More Sustainable Asphalt Experiences in California: Technologies, Cost and Environmental Impacts

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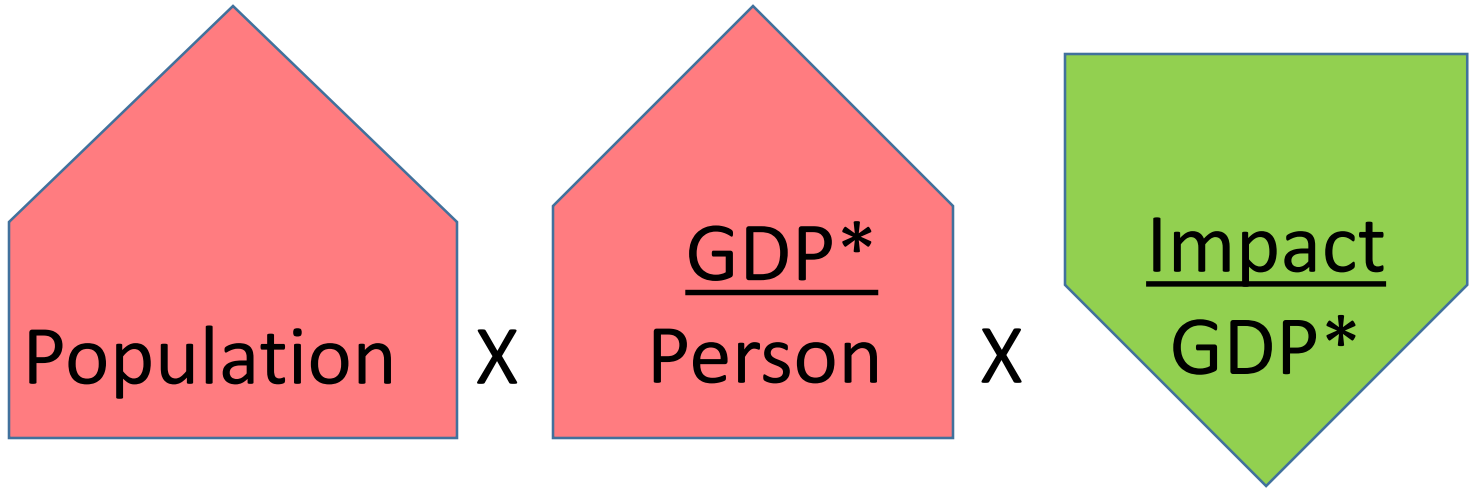
Outline

- Environmental problems and goals
- Legislation
- Implementation of LCA
- LCA and LCCA framework
- Use of RHMA in California
- Management of smoothness for greenhouse gas reductions
- Local government compaction
- EPDs
- Conclusions

Sustainability:
Master equation for environmental impacts

Environmental impact =

*Is GDP the best measure for economic activity producing happiness?



Need enough young people for social stability

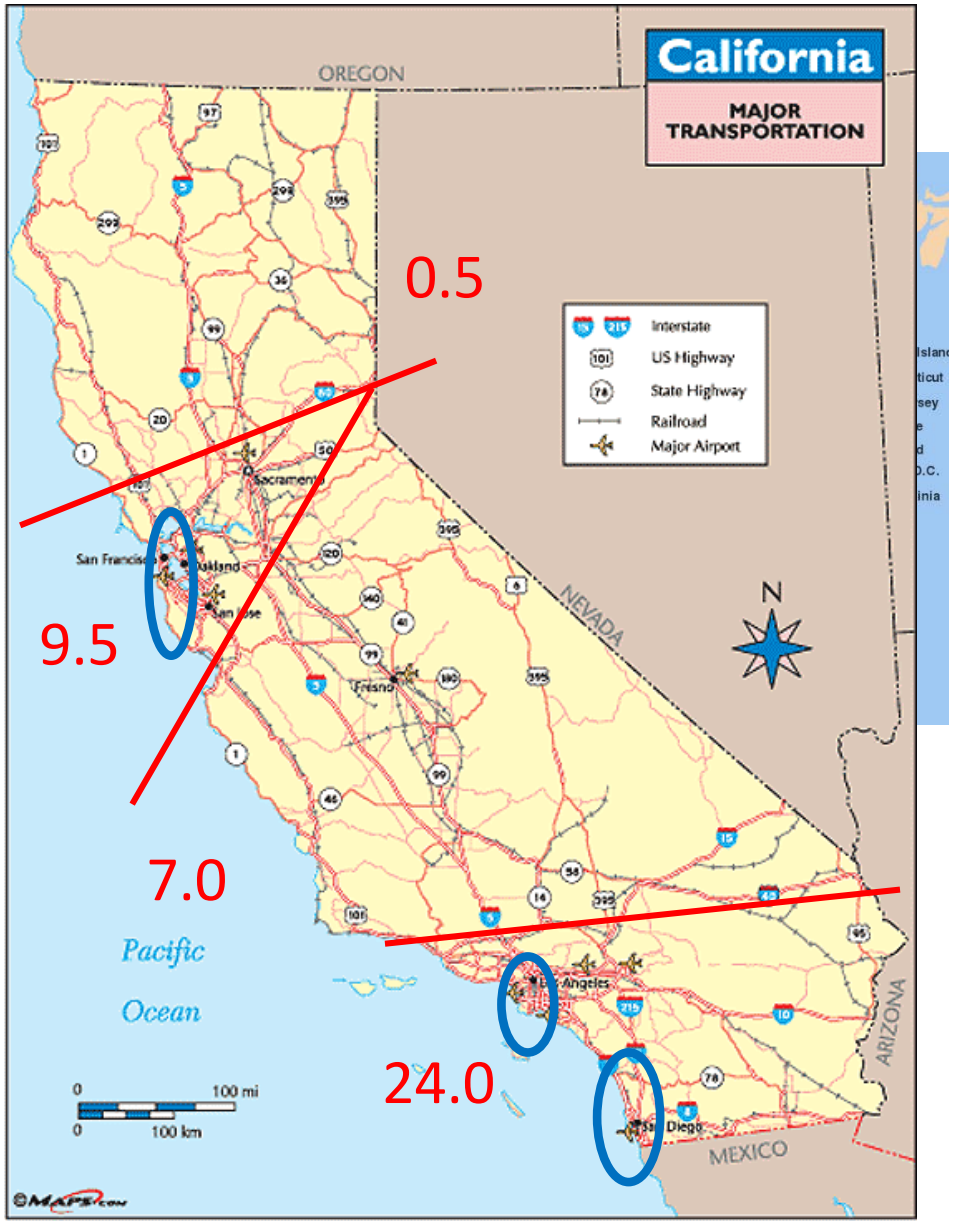
Increase in wealth and economic activity

New technology, organization and implementation

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

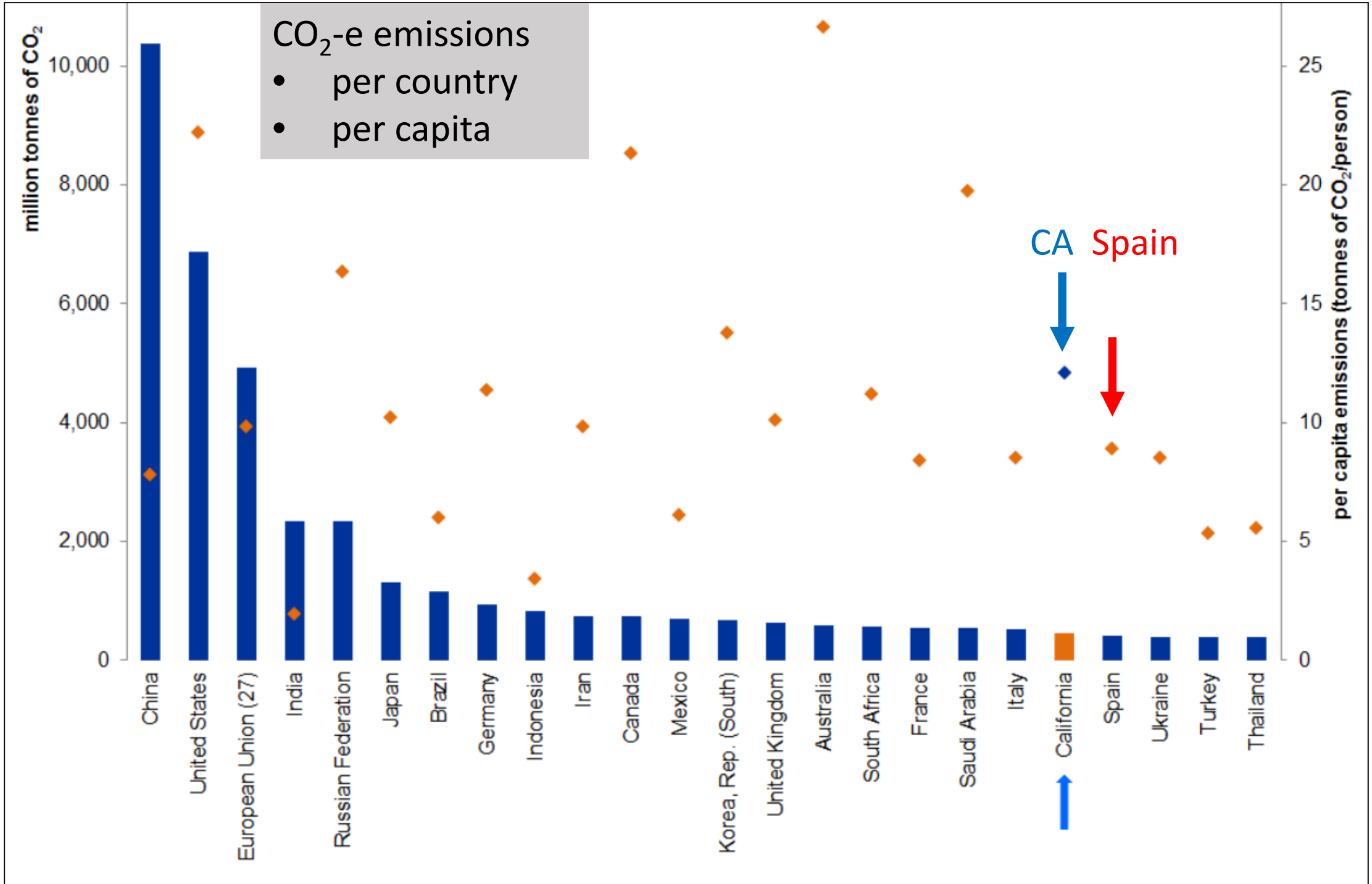
California context

- 40 million people
  - 35th in world
  - 12% percent of US
  - 3 of 10 largest US cities
- 5th largest GDP in the world
  - 14% of US
  - Trade-driven fast growing economy
  - 80,000 lane-km state highways
  - Great inequality of income, standards of living
  - Housing shortages
  - Long distances between housing, jobs, relying on highways for transportation



Primary California Rules and Legislation on GHG

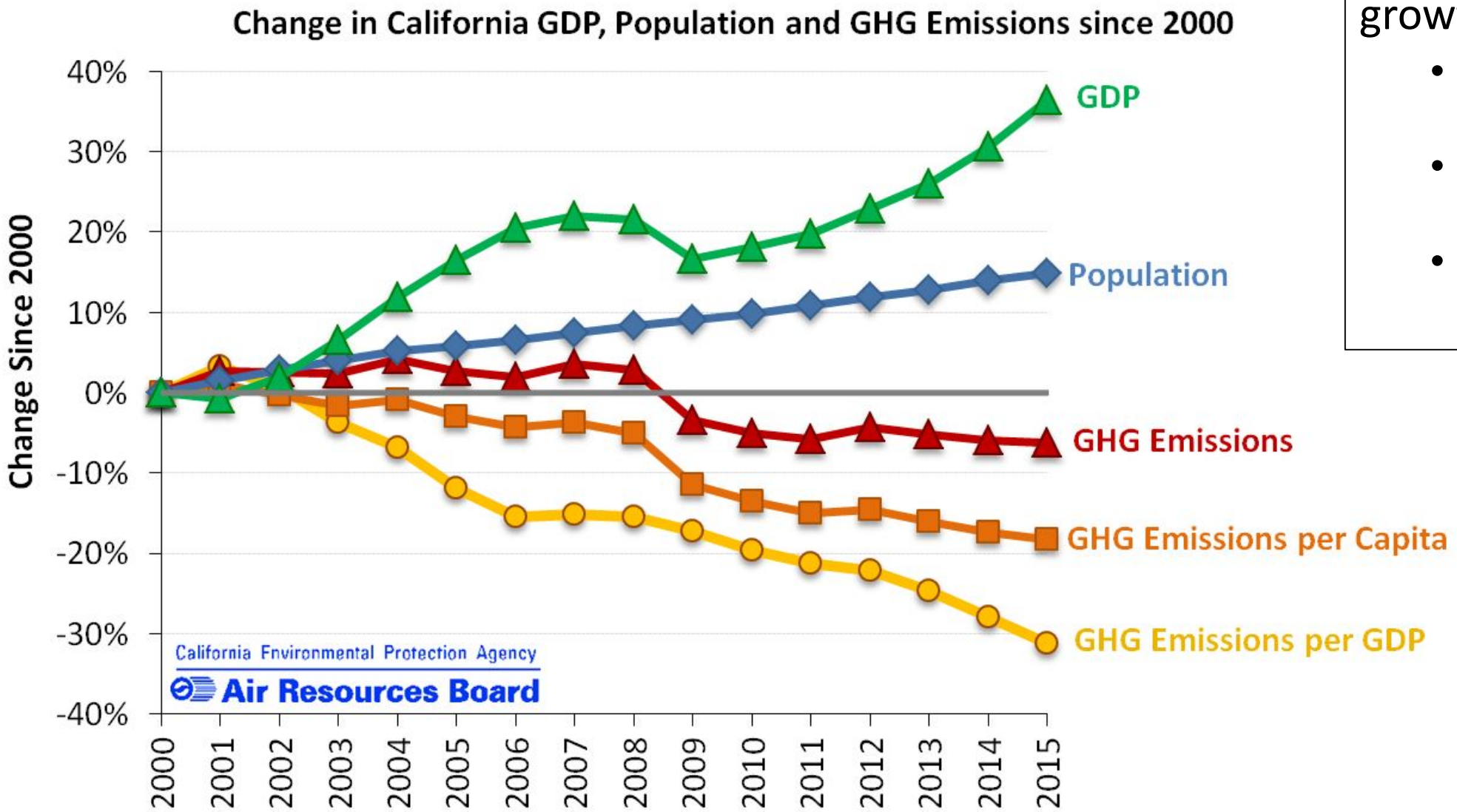
- 2005 Governor's Executive Order S-3-05 requires:
  - Reduction of GHG emissions to 1990 levels by 2020
  - Reduction to 80 percent below 1990 levels by 2050
- 2006 Climate Change Solutions Act (Assembly Bill 32)
  - Made 2020 reductions law
  - State agencies and local governments must help to meet those goals
- 2008 Sustainable Communities and Climate Protection Act (SB 375)
  - Integrates transportation, land use planning, housing to reduce GHG
- 2015 Governor's Executive Order B-30-15 requires:
  - Reduction of GHG to 40 percent below 1990 levels by 2030
- 2016 addition to 2006 Climate Change Solutions Act (Senate Bill 32)
  - Made 40 percent reduction law
- 2018 Executive Order B-55-18 requires:
  - Carbon neutrality for the state by 2045



2012 data

California Air Resources Board report

Climate Change and Economy: How Are We Doing? (2000 to 2015)



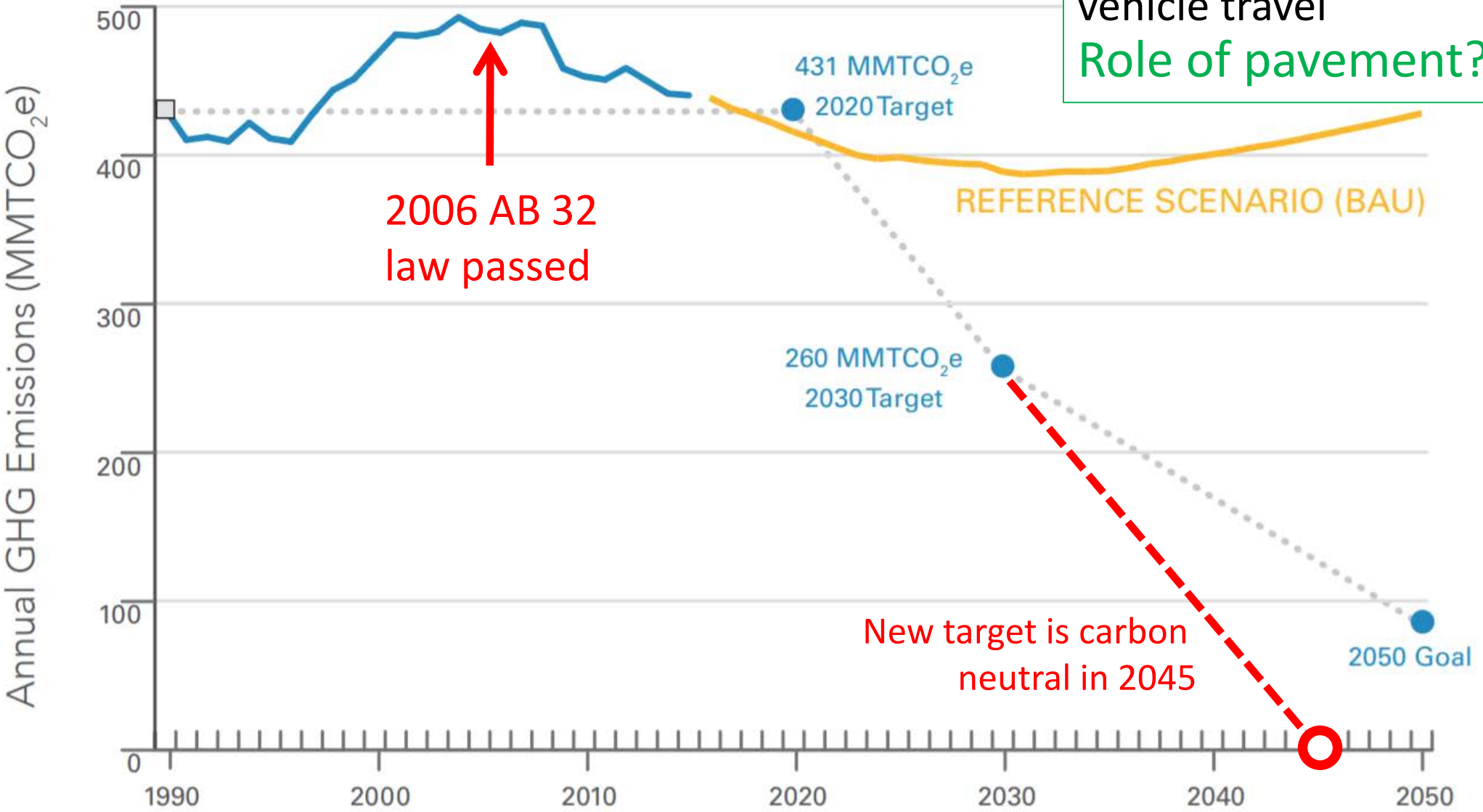
Population growth:

- 2000: 34 million
- 2017: 39 million
- 2055: 50 million

Climate Change Targets and Transportation Strategies (ref 2015)

1. Land use planning; 2. Change trucks and cars to natural gas, electric, fuel cell; 3. Reduce vehicle travel

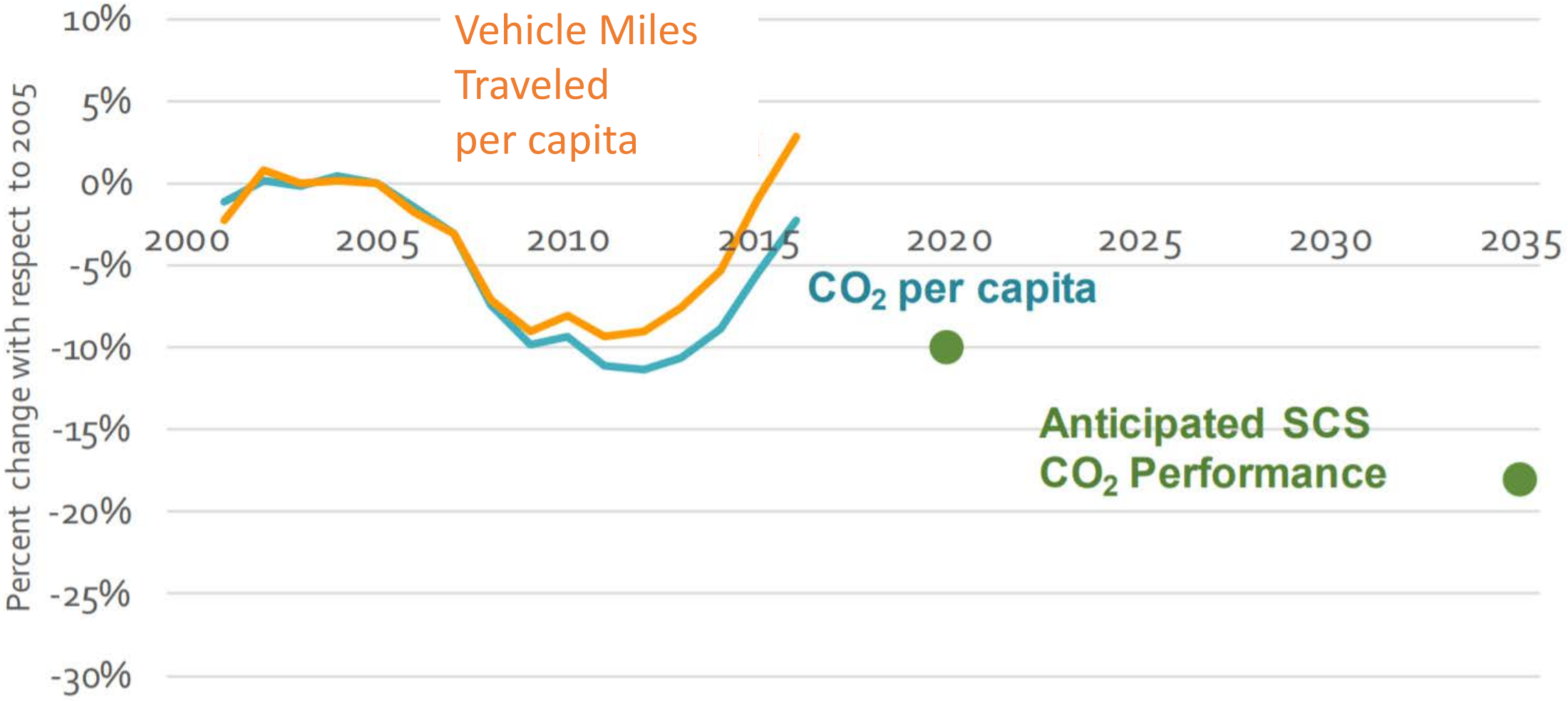
Role of pavement?



https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

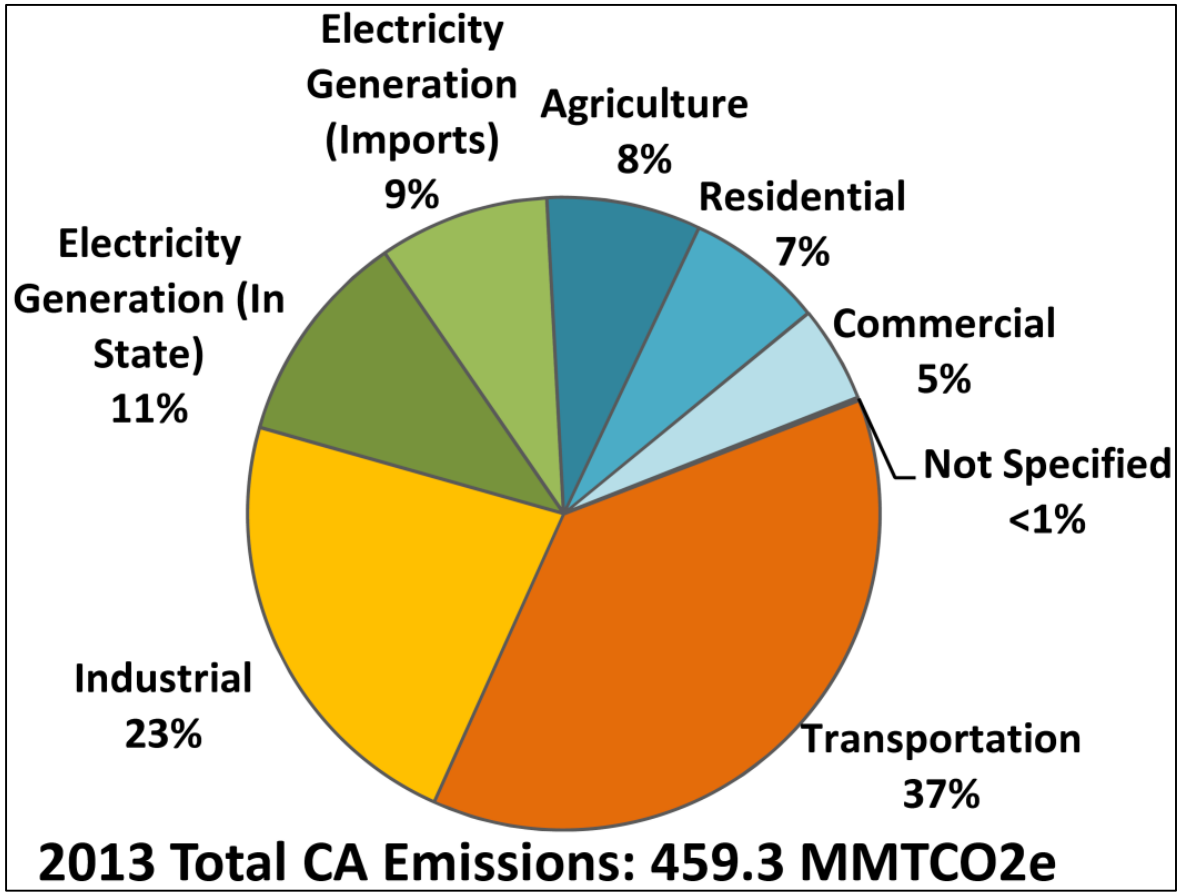
How Are We Doing? New data to 2016

Changes since 2005



Pavement Contributions to 2013 California GHG Emissions

- Out of 459 MMT CO2e
  - On road vehicles 155 MMT
    - Roughness, texture, deflection energy about 1-2% of fuel use
  - Refineries 29 MMT
    - Paving asphalt about 1-2 % of refinery production
  - Cement plants 7 MMT
    - Paving cement about 5-10 % of cement plant production
  - Commercial gas use 13 MMT
    - Very small amounts for asphalt mixing plants
  - Mining 0.2 MMT
    - Mostly aggregate mining



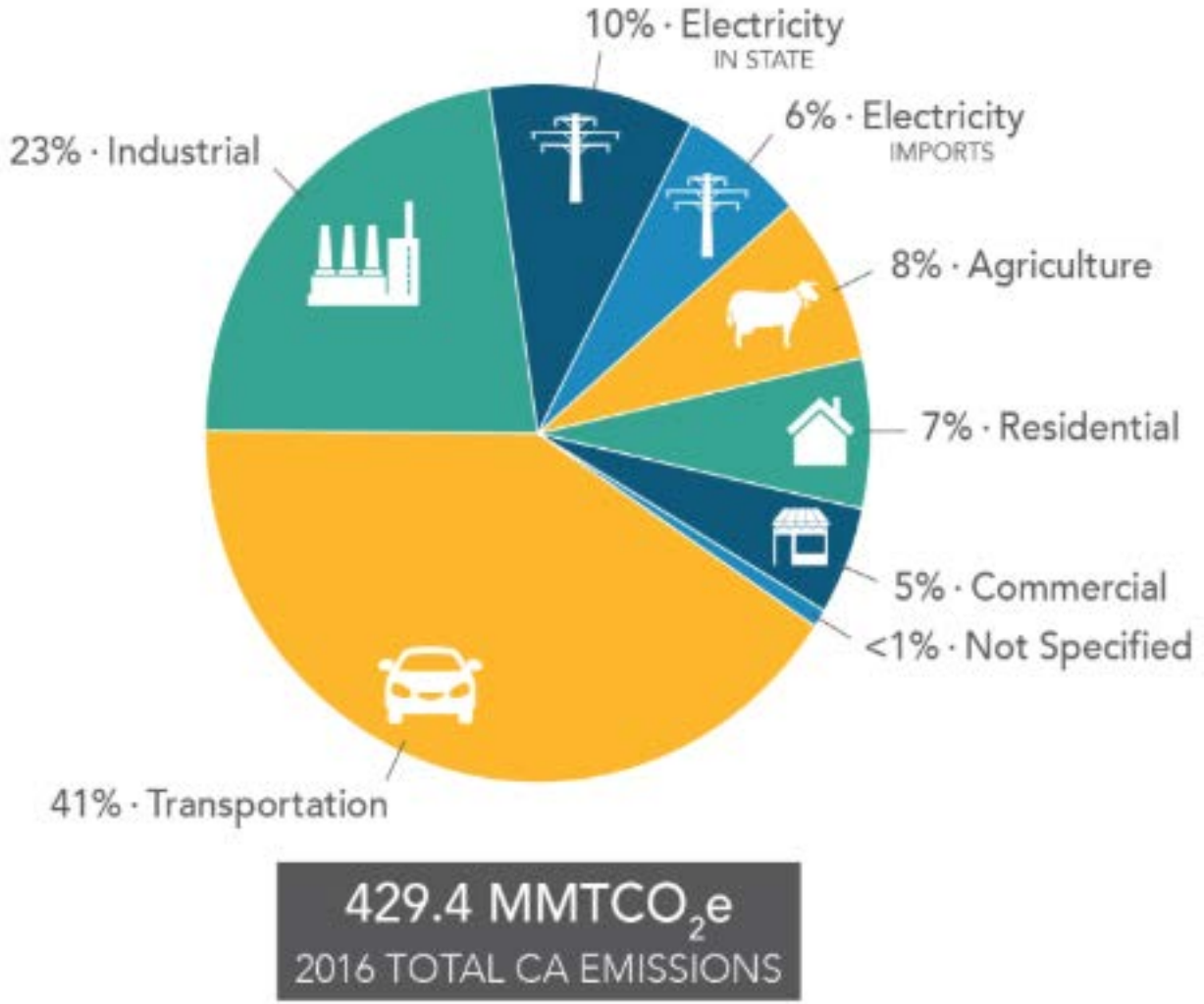
http://www.arb.ca.gov/cc/inventory/data/data.htm

Estimated Potential Pavement-Related Reductions to 2016 California GHG Emissions

Possible Pavement Reductions	MMT/ year
Rolling resist to optimum	1.5 to 3.0
Reduce cement use 50%	0.2
Reduce virgin asphalt use 50%	0.7
Reduce hauling demolition, oil, stone haul 10%	0.6
TOTAL	**3.0 to 4.5**

0.7 to 1.0 % of 429 MMT state total

1.0 to 3.6 % of 126 MMT transportation total



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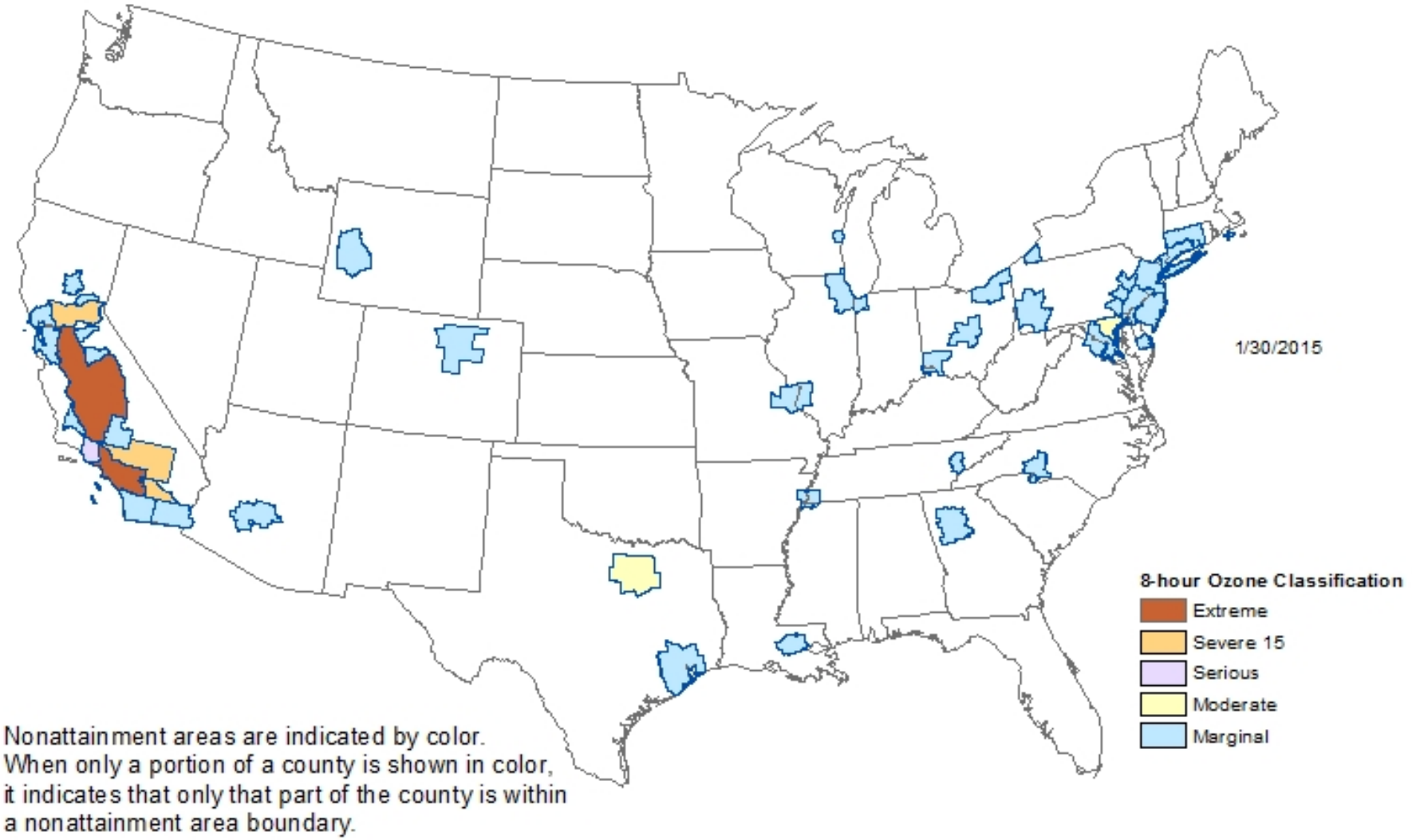
Other types of environmental impact:
8 hour ozone non-attainment by county (2008)



http://www.epa.gov/oaqps001/greenbk/map8hr_2008.html

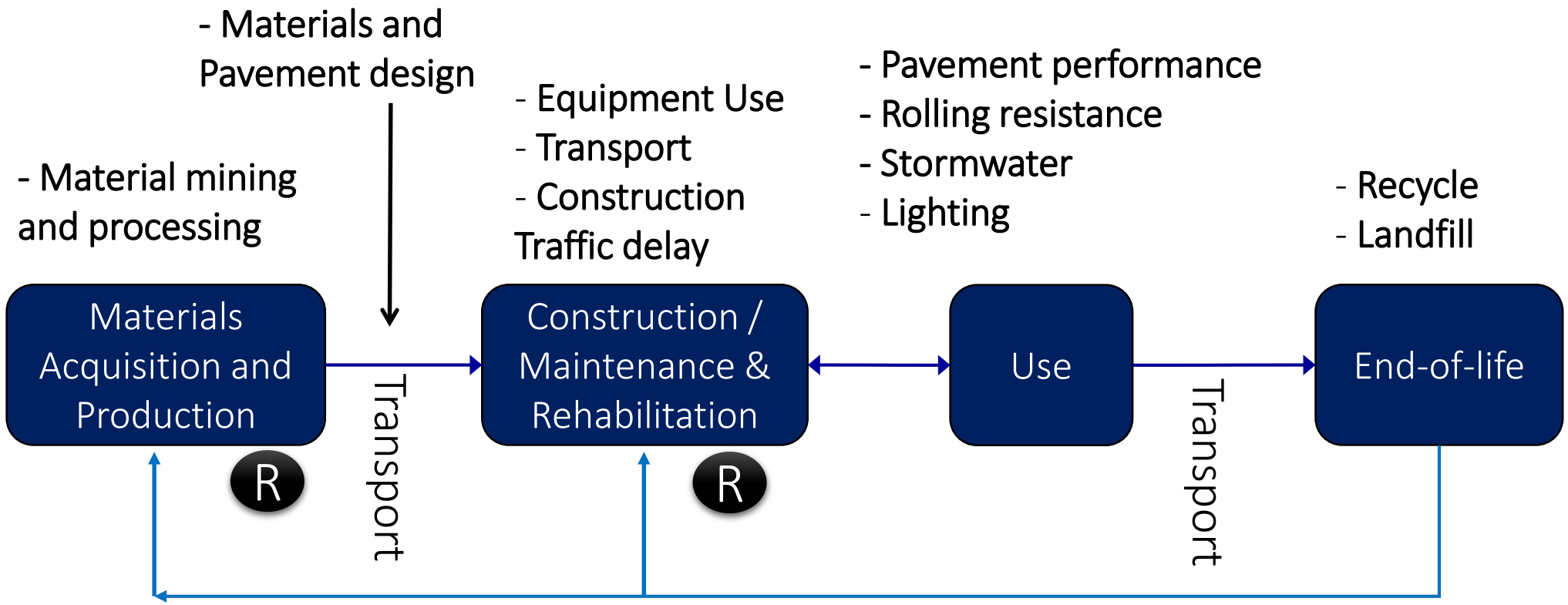
Public Awareness of Effects of Climate Change

- Wildland fire
  - Three years of large intense fires
  - Fires enter into cities
- 2018 fires:
  - 766,439 ha burned
  - US$3.5 billion damage
  - US$1.8 billion firefighting costs
  - 86 killed
  - 18,000 houses lost
  - Largest electricity company is bankrupted because equipment caused fires

Washington Post, ABC News Sacramento

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

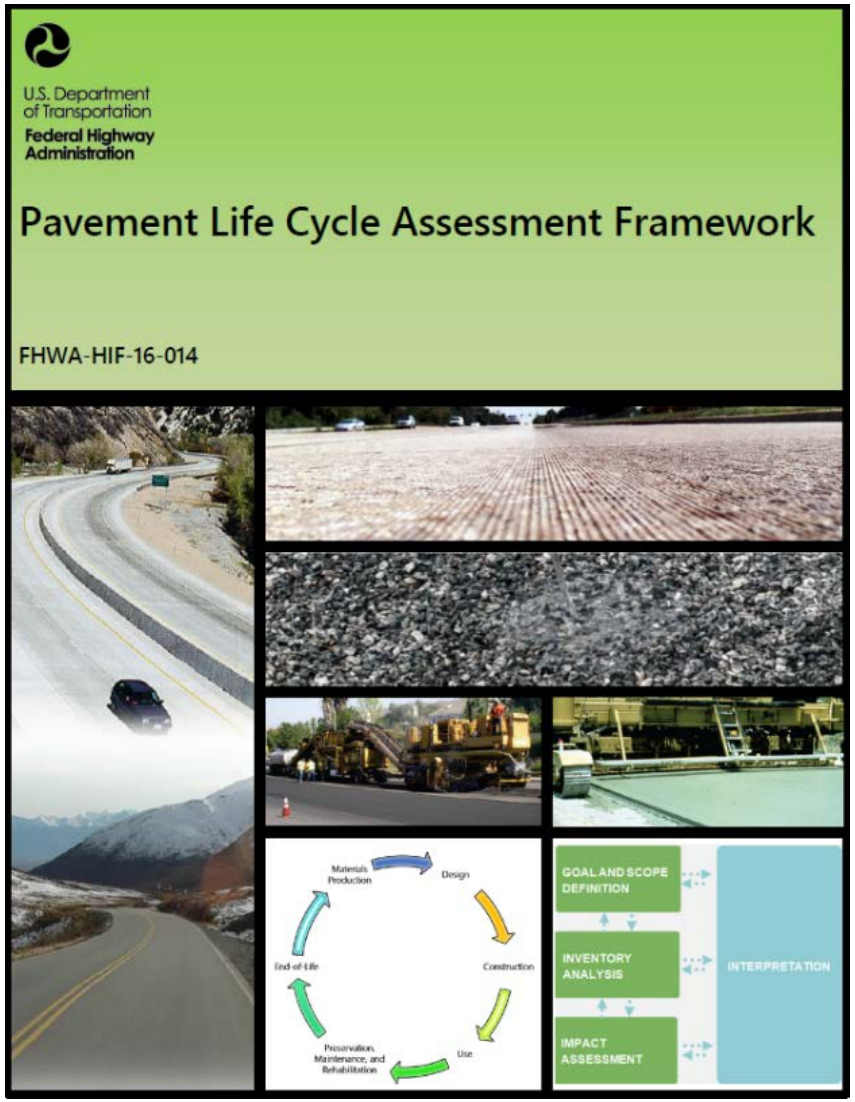


R : Recycle

From: Kendall et al., *2010*

FHWA Pavement LCA Framework Document

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



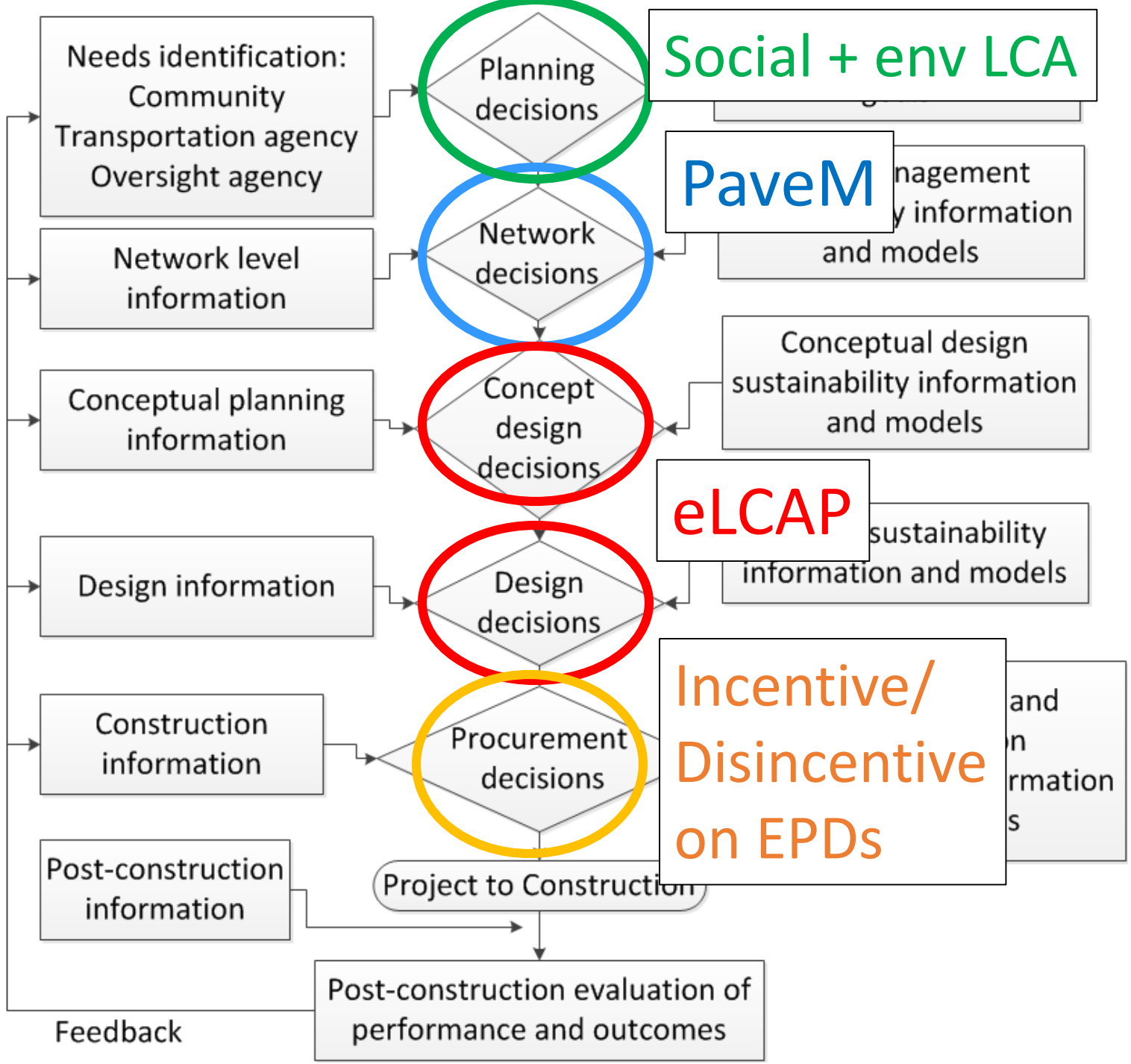
The need for pavement LCA tools

- Pavement LCA information awareness and knowledge growing; need to start doing
- Users want tools to use what they have learned about, check their processes, respond to coming demand for LCA information
- Must be able to
  - Perform complete analysis in 4 to 8 hours
  - Have all relevant data for processes included
- Network analysis
  - Caltrans PMS tool operating
- Project design
  - Currently working on national FHWA spreadsheet tool (2020)
  - Updating Caltrans web tool (eLCAP), also make available to local government (2019)

Objective: web-based integrated tools for:

- Planning
- Network
- Concept
- Design
- Procurement

With complete life cycle data regionally applicable data

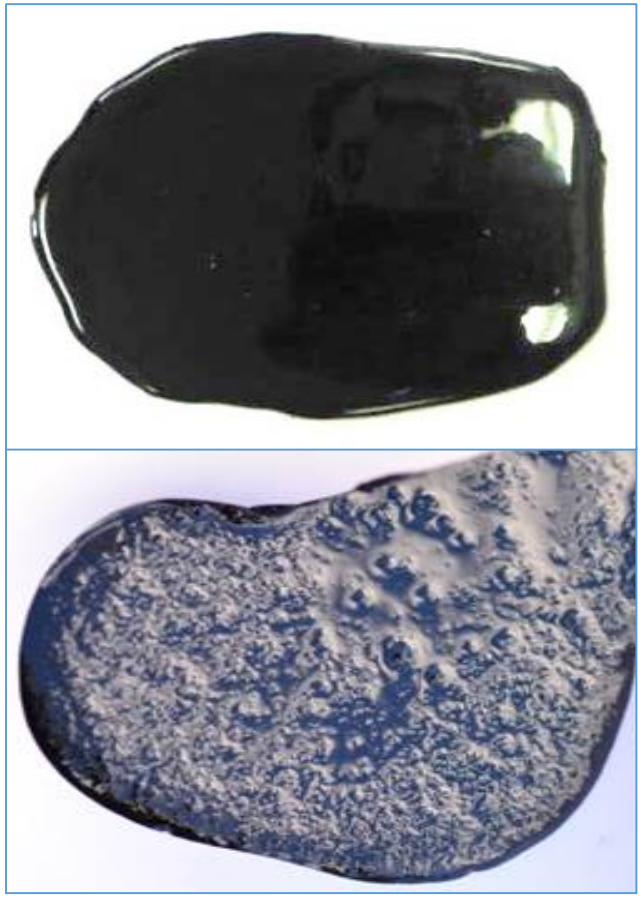


Current Approaches to Reduce Life Cycle Cost and Environmental Impacts

- Use of recycled tire rubber (discussed in detail today)
- Use of RAP (not discussed today)
- Pavement management roughness triggers
- Prioritization of strategies with LCA and LCCA
- Improvement of local government pavement practice
- Environmental Product Declarations

Recycled Tire Rubber: California Experience

- Goals: use tires, same or better performance
- Two primary approaches
  - Terminal blend
    - Produced at terminal or refinery
    - Alternative to polymer in dense-graded mixes
    - Used in gap- and open-graded mixes
  - Wet process
    - Produced at or near AC plant
    - Used in gap-graded and open-graded mixes
  - Asphalt rubber also used in chip seals
- Dry rubber is not used in California
  - Rubber can hurt performance



Caltrans specifications for wet process and terminal blend asphalt rubber

- Wet process
  - Meets ASTM 6114, but:
    - 100% passing 2.36 mm sieve
    - Must contain 18 – 22% CRM by mass of binder
    - CRM must contain 25% natural rubber (from truck tires)
    - Must contain extender oil
  - Quality control essentially based on viscosity
- Terminal blend
  - 100% passing 0.25 mm sieve
  - CRM fully blended in binder
  - Must meet PGM specifications (similar to PG)

Background

- Based on preliminary work in Arizona
- 1975: Initial laboratory and field test experimentation
- 1980: Pilot sections on major highways
- 1983: 14 test sections to compare overlay performance
  - HMA, RHMA-G and RHMA-D sections constructed
  - Thin RHMA-G sections outperformed thicker HMA and RHMA-D sections
  - Half-thickness RHMA-G had lowest cost
- 1992: First design guide
  - Focused on structural and reflection crack equivalencies
- 1993: Terminal blend rubber modified binder specification
  - Test sections constructed to evaluate
- 1995: > 100 Caltrans and 400 local projects
  - Most problems were related to construction
  - Considered as “standard practice” after 1995

Panoche Tire Fire 1998-2000

- 7 million tires burned for two years
- Led to development of waste tire reuse strategy by CalRecycle
- Assembly Bill 338 (2004) mandating use of tire rubber in asphalt pavement by Caltrans
  - Mandates Caltrans to use rubber in 35% of all AC placed in California each year
  - Equates to ±7 million tires/year (4.5m PTEs)
  - Local government not included

EastBayTimes.com
Papamiket.com

Background

- 2013: Assembly Bill 513
  - New fee on purchase of tires to subsidize city and county projects
- 2016: Caltrans mandate
  - All surface courses below 1,000 m elevation must be rubber

1995-1996 Mechanistic Analysis and Heavy Vehicle Simulator Performance Comparison – Rutting and Cracking

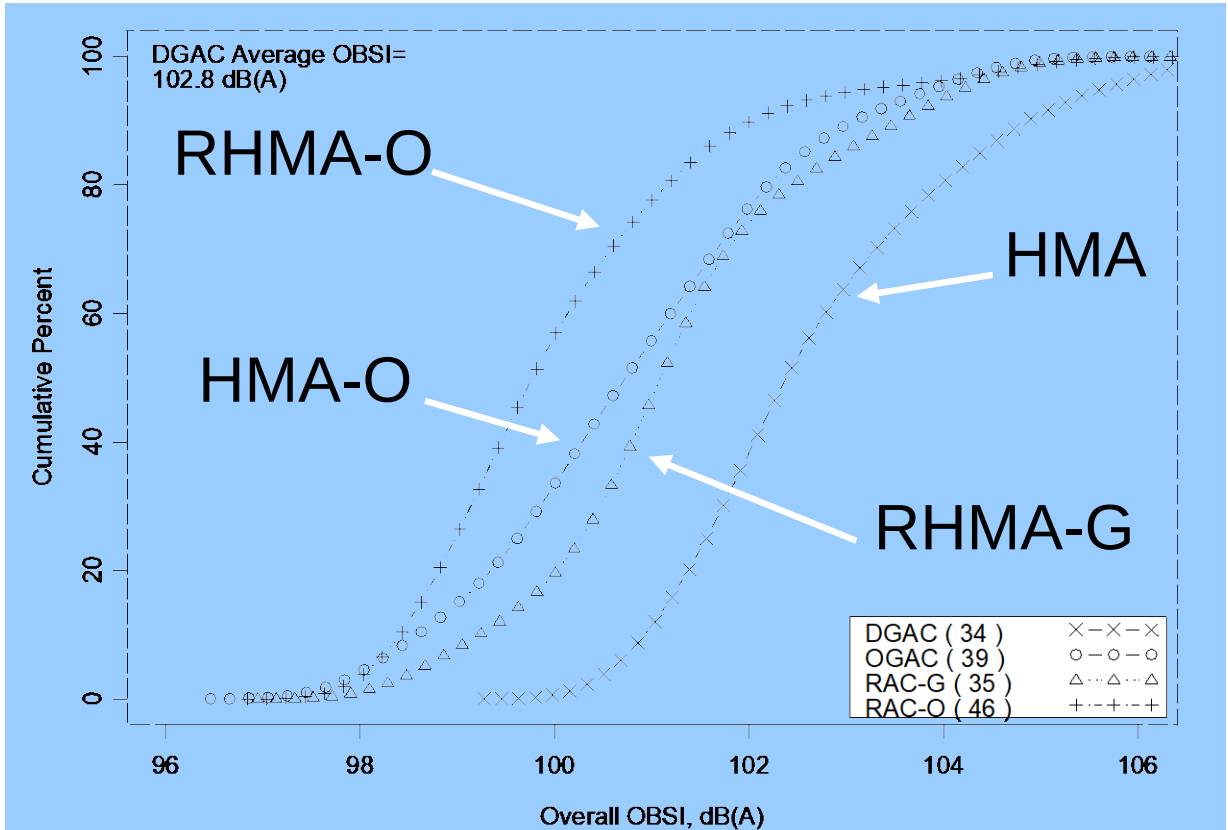
- 75mm HMA vs. 38mm RHMA-G
- Rutting
  - Equal rutting performance
- Reflective cracking
  - 38mm RHMA-G had similar performance to 75mm HMA
  - Performance dependent on compaction
  - Half-thickness approach adopted for RHMA-G reflective cracking overlay design

2000-2006 Mechanistic Analysis and Heavy Vehicle Simulator Reflective Rutting and Cracking Study

- Six overlay sections on 90mm cracked HMA
  - HMA (90mm), RHMA-G/wet process (45mm)
  - Terminal blends MB7 (45mm, 90mm), MB15 (45mm), MAC15 (45mm)
- Control overlays reflective cracking
  - HMA: 2.5m/m2 after 16M ESALs
  - RHMA-G: 2.5m/m2 after 60M ESALs
- MB overlays reflective cracking
  - MB7-G: None after 66M ESALs
  - MB15-G: None after 88M ESALs
  - MAC15-G: None after 91M ESALs
  - But poor rutting due to gap-grading
- <u>Terminal blend now competes with wet process</u>

Quieter Pavements

- Six year study on 54 road sections
  - HMA, RHMA-G, HMA-O, RHMA-O
  - Sections up to 18 years old
- RHMA-O had best performance
  - 15 year life compared to 10 year life of HMA-O
    - Based on noise, raveling, cracking, IRI
  - Raveling, permeability loss main reasons for noise increase over time
    - Rubber does not “absorb” noise
  - <u>Most open-graded friction courses are now RHMA-O</u>



Rubberized Warm-Mix Asphalt Evaluation with HVS and in Field

- HVS Track:
  - 7 RWMA technologies, 2 RHMA controls, produced at two AC plants
  - RWMA mixes:
    - Less smoke, odors, and emissions; more workable
    - Equal performance to RHMA
- Field
  - Better performance to RHMA on field projects
  - Key advantages:
    - Long hauls, early/late season paving, night paving, thin lift construction, construction in urban areas, etc.
- <u>Contractor option in specifications</u>

Study of Full-Depth Reclamation and Partial-Depth Reclamation of of RHMA-G Pavements

- Findings
  - Some blue smoke during milling
  - Rubber is visible in recycled layer
  - Similar performance to FDR of HMA
  - <u>No changes to current designs/ specifications required</u>

Use of RAP in RHMA-G Mixes

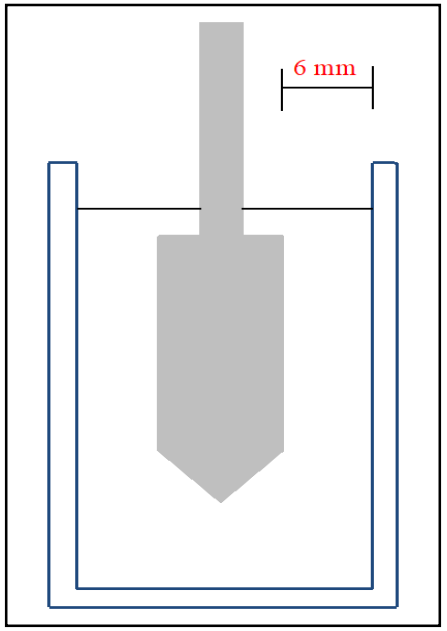
- Current spec does not allow RAP
- Study focused on binder replacement and blending of new and old binders
  - Improved rutting performance, but diminished cracking performance
  - If implemented, would reduce quantity of rubber used
  - New study allowing 10% coarse RAP in rubber, no binder replacement

Use of Rubberized RAP in HMA

- Early RHMA-G projects are starting to be rehabilitated, showing up in RAP
- Study compared mixes with RAP and R-RAP
  - R-RAP mixes had equal or slightly better performance to HMA with no RAP in laboratory
  - No requirement to have separate RAP and R-RAP piles

Development of PGAR Specification and Tests

- Goal
  - Specification of asphalt with less than fully blended particles using PG tests
  - Max particle size is 1.4 or 2.36 mm
- New test methods developed for AR binders:
  - Concentric cylinder geometry in DSR (6mm/9.5mm gap)
  - RTFO (190°C and 45g of binder vs. 163°C and 35g)
  - BBR modified specimen mold (wide mouth to pour)
  - Validation with field mixes in progress to determine what DSR/BBR values mean



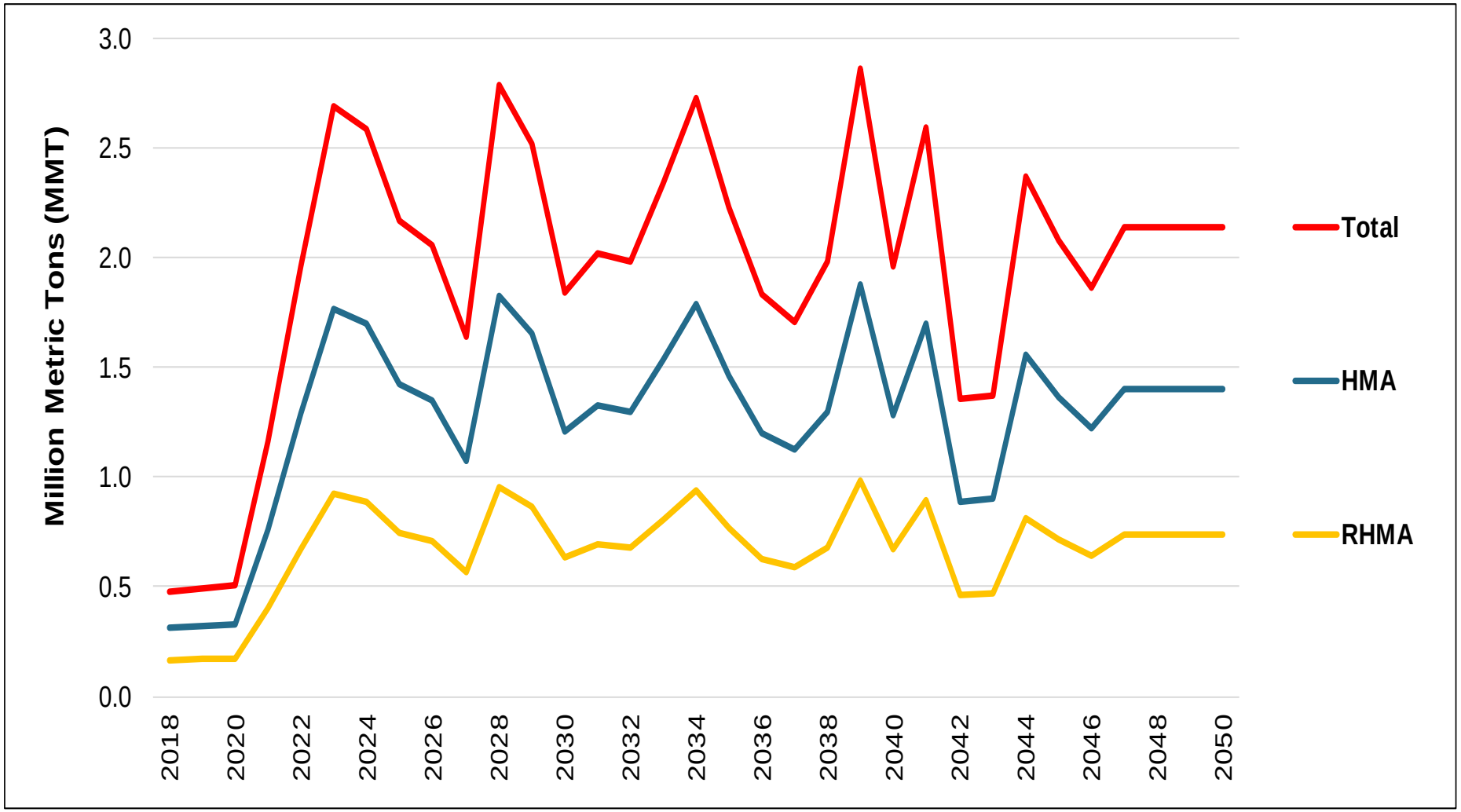
Greenhouse Gases HMA vs RHMA

- Same design for 10 year overlay on highway
- HMA emits 26% more CO2e

Strategy for Overlays	Materials (MT GHG)	Construction (MT GHG)	Total (MT GHG)
45 mm mill + 75 mm HMA with 15% RAP	1,650	505	2,155
30 mm mill + 60 mm RHMA	1,310	396	1,706
HMA/RHMA	1.26	1.28	1.26

Estimated Asphalt Quantities on State Highways

- Increase in fuel tax passed in 2016, confirmed by direct vote in 2018
- US$0.033/liter
  - US$2.5 billion more for state highways
  - US$2.0 billion more for local roads



Ground Tire Rubber vs SBS Environ-mental Impacts

Asphalt Institute LCA for binders 2019

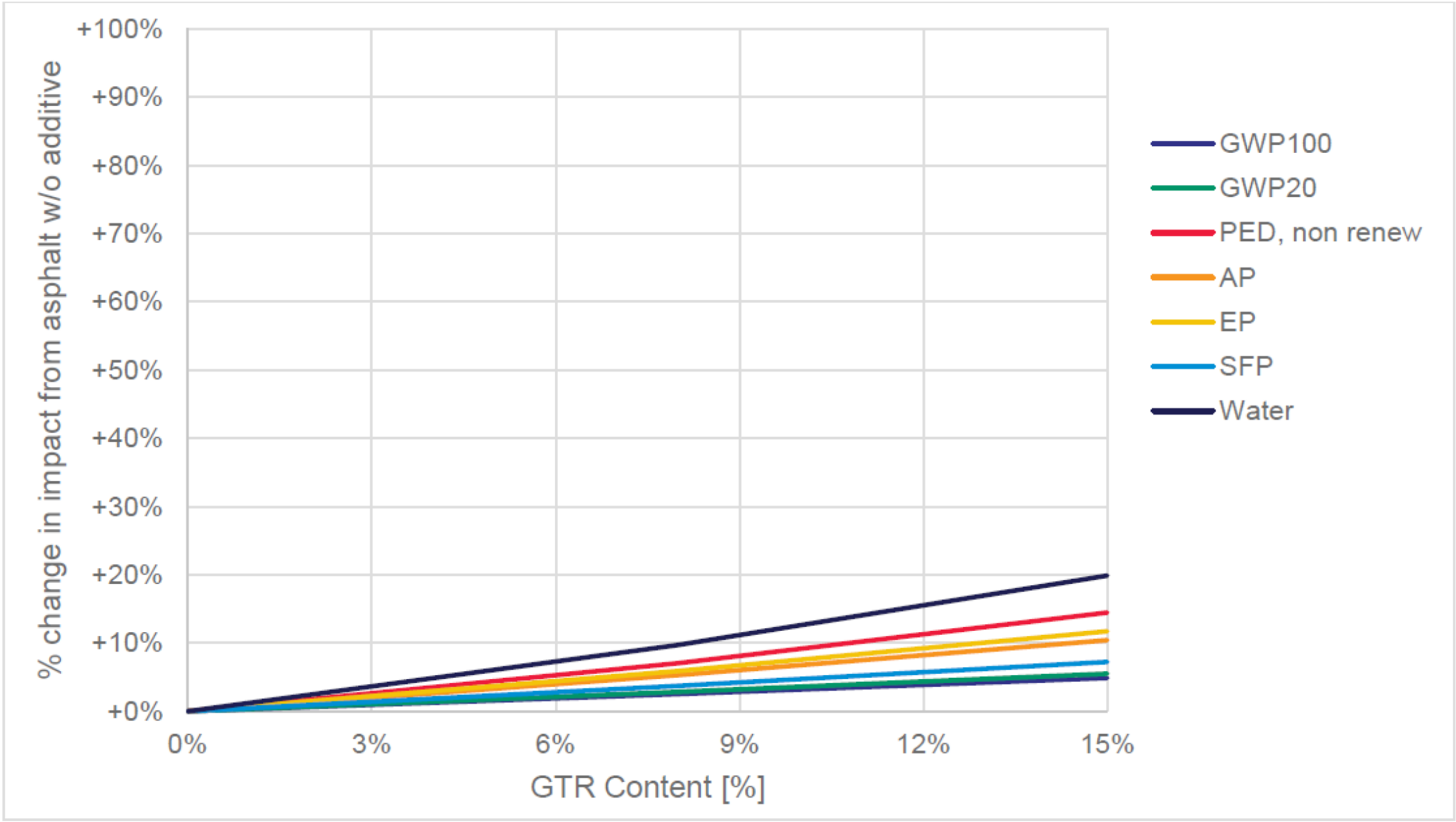


Figure 4-8: Sensitivity of results to GTR content

Ground Tire Rubber vs SBS Environ-mental Impacts

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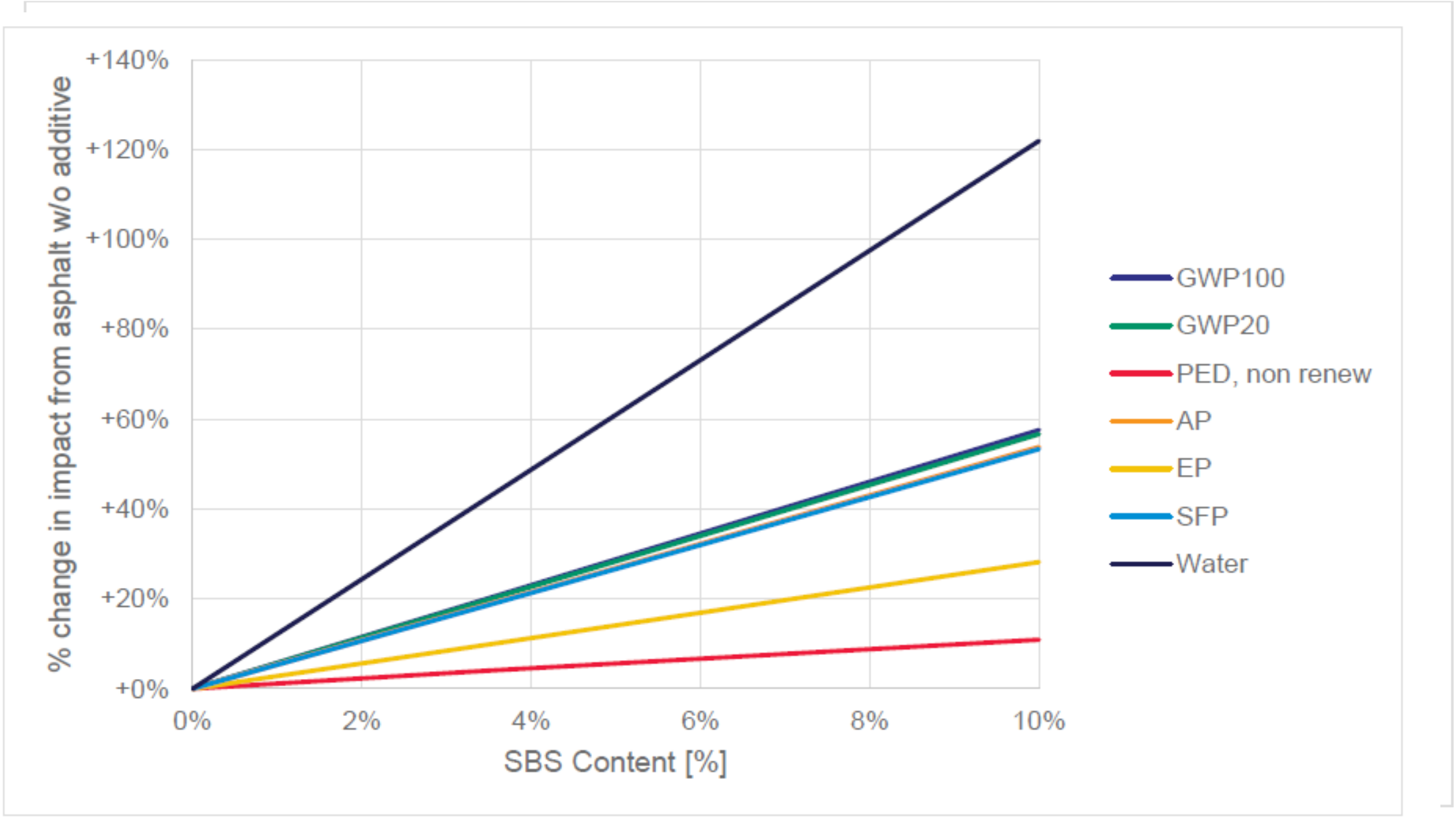
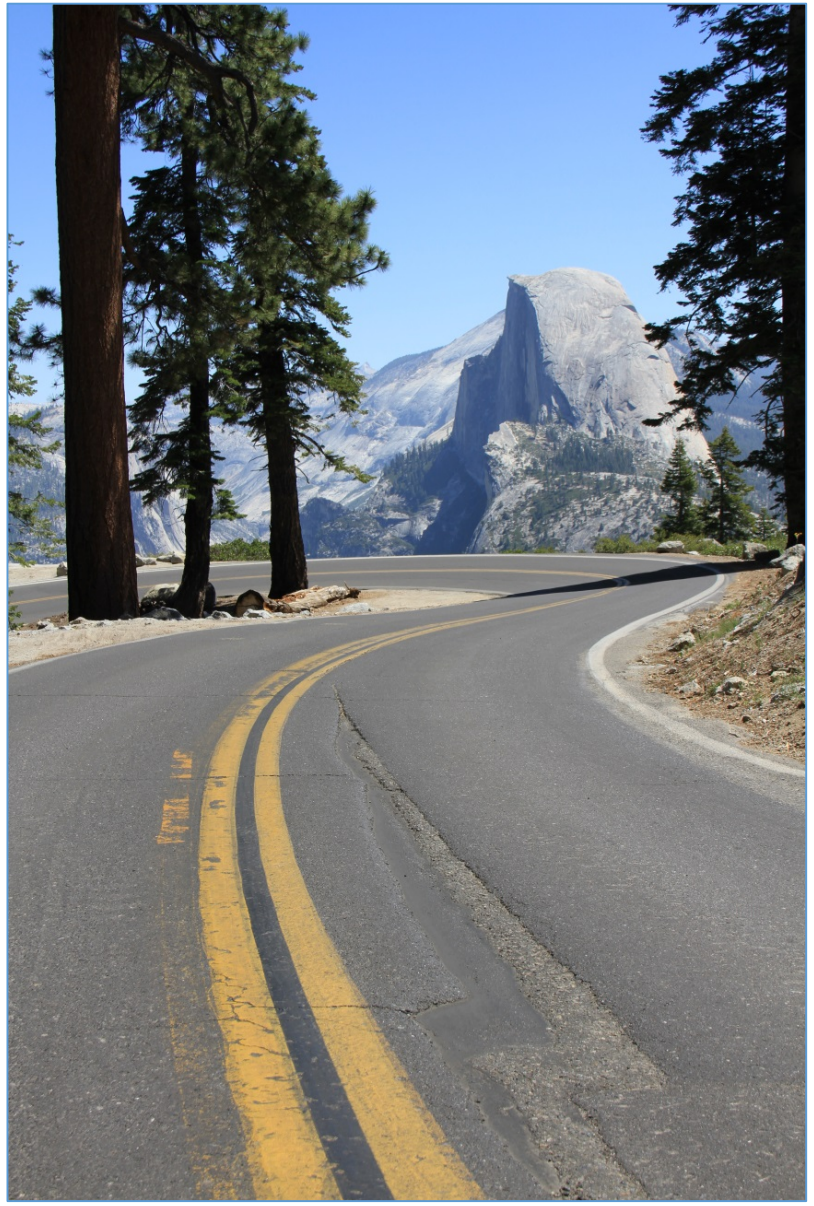


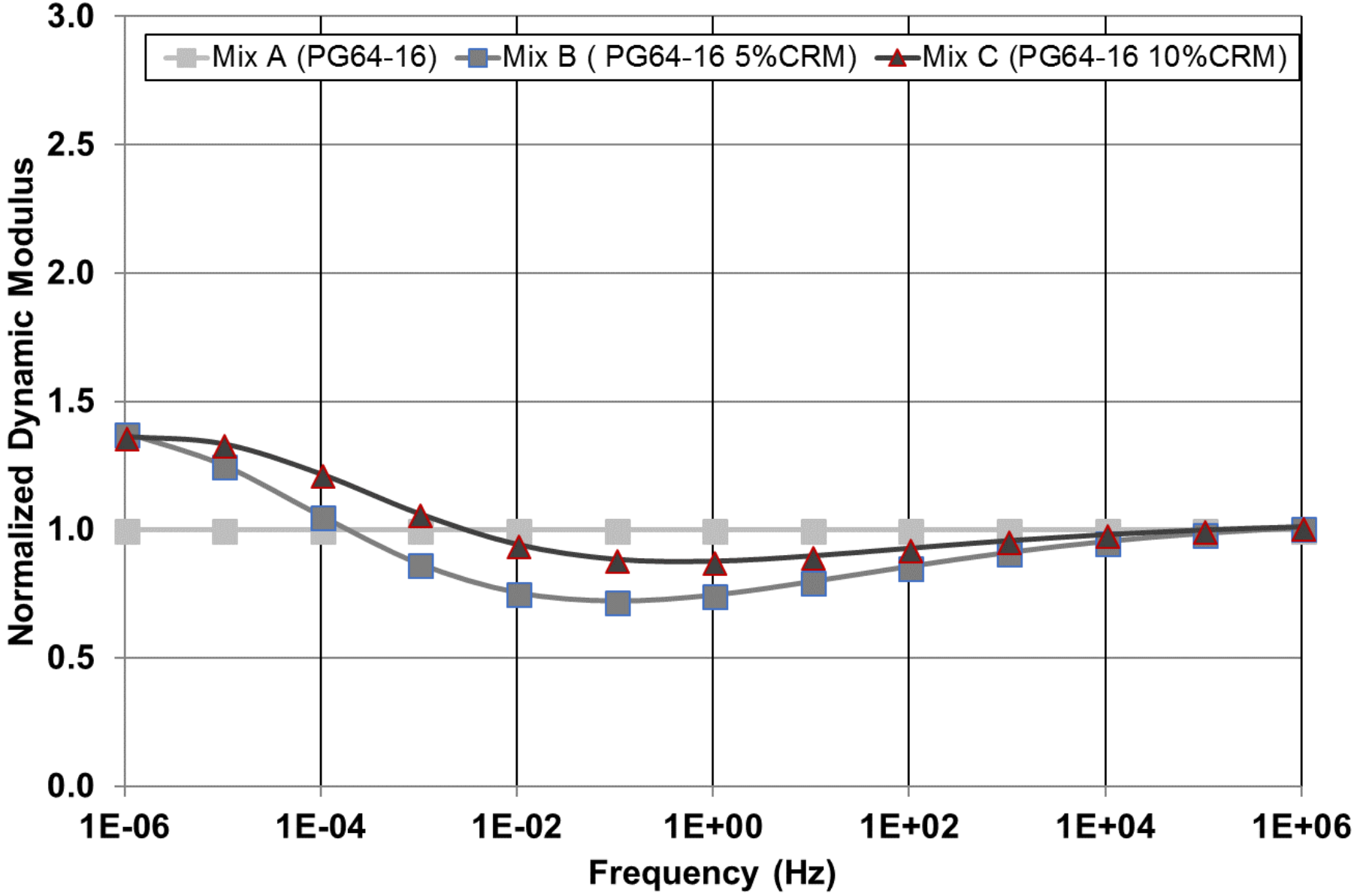
Figure 4-6: Sensitivity of results to SBS content

PG+X Rubber

- Caltrans initiative to use more rubber in dense-graded mixes
- Between 5% and 10% rubber in all binder, must meet base binder PG grading
- Four approaches considered:
  - Terminal blend
  - Standard wet process
  - Modified wet process
  - Dry process

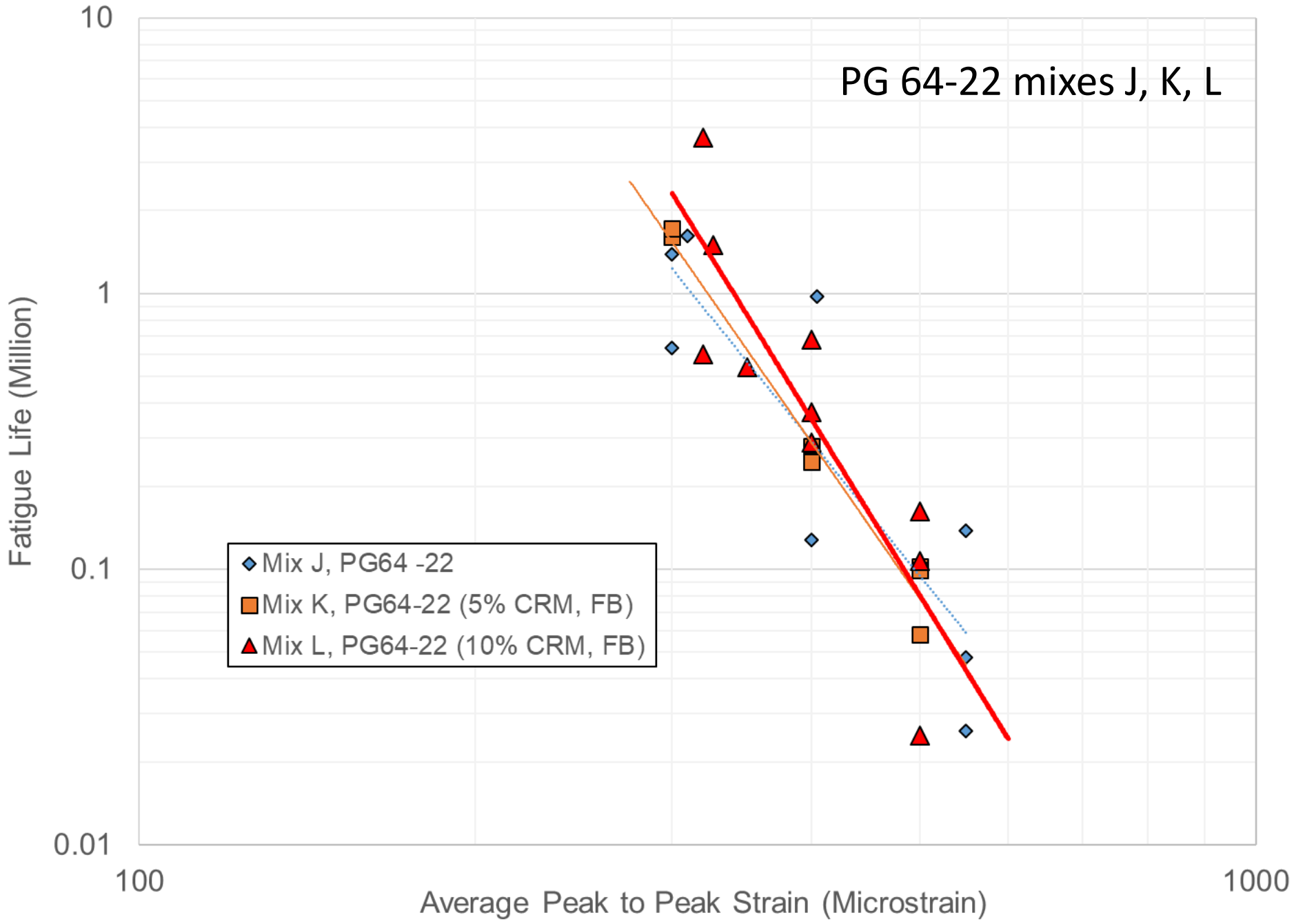


Similar Flexural Stiffness Alon PG (PG 64-16)



Similar to superior controlled deformation flexural fatigue performance

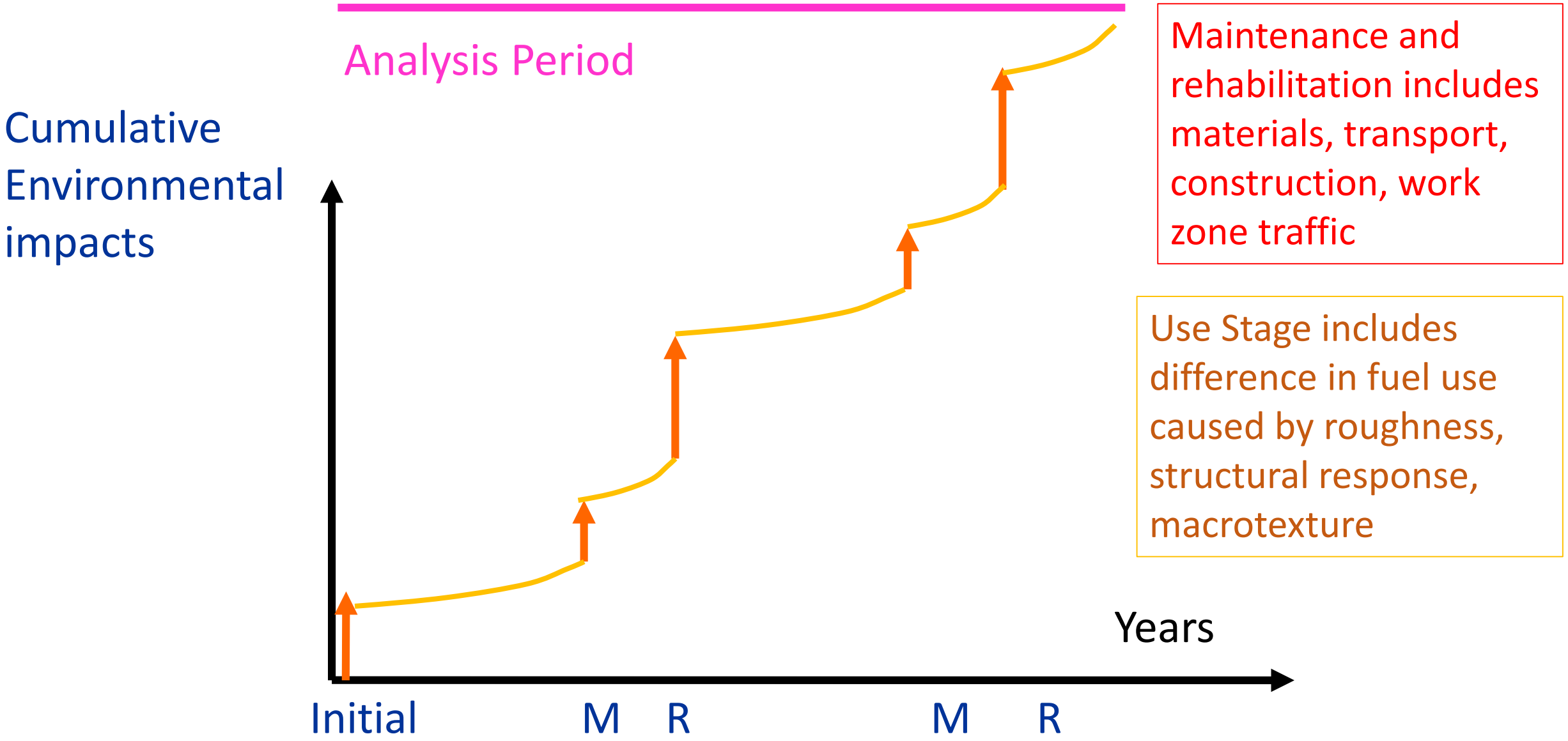
Evaluation of performance with CalME mechanistic-empirical performance shows generally better performance than HMA



Asphalt Rubber Use and Cost

- Use
  - California generated an estimated 48.5 million tires in 2017, projects using asphalt rubber, and other uses, used over 4.7 million tires
- 2017 Costs per US ton
  - HMA/RHMA-G life cycle cost about equal
    - HMA-Dense: US$ 77
    - RHMA-Gap: US$ 94
  - RHMA has lower life cycle cost than HMA-O
    - HMA-Open: US$ 126
    - RHMA-Open: US$ 93
- Overall conclusion: asphalt rubber has helped cost and environment
  - New technologies may use more tires and further reduce cost

Network Optimization of M&R Triggering Pavement Life Cycle



Maintenance and rehabilitation includes materials, transport, construction, work zone traffic

Use Stage includes difference in fuel use caused by roughness, structural response, macrotexture

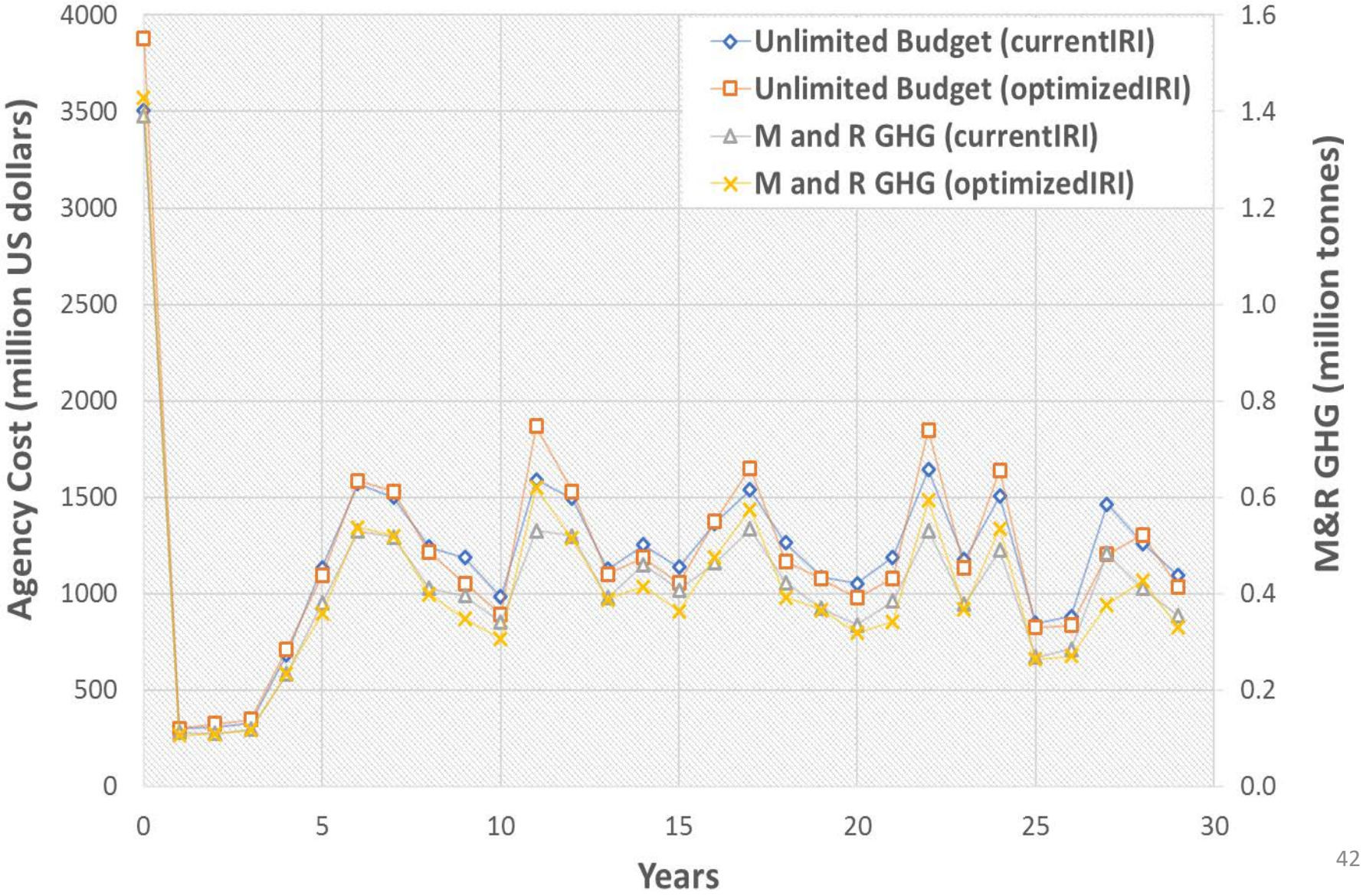
Caltrans Network: Use of Optimized IRI Triggers for Maintenance and Rehabilitation in Pavement Management System

Daily Passenger Car Equivalent traffic of lane-segments range	Total lane-miles	Percentile of lane-mile	Optimal IRI triggering value m/km, (inch/mile)
<2,517	12,068	<25	-----
2,517 to 11,704	12,068	25-50	2.8 (177)
11,704 to 19,108	4,827	50-60	2.0 (127)
19,108 to 33,908	4,827	60-70	2.0 (127)
33,908 to 64,656	4,827	70-80	1.6 (101)
64,656 to 95,184	4,827	80-90	1.6 (101)
>95,184	4,827	90-100	1.6 (101)

Wang et al 2014

Output from Caltrans PMS for the California Highway Network, Imad Basheer, Caltrans

- Difference in GHG with optimized IRI triggers
- All segments repaired in first 2 years
- Considers materials, construction, use stage
- 11.7 MMT reduced over 30 years
- $9/MT
- Cap-and-trade value of 1 MT = $10 to $20



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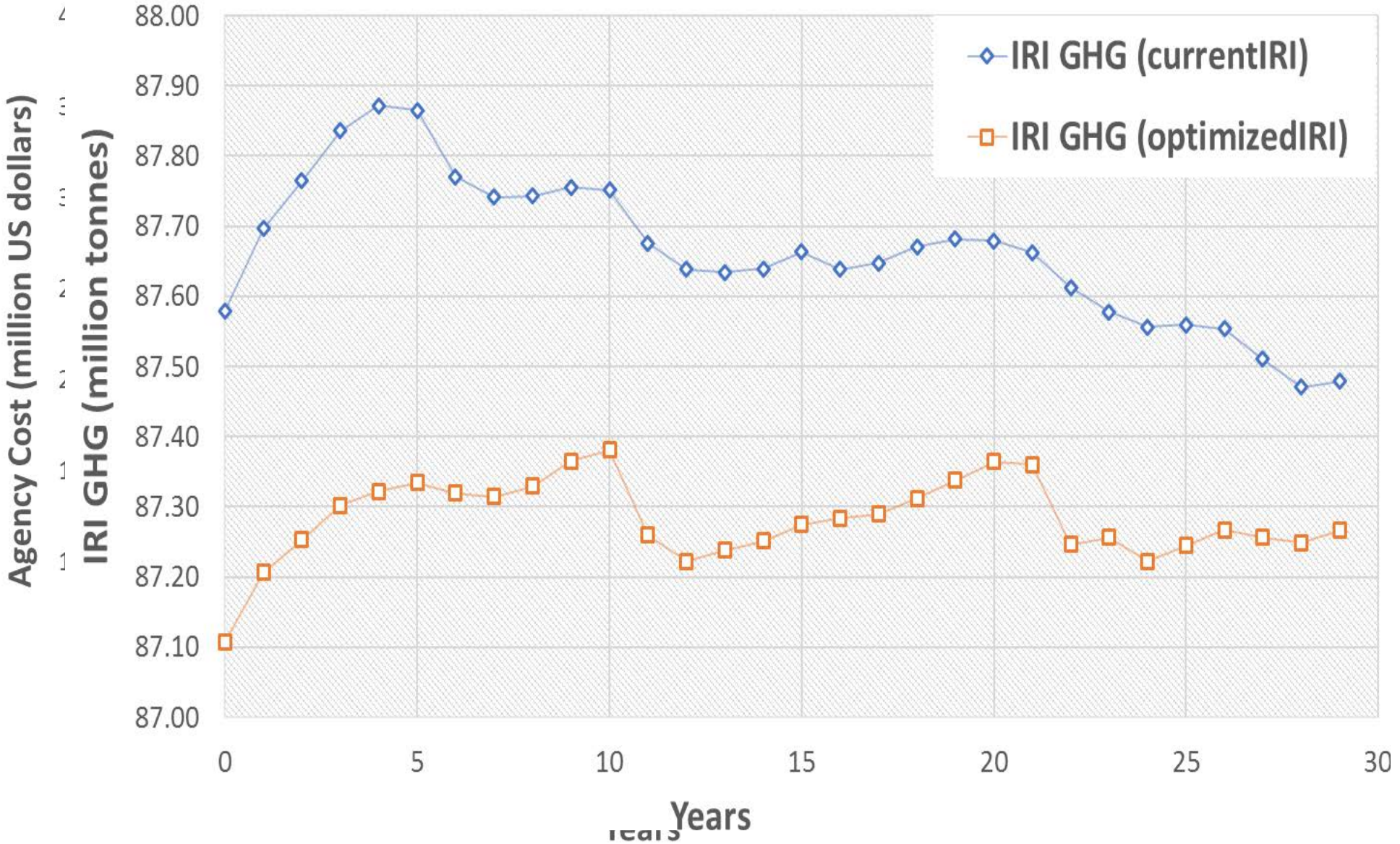

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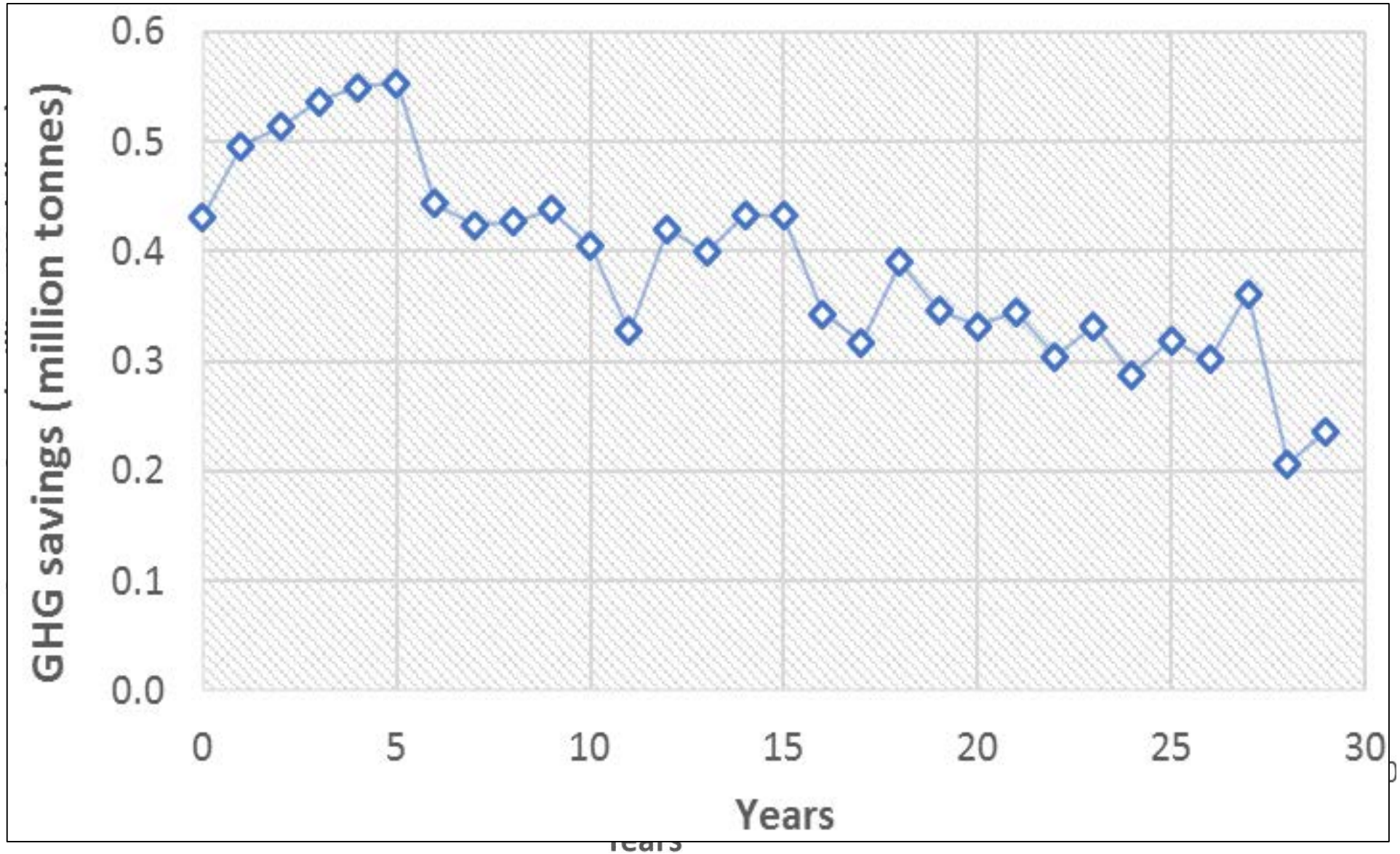
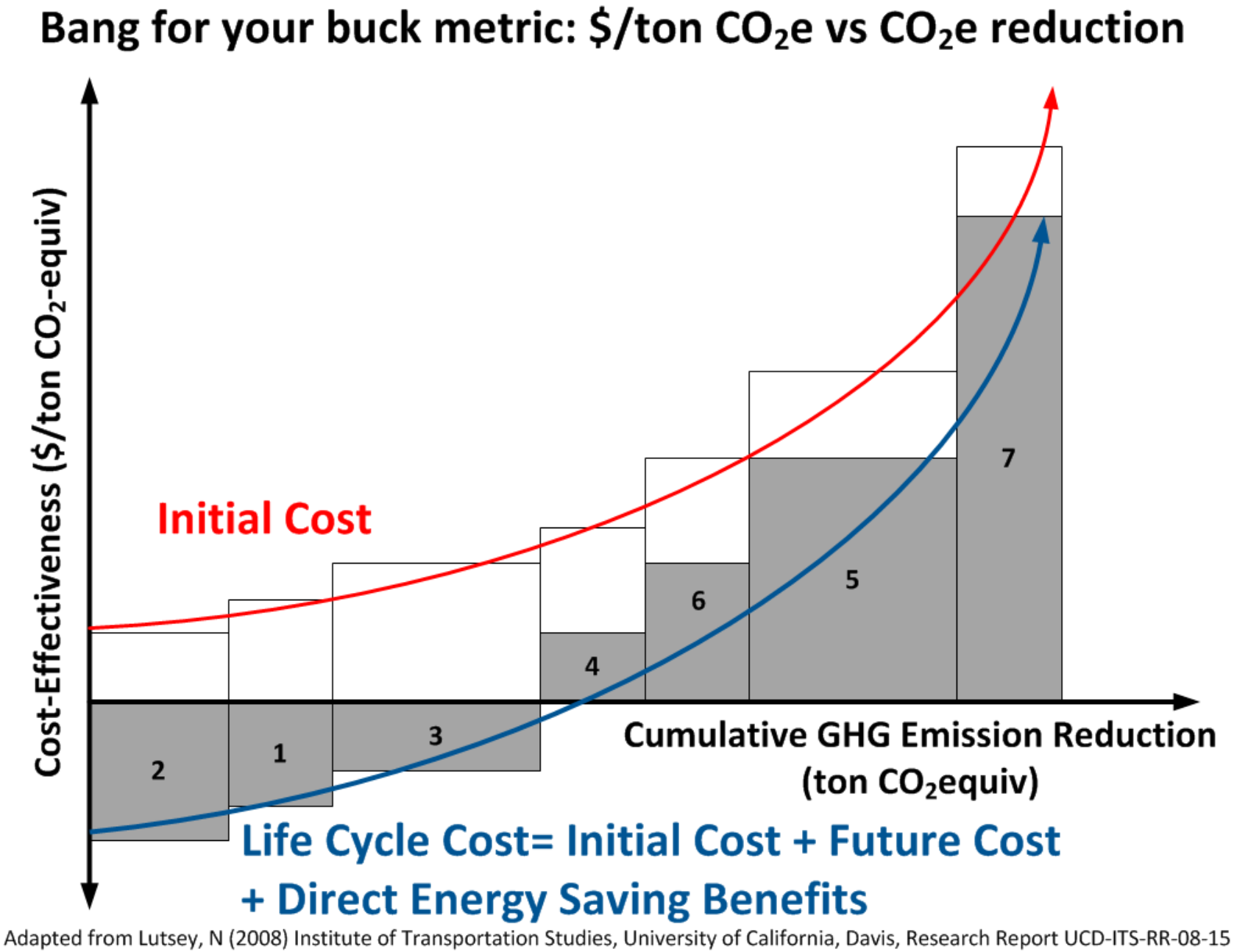


How Does State Government Currently Select More Sustainable Practices?

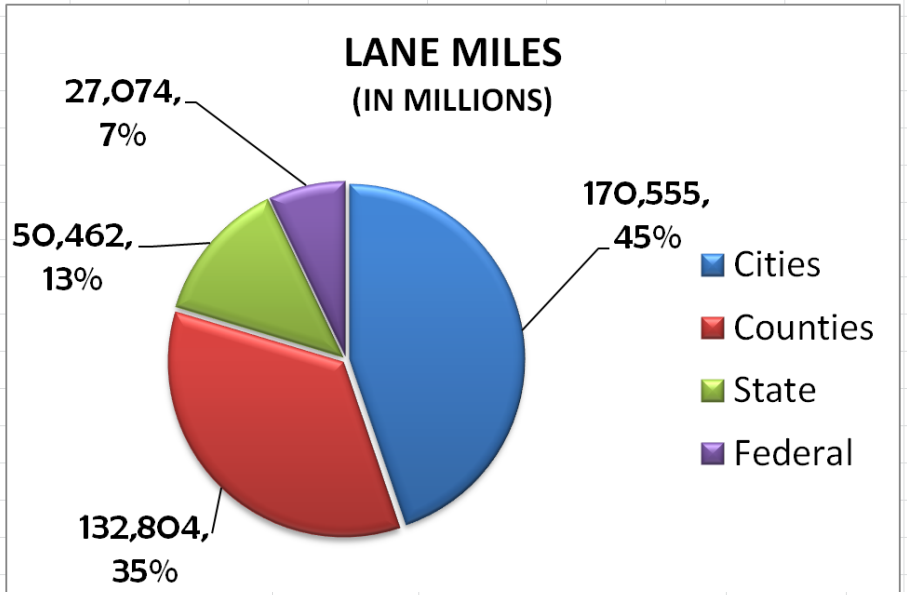
- Goals set by legislation and regulation
- Agencies develop strategies based on information from:
  - Lobbyists
  - Consultants
  - Universities
- Additional state legislation proposed for specifics of different industries, new technologies
  - Sometimes good science, sometimes not so good
  - Often driven by non-governmental organizations (NGO)
  - Industry tries to shape to capability and interests
- How to prioritize many ideas is a major problem for California Air Resources Board, Caltrans and local agencies

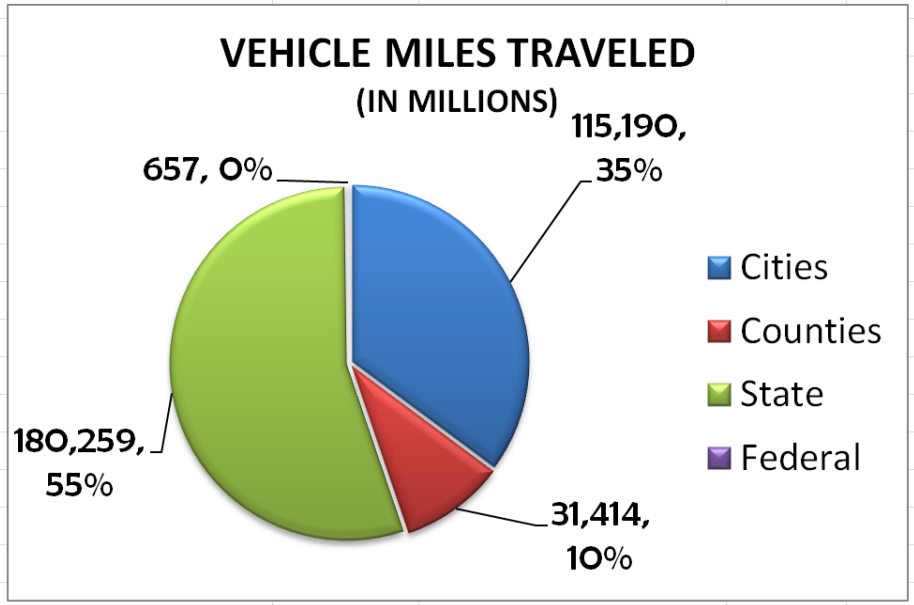
- Need first-order analysis prioritize which ideas to further investigate
- “Supply curve”
- Pilot projects at UCPRC
  - Caltrans changes to internal operations
  - Local government review of climate action plans



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

Why is Local Government Pavement Important to Sustainability?





Pavement Spending

- Local $/State $ about 0.8/1
- Use about 50% of the asphalt in the state

New Funding from SB 1

- $ 2.5 billion for state highways
- $ 2.0 billion for local government

New City and County Pavement Improvement Center

- Started in 2018 to provide training to local government
- Consortium of local government, research and teaching universities

UCPRC | City and County Pavement Improvement Center

Welcome To CCPIC

Our Mission

CCPIC works with local governments to increase pavement technical capability through timely, relevant, and practical support, training, outreach and research

Our Vision

Making Local Government-Managed Pavement Last Longer,

Best Practices More

Answers to common problems

- Writing and Enforcing Specs for Asphalt Compaction
- Writing Concrete Specs for Durability and Sustainability
- Unpaving to Create Affordable, Safe, Smooth Gravel Roads

Training Classes More

Pavement Training

- About CCPIC subsidized training
- Currently offered training classes
- Subscribe to monthly training update eamils
- Survey on your Agency's pavement training needs. Thanks.

Web Training & Webinars More

Coming Soon!!

- Item 1
- Item 2

Presentations More

Sample Specs More

Tools More

News And Events

Survey on Pavement Training Needs

Please take 5 minutes to fill out a short survey on your agency's pavement training needs. Thanks.

October/November 2018

CCPIC subsidizes cost of in-person training classes on pavement management and asphalt maintenance and rehab
ITS Berkeley

September 15-18, 2019

12th TRB International Conference on Low-Volume Roads
Kalispell, MT

Local Government LCCA and LCA example: Asphalt Compaction 8% vs 12% air-voids

- Assumptions:
  - 4 miles of two-lane rural county road
  - Pulverize cracked HMA, compact, 100 mm HMA overlay
  - $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

Environmental Product Declaration (EPD)

- Results of a critically reviewed LCA for a product
  - Produced by industry
  - National industries have EPD programs
- Caltrans is piloting requiring EPDs for pavement materials in 2019
- Potential use later in procurment

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 Pavement Interactive

Conclusions

- Pavement can play its role in reducing climate change, and often also reduce cost
- LCA and LCCA are tools to be used to quantify and prioritize
- There are no magic bullets, every sector needs to prioritize what it can do to both reduce environmental damage and cost
- Think full system and life cycle
- Demonstrated here were several strategies being used in California
  - Rubberized asphalt
  - Optimization of smoothness in PMS
  - Prioritization of new technologies using LCA and LCCA
  - Local government improved practice
  - EPDs

PAVEMENT
ROADWAYS
BRIDGES

LCA2020

June 3-6, 2020 • Sacramento, California, USA

International Symposium on Pavement, Roadway, and Bridge Life Cycle Assessment 2020

Sacramento, California, USA
June 3-6, 2020

The week before RILEM in Lyon

Abstracts due June 15, 2019

www.ucprc.ucdavis.edu/lca2020

Search on “pavement LCA 2020”

Thank you on behalf of UCPRC team

www.ucprc.ucdavis.edu
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