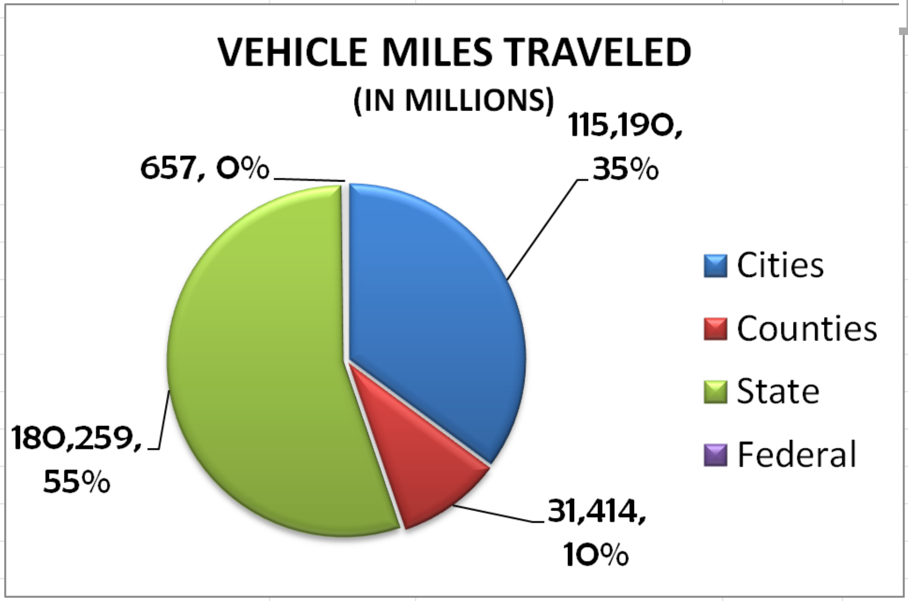


Sustainability Considerations

- Cost
- Human quality of life
- Natural systems that support human quality of life

Why is sustainability of both state and local government pavements important?





National $ Spent on Transportation in 2008 (US Census Bureau)

STATE GOVERNMENT	LOCAL GOVERNMENT
97,508,989	61,053,150

Measuring Sustainability

- Life Cycle Cost Analysis (LCCA)
  - Economic
- Life Cycle Assessment (LCA)
  - Range of environmental impacts, quantitative
- Sustainability Rating Systems (e.g., INVEST)
  - Environmental and social impacts, qualitative

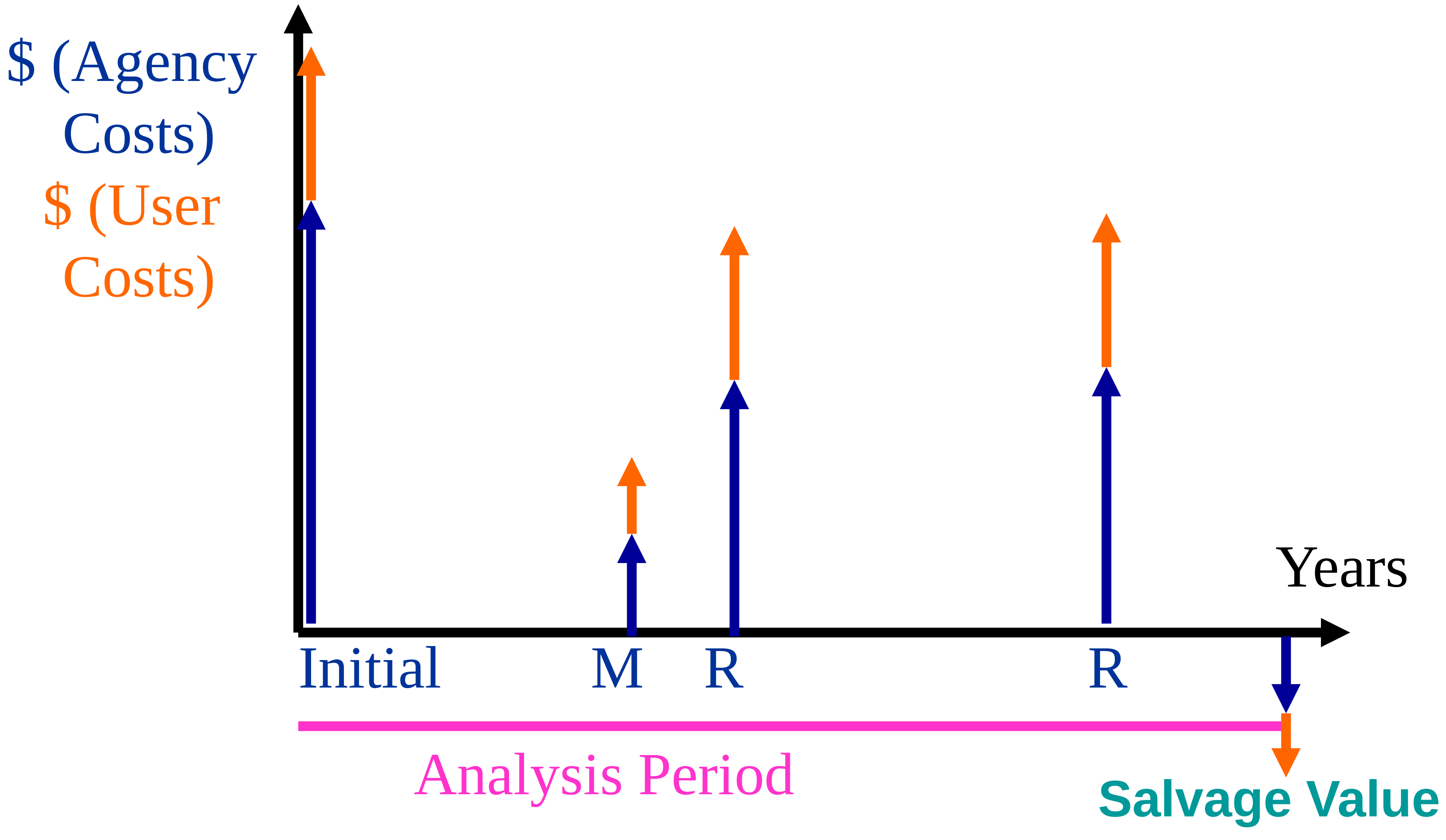
<u>Reasons to Measure</u>

Decision support: design, procurement

Establish baselines for process improvement

Reporting for public, industry and government

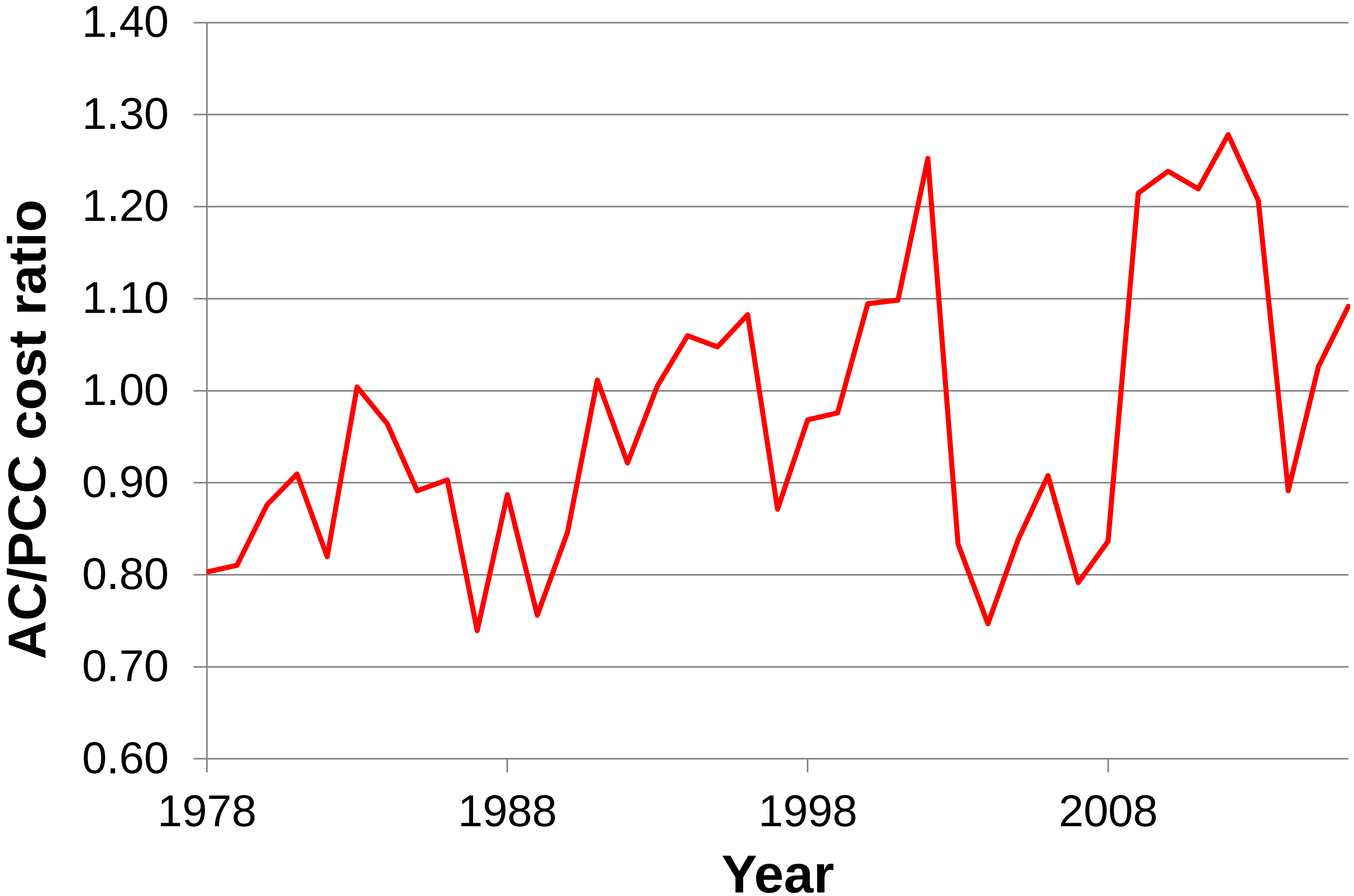
Life Cycle Cost Analysis (LCCA)



Where can LCCA be implemented?

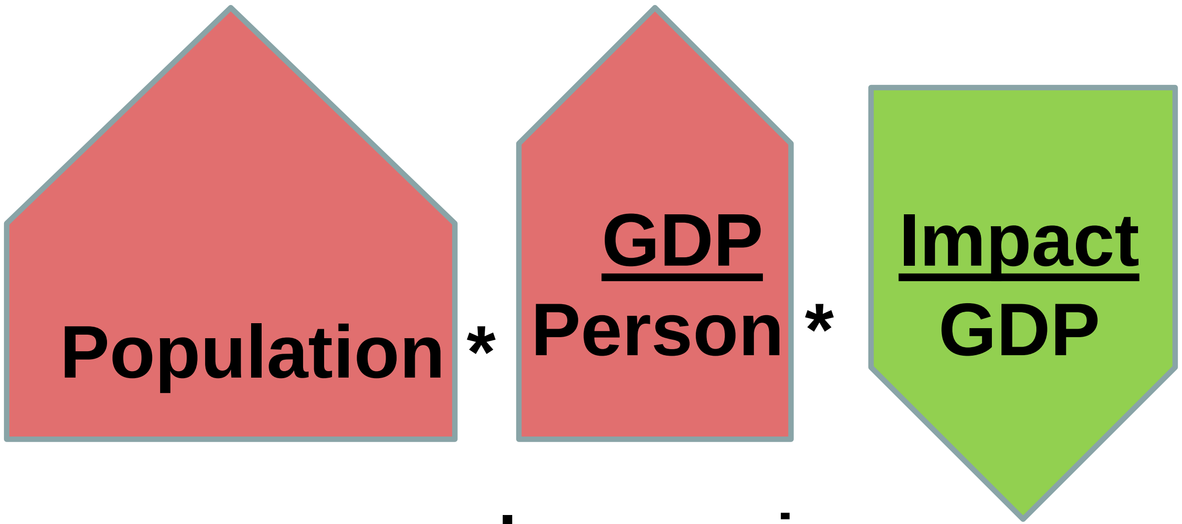
- PMS decision tree optimization
  - Condition trigger levels for treatment (timing)
  - Treatment selection
- Pavement type selection
- Policy evaluation
  - Materials changes
  - Construction quality specifications
  - Design policies

California Relative Asphalt and PCC Costs by volume 1978-2017



Master equation for environmental impacts

Environmental impact =



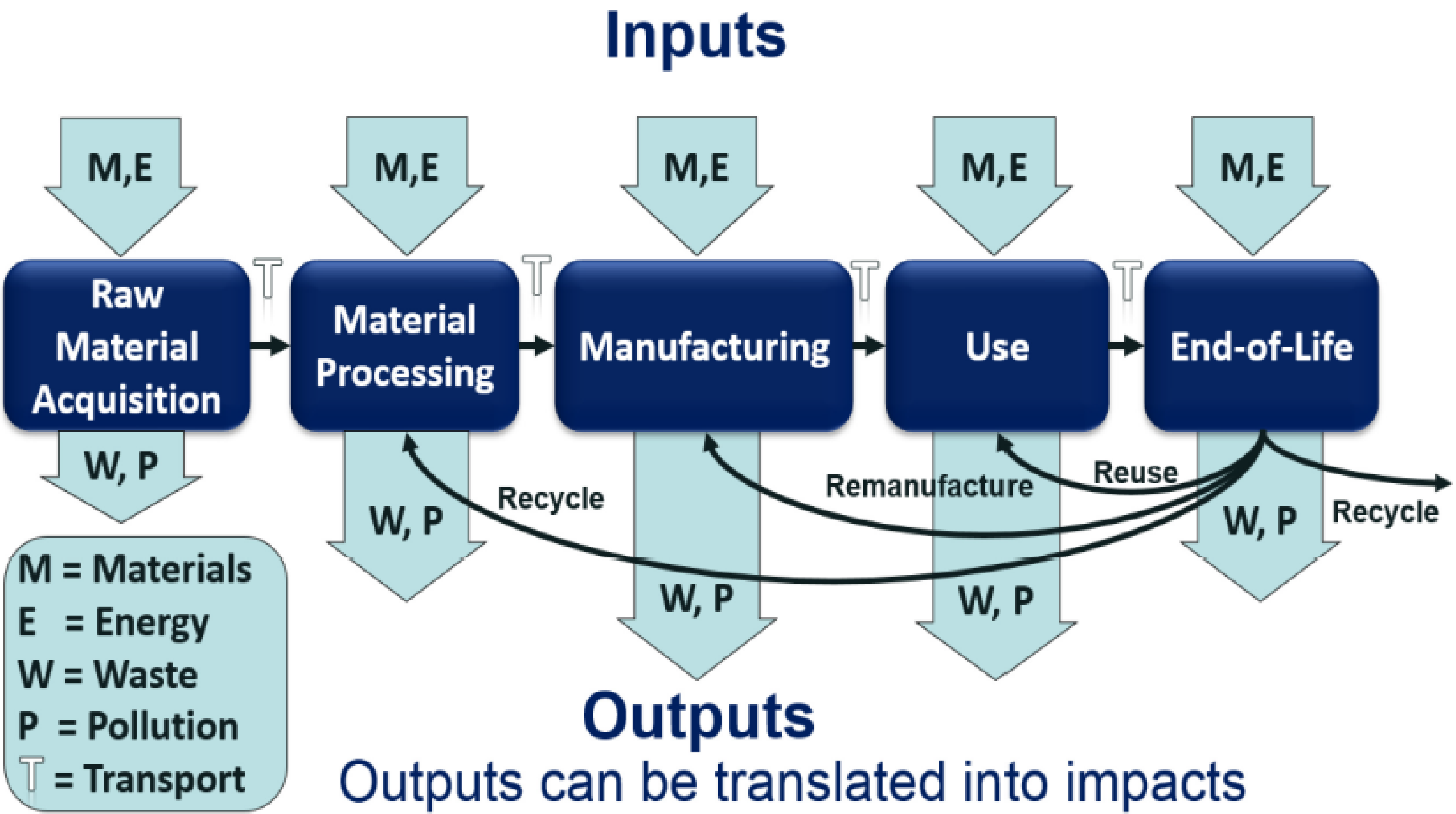
Increase in wealth and economic activity

Technological efficiency

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

Product Life Cycle and Flows

Kendall (2012)



Four Key Stages of Life Cycle Assessment

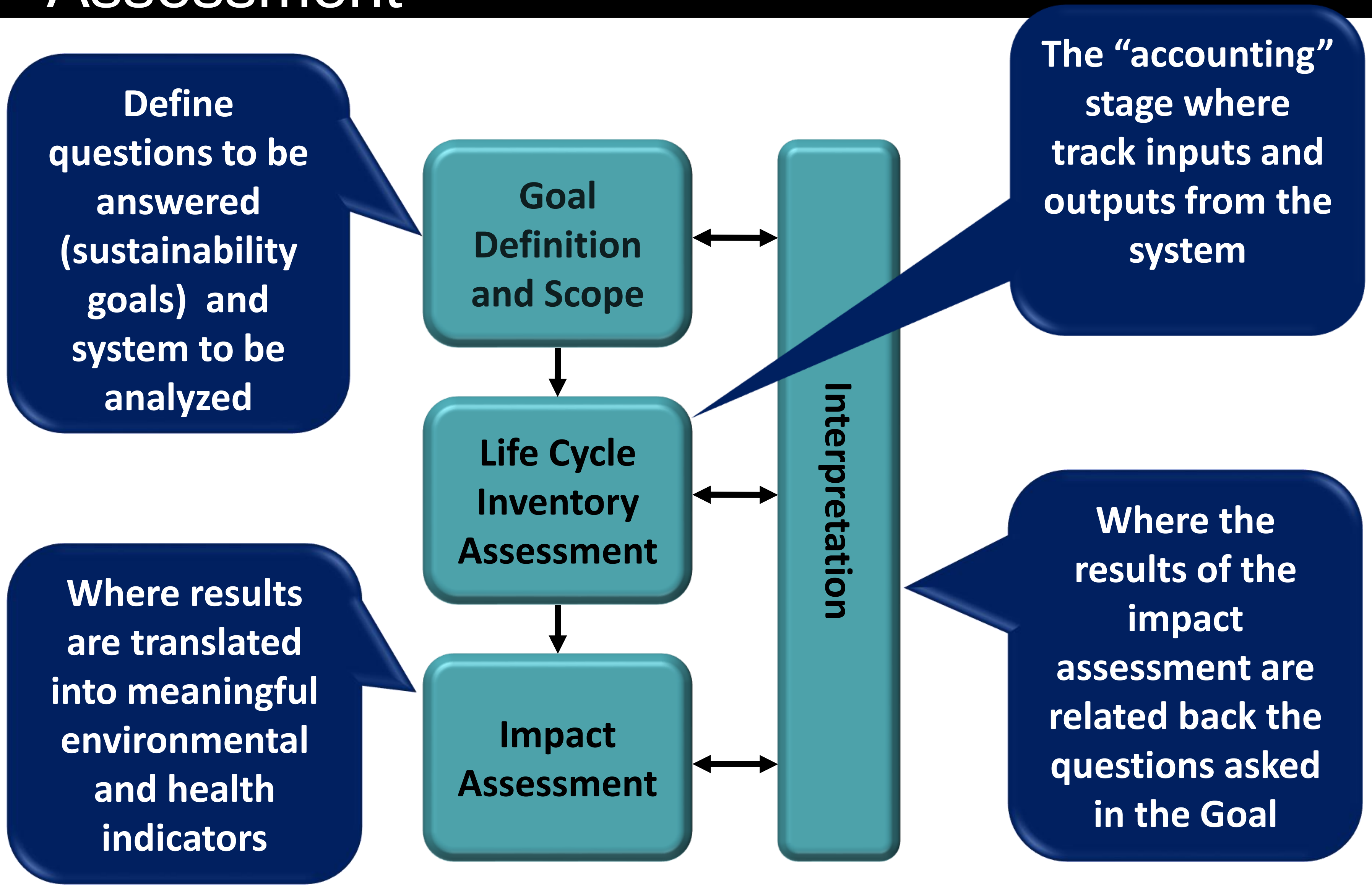


Figure based on ISO 14040, adopted from Kendall

US EPA Impact Assessment Categories

(TRACI – Tool for the Reduction and Assessment of Chemical and other environmental Impacts)

- Global warming
- Stratospheric ozone depletion
- Acidification
- Eutrophication
- Photochemical smog
- Terrestrial toxicity
- Aquatic toxicity
- Human health
- Abiotic resource depletion
- Land use
- Water use

Impacts to people

Impacts to ecosystems

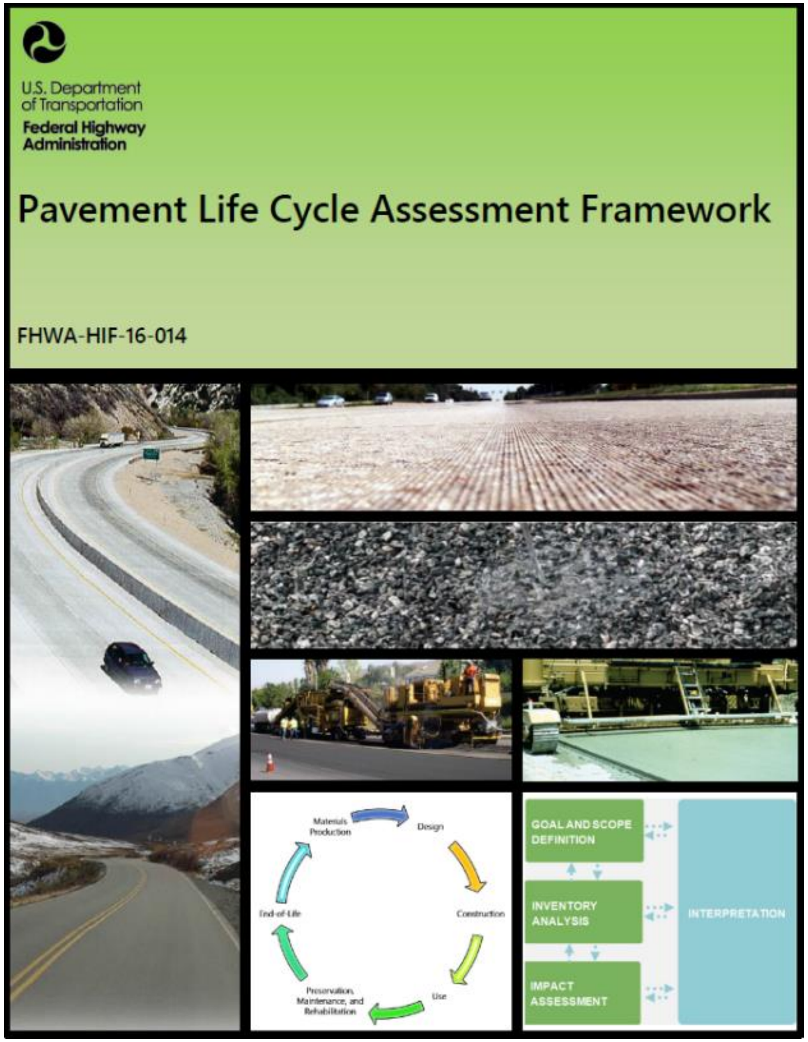
Depletion of resources

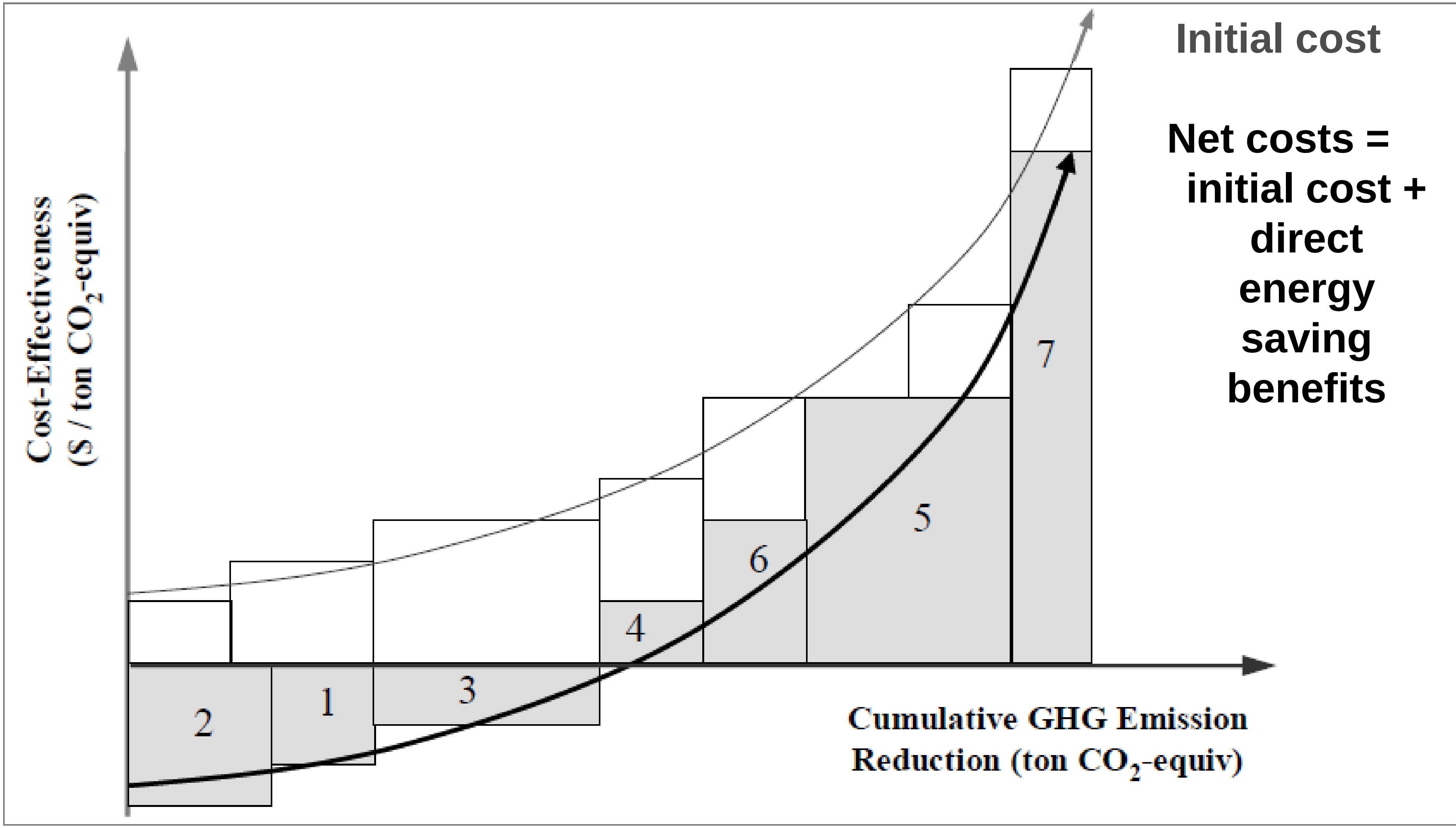
Sustainability indices can be used for non-quantitative assessment including social

From Saboori   ***Image sources: Google***

FHWA Pavement LCA Framework Document

- Published January 2016
- Guidance on uses, overall approach, methodology, system boundaries, and current knowledge gaps
- Specific to pavements
- Includes guidelines for EPDs
- Search on “FHWA LCA framework”

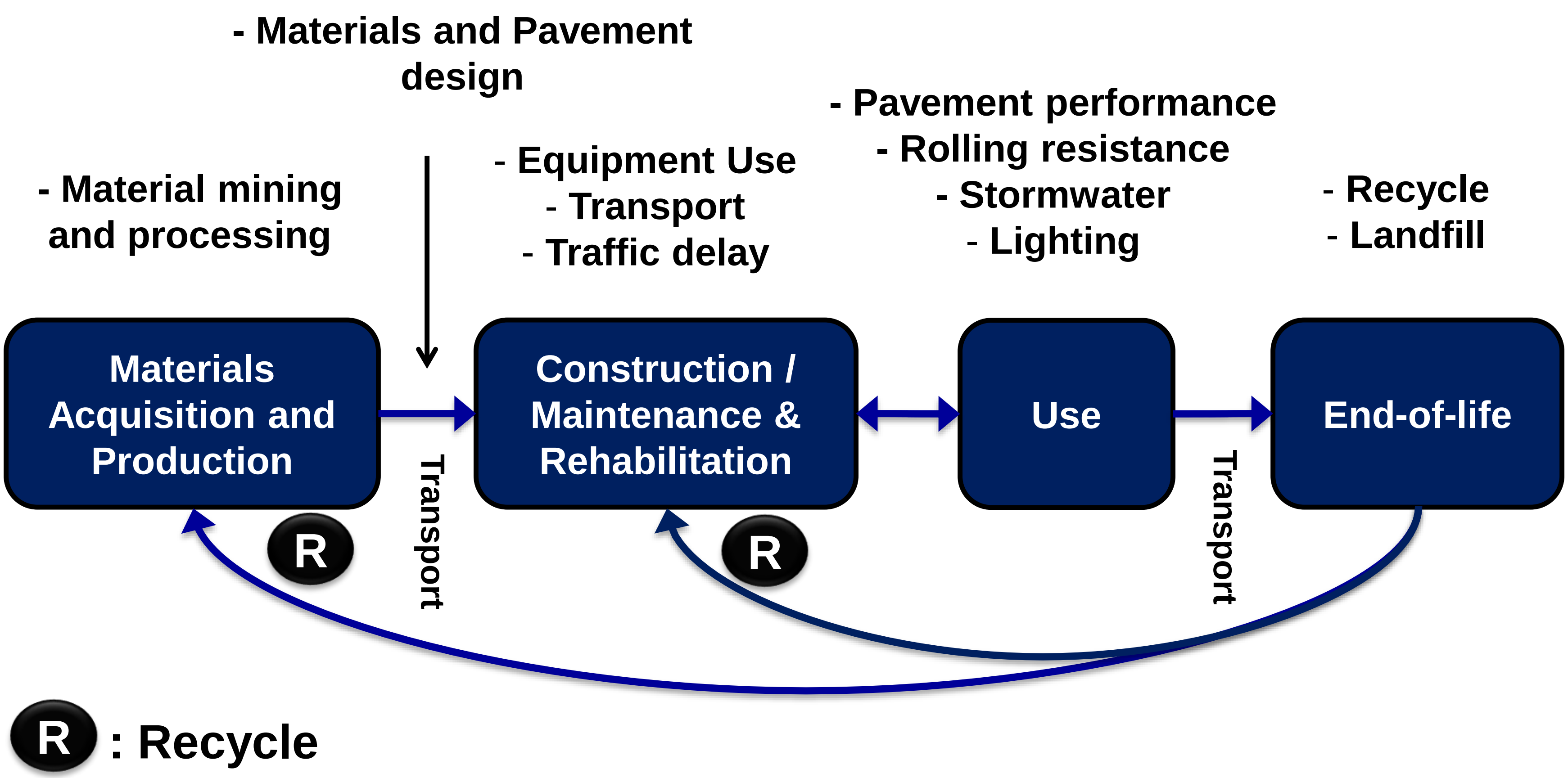




- Bang for your buck, apply to any environmental goal here: $/ton CO_2e vs CO_2e reduction
- Lutsey, N. (2008): ITS-Davis Research Report UCD-ITS-RR-08-15

Where can cost and environmental impacts be reduced?

- **Use Life Cycle Assessment (LCA) to find out**
- **Use Life Cycle Cost Analysis (LCCA) to prioritize based on improvement per $ spent**



From: Kendall et al., *2010*

Pavement Management

- Does preservation pay?
  - LCCA study 1998 to 2003
- What is the optimal IRI to trigger treatment for energy and greenhouse gases?
  - LCA study 2014

LCCA Study

- Data
  - Treatments placed between 1997 and 2003
  - Performance data from 1997 to 2007
  - 718 projects
  - High Desert/Mountain, Bay Area, Mojave Desert
- Focus on HM-1 thin overlays and chip seals, and Rehab overlays

Cracking at time of treatment 1998-2003

PP Strategy	Existing Cracking Type	Program Type					
		CAPM		HM-1		REHAB	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
ACOL-DG	Alligator A	9	*13*	10	*11*	9	*11*
	Alligator B	12	*14*	17	*18*	16	*20*
	Alligator A+B	21	*22*	27	*24*	25	*26*
ACOL-OG	Alligator A	12	*7*	10	*11*	8	
	Alligator B	16	*8*	14	*16*	19	
	Alligator A+B	28	*15*	25	*21*	27	
ACOL-RAC	Alligator A	10	*12*	9	*11*	26	*12*
	Alligator B	13	*16*	21	*19*	45	*29*
	Alligator A+B	23	*25*	30	*24*	71	*34*
ChipSeal-AC	Alligator A			8	*10*		
	Alligator B			10	*12*		
	Alligator A+B			17	*18*		

50th Percentile Years to Cracking Failure

PP Strategy		Sample Size	Alligator B Cracking		A+B Cracking	
			Years to 10%	Years to 25%	Years to 10%	Years to 25%
ACOL-DG	HM-1	567	5	8	4	6
ACOL-DG	REH	222	10	12	9	11
ACOL-OG	HM-1	127	6	N/A	6	6
ACOL-RAC	HM-1	29	10	N/A	8	N/A
ChipSeal-AC	HM-1	169	6	N/A	3	8

Questions and answers from project

- Question: Is it more beneficial to apply pavement preservation (HM-1) or just wait until trigger rehabilitation?
  - Rehab, Rehab, Rehab… vs.
  - Rehab, PP, PP, Rehab, PP
- Answer:
  - Two PP treatments between Rehabs shows life-cycle savings 13 percent to 47 percent lower than Rehab without PP

Questions to Answer with LCCA

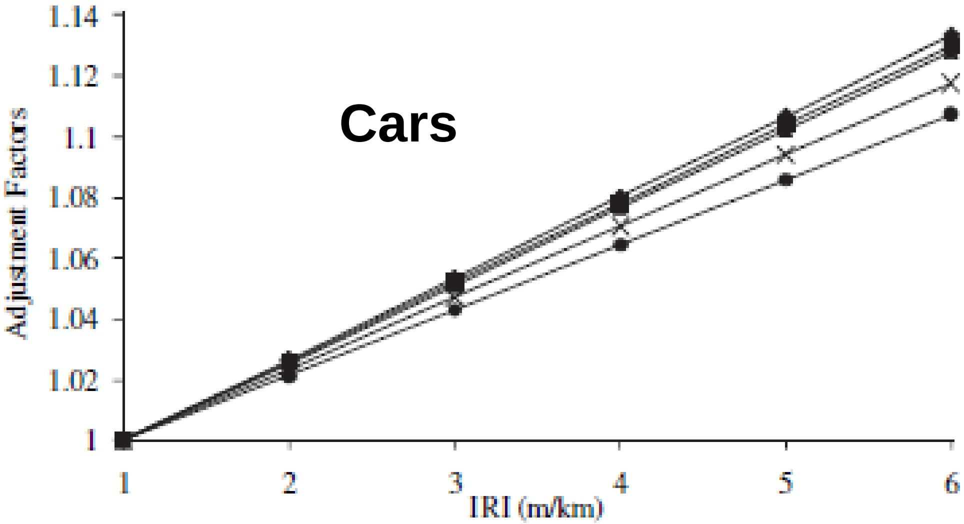
- Should pavement preservation be applied at an earlier or a later stage of cracking?
  - waiting until later stages of cracking results in life-cycle costs up to 14 percent higher than if treatments are placed at an earlier stage of cracking

Managing Roughness for User Fuel Use and Emissions

- How pavement influences vehicle fuel use
  - Roughness consumes energy in shock absorbers, tires
  - Texture consumes energy in tire tread
  - Pavement deformation consumes energy through viscoelasticity and damping
- Roughness vs fuel use and emissions
  - Smoother pavements result in less vehicle fuel use
  - Keeping pavements smooth requires more maintenance, which produces more GHG
- M&R doesn’t give full benefit if don’t get smoothness from construction
  - Enforce smoothness specifications so not “born rough”

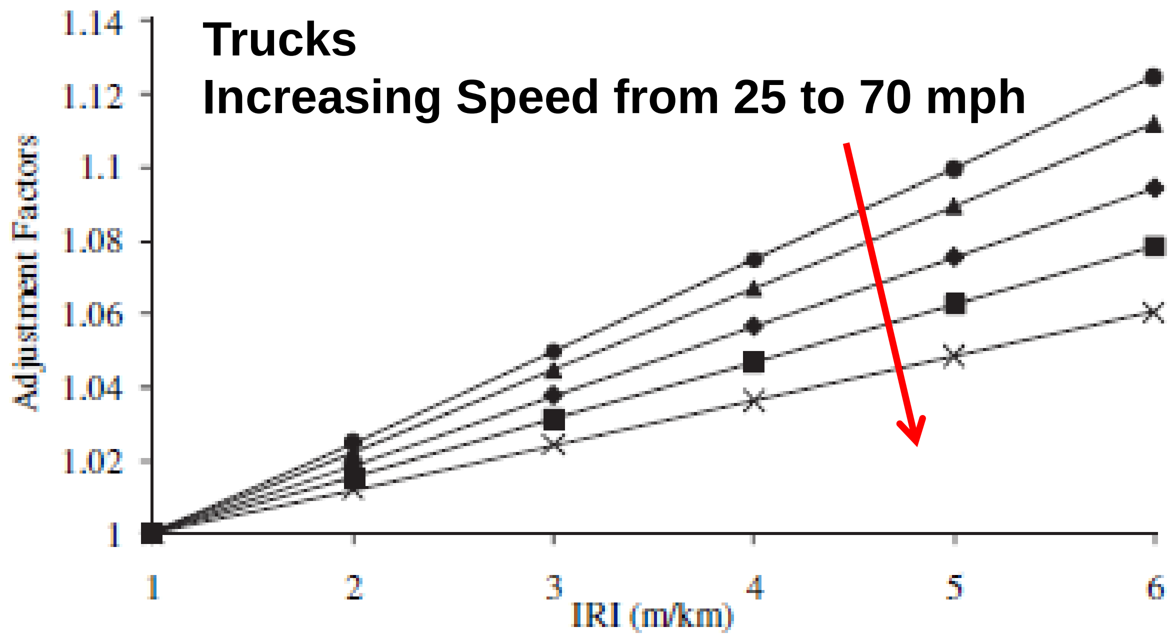
Use Stage: Fuel Use, Speed, IRI

Zaabar & Chatti, NCHRP 720



(a) Passenger car

- Roughness increases vehicle fuel use 0 to 8 percent across range of typical IRI
- Can be some offset from faster driving on smoother pavement



(e) Articulated truck

Caltrans Network: Optimal trigger by traffic group for GHG

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

Wang et al 2014

Materials and Construction

- Materials impacts greater than construction equipment and transport impacts
  - And most of the impact in the material is in the asphalt or cement binder
- Construction quality is very important

Impacts in cradle to gate for two asphalt overlays

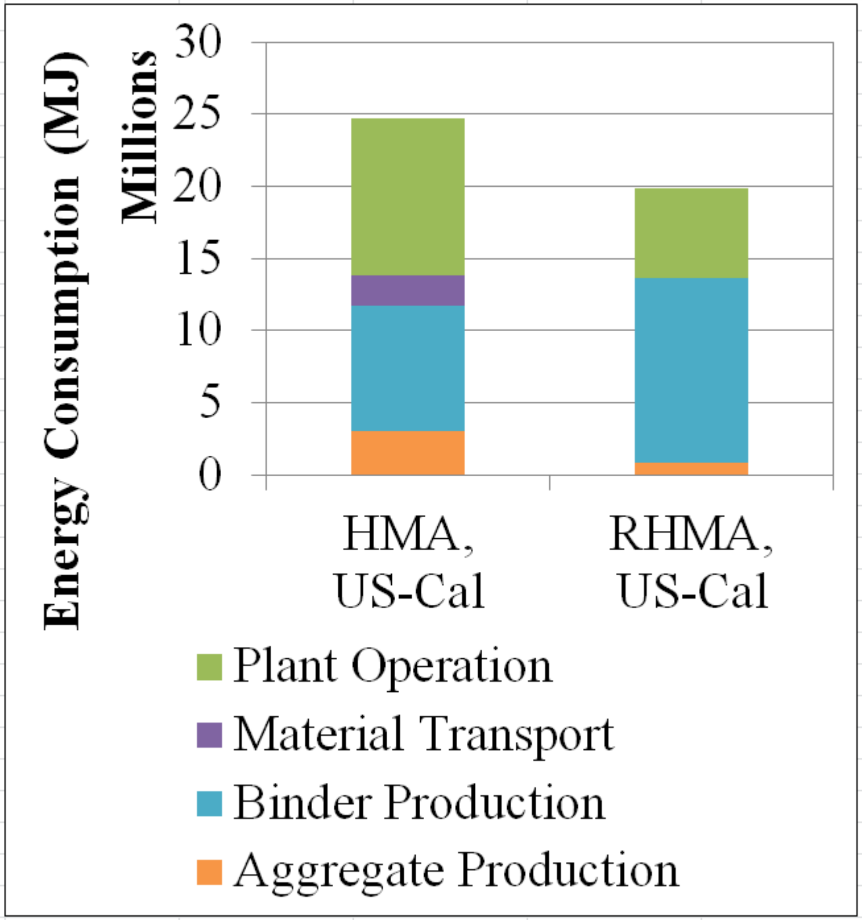
- Two overlays, same expected reflective cracking performance on heavy traffic interstates
  - HMA overlay
  - RHMA overlay

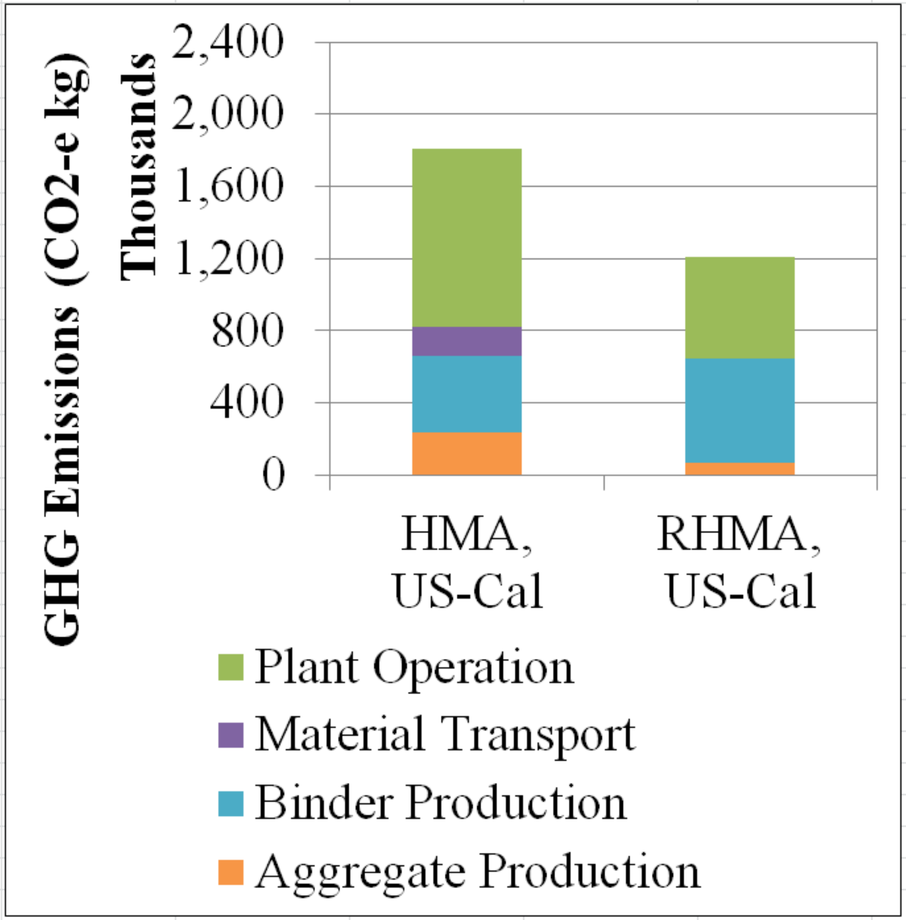
Construction Strategy	Design Life	Cross Section
Pavement preservation, HMA Overlay	5 years	45 mm (0.15 ft.) mill + 75 mm (0.25 ft.) HMA with 15% RAP
Pavement preservation, RHMA Overlay	5 years	30 mm (0.1 ft.) mill + 60 mm (0.20 ft.) RHMA

Impacts in cradle to gate for two asphalt overlays

- Warm mix affects plant production
  - Use to reduce mix temperature
  - Use to improve compaction

Wang et al, 2012

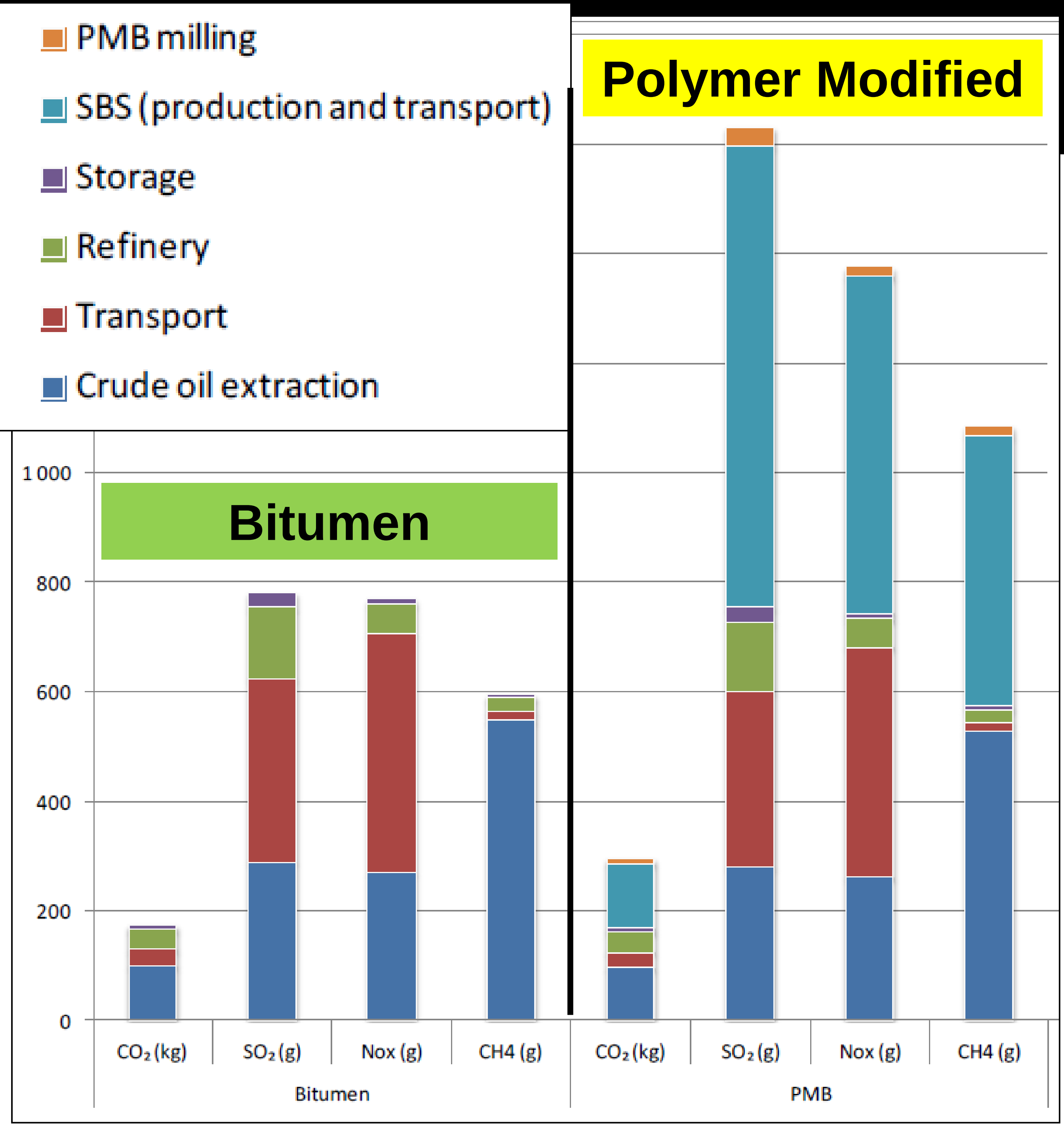




Materials, transport to site, construction impacts in a thin asphalt overlay

- Materials is main source of impact

	GWP [kg CO_2e]	Ozone [kg O_3e]	PM2.5 [kg]	Energy (total) [MJ]
Material	79%	53%	82%	93%
Transport	10%	12%	5%	3%
Construction	11%	35%	13%	3%



PMB causes about 60% more air emissions than straight bitumen

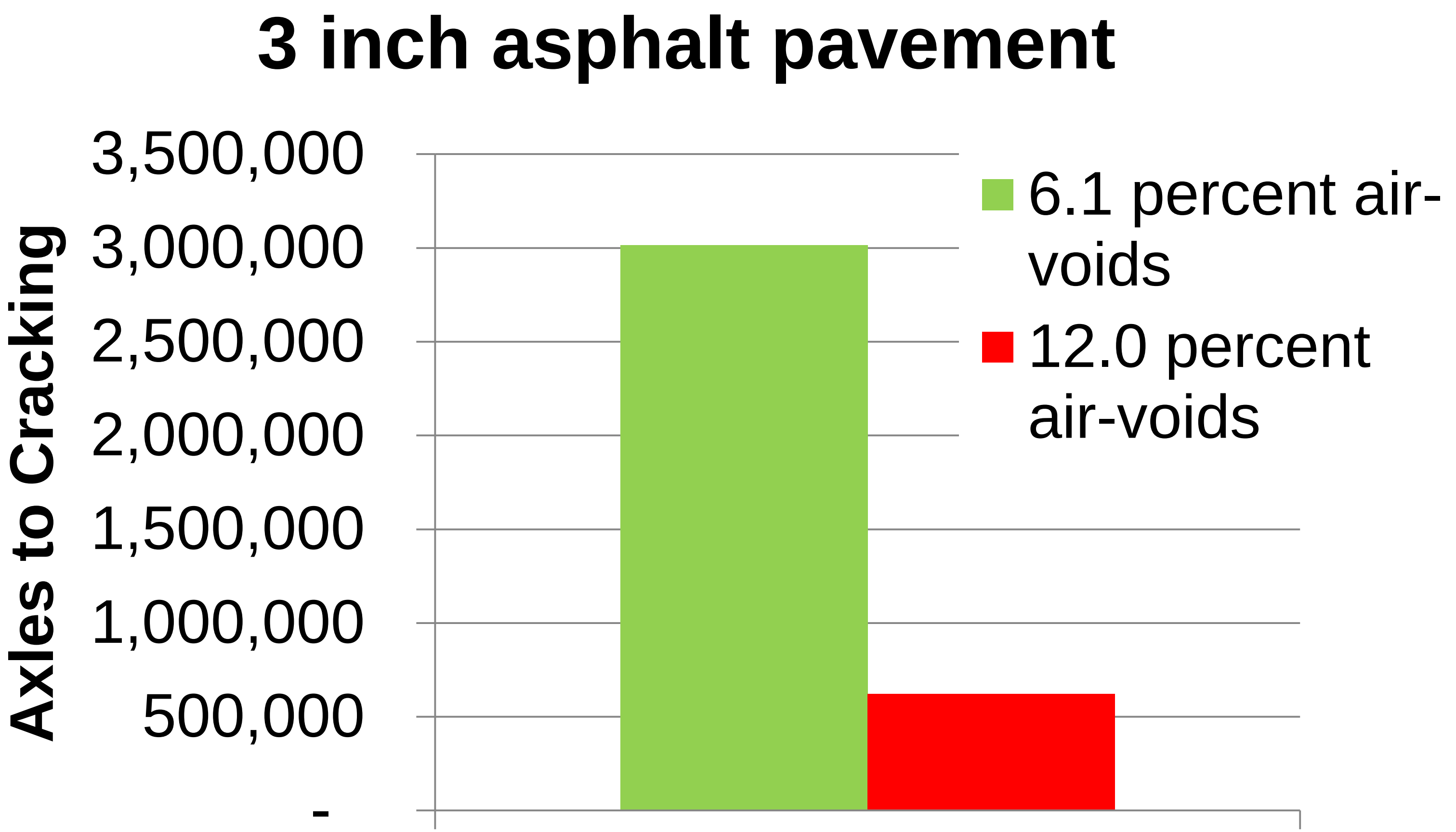
Eurobitume LCI
Bernard et al. Nantes LCA 2012

Materials and Construction

- For a given amount of material, increased life of treatment decreases life cycle environmental impacts
  - Compaction
  - Preservation
- Double the life, halve the environmental impact (and the cost!)

Compaction of asphalt

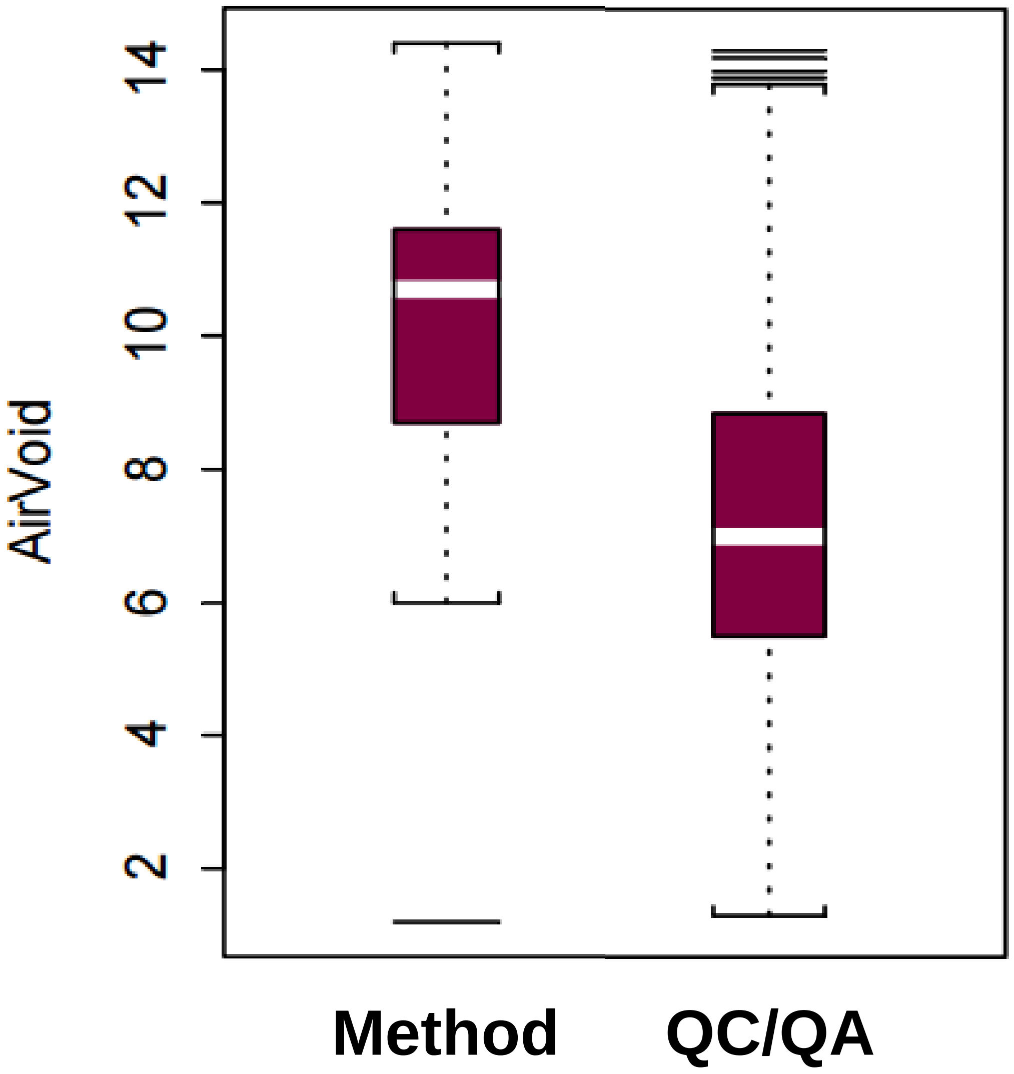
- 1% increase in air-voids = 10 to 15% shorter life



Westrack mix, mechanistic simulation

Caltrans QC/QA vs Method Spec

- Method spec typical result is 10 to 14%
- End-result QC/QA brings down to less than 8%
- Included
  - Disincentives if > 8% air-voids
  - Incentives if extremely good



Preservation
2.5 inch Overlays vs Seal Coats

- Preservation can reduce impacts:
  - Seal coats have much lower impact than asphalt
  - Thin overlays extend time between thicker overlays

From Saboori

	GWP [kg CO2e]	Ozone [kg O3e]	PM2.5 [kg]	Energy (total) [MJ]
Slurry Seal	2.2E+03	5.5E+02	1.7E+00	1.5E+05
Chip Seal	4.9E+03	1.0E+03	3.7E+00	3.6E+05
Cape Seal	7.2E+03	1.6E+03	5.4E+00	5.1E+05
Conventional Asphalt Concrete (mill and fill)	3.2E+04	4.35E+03	2.1E+01	1.4E+06

Studies on
rubber in asphalt and reclaimed pavement

- Rubber in asphalt
  - Asphalt rubber (AR, <2.4 mm particles, reacted)
    - Gap graded, open-graded, chip seals
  - MB/TR type materials (<0.2 mm particles, mixed at terminal)
    - Dense graded, gap graded, open graded, slurries
  - PG+5 initiative
    - All asphalt products
- Reclaimed asphalt pavement
  - RAP in HMA
  - RAP in RHMA
  - Rubberized RAP (RRAP) in HMA

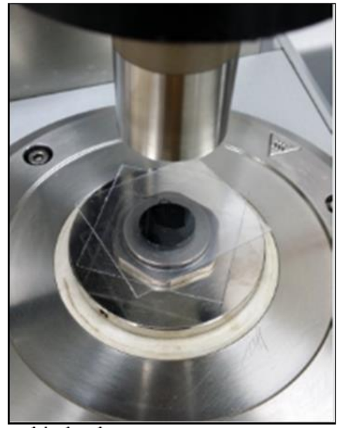
Do RAP and Virgin Binder Blend? Two-layer asphalt binder testing

Objective:

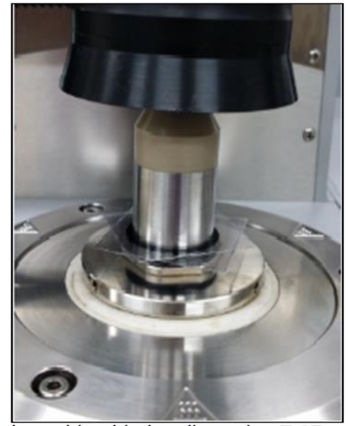
Evaluating degree of blending/diffusion between reclaimed and fresh binder at various stages of production

Approach:

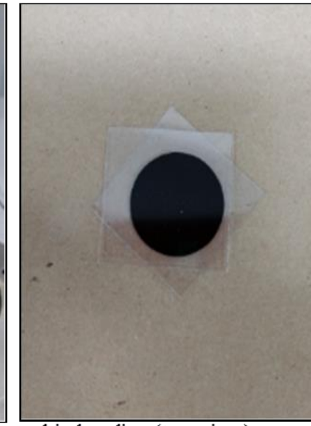
- **Testing of properties of composite asphalt binders using DSR**
- **Modeling diffusion/aging mechanism**



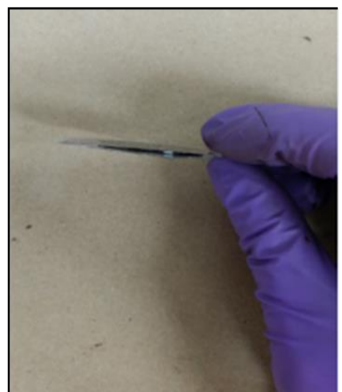
a. binder between two transparency sheets



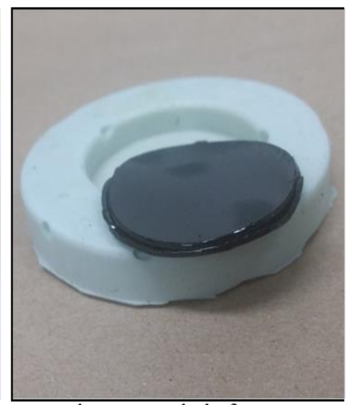
b. making binder disc using DSR



c. binder disc (top view)



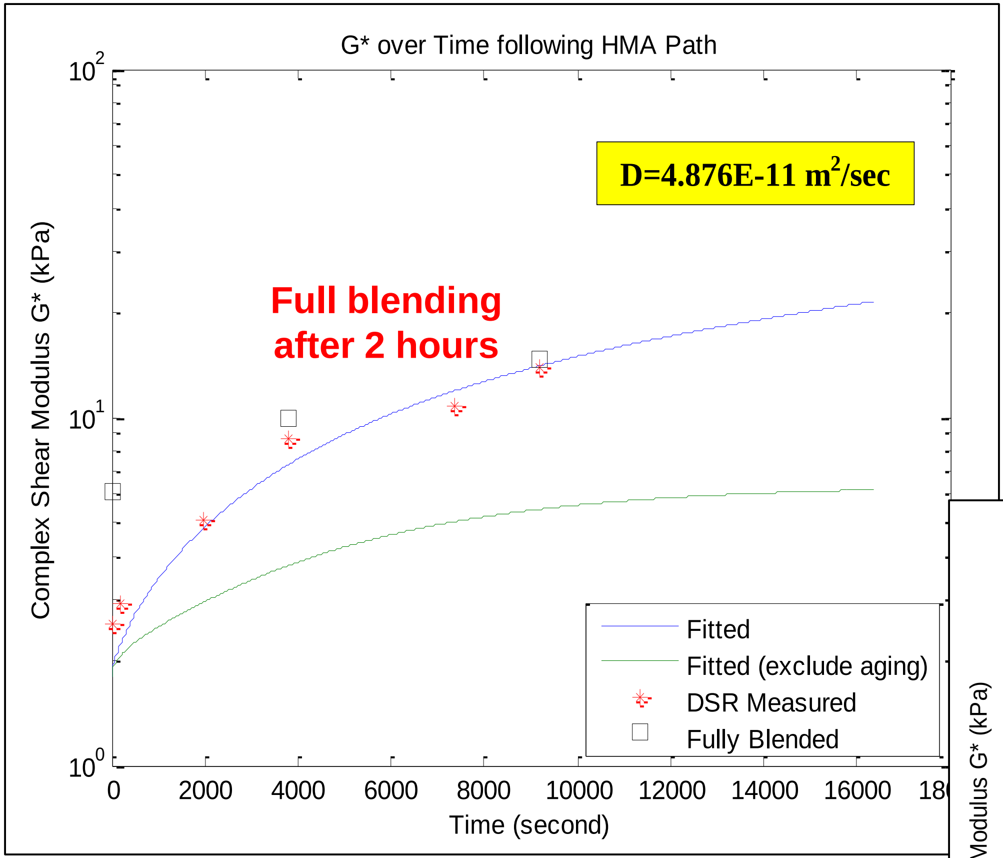
d. binder disc (cross sectional view)



e. two-layer sample before oven conditioning

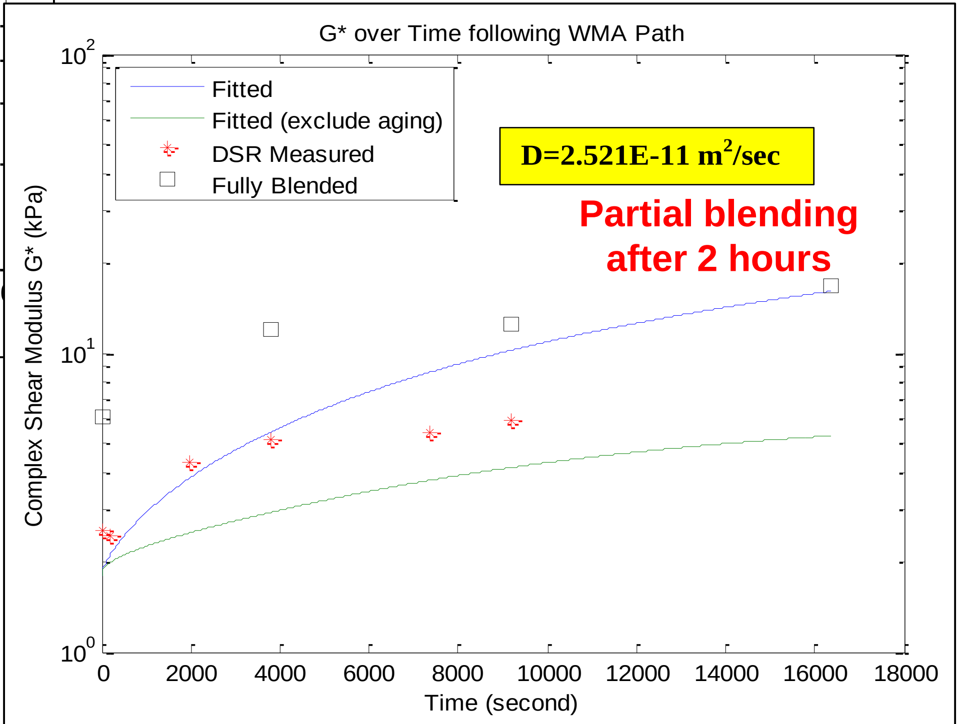
f. two-layer sample after oven conditioning

Effect of WMA on RAP diffusion
Two-layer asphalt binder testing



HMA production

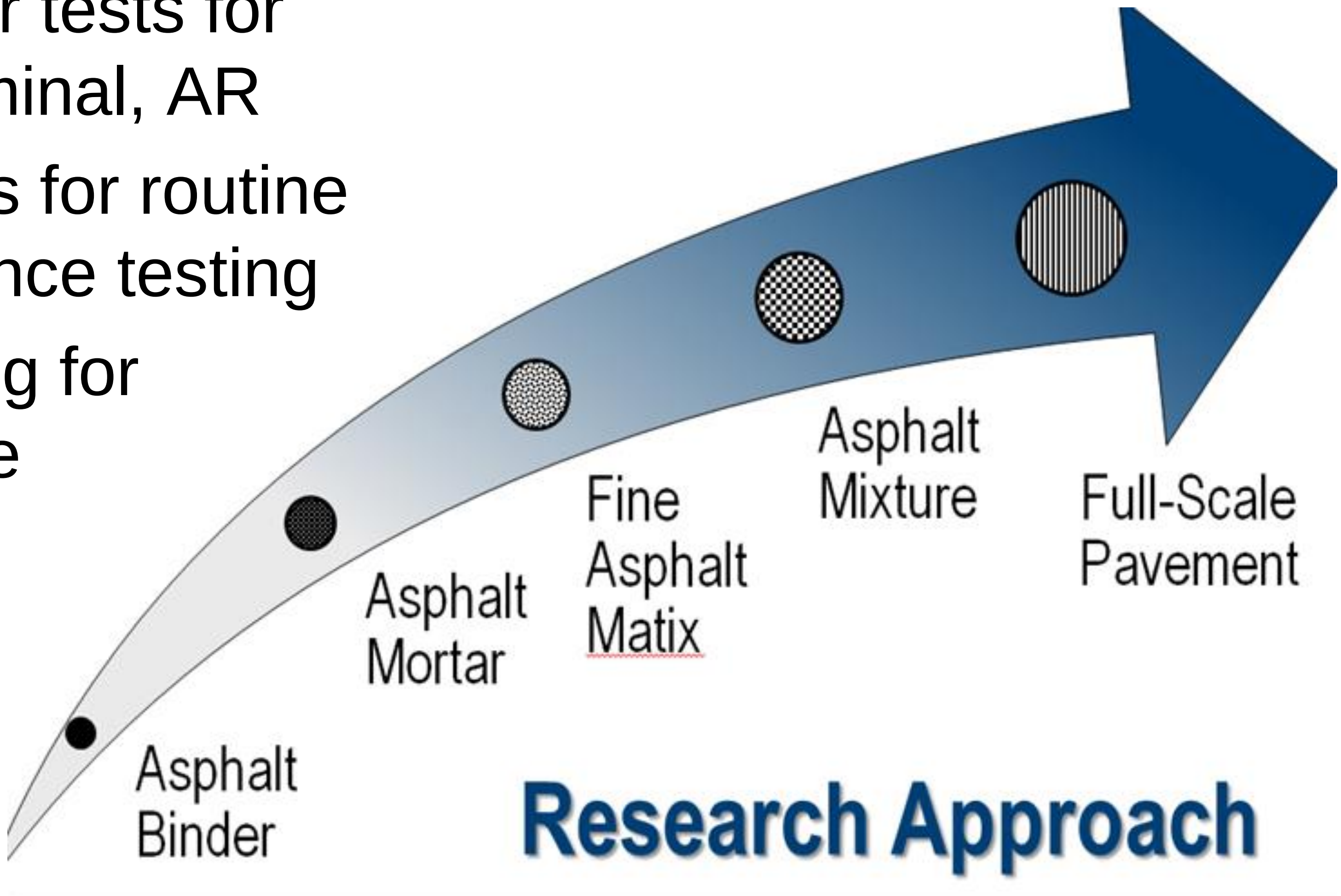
WMA production



Towards faster, cheaper performance related specifications for asphalt mixes

Vision:

- PG binder tests for neat, terminal, AR
- FAM tests for routine performance testing
- Mix testing for expensive project mix design approval

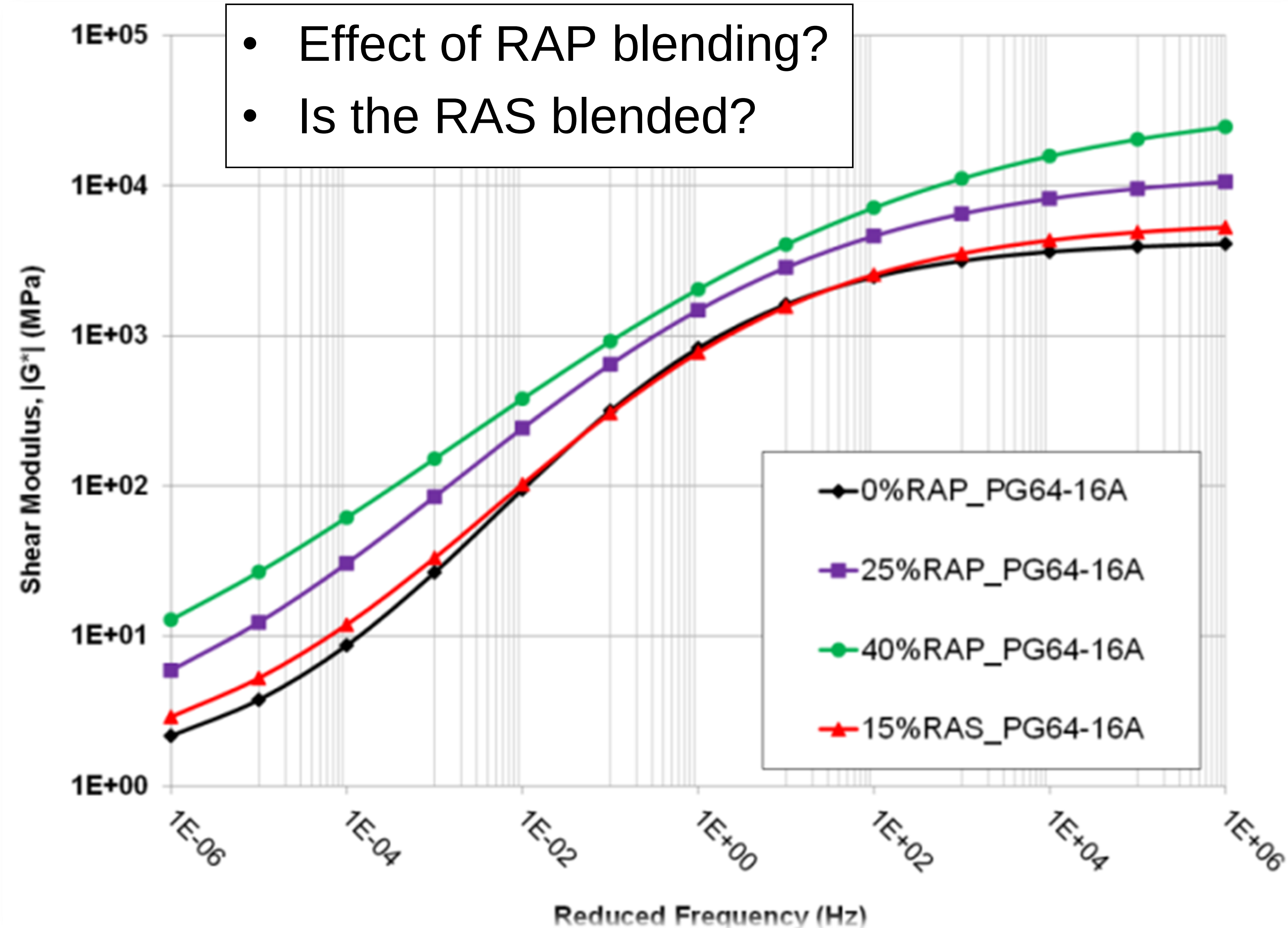


FAM Mix Testing as a Solvent-Free Approach to Evaluate RAP + Virgin Blending

FAM consists of fine aggregate, fine RAP/RAS, and virgin binder
Same gradation and binder content as fine portion (passing #4 or #8) of a full-graded mix

Evaluation of blending and blending effects using FAM

- Effect of RAP blending?
- Is the RAS blended?



CalRecycle Project
Effect of adding RAP to RHMA

RAP in RHMA-G

- Initial RHMA-G results
  - Maximum of 10 percent RAP binder replacement before gap-gradation specification not met
- Adding RAP to RHMA-G mixes appears to cause
  - Some improvement in overall rutting performance
  - Potentially overall negative effect on fatigue cracking performance

CalRecycle Project
Effect of R-RAP on HMA

R-RAP in HMA

- 15 and 25 R-RAP binder replacement
  - Volumetric properties met
- Preliminary indications are that putting R-RAP in new HMA mixes will generally
  - Improve rutting performance
  - Improve cracking performance
- No reason at this time to separate R-RAP and RAP at asphalt plants

Summary of Materials, Construction, Management Strategies to Improve Sustainability of Asphalt

- <u>Improve durability through compaction specs</u>
  - +1% air-voids = -10 to 15% cracking life
  - Allow contractors to use warm mix as compaction aid
  - Maintain and enforce strict compaction requirements
- Reduce total asphalt used over the life cycle
  - Improved pavement design methods
  - Properly timed preservation treatments
  - Better compaction
  - RAP, rubber
- Use In-place recycling
  - CIR, current status, concerns and research
  - FDR, current status, concerns and research

Environmental Product Declaration (EPD)

- Results of an LCA for a product
  - Produced by industry
  - Most pavement industries working on EPDs now

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 other Use Stage considerations

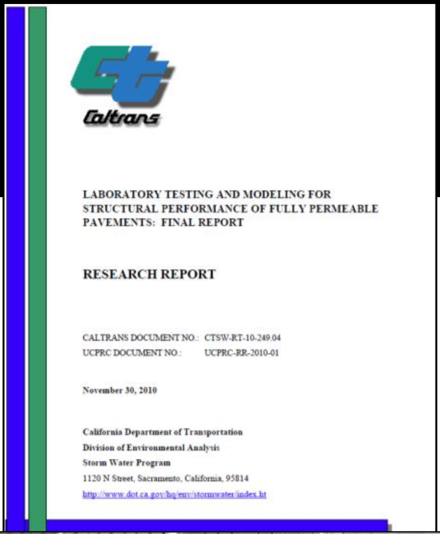
- Stormwater management and permeable pavements
- Bicycles, texture and roughness
- Heat island

Permeable Pavement for Stormwater Management

- Impervious pavement in urban areas contributes to
  - Water pollution (*oil, metal, etc*.)
  - Reduced groundwater recharge
  - Increased risk of flooding
  - Local heat island effect (*less evaporation*)

- Permeable pavement could help address the issues related to stormwater runoff volume and quality
- Initial analysis indicates that can have lower life cycle cost than other BMPs

Design methods for permeable pavements for heavy vehicles


Caltrans

LABORATORY TESTING AND MODELING FOR STRUCTURAL PERFORMANCE OF FULLY PERMEABLE PAVEMENTS: FINAL REPORT

RESEARCH REPORT

CALTRANS DOCUMENT NO.: CTSW-RT-10-249.04
UCPRC DOCUMENT NO.: UCPRC-RR-2010-01

November 30, 2010

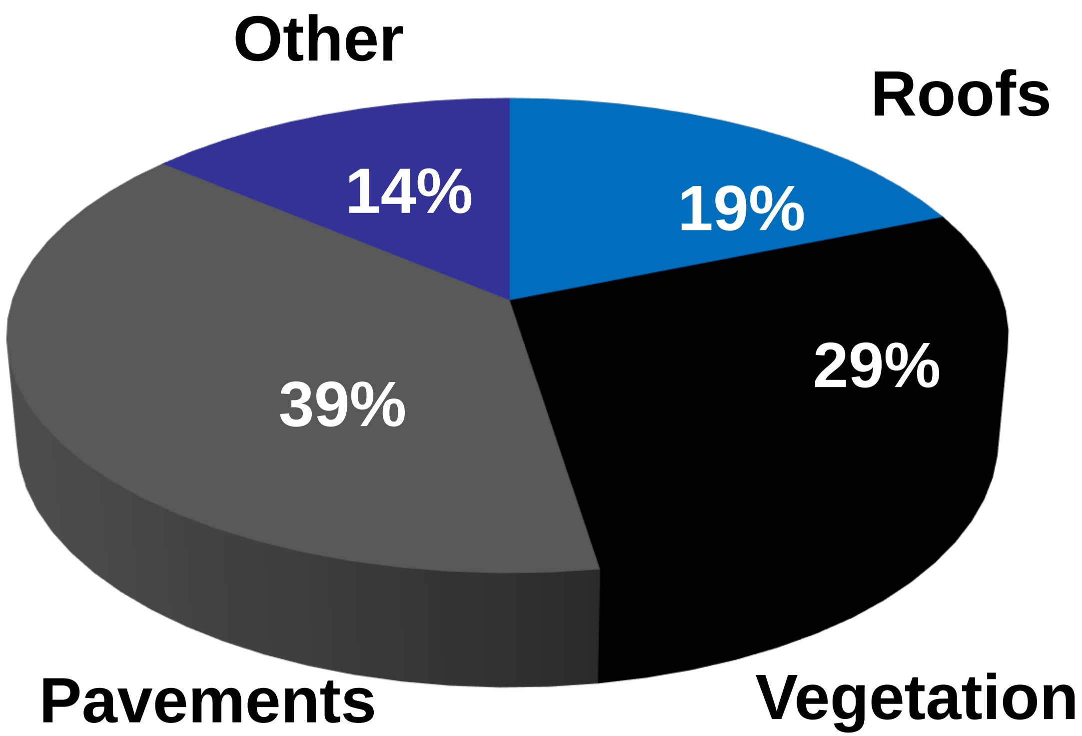
California Department of Transportation
Division of Environmental Analysis
Storm Water Program
1120 N Street, Sacramento, California, 95814
http://www.dot.ca.gov/hq/env/stormwater/index.ht

- Pervious Concrete and Porous Asphalt for Heavy Traffic
  - Preliminary permeable pavement designs that can be tested in pilot studies under typical California traffic and environmental conditions
  - http://www.ucprc.ucdavis.edu/PDF/UCPRC-RR-2010-01.pdf
- Permeable Interlocking Concrete Pavement for Heavy Traffic
  - Design method and validation results
  - Being incorporated into ICPI and ASCE designs
  - http://www.ucprc.ucdavis.edu/PDF/UCPRC-RR-2014-04.pdf

Heat Island/Cool Pavement

Albedo = reflectivity

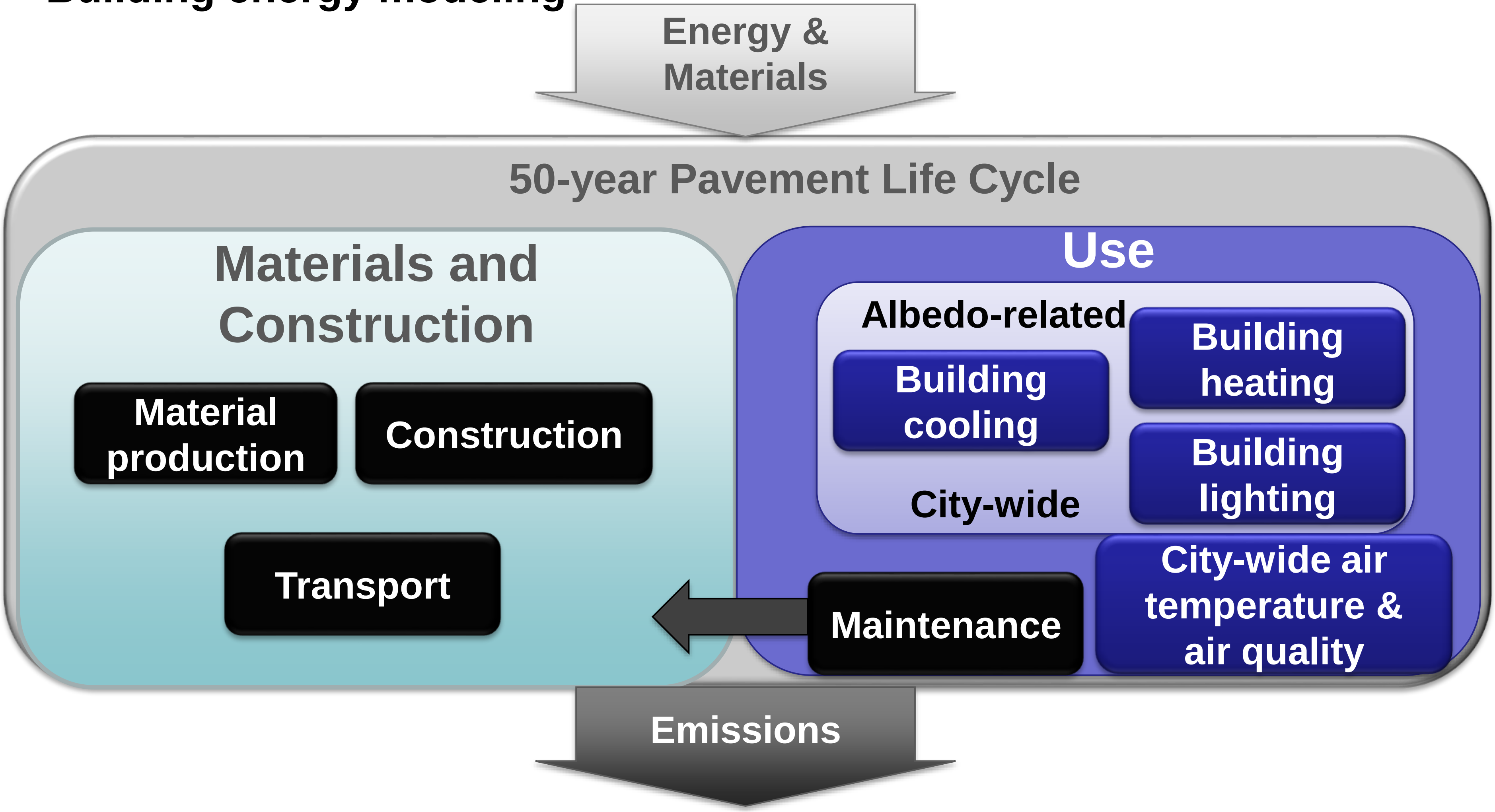
Question: what is net impact of changing surface materials to change albedo?



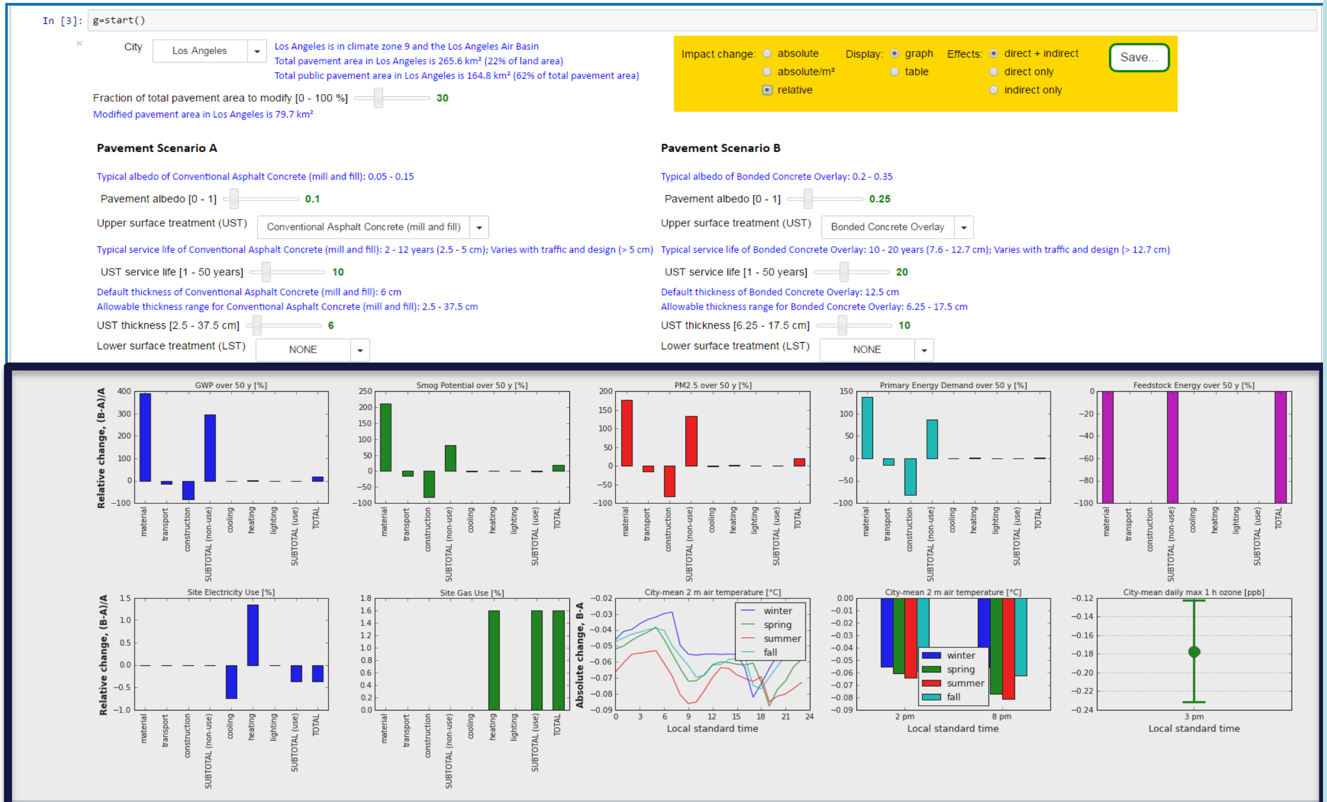
Urban fabric above tree canopy in Sacramento, California

The scope of the pLCA tool includes the non-use and use phases of the pavement life cycle

- Pavement materials and construction models
- State-wide WRF climate change model response to albedo
- Building energy modeling



pLCA tool



Provides comparison between treatments

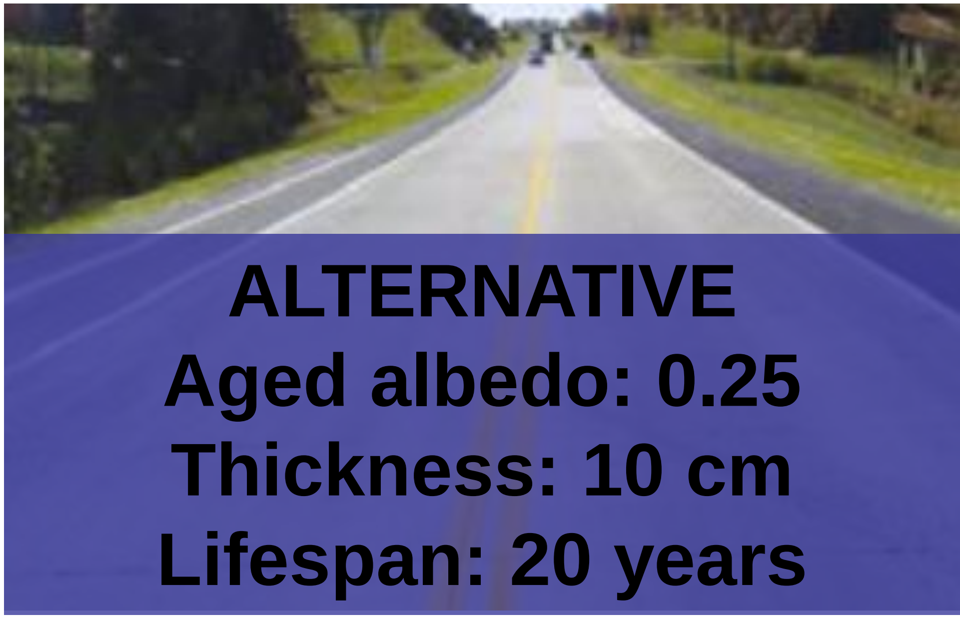
User inputs:

- City
- Percent of city repaved
- Treatment lives, thicknesses, albedos

Case studies: 1. compare chips, slurries and reflective coatings 2. compare rehabilitation treatments

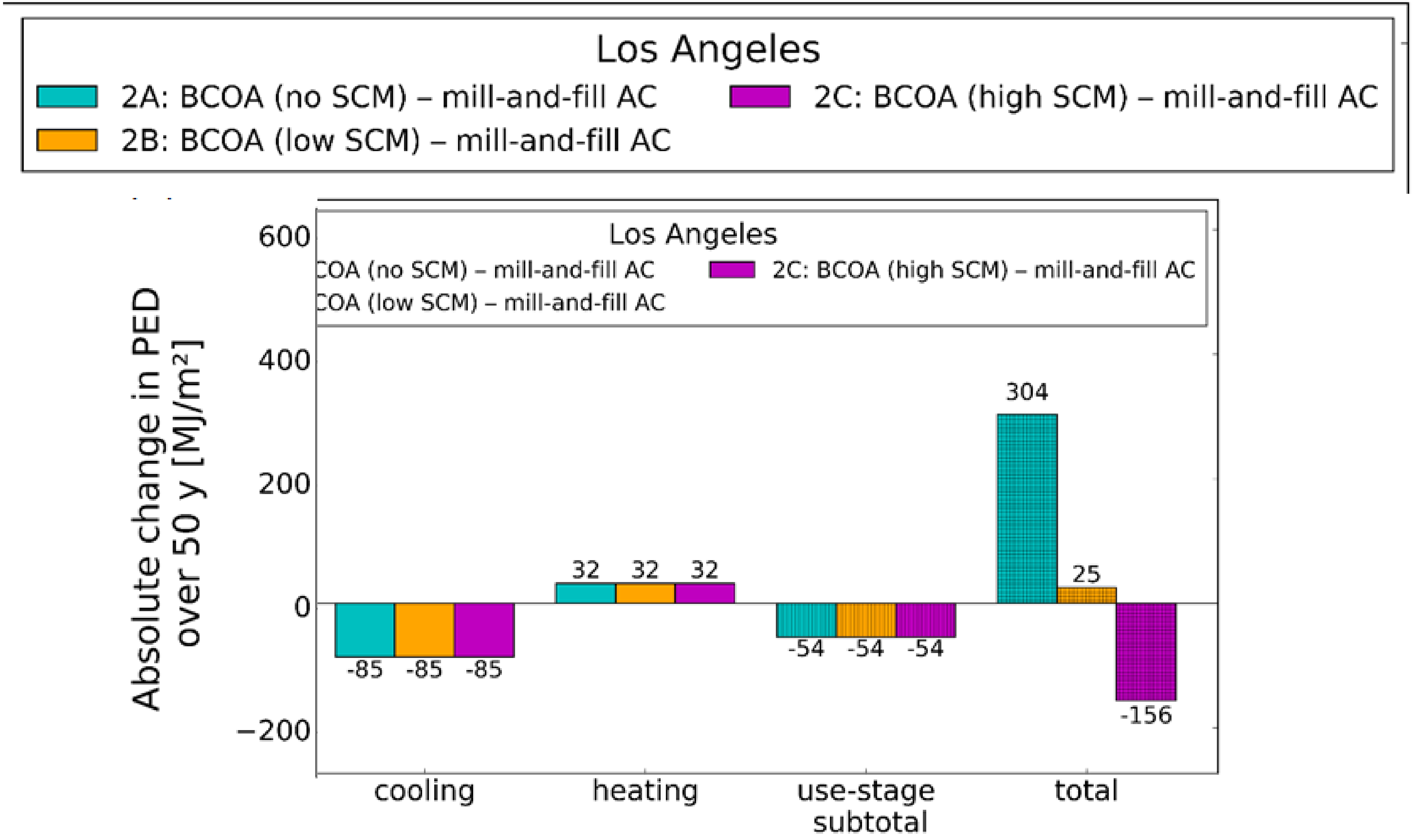
Example calculations

Mill-and-fill conventional asphalt concrete

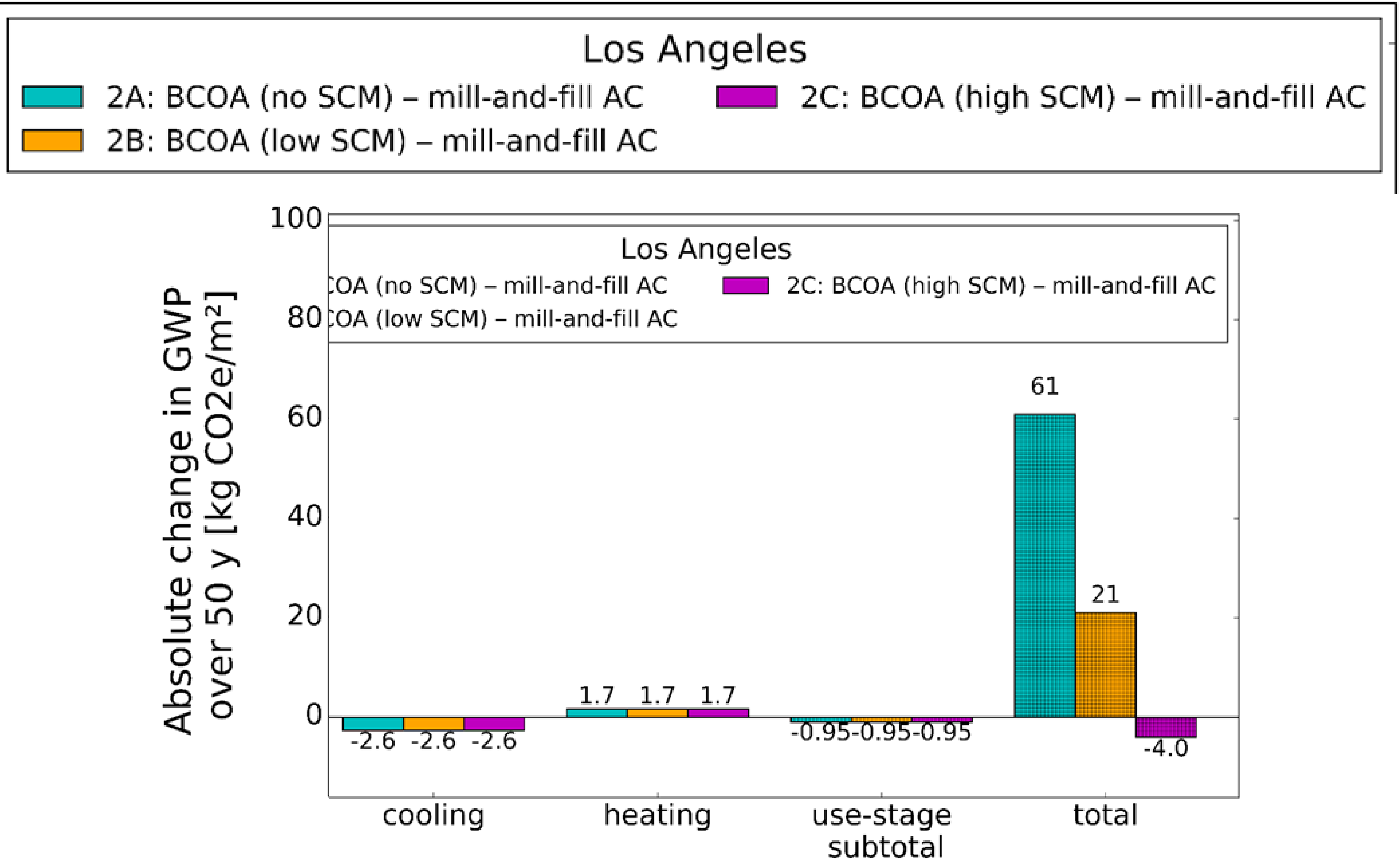


Bonded cement concrete overlay

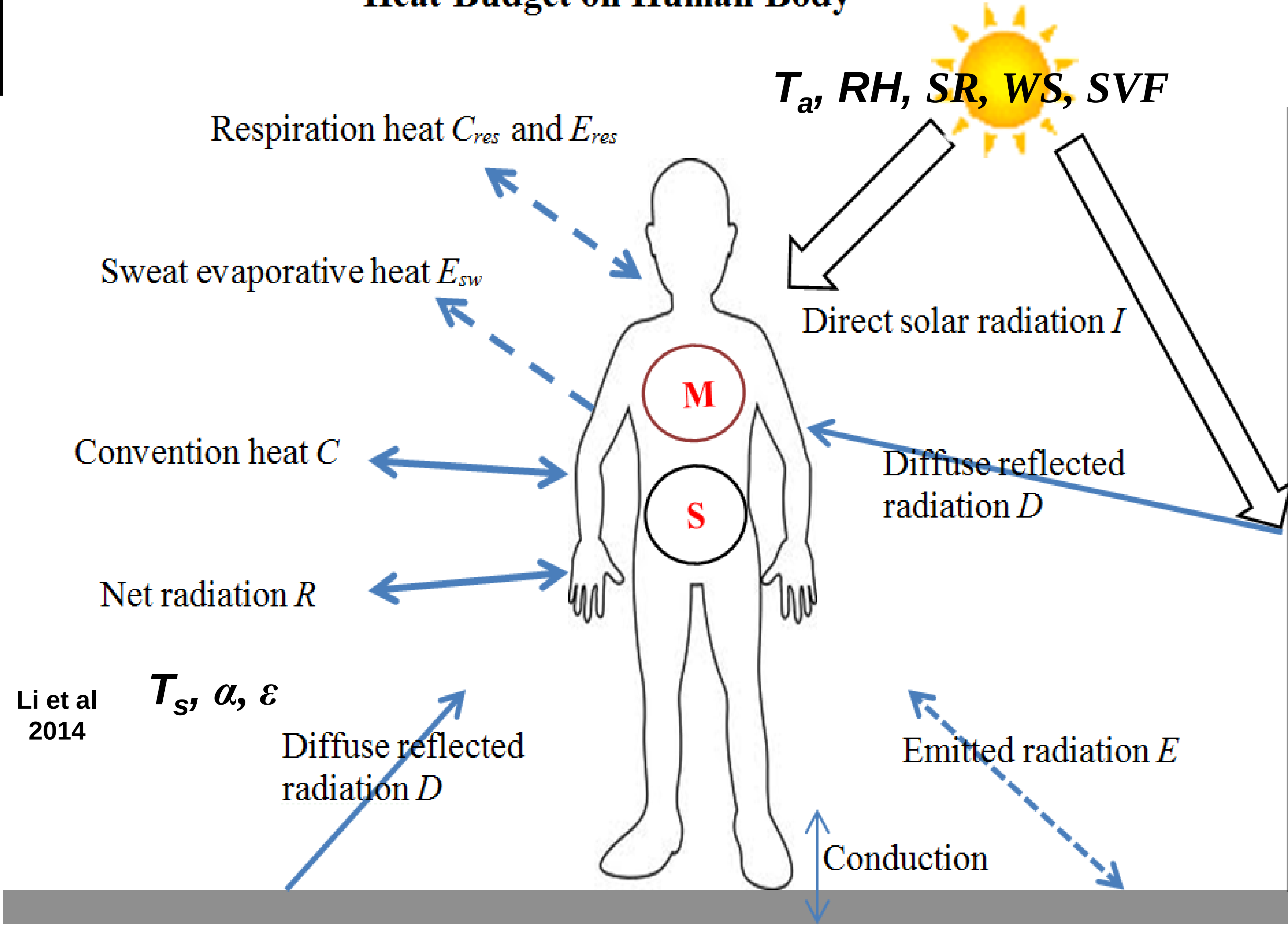
Example rehab results
Los Angeles, primary energy demand



Example rehab results
Los Angeles, global warming potential



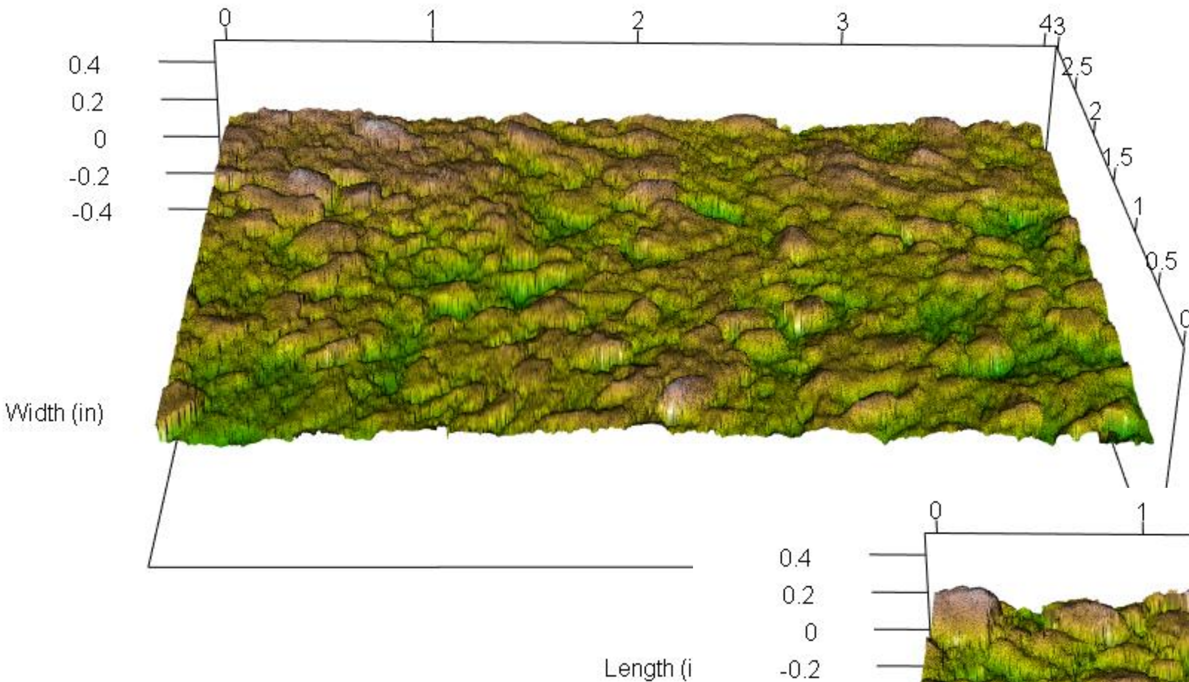
Heat Budget on Human Body



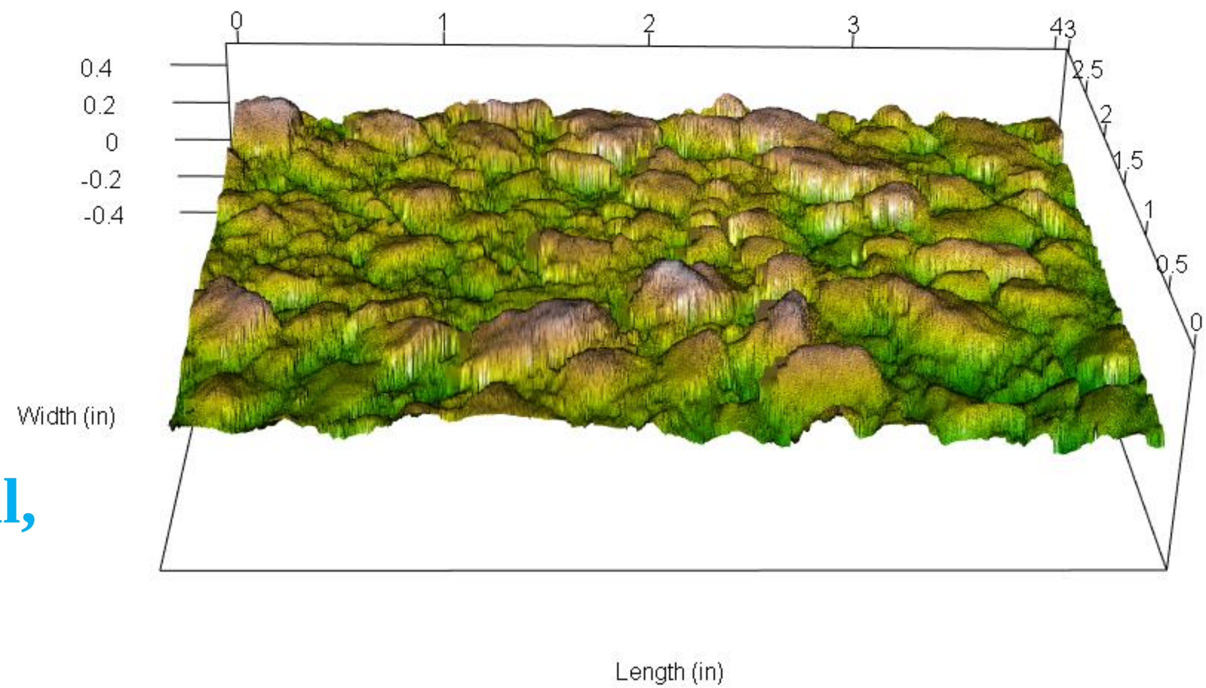
Pavement and Bicycle Riders

- Develop guidelines for design of preservation treatments suitable for bicycle routes on state highways and local streets in California
  - Surveys of bicycle ride quality
    - 6 bicycle clubs, General public in Davis, Richmond, Chico, Sacramento, Reno

Example 3D Macrotexture Images of MPD



Microsurfacing, MPD = 1.1 mm



Coarser 9.5mm chip seal, MPD = 2.3 mm

Conclusions from Bicycle Studies

- 80% of riders rate pavements with Mean Profile Depth values 1.8 mm or less as acceptable
- Most slurries on city streets produce high acceptability across all cities
- The presence of distresses, particularly cracking, reduces ride quality
- Chip seal specification recommendations in Caltrans report
- Consider “Complete Pavement” like Reno

Caltrans Quieter Pavement Research Program

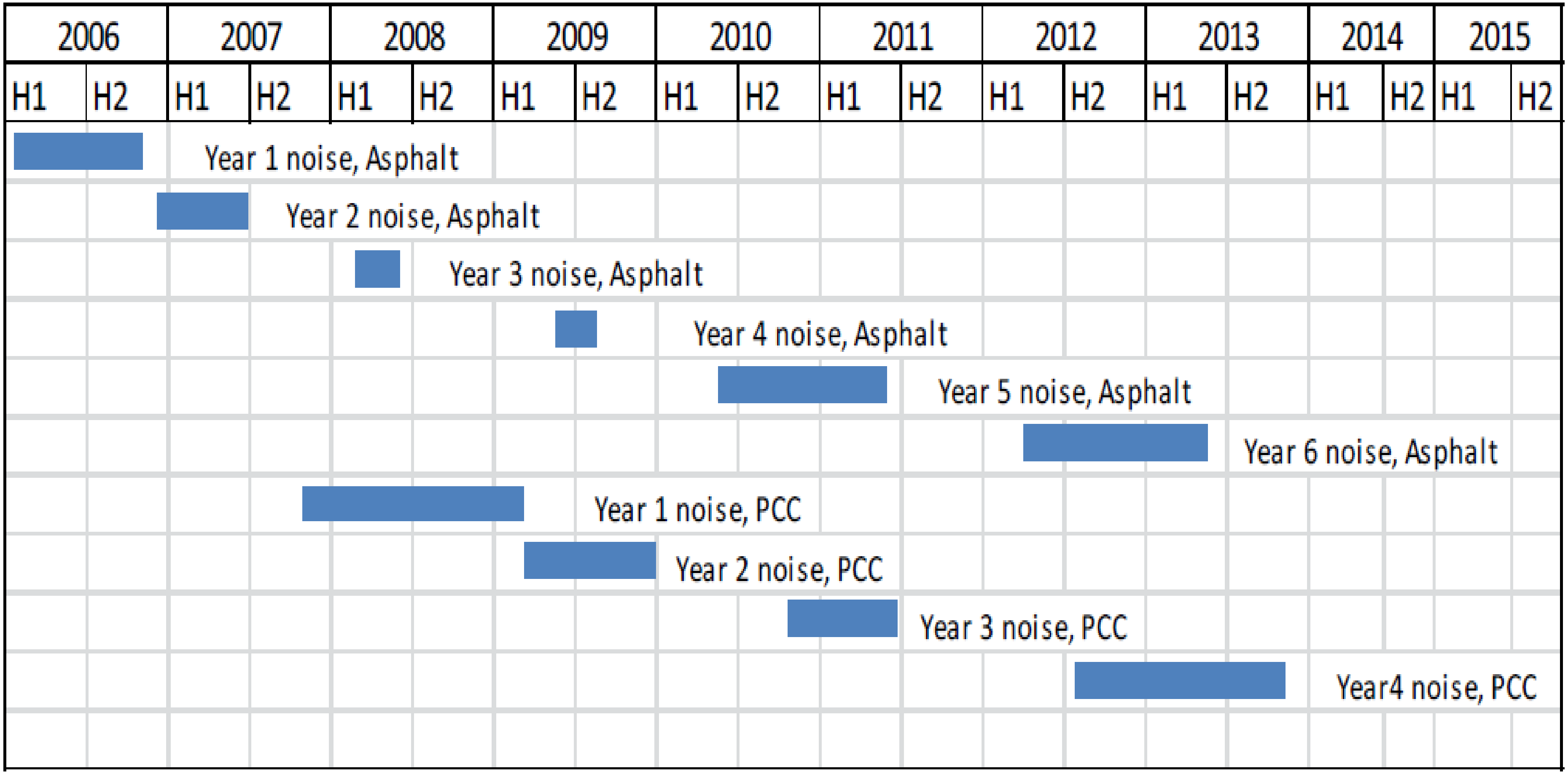
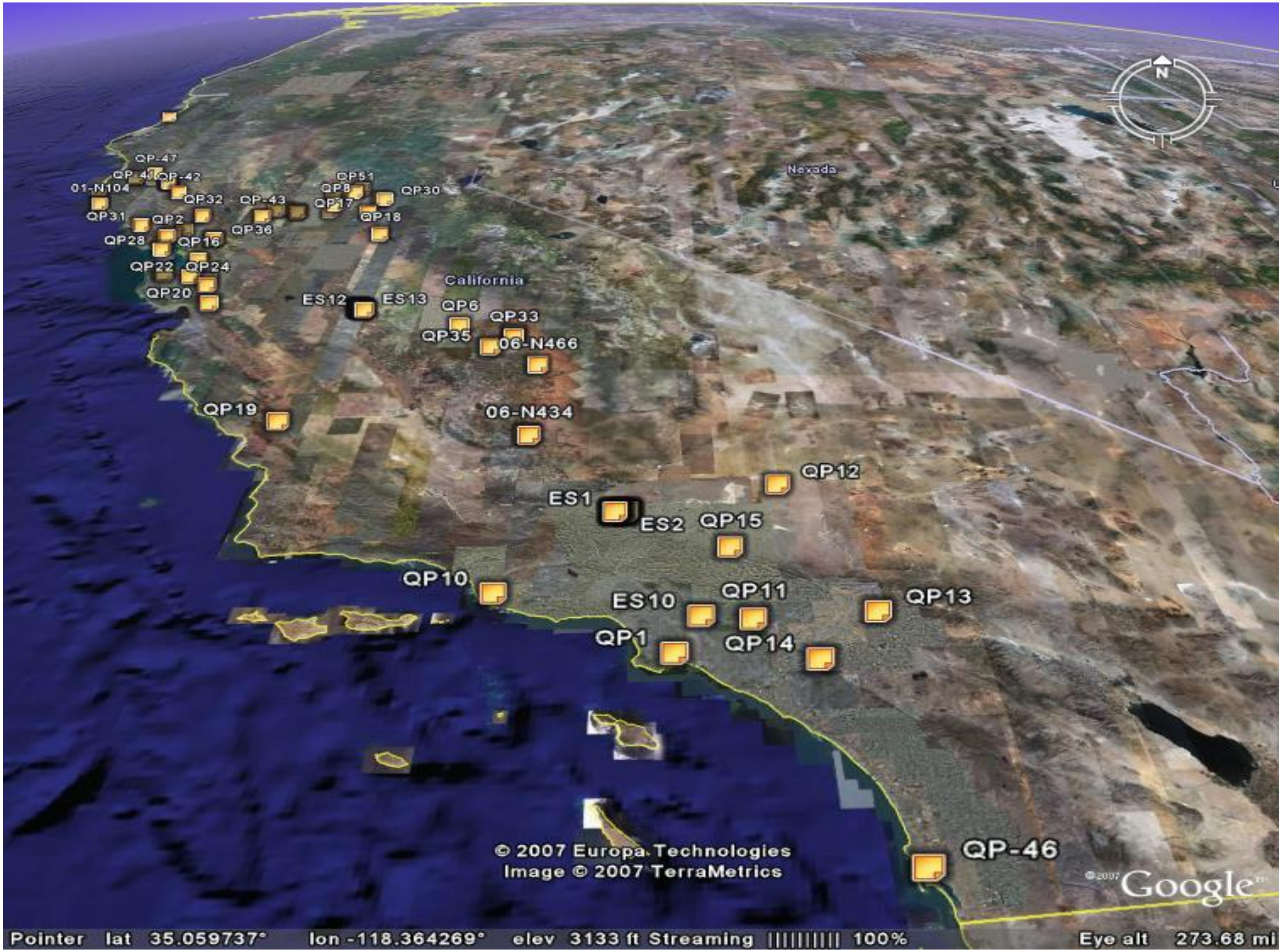


Figure 1.1: Timeline of completed data collection periods for asphalt and concrete pavement noise studies.

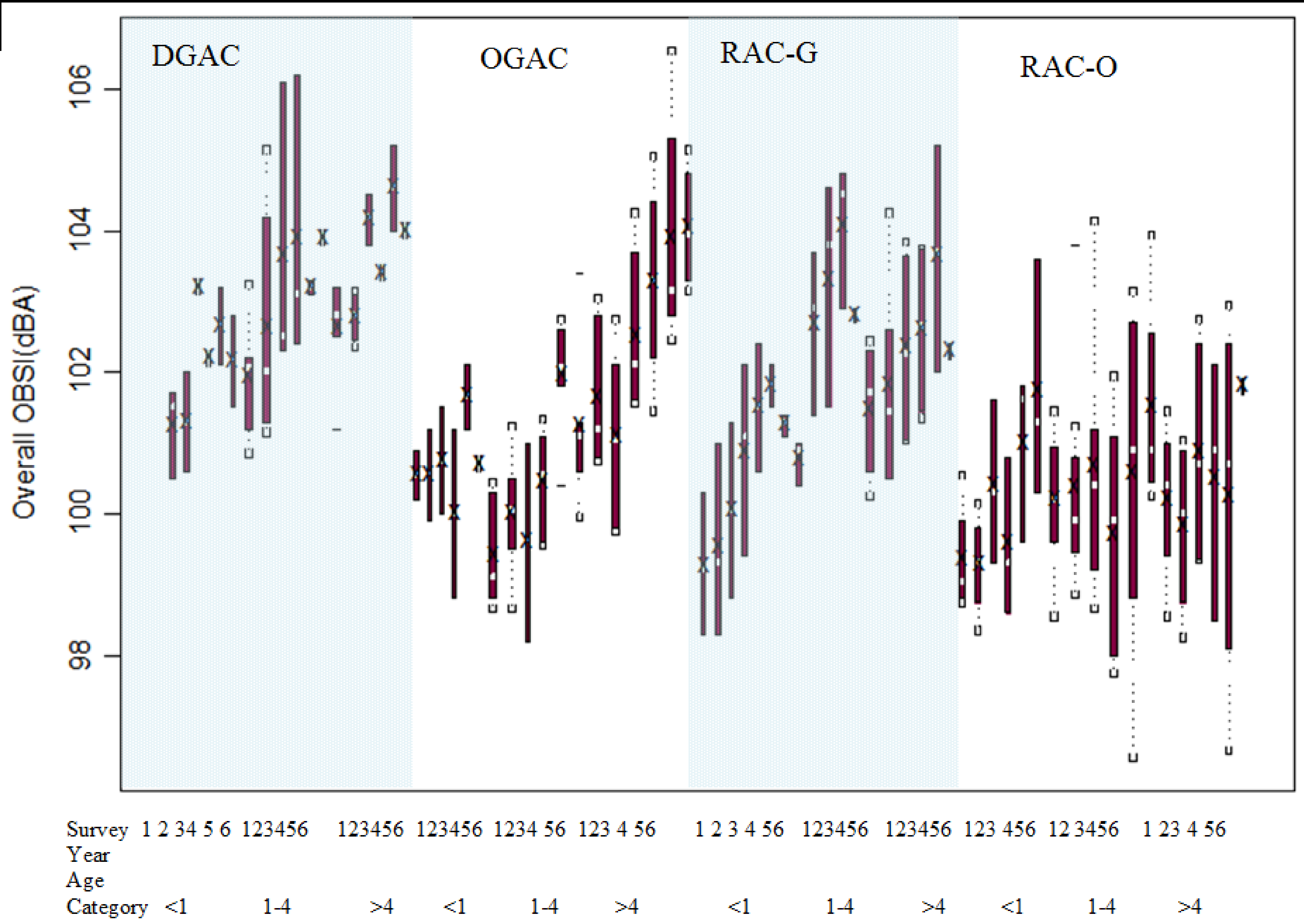
Caltrans Quieter Pavement Research Program

Instrumented car measures OBSI, IRI and macro-texture

Asphalt test sections:



OBSI for each age category over 6 years



Asphalt noise study conclusions

- RAC-O gave 13-15 years of noise benefit compared with HMA
- OGAC gave 9-11 years
- RAC-O also stayed smoother than other treatments

Conclusions

- "State of the Knowledge" recommendations for improving pavement sustainability are available
  - Cost
  - Environment
- Improving environmental sustainability often also brings lower life cycle cost
  - Agency cost and user cost
- Improvements become permanent from reviewing and changing standard practices

Questions

All reports downloadable:

www.ucprc.ucdavis.edu