Reducing Pavement Life Cycle Costs and Greenhouse Gases

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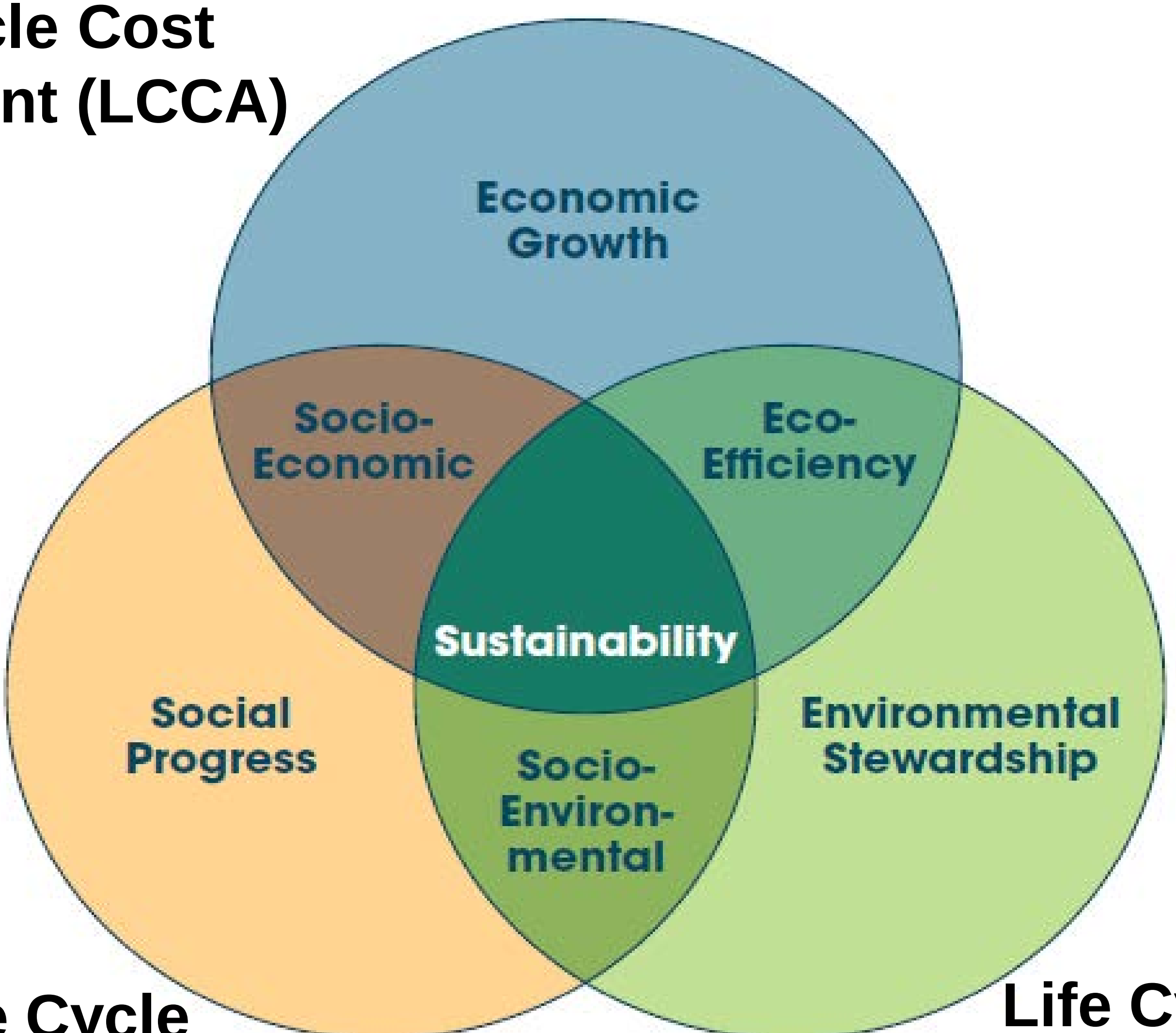
Outline

- Goals for Sustainability
- Tools for measurement and prioritization
- Main concepts and interactions
- Specific actions and examples
- Examples from City of San Jose
- Final thoughts
- Questions

The Sustainability Triple Bottom Line

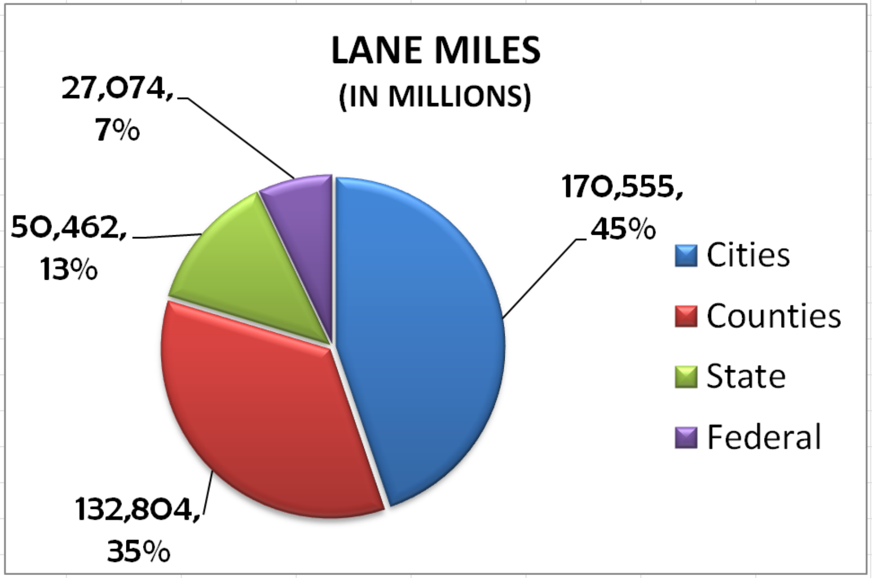
Life Cycle Cost Assessment (LCCA)

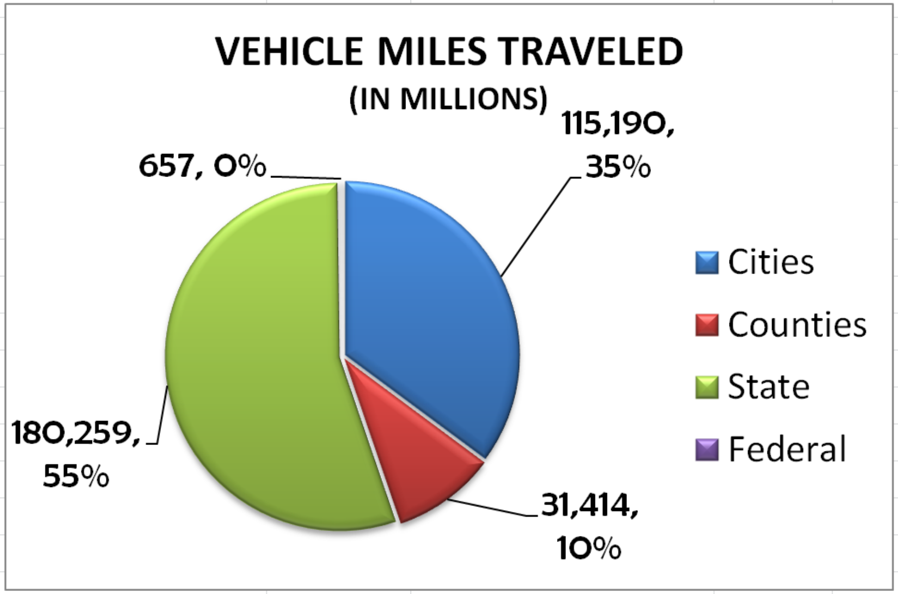


Social Life Cycle Assessment (S-LCA)

Life Cycle Assessment (LCA)

Why is Local Government Pavement Important to Sustainability?





Pavement Spending

Local $/State $ usually about 0.8 to 1

SB 1

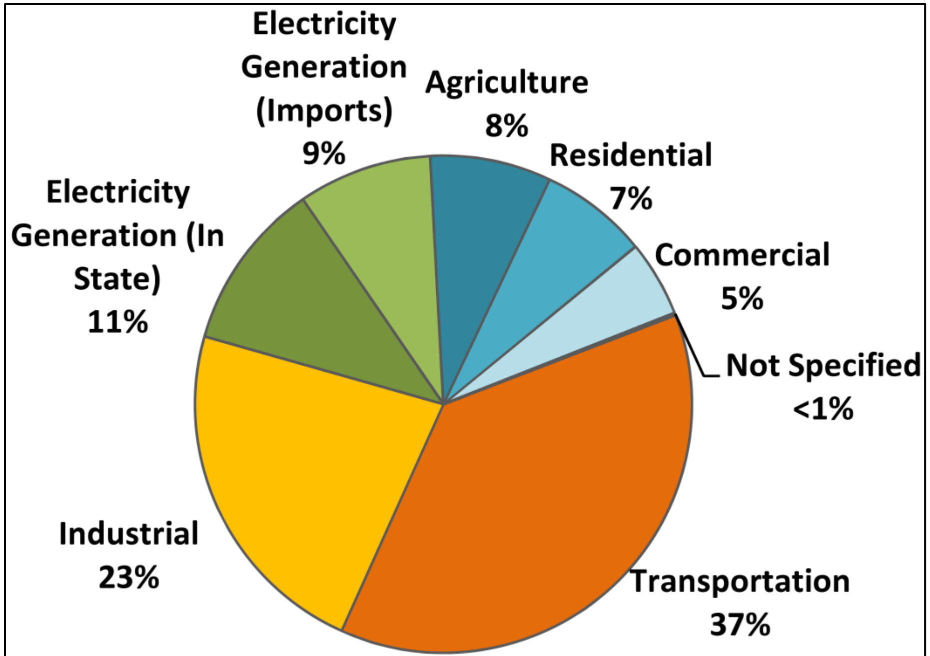
$ 2.5 billion for state highways

$ 2.0 billion for local government

How do Pavements Contribute to California GHG Emissions?

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

- 459 MMT CO2e in 2013
  - On road vehicles 155 MMT
    - Optimizing smoothness, texture, deflection energy on state network reduces by 1% of this
  - 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



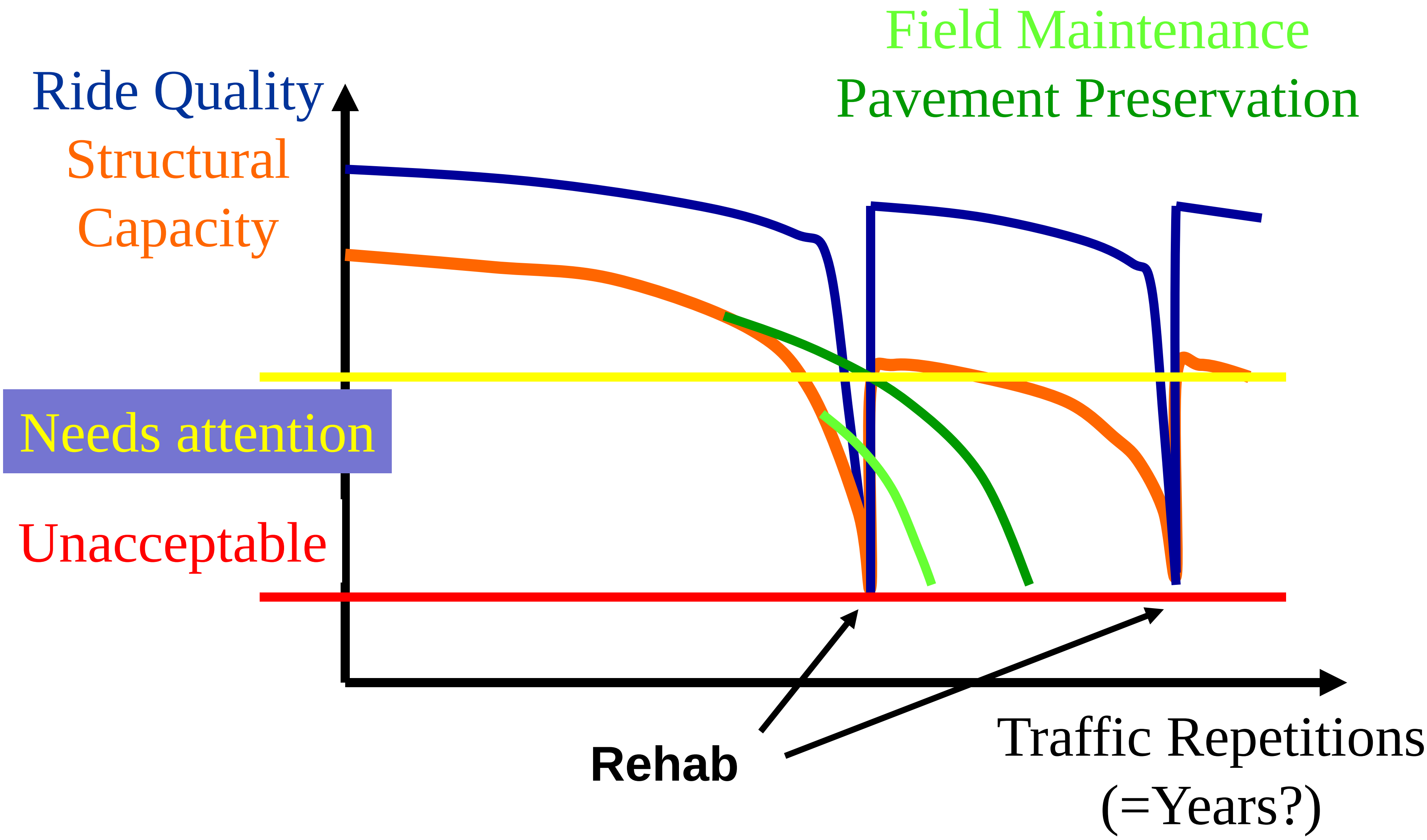
2013 Total CA Emissions: 459.3 MMTCO2e

Possible Pavement Reductions	MMT/year
Rolling resist to optimum	1.5
Reduce cement use 50%	0.2
Reduce asphalt use 50%	0.7
Reduce hauling 10%	0.6
TOTAL	**2.9**

Measuring Sustainability

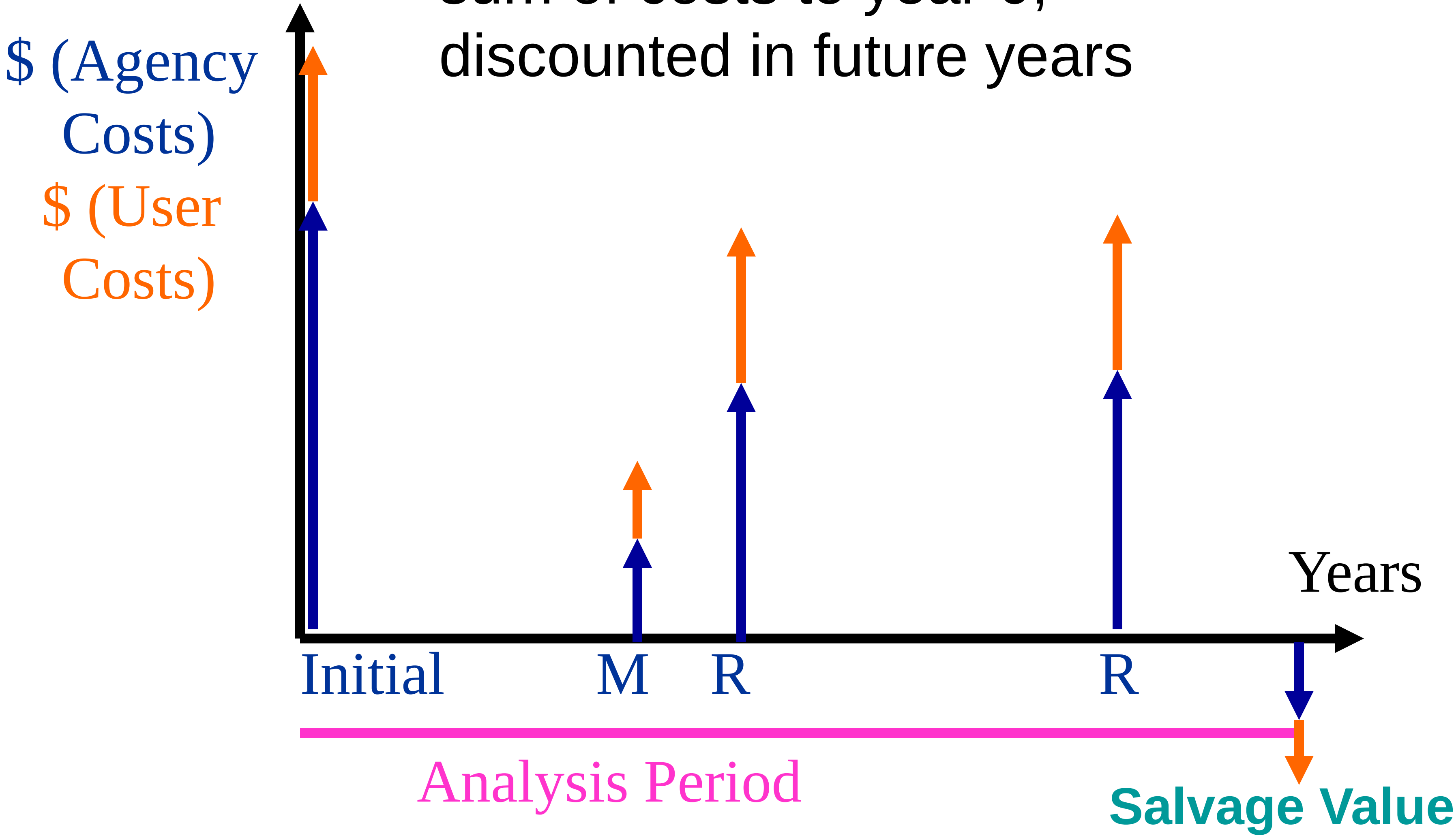
- Life Cycle Cost Analysis (LCCA)
  - Economic analysis
  - Agency perspective typical
  - Can include user costs
- Life Cycle Assessment (LCA)
  - Range of environmental impacts
  - Used for many types of products
  - Being implemented for pavement (paving industry, FHWA, Caltrans, other DOTs)
- Social Life Cycle Assessment (S-LCA)
  - Being developed world-wide
  - Implications for pavement (Complete streets/active transportation, urban hardscape and quality of life)

Life Cycle Cost Basics



LCCA calculations

- Net present value = sum of costs to year 0, discounted in future years



Four Key Stages of Life Cycle Assessment

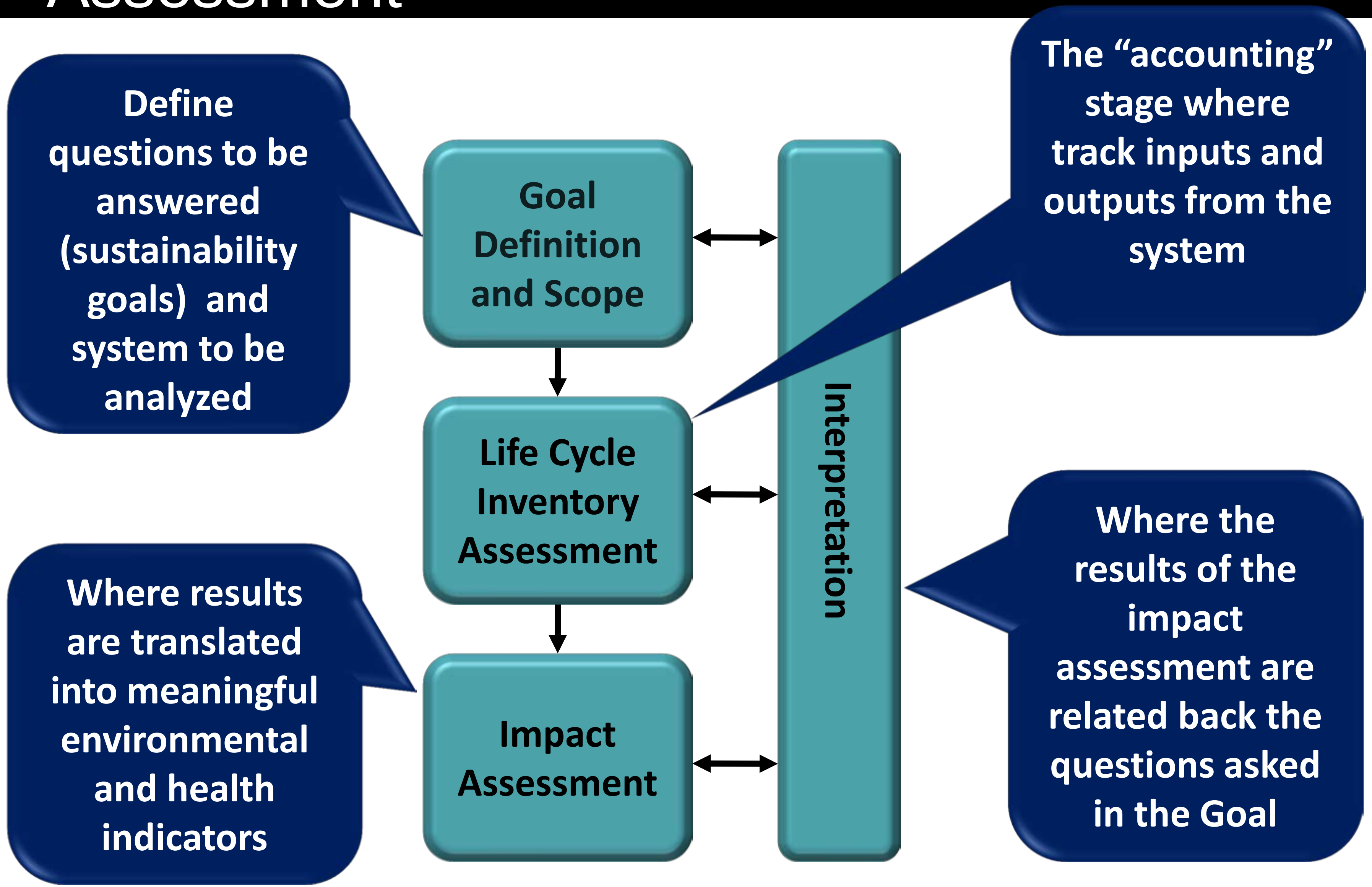


Figure based on ISO 14040, adopted from Kendall

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

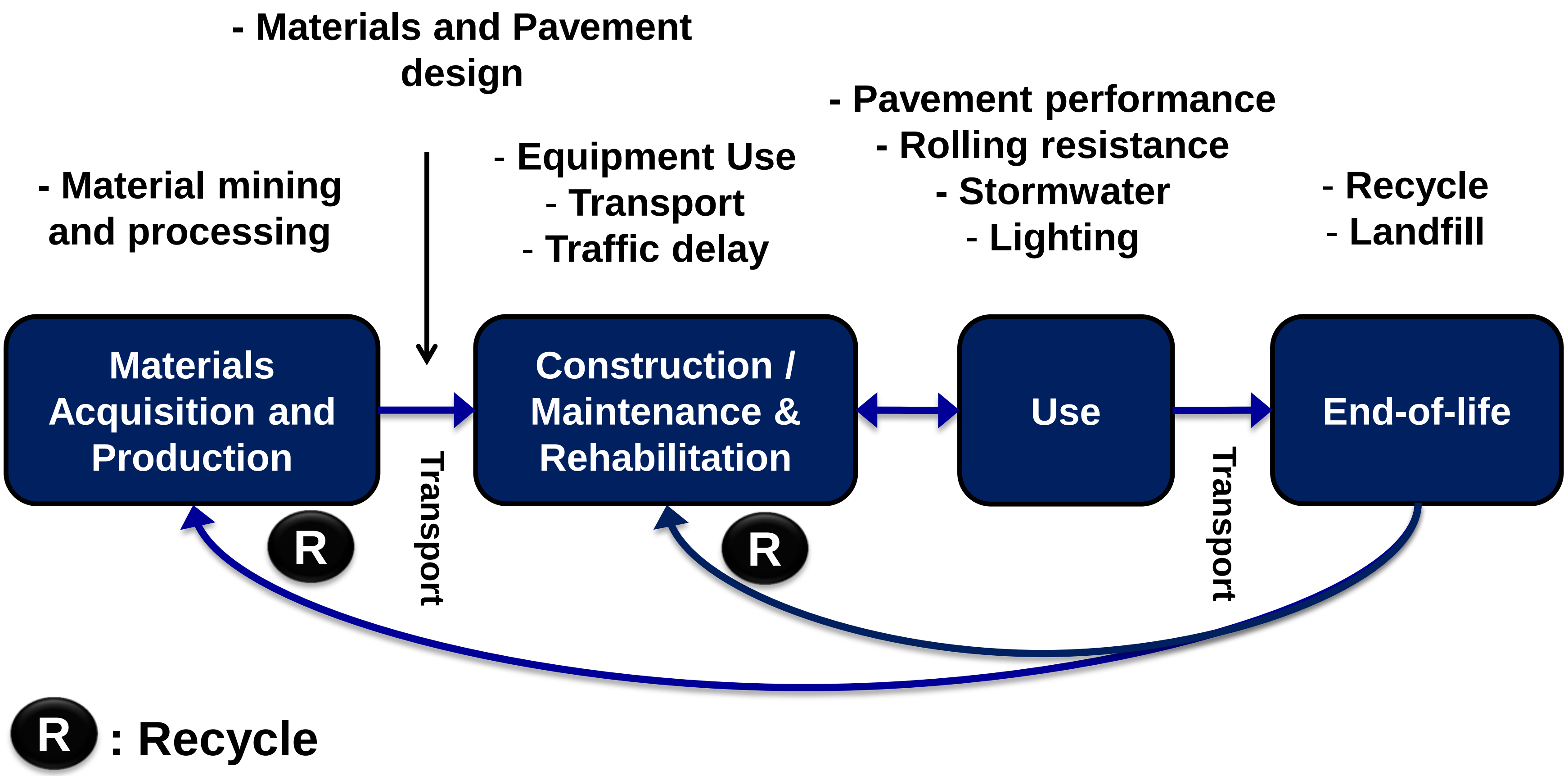
Depletion of resources

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

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

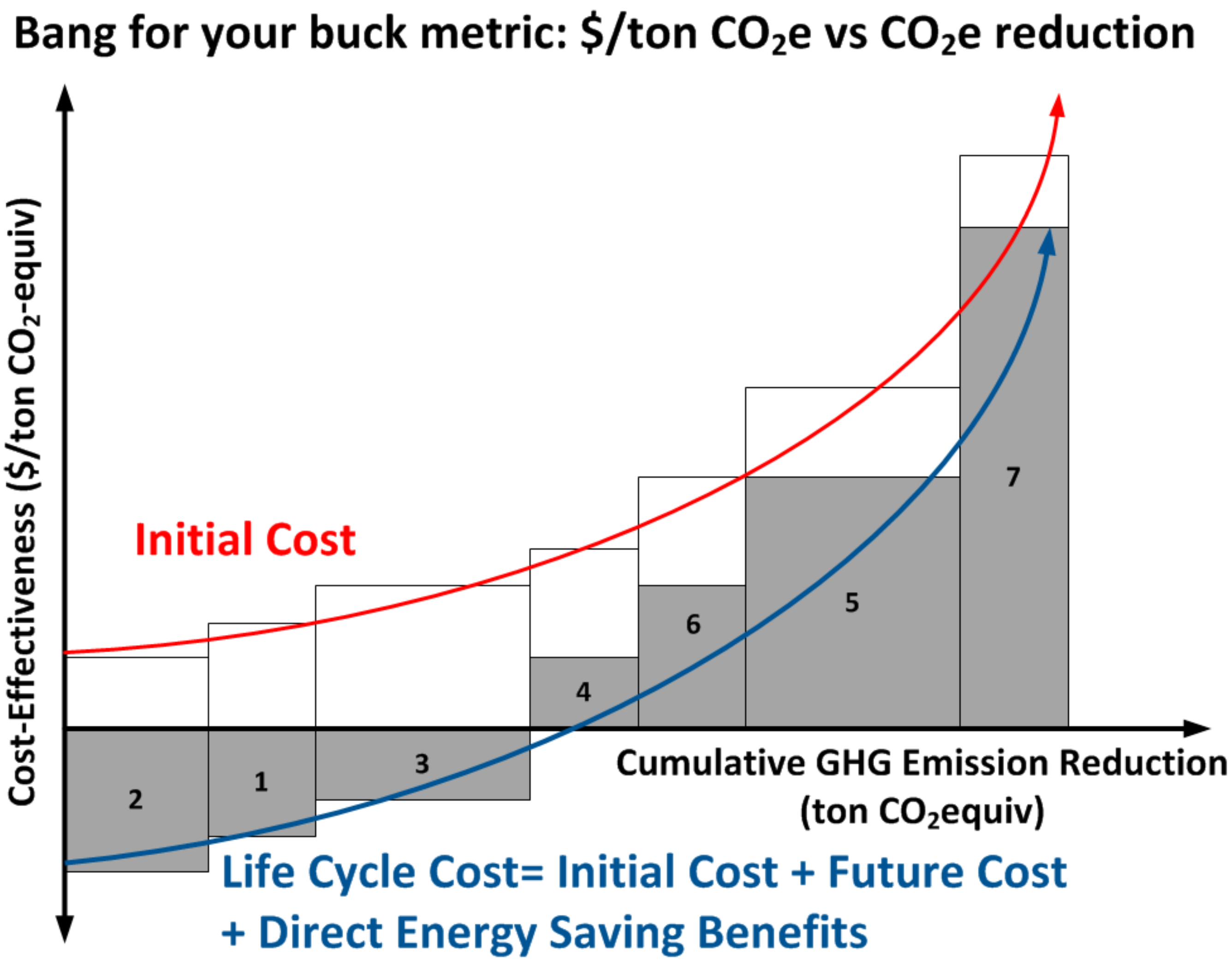
Where can environmental impacts be reduced?

- **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***

What Actions Should be Taken for Environmental Sustainability?



Adapted from Lutsey, N (2008) Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-15

- Many alternatives to improve sustainability
- How to prioritize?
- Cost from Life Cycle Cost Analysis (LCCA)
- Environment from Life Cycle Assessment (LCA)

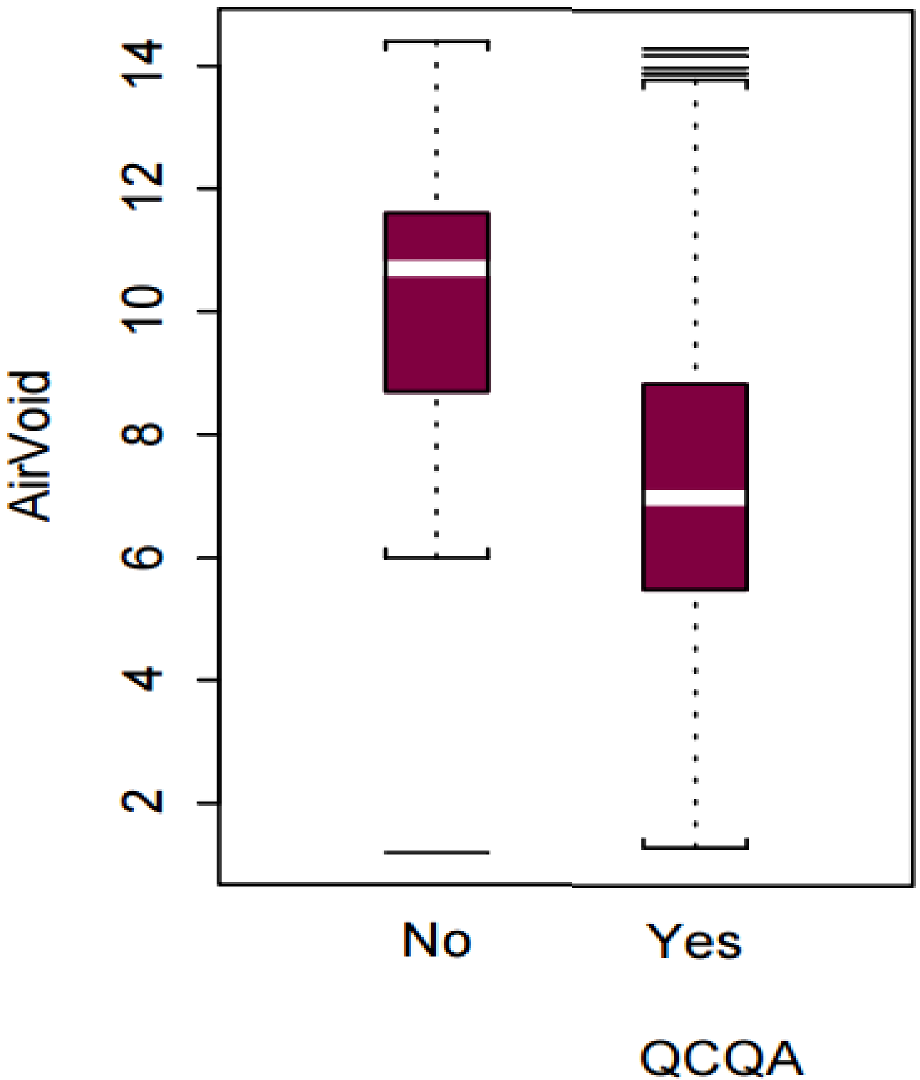
Changes to improve sustainability

- Asphalt compaction
- Concrete mix specifications
- Unpaving
- Pavement management and preservation
- Measuring impacts of material you buy
- Heat island
- Preservation and bicycles

Asphalt compaction specifications

- Is your asphalt living only half as long as it could?
  - Increase in air-voids of 1% = 10% shorter life
  - Typical air-voids achieved
    - If no measurement/penalties = 10 – 14%
    - If measurement/penalties if > 8% = 6 to 8%
    - Difference in life = **-40% = -8 years**
  - Why?
    - More air permeability = aging = raveling + cracking
    - More holes in it = cracking
    - More water permeability = moisture damage + aging

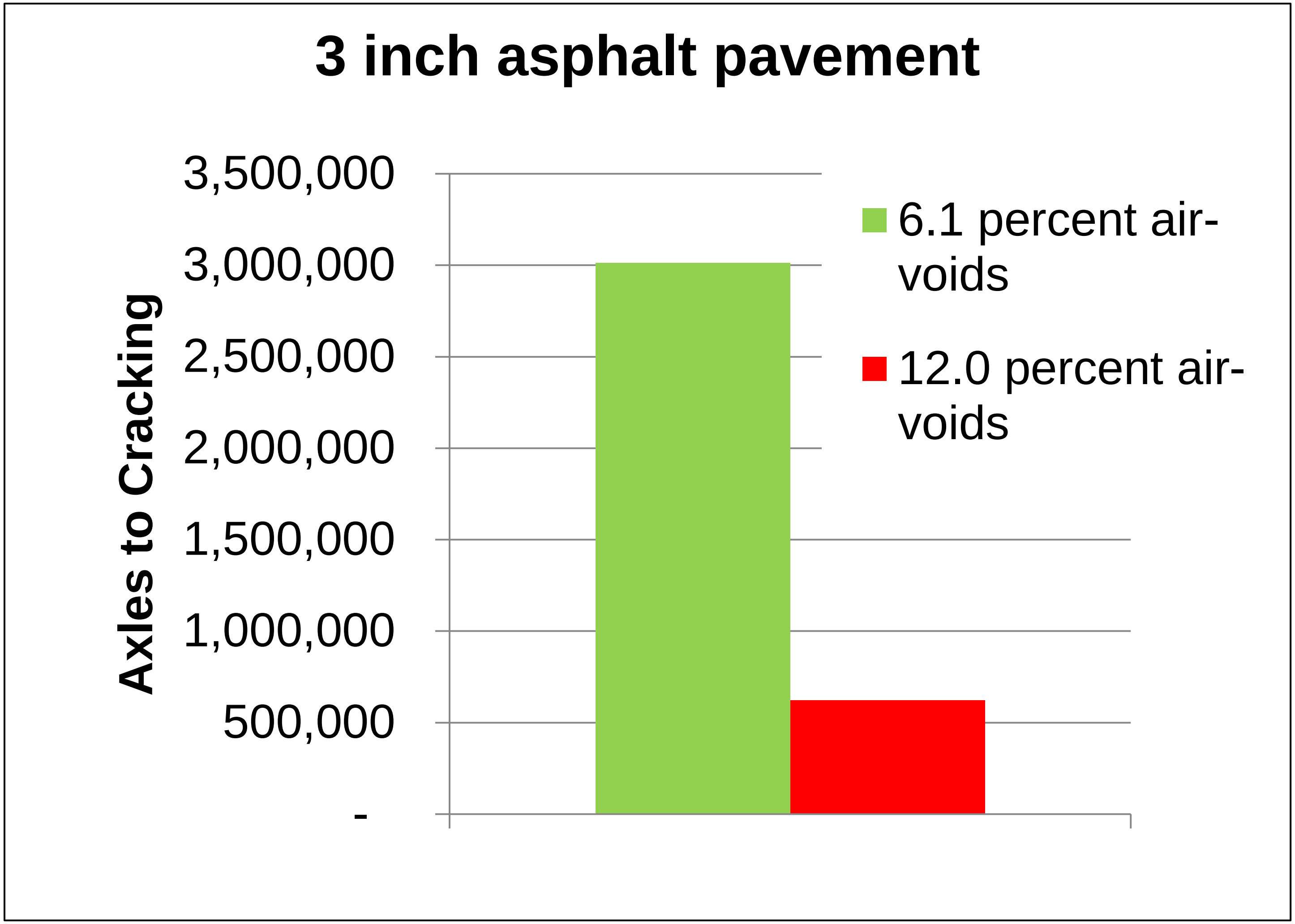
Caltrans experience with method spec vs using in-place measurement and penalties (QC/QA)



- Spec changed in 1996-98
- Very large culture change in Caltrans

"Trust but verify"

Effect of compaction on axle loads to cracking



Simulation based on FHWA Westrack project field results

What you need to do

- Use a quantitative (QC/QA) specification to measure compaction, do not mix method requirements (how to do the compaction) in the specification
- Write spec in terms of *in-place bulk density* and *theoretical maximum density* (TMD) and not *laboratory theoretical maximum density* (LTMD)
- Use cores or nuclear gauges calibrated for the specific mix/project to provide daily feedback to contractor and agency
- Collect and keep cores in case of a dispute
- Apply payment reductions if they don't meet your specification, <u>and enforce those payment reductions</u>

LCCA and LCA example: 8% vs 12% air-voids

- Assumptions:
  - Rural pulverize HMA, compact, 4 in. HMA
  - $26/sy
  - 12% air-voids = 12 year life
  - 8% air-voids = 18 year life
- Net present cost* over 50 year period:
  - 12% air-voids = $4.36 million
  - 8% air-voids = $3.09 million = **29 % less cost**
- Greenhouse gas emissions are **34% less**

***2% discount rate**

But what about?

- Won’t this increase the bid cost for my asphalt?
- Isn’t the cost of managing this specification high?
- Won’t coring damage my new pavement?
- What can I do to help my contractors meet and exceed the specification and further increase the life of my overlays?

Concrete mix specifications

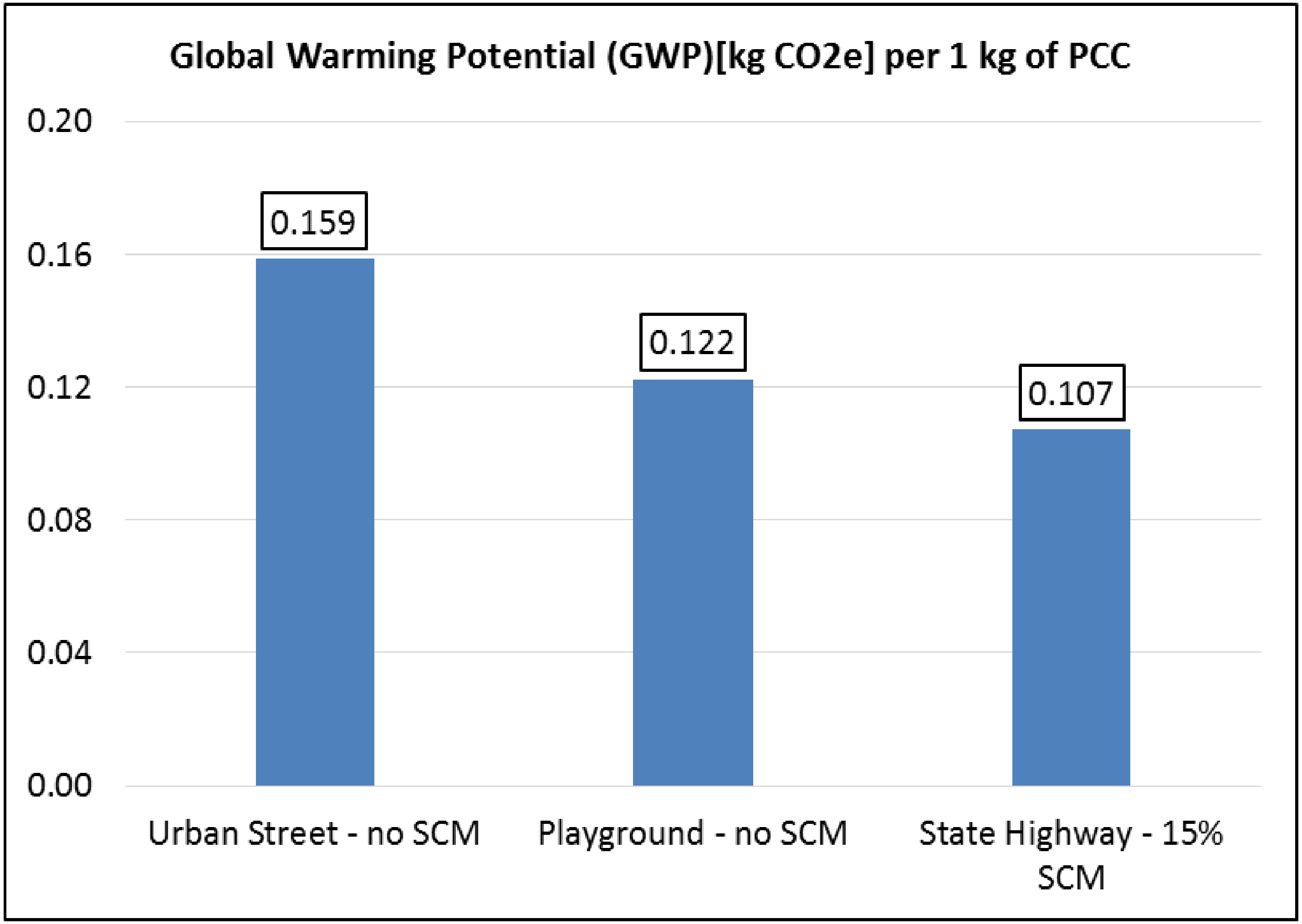
- Older concrete specifications
  - Written to ensure enough cement to meet strength and durability requirements
  - Often included minimum cement content
- Modern concrete mix designs
  - Minimize need for portland cement
  - Replace with supplementary cementitious materials (SCM
  - Minimize amount of cement paste in the mix:
    dense aggregate gradations

Concrete mix specifications

- What are SCMs?
  - Fly ash, natural pozzolans, slag cement
  - These can come pre-blended (new ASTM specs)
  - Caltrans also allows 5% replacement with ground limestone
    - Agencies are evaluating up to 15%
- These changes to mix design specs
  - Decrease cost
  - Decrease environmental impact
  - Increase durability of the concrete
- When was the last time you reviewed your concrete specifications?

Effects on greenhouse gas emissions

- Mix designs from a city that hasn't reviewed specs and Caltrans



What you need to do

- *Use dense aggregate gradations:* Reduces cost, shrinkage
- *Specify limits on shrinkage and strength:* Reduces water contents
- *Require quality control and quality assurance testing for strength, shrinkage, other properties of interest.* Small cost for sampling and testing
- *Require use of supplementary cementitious materials.* Tend to reduce shrinkage, improve durability, reduce greenhouse gas emissions, may reduce cost
- *Allow the use of blended cements (ASTM C595)*
- *Work with a concrete mix design expert to review your specifications and change them*

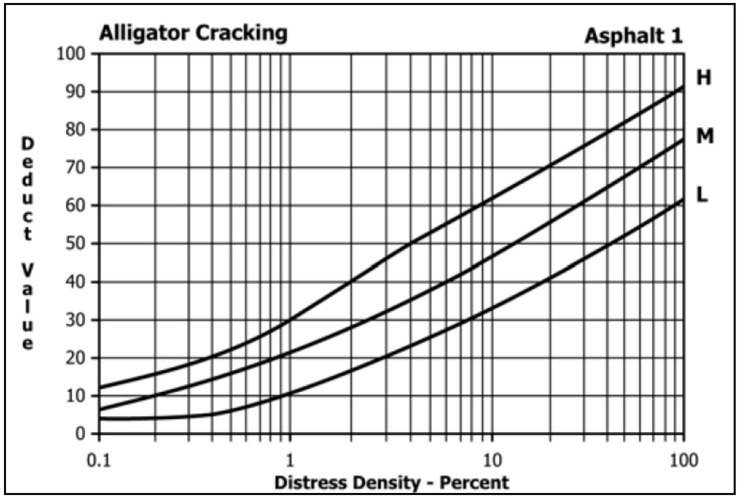
But what about?

- How do I know that these mixes will give me good performance?
- Will these changes in specifications cost me more?
- Are there any other issues such as constructability with these mixes?

Image: robert's ready mix www.rrmca.com/

Pavement management
Use of PCI vs measured cracking, rutting

- PCI is amalgamation of different distresses
- Can have same PCI for very different conditions
- Engineering meaning in the condition survey is lost



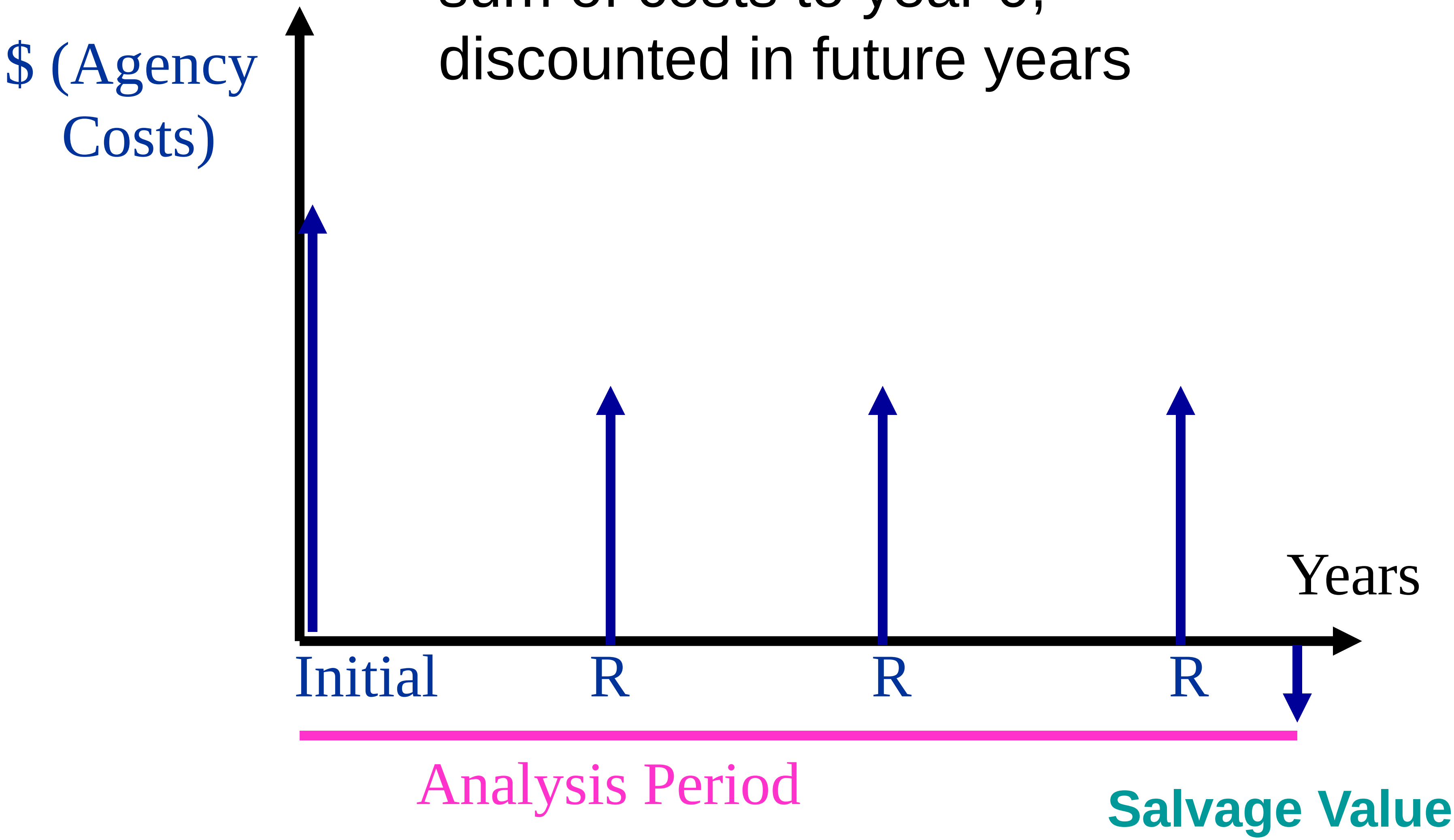
- Recommend
  - Use PCI as communication tool for management/public
  - Manage asphalt pavement considering:
    - Cracking type (traffic related wheelpath cracks, aging/shrinkage related out of wheelpath cracks)
    - Other distresses (rutting, raveling)

Same PCI, different pavement condition

CASE 1: TRAFFIC LOADING RELATED, PCI = 34			
DISTRESS	SEVERITY	QUANTITY	DV
Alligator Cracks	High	1x6	18
Alligator Cracks	Medium	1x4 1x5 1x7	17
Potholes	Medium	3	48
Potholes	Low	3	30
Rutting	Low	2x5 2x8	10
CASE 2: AGE, CONSTRUCTION, UTILITIES, OTHER FACTORS, PCI = 32			
Long/Trans Crack	High	15 20 8 6 12 18 6x7	43
Long/Trans Crack	Medium	25x2 18 13 9 10	20
Patching/Utility	High	25x4 25x2	40
Patching/Utility	Medium	12x6 4x7	20
Block Cracks	High	4x6 6x5	13

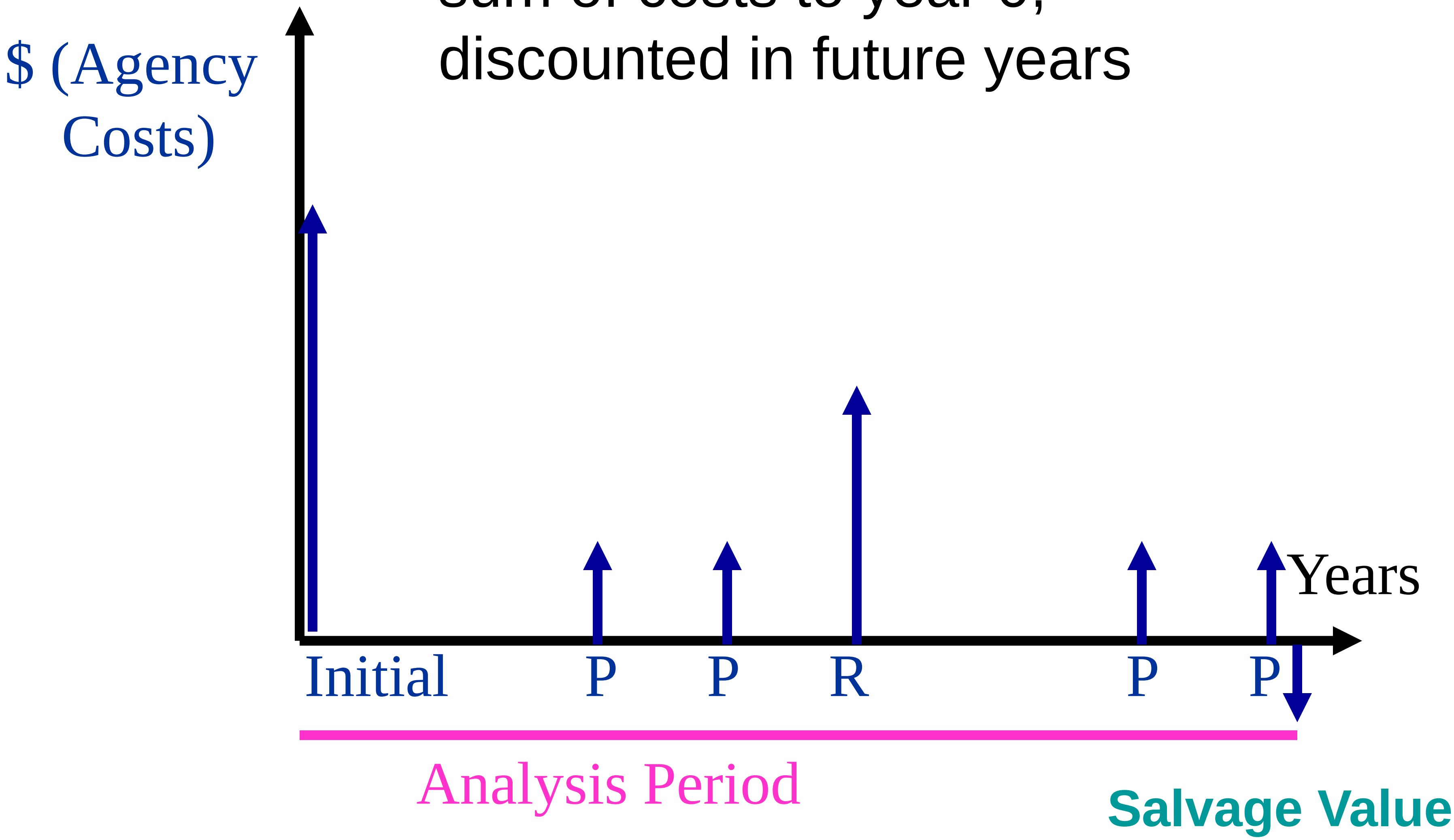
Pavement management
Rehab with no preservation

- Net present value = sum of costs to year 0, discounted in future years



Pavement management
Rehab with preservation

- Net present value = sum of costs to year 0, discounted in future years



LCCA results Urban examples

Activity	$/sy	Year
HMA 2 inch mill and fill	38	0
HMA 2 inch mill and fill	38	20
HMA 2 inch mill and fill	38	40

Activity	$/sy	Year
HMA 2 inch mill and fill	52	0
Remove, replace 6 inches HMA	52	25

Activity	$/sy	Year
HMA 2 inch mill and fill	38	0
Slurry seal	7	12
Slurry seal	7	19
Slurry seal	7	26
HMA 2 inch mill and fill	38	33
Slurry seal	7	45

- 50 year analysis, 2% discount rate
- Remove and replace scenario 14% more cost
- Preservation scenario 12% less cost; 8% less GHG

What you need to do

- Pavement management
  - Do engineering work based on truck traffic level, cracking and surface defects data, not PCI
  - Use your costs and LCCA to develop best treatment practice and preservation timing
    - Need performance models
    - Requires condition survey, traffic and as-built data
  - Learn to use LCCA to discuss preservation spending with council/board

How Industry Communicates Environmental Impact: Environmental Product Declaration (EPD)

- **California High Speed Rail requiring EPDs**
- **Pilot Caltrans program for requiring EPDs for concrete, asphalt, steel expected in 2018**

Adapted from Pavement Interactive

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

Why would you ask for EPDs? And steps towards using them

- Concrete and asphalt producers in California are ready to deliver EPDs at low cost
  - Through NRMCA and NAPA
  - Preservation treatments soon
- 1-2 years, ask for EPDs for information only
  - Provides reporting data for your use of pavement materials
  - Focuses contractors on their own operations
- 3-5 years, begin to use data in engineering
  - Use results in design to reduce enviromental impacts
- Beyond 3-5 years
  - Use to select materials or set impact thresholds?

HEAT ISLAND GROUP

Life-Cycle Assessment and Co-benefits of Cool Pavements

Lawrence Berkeley National Laboratory

University of California – Davis

University of Southern California

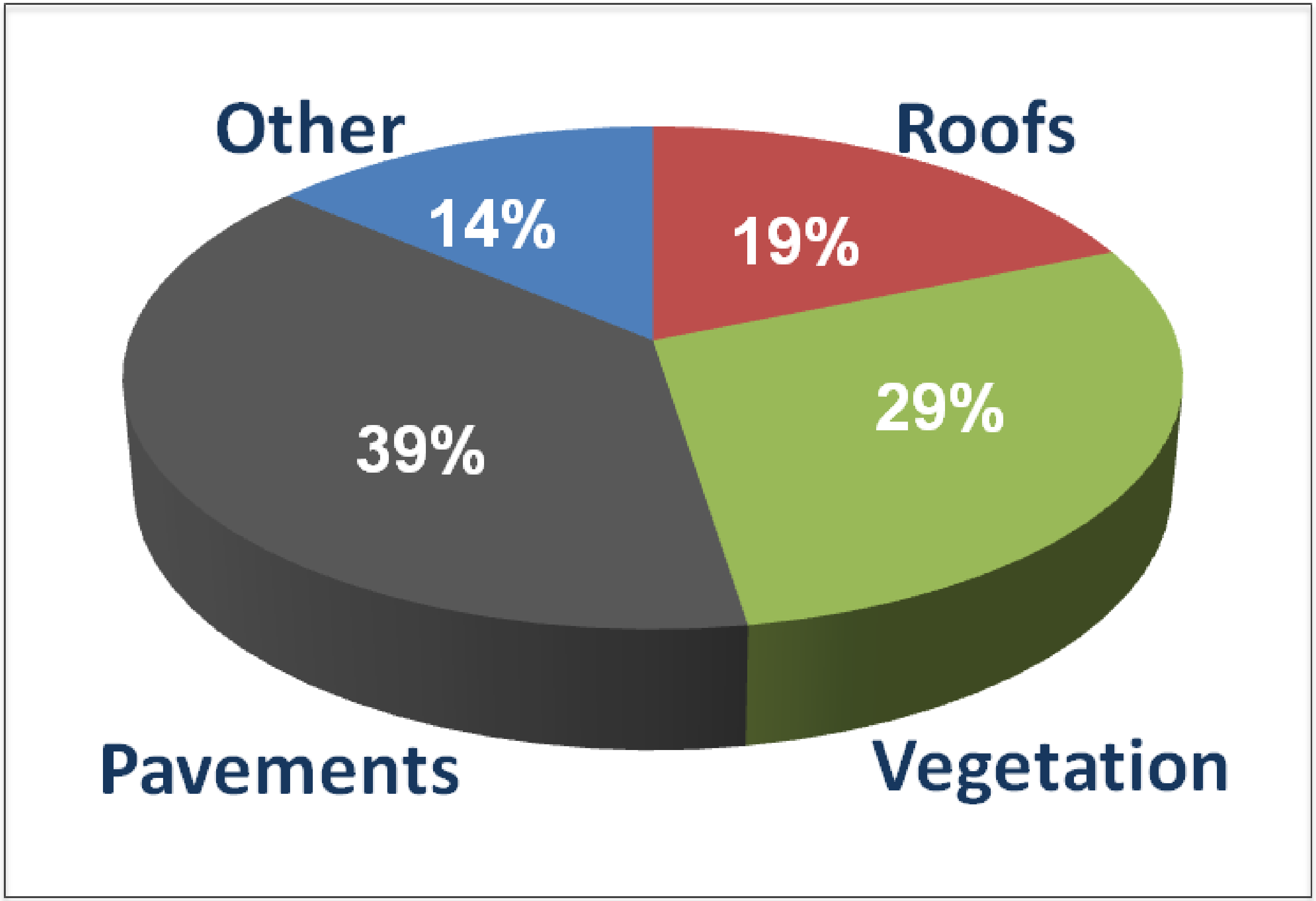
thinkstep, Inc.

ARB Research Seminar

May 3, 2017

Sacramento, CA

Pavements are an important part of the urban environment

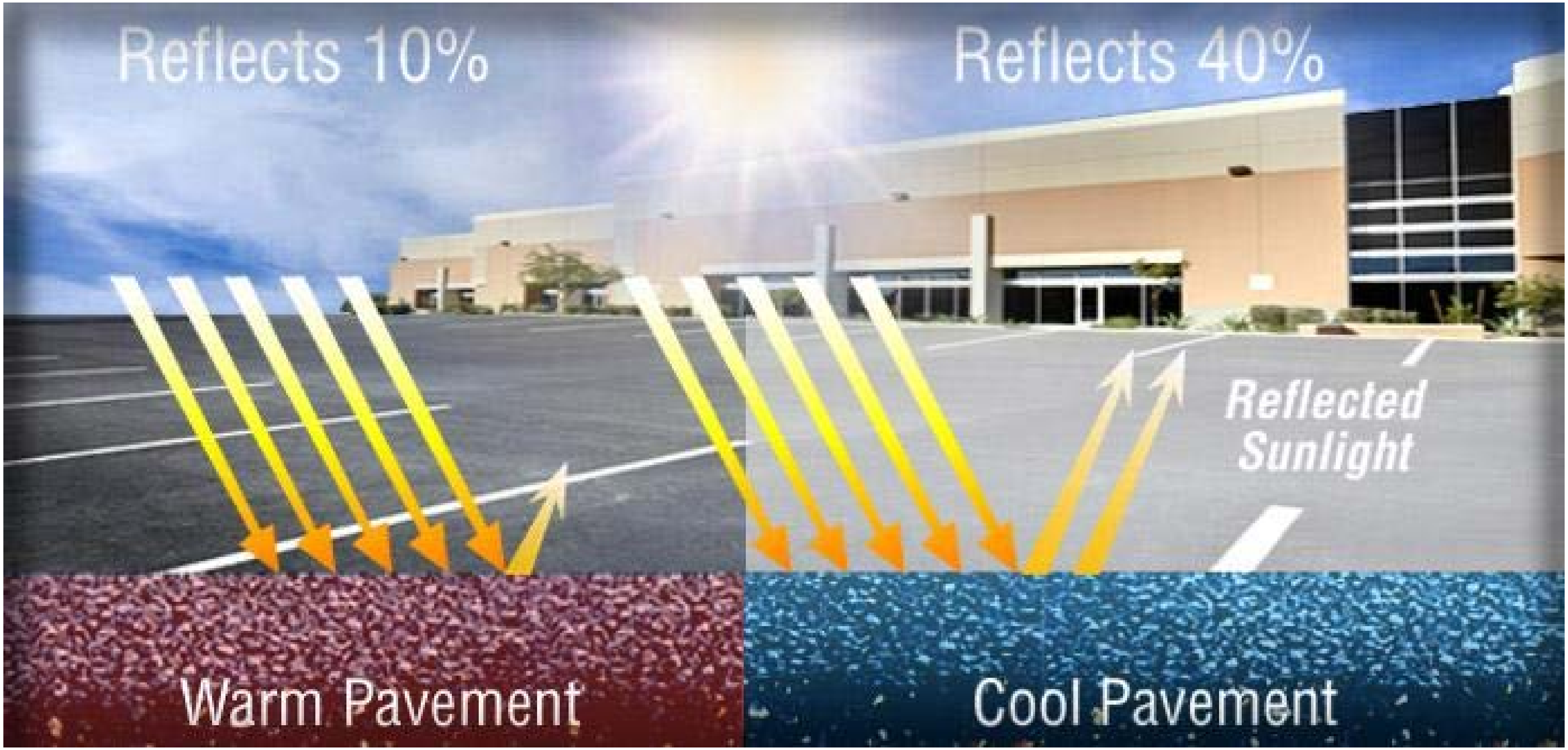


Sacramento

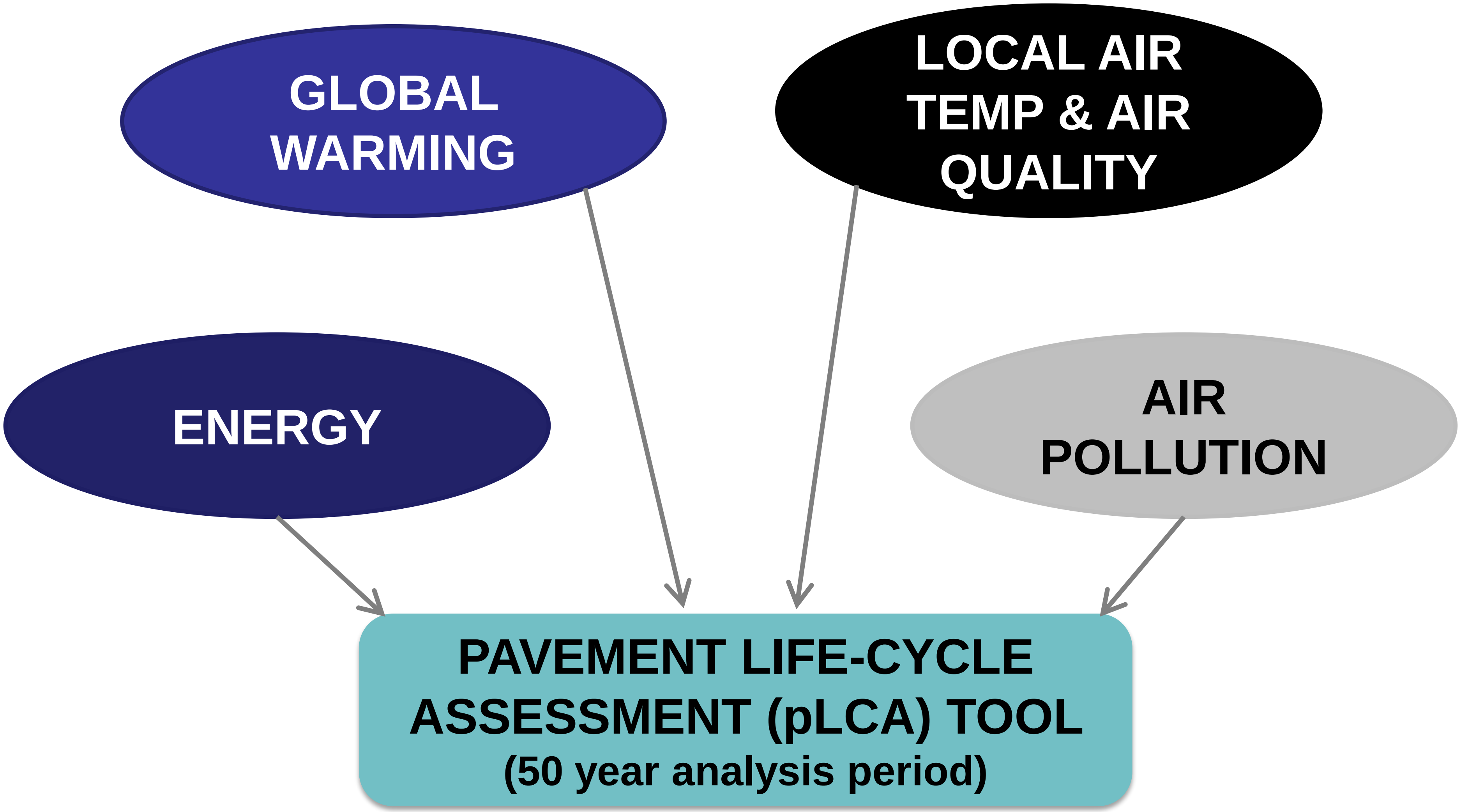
Fractions of land area were measured above tree canopy

Akbari et al. 2003 <doi:10.1016/S01692046(02)00165-2>

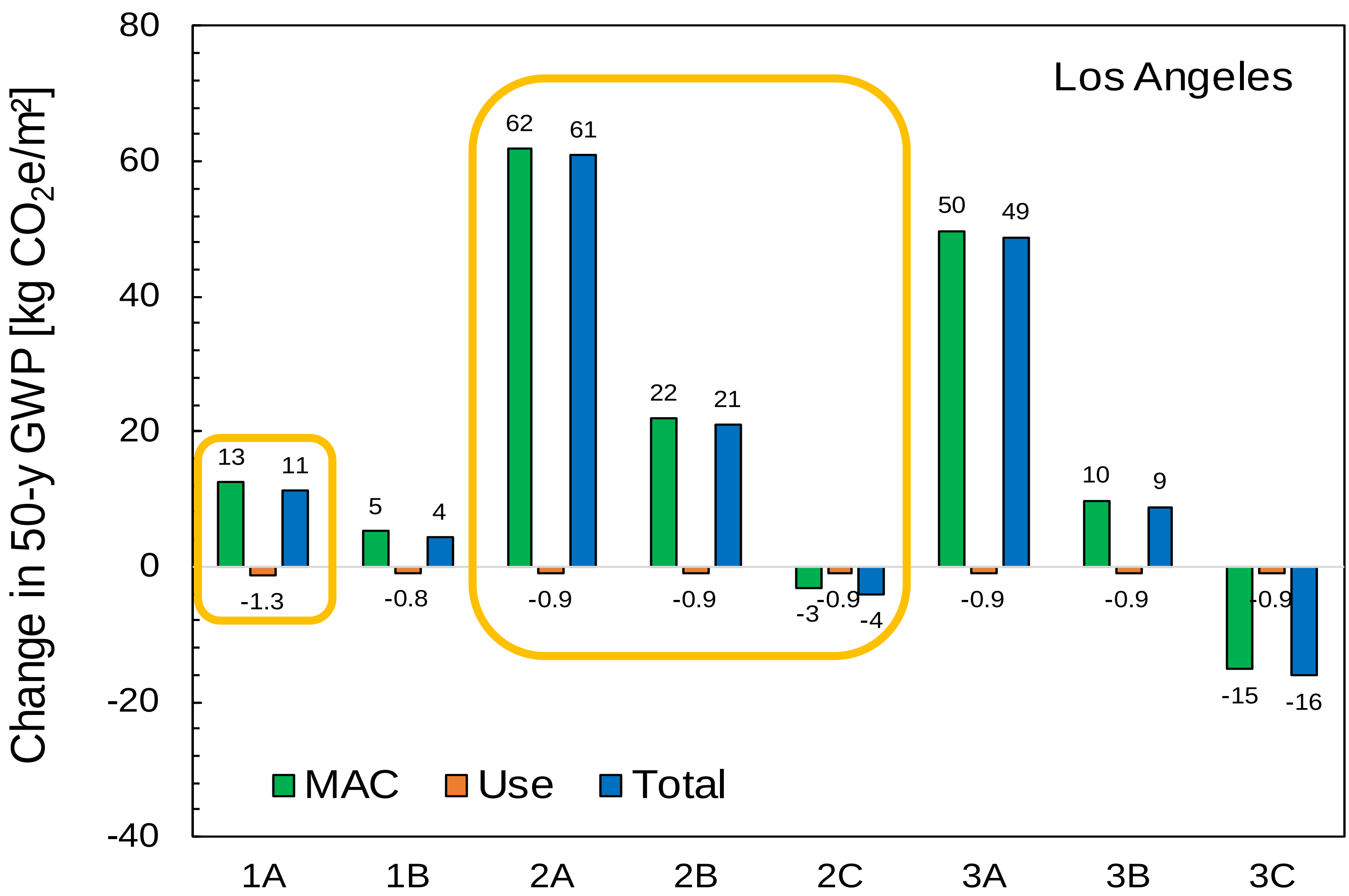
Pavements can contribute to urban heat islands but can be designed to stay cooler



Project seeks to advise communities on energy and environmental consequences of "cool" pavements

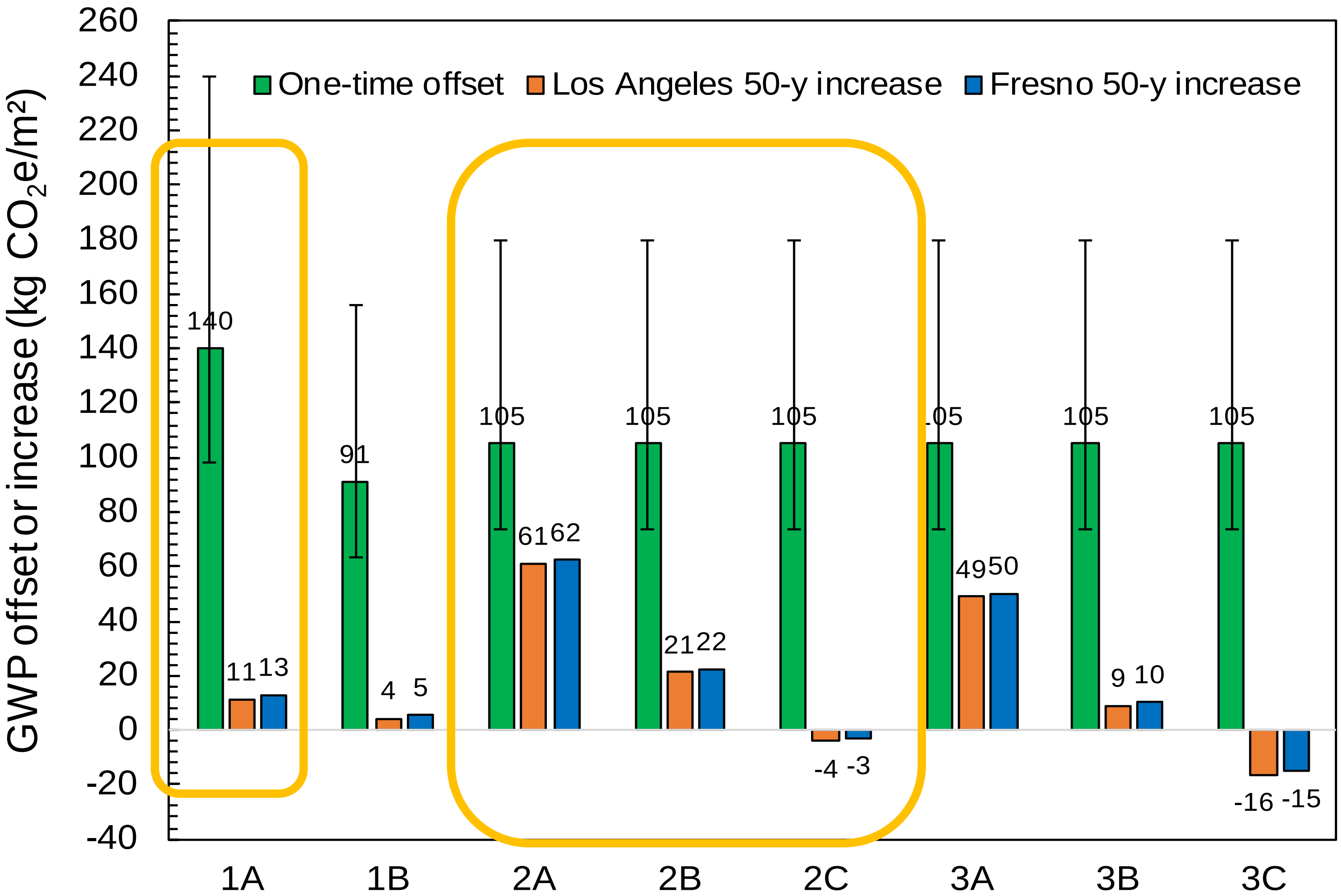


The materials/construction-stage global warming potential changes exceed use-stage changes in LA



1A = slurry seal → reflective coating;
2A, 2B, 2C = mill-and-fill AC → no-, low-, or high-SCM BCOA

The *one-time* GWP offset from global cooling exceeds the changes in 50-y life-cycle GWP; best bang for buck?



IPCC AR5; Akbari et al. 2012 <doi:10.1088/1748-9326/7/2/024004>

1A = slurry seal → reflective coating;
2A, 2B, 2C = mill-and-fill AC → no-, low-, or high-SCM BCOA

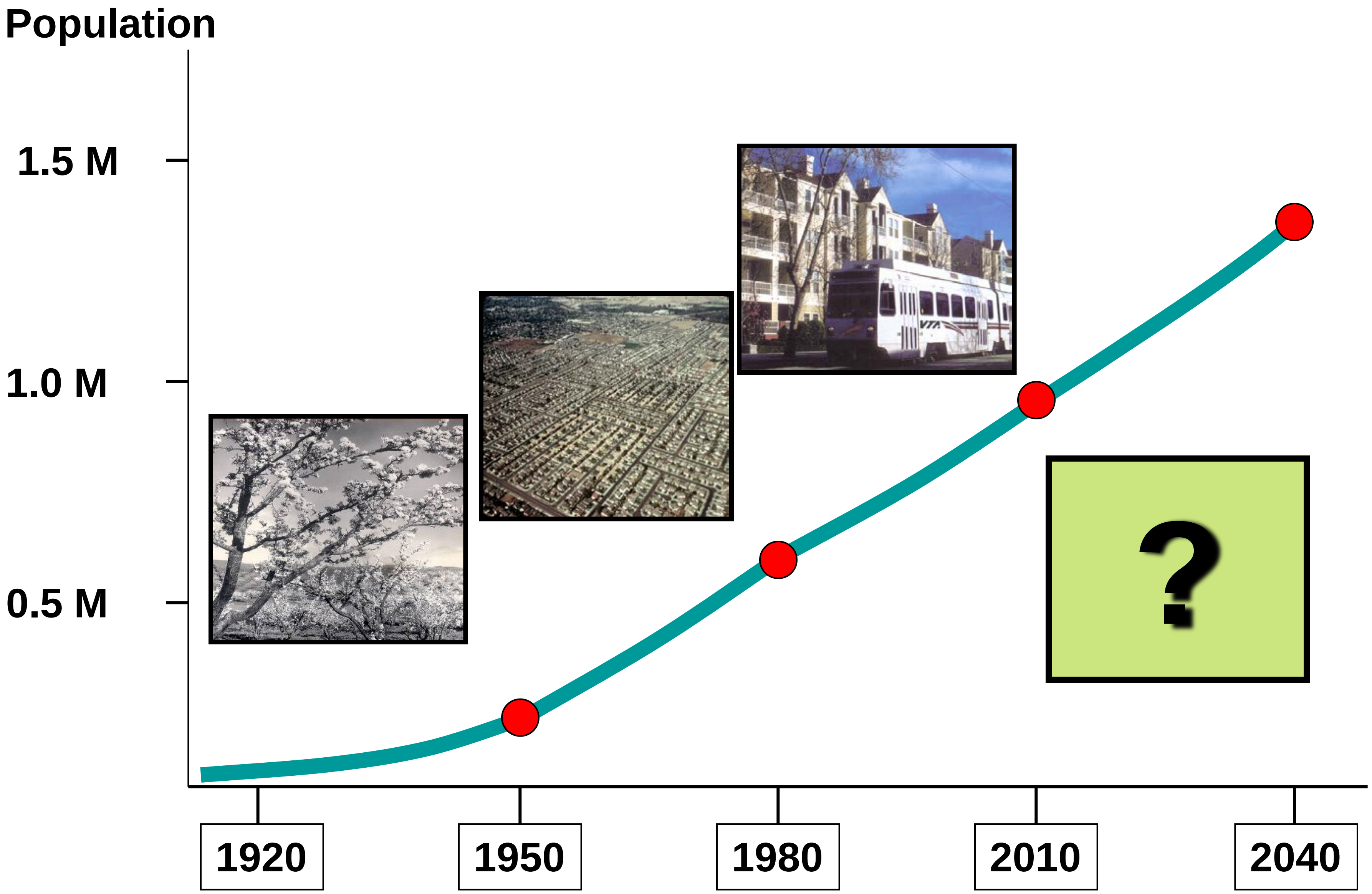
Pavement and Bicycle Ride Quality

- Develop guidelines for Caltrans
  - Design of preservation treatments suitable for bicycle routes on state highways (Phase I) and local streets (Phase II) in California
- Tasks
  - Pavement texture measurements
  - Bicycle vibration measurements
  - Surveys of bicycle ride quality
    - 6 bicycle clubs
    - General public in Davis, Richmond, Chico, Sacramento, Reno
  - Correlate pavement texture, bicycle vibration, ride quality

Conclusions from Bicycle Ride Quality Studies

- Most slurries on city streets produce high acceptability across all cities
- Chip seal spec recommendations in Caltrans report
  - Consider bike riders when selecting seal coat specs
- The presence of distresses, particularly cracking, reduces ride quality

San José Growth History



Development Strategies

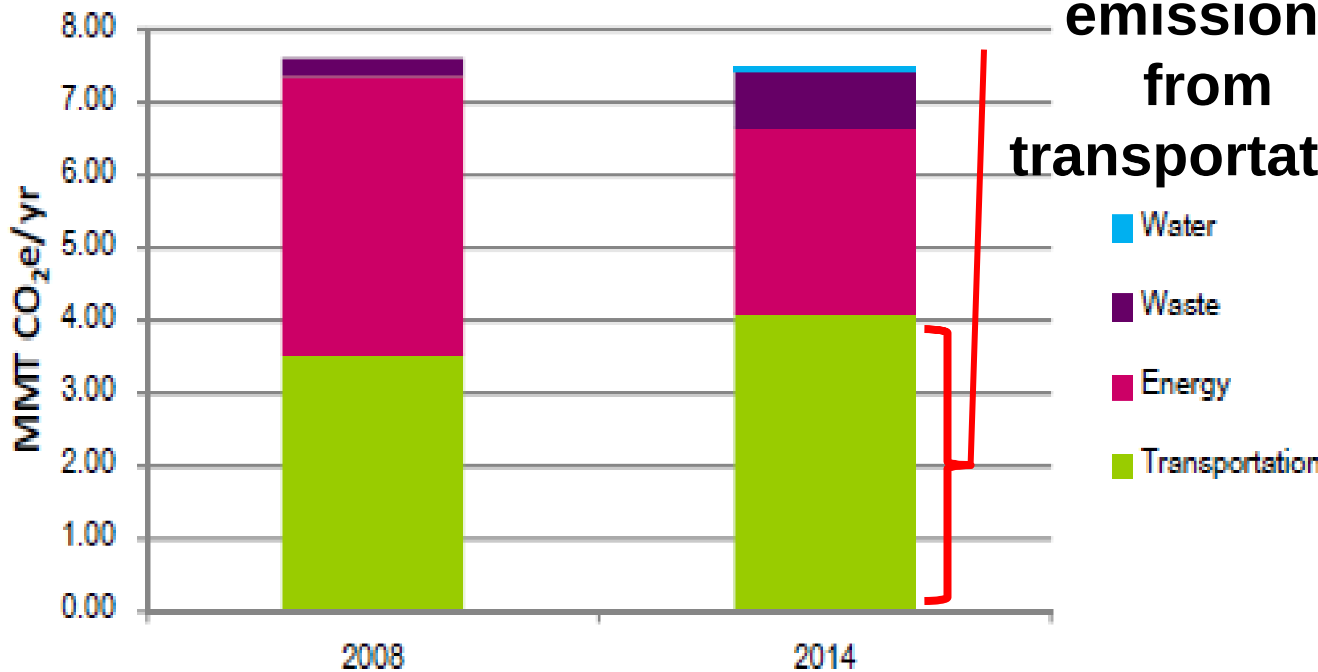
(Land Use and Transportation)

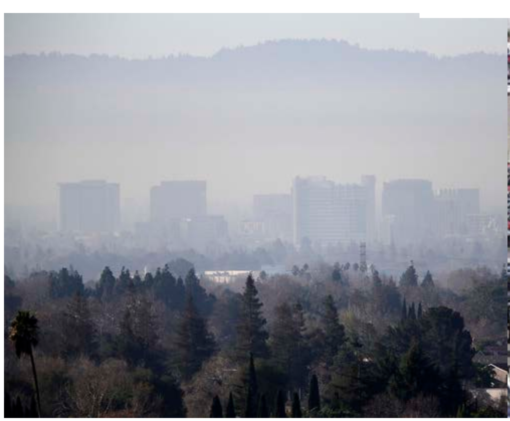
- Balance Jobs/ Housing; Mix Land Uses
- Focus Development Along Transit Corridors
- Provide Safety, Livability, and Transportation Mode Choices
- Prioritize Investments to Support Economic Development
- Promote Efficient Operations and Preserve Infrastructure Conditions

Environmental Leadership

54% of City emissions from transportation

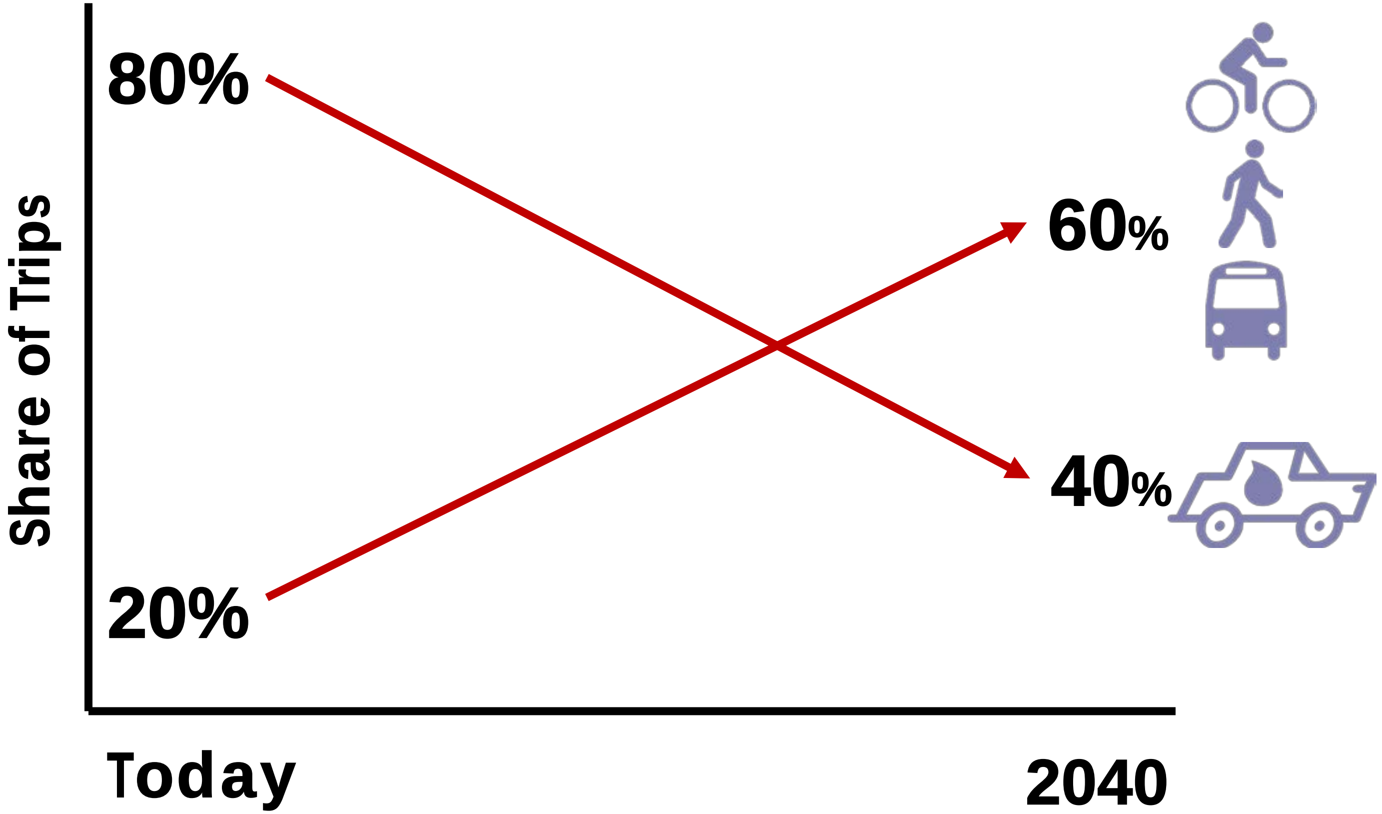
Greenhouse Gas Emissions 2008 and 2014 Community Inventory Comparison





San Jose Environmental Sustainability Plan – On a Pathway to Paris

Mode Shift Goals



Leveraging Pavement Projects

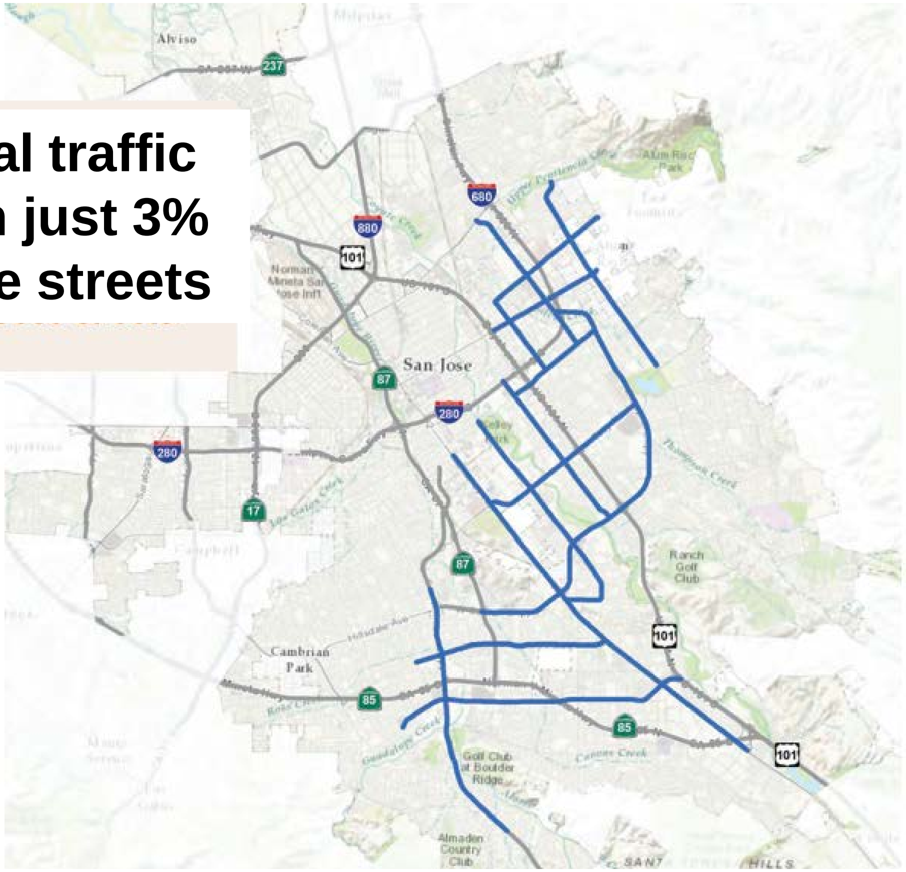
- Promoting Walkability and Livability
  - Green bike lane
  - Buffered bike Lane
  - Protected Bike Lane
- Vision Zero (zero fatal accidents)
  - Road diets, complete street improvements

On-street Bikeway Miles	
2009	200
2014	238
2015 (+21 mi new bike lanes)	259
2016 (+26 mi new on-street)	285
2020	400

Vision Zero (Zero Fatal Accidents)

- Safety Priority Streets
  - 14 corridors
  - Combine pavement projects with other complete street improvements
  - Buffered bike lanes, sidewalk gap closures, road diets

50% of fatal traffic crashes on just 3% of San Jose streets



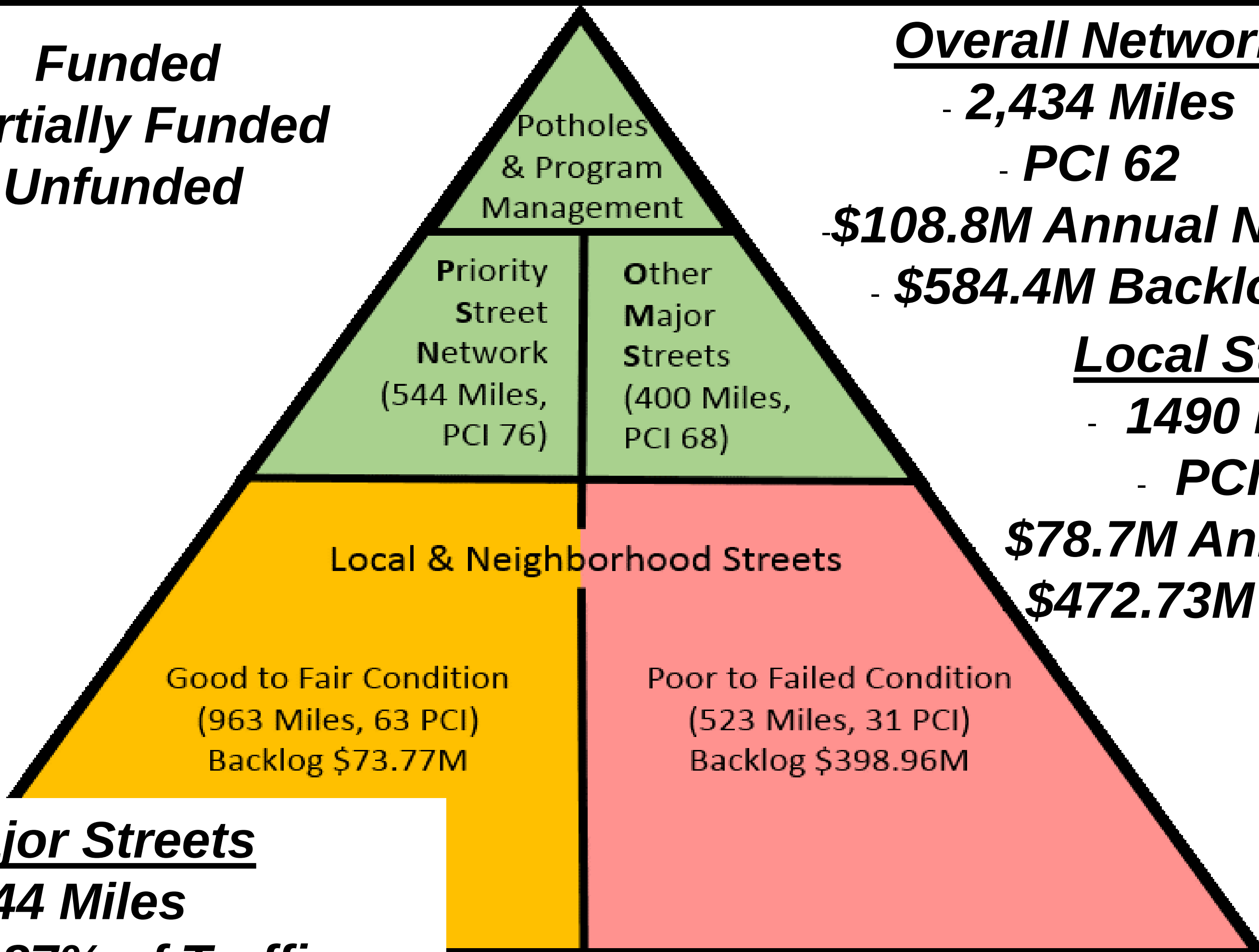
City of San Jose
Pavement Asset Management

- Fully automated pavement data collection system
- Downward and right of way image collection
- Crack mapping and data analytics using IVISION
- Smoothness using IRI (International Roughness Index)
- Other related asset inventory and condition collection (i.e., ADA ramps, signs, markings, traffic signals, and etc.)
- Software tool: StreetSaver and PCI info

Pavement Condition Survey-San Jose

Pavement Needs and Funding

Funded
Partially Funded
Unfunded



<u>Overall Network</u>
- ***2,434 Miles***
- ***PCI 62***
- ***$108.8M Annual Need***
- ***$584.4M Backlog***

<u>Local Streets</u>
- ***1490 Miles***
- ***PCI 54***
- ***$78.7M Annual Need***
- ***$472.73M Backlog***

<u>All Major Streets</u>
- ***944 Miles***
- ***Carries 87% of Traffic***
- ***PCI 73***
- ***$23.9M Annual Need***
- ***$111.68M Backlog***

“Grading” San Jose Street Conditions

Major Streets (944 miles; PCI 73)		Local Streets (1490 miles; PCI 54)	
A, B — Good to Excellent	67%	A, B — Good to Excellent	25%
C — At Risk to Fair	25%	C — At Risk to Fair	40%
D, F — Poor to Failed	8 %	D, F — Poor or Failed	35%

“Grades” based on 2016 PCI Ratings

Network Summary

- Condition of Major Streets has stabilized to overall "good" (PCI 73)
  - Over 300 lane miles to be completed in 2017
  - Ongoing funding sufficient to properly maintain major streets
  - Driving the completion of Bike Plan 2020
- Over 625 lane miles of streets including neighborhood streets in 2018

City of San Jose
Asphalt Compaction

- Standard QC/QA specification for resurfacing projects (thickness is at least 0.15 foot)
- Contractor is required to submit a QC plan and do nuclear density in the field
- Process:
  - Contractor takes the density cores (every 250 tons)
  - City determines the percent of maximum theoretical density
  - Contractor agrees to use the Gmm that City provides
  - Reduced payment factor: densities between 89-91 and 97-99 percent of maximum theoretical density. Remove and replace <89 and >99

Reduced Payment Factrors

HMA Type A percent of maximum theoretical density	Reduced payment factor	HMA Type A percent of maximum theoretical density	Reduced payment factor
91.0	0.0000	97.0	0.0000
90.9	0.0125	97.1	0.0125
90.8	0.0250	97.2	0.0250
90.7	0.0375	97.3	0.0375
90.6	0.0500	97.4	0.0500
90.5	0.0625	97.5	0.0625
90.4	0.0750	97.6	0.0750
90.3	0.0875	97.7	0.0875
90.2	0.1000	97.8	0.1000
90.1	0.1125	97.9	0.1125
90.0	0.1250	98.0	0.1250
89.9	0.1375	98.1	0.1375
89.8	0.1500	98.2	0.1500
89.7	0.1625	98.3	0.1625
89.6	0.1750	98.4	0.1750
89.5	0.1875	98.5	0.1875
89.4	0.2000	98.6	0.2000
89.3	0.2125	98.7	0.2125
89.2	0.2250	98.8	0.2250
89.1	0.2375	98.9	0.2375
89.0	0.2500	99.0	0.2500
< 89.0	Remove and replace	> 99.0	Remove and replace

City of San Jose
Asphalt Compaction

- QC/QA Compaction specifications
  - Used on all HMA and Rubberized HMA layers greater than 0.15 feet in thickness
  - Has not seen any bid price cost increases both for HMA and RHMA
  - Holds both contractor and agency accountable for a quality in-place material
  - Longer life cycle

Image: rginc.com

RHMA Construction

City of San Jose
Pavement Management Use of PCI

- PCI does not tell you the whole story. Only used in planning phase:
  - PCI > 90: do nothing
  - 70<PCI<90: Pavement Preservation
  - 40<PCI<70: Pavement Rehab
  - 0<PCI<40: Capital Rehab/Reconstruction

Image: mercurynews.com

City of San Jose
Pavement Design and Evaluation

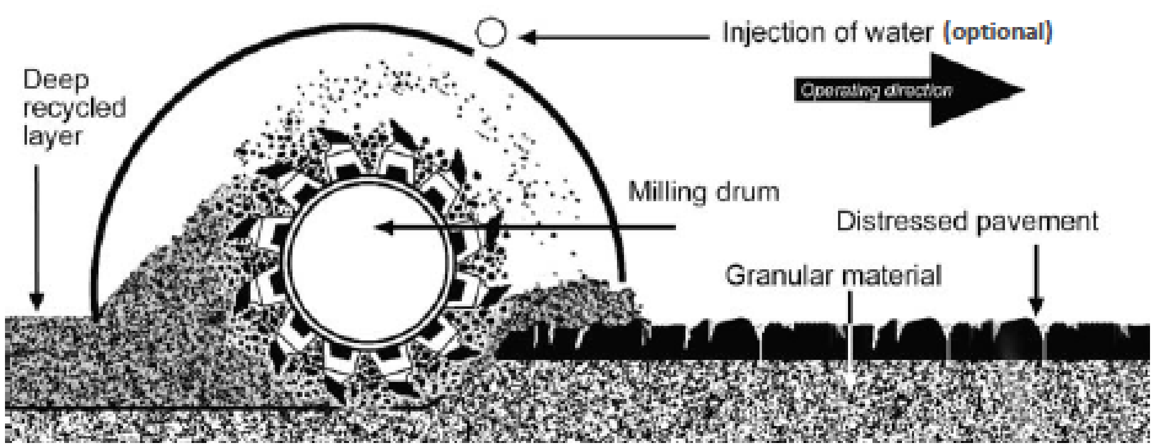
- For Streets less than PCI of 70
  - Conduct a field review by a pavement expert
  - Generate a cracking map of the segments using collected automated condition Surveys
  - Cracked area > 15% of the total area: consider Cold-in-place recycling
  - Conduct non-destructive deflection testing to evaluate structural integrity
  - Compare and contrast treatment options using LCCA

Cold-in-Place Recycling (Foam Technology)

- Have been using CIR since 2011
- CIR depth between 4 to 6 inches
- Sections get overlaid with an RHMA overlay
  - 1.5 to 2.5 inches depending on the design results
- Sections constructed in 2011 have not shown any signs of premature distresses or failures
- Provides a smooth final ride quality
- Our spec: Reduced payment factor on in-place compaction and soaked indirect tensile strength (IDTS)

Image: grcinc.com

Cold-In-Place Recycling (Foam Technology)



Note: depending on the in-situ moisture content, water may be injected in the mixing drum during pulverization.

Local & Neighborhood Streets - Examples

Clemence Ave: PCI 74, 2011 Cape Seal

Florence Ave: PCI 51, 2004 Chip Seal

Idaho St: PCI 46, 1998 Chip Seal

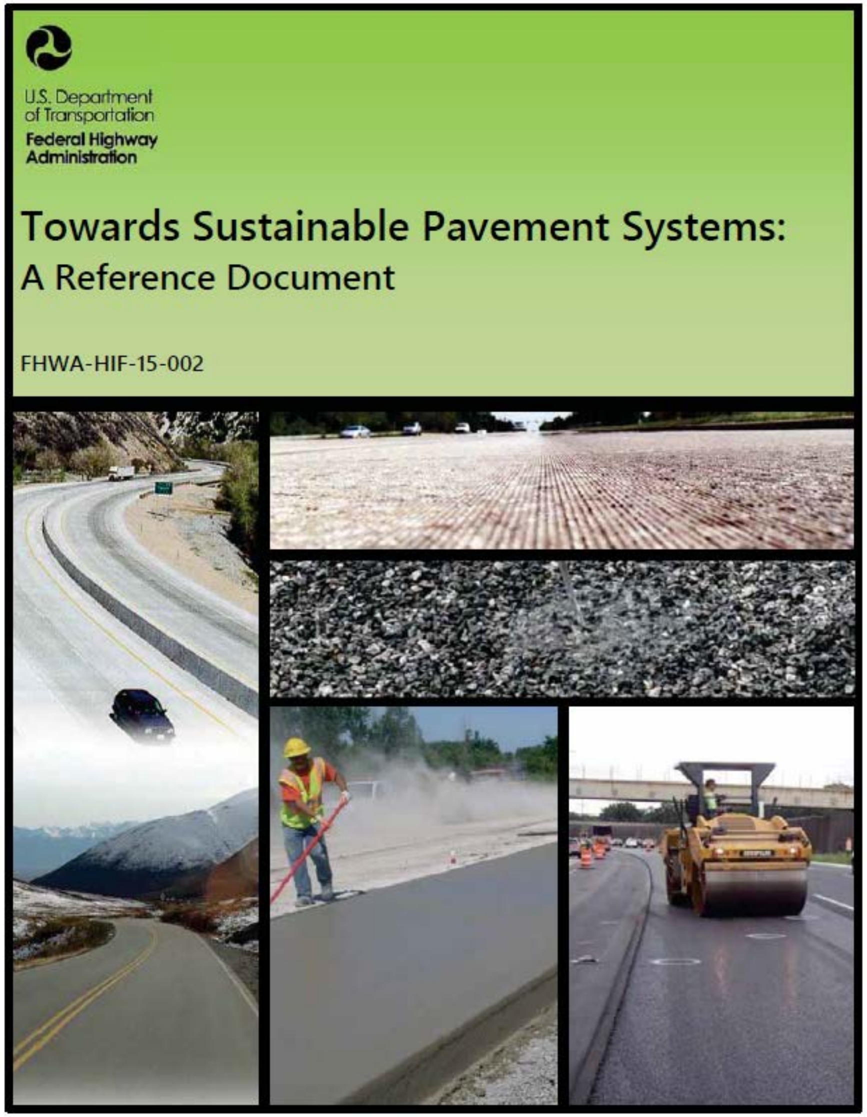
Las Plumas Ave: PCI 37, 1991 Chip Seal

City of San Jose
ADA Ramp Construction

- Average of 1,000 ADA ramps constructed annually combined with pavement projects
- Have not checked concrete mix spec

FHWA Pavement Sustainability Reference Document: Cost and Environment

- State of the knowledge and recommendations on improving pavement sustainability
- Search on “FHWA pavement sustainability”
- Tech briefs at same web site



Final Thoughts: Expectations for Transportation Segment of the Economy

S. David Freeman
UCLA Seminar: Infrastructure Investment for Sustainable Growth (October, 2010)

– Transportation sector about to enter a period of profound change similar to energy sector in 1970s and 1980s
– Regulations will be implemented requiring increasing energy efficiency and environmental performance
– Transformation necessary to maintain economic competitiveness of US
– **We are no longer rich enough to make many mistakes and still be able to achieve our goals**
– **I would add: we need to translate research results into practice, and communicate what we are doing to the public to achieve our goals**

Final Thoughts: Communicating with the Public about Pavement

- What is our message about what is being done that is positive and better
- Livability and Quality of Life, relate to people's lives and wallets/purses
  - Access by different modes, shared prosperity, environmental impact, public participation, safe and healthy communities, wise use of resources
- Set goals and measure and report progress
- Have the right messengers
  - Trusted messengers who are informed about pavement progress, not necessarily pavement engineers!

Thank you, Questions?

- Tech briefs and other information at:
  - www.ucprc.ucdavis.edu/ccpic
- John Harvey
  - University of California Pavement Research Center (Davis, Berkeley)
  - jtharvey@ucdavis.edu
- Frank Farshidi
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