Asphalt Pavement Life Cycle Assessment: Review and Future Outlook

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Outline

- Review of sustainability goals
- Changes in transportation that will affect pavement
- Tools for measuring sustainability
- Implementation
- Prioritization
- Conclusions

Sustainability:
Master equation for environmental impacts

Environmental impact =

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

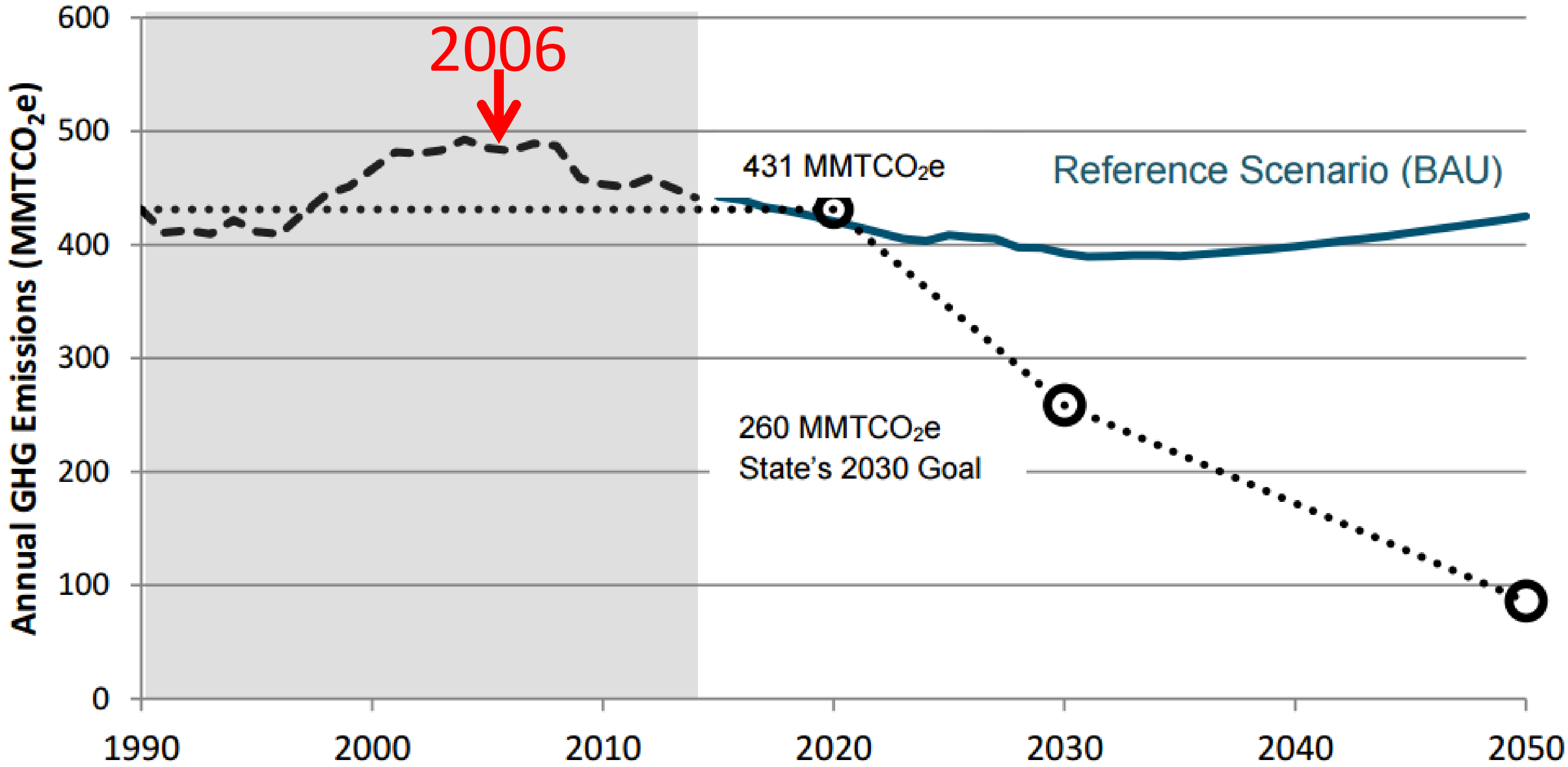
Increase in wealth and economic activity

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

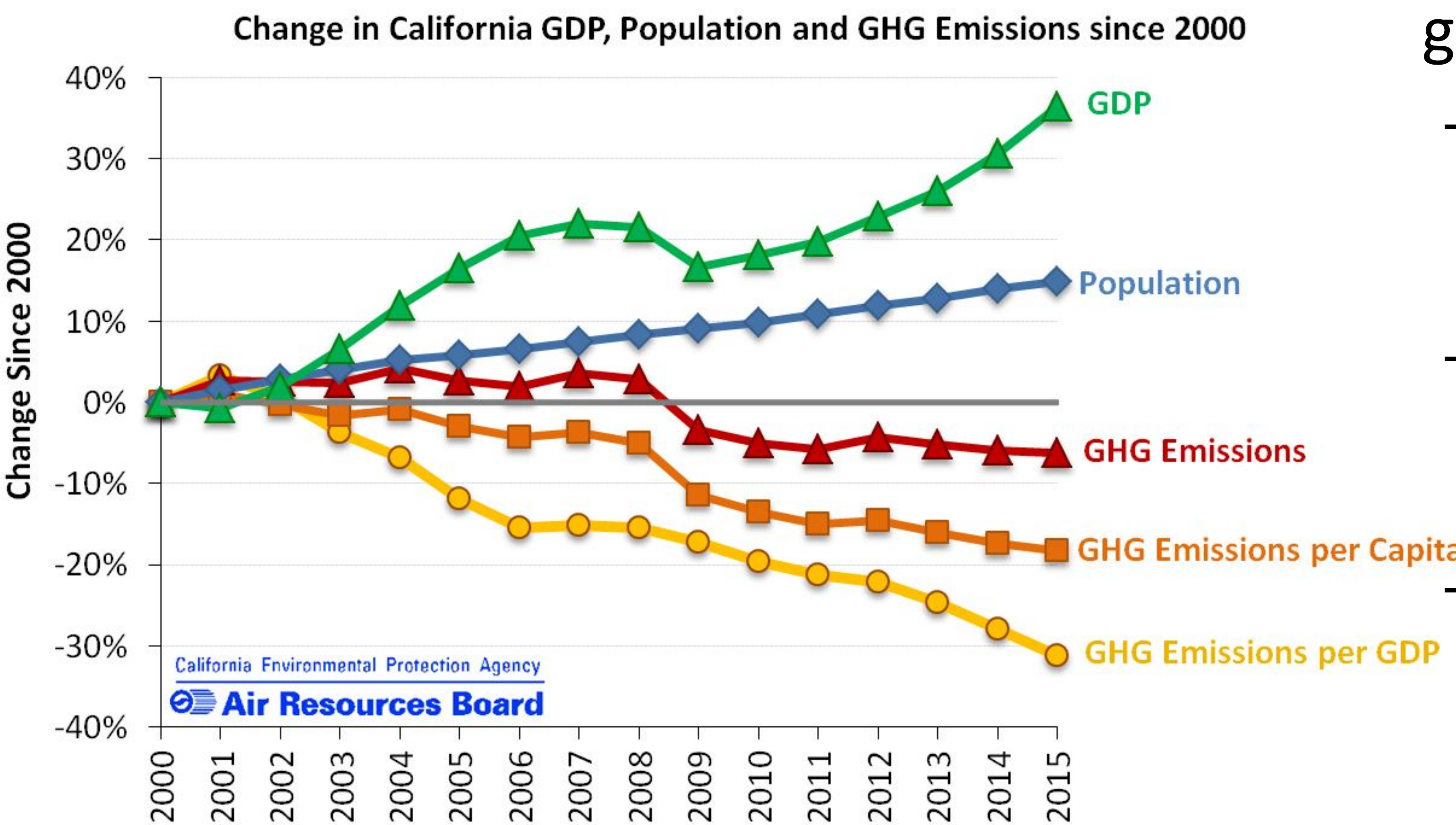
Climate Change: California targets for GHG

- State Law signed in 2006, economic recession 2008-2015
- State law remains; federal withdrawal from Paris Agreement
- 2020 targets: will be met, primarily in energy sector
- 2030, 2050 targets: much harder, requires many more strategies



Air Resources Board Climate Scoping Plan

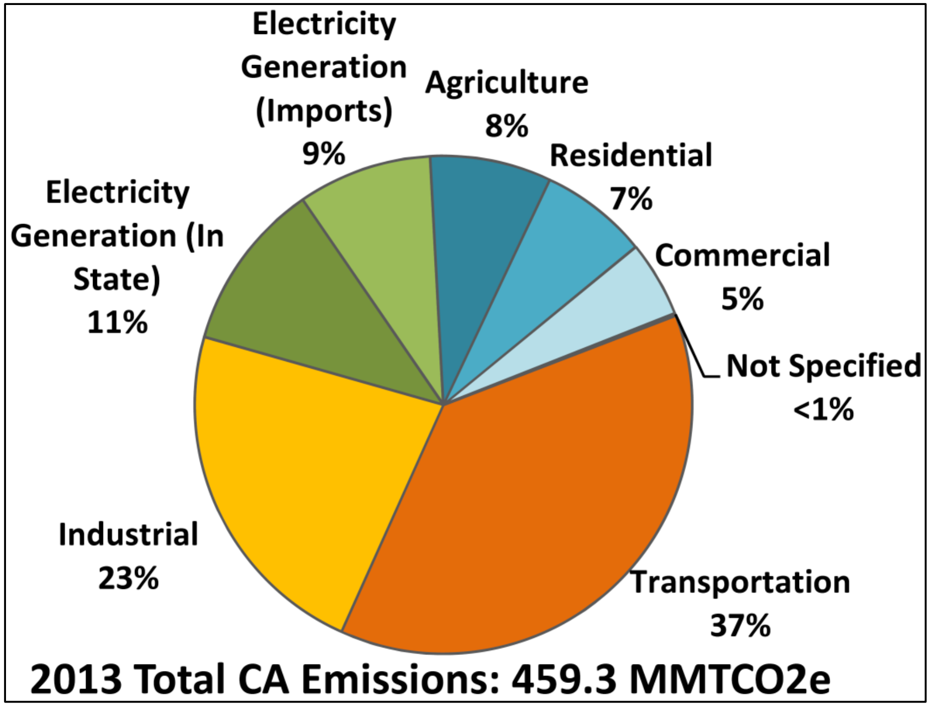
Climate Change: can California state goals be met and keep a strong economy?



- Population growth:
  - 1990: 30 million
  - 2017: 39 million
  - 2055: 50 million

How could changes in pavements reduce California GHG emissions?

- Out of 459 MMT CO2e in 2013
  - On road vehicles 155 MMT
    - Reduce rolling resistance to optimum = - 1.5 MMT
    - Reduce hauling of stone 10% = - 0.6 MMT
  - Refineries 29 MMT
    - Reduce asphalt use 50% = - 0.7 MMT
  - Cement plants 7 MMT
    - Reduce cement use 50% = - 0.2 MMT
- Total pavement reductions
  = - 2.9 MMT
  = 0.6% of state total GHG



- These are important contributions to GHG reduction
- Equally important is what changes in other parts of economy will do to pavement

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

Pavement Materials Resource Depletion and Replacement

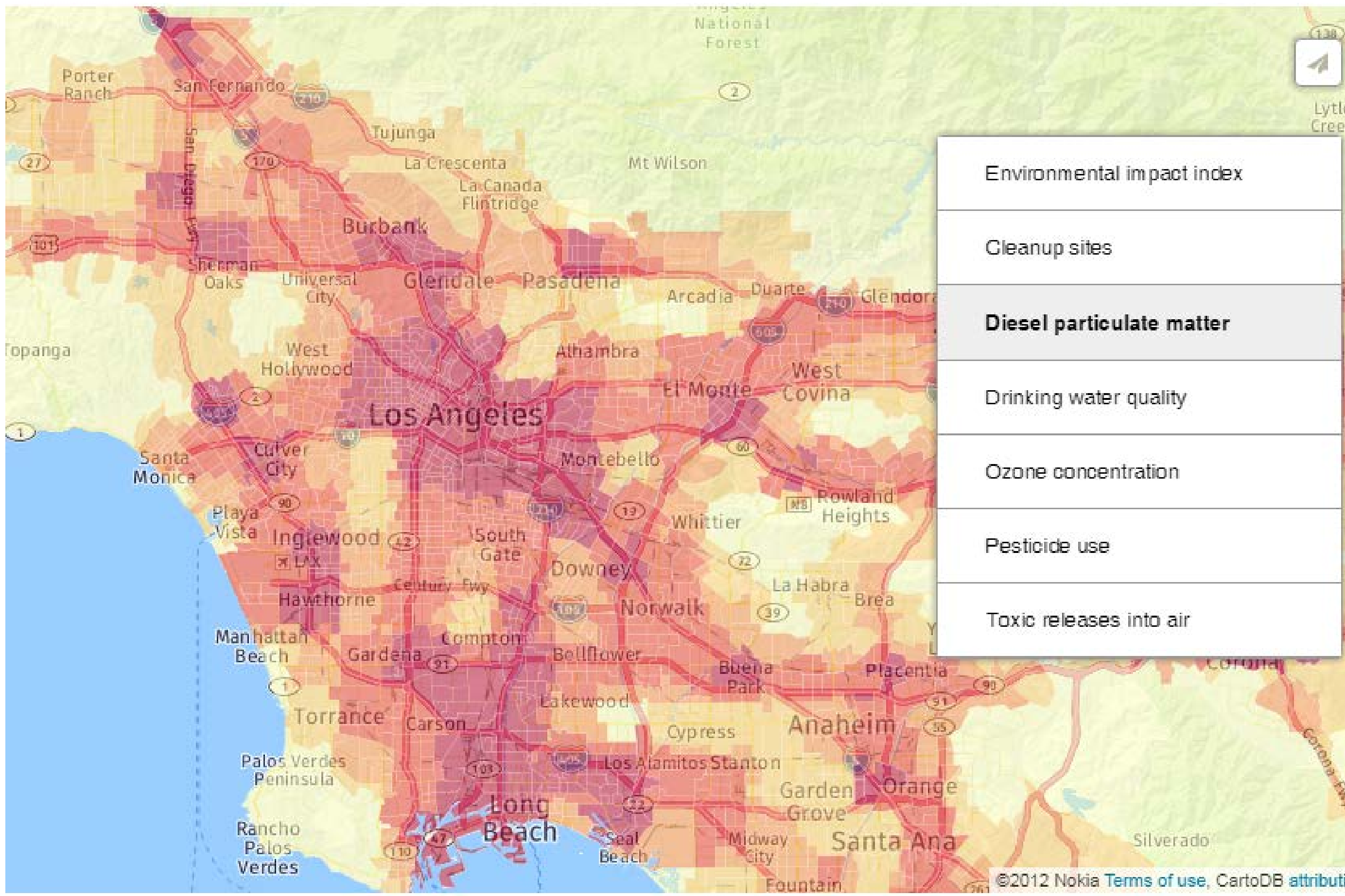
- Aggregate:
  - Local future shortages and quality issues
  - Large quantities of aggregate moved on the roads, = lots of fuel use, high levels of damage on roads
- Asphalt:
  - US: supply and demand balanced, because large amounts of asphalt are coked for liquid fuels
  - If oil demand for transportation fuel diminishes, there is a nearly infinite future supply of asphalt
  - Will there be a business model to refine oil for asphalt?

Air Pollution Toxicity is also very important

- Transportation related factor of most importance is air pollution, especially diesel trucks

✓ Requiring changes in vehicle energy sources, especially trucks

✓ Less oil refining



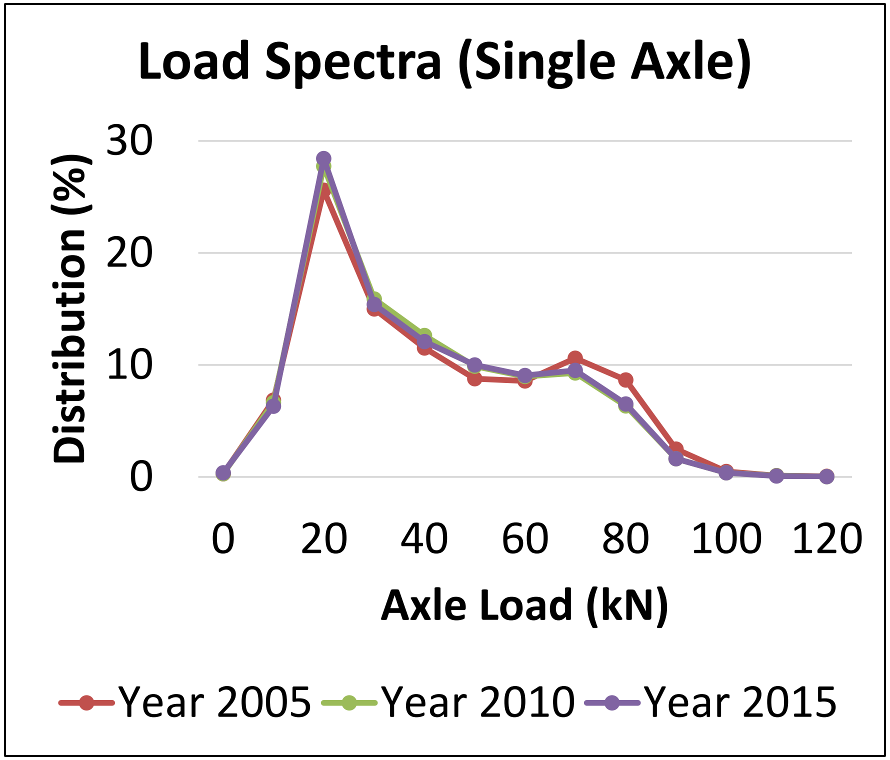
Source: URS, August 3, 2015.

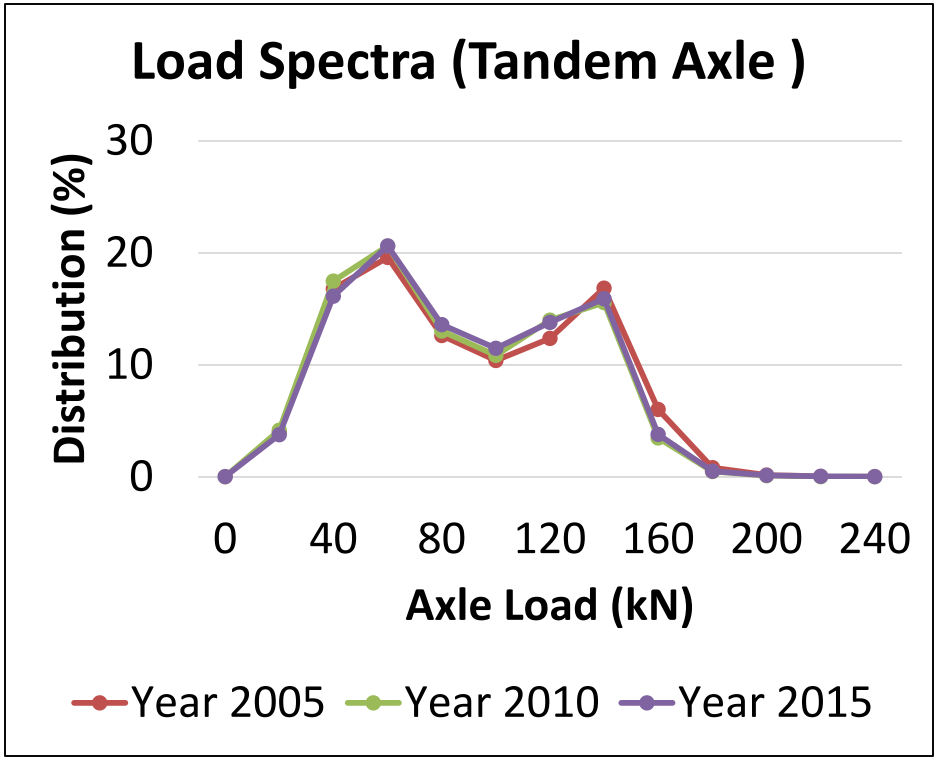
http://graphics.latimes.com/responsivemap-pollution-burdens/

https://www.uschamber.com/issue-brief/ozone-national-ambient-air-quality-standards

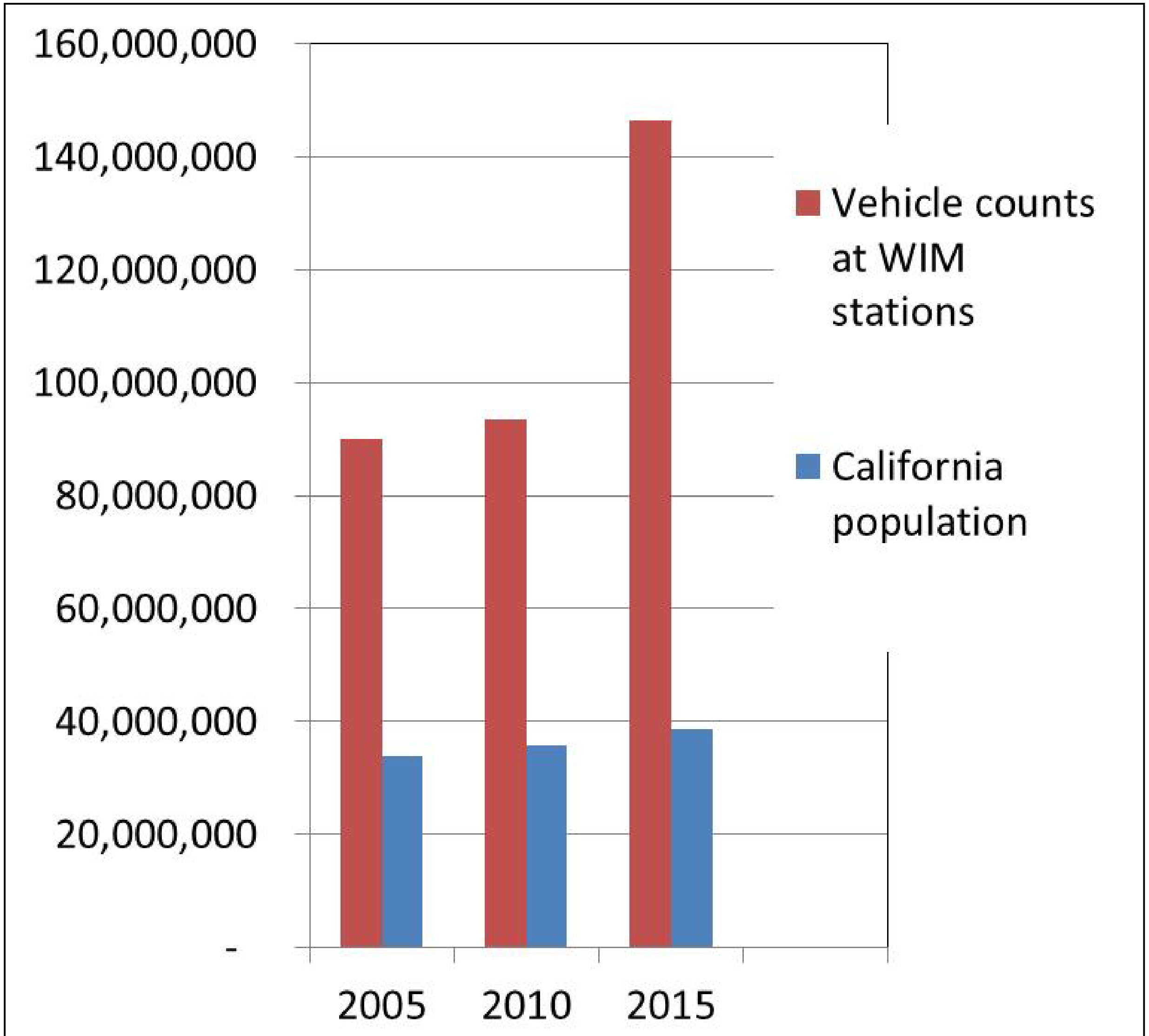
Truck traffic axle weights increasing?

- State-wide average axle loads (115 WIM stations) virtually unchanged in 10 years
- Gross vehicle weights slightly reduced





Freight growth: more trucks

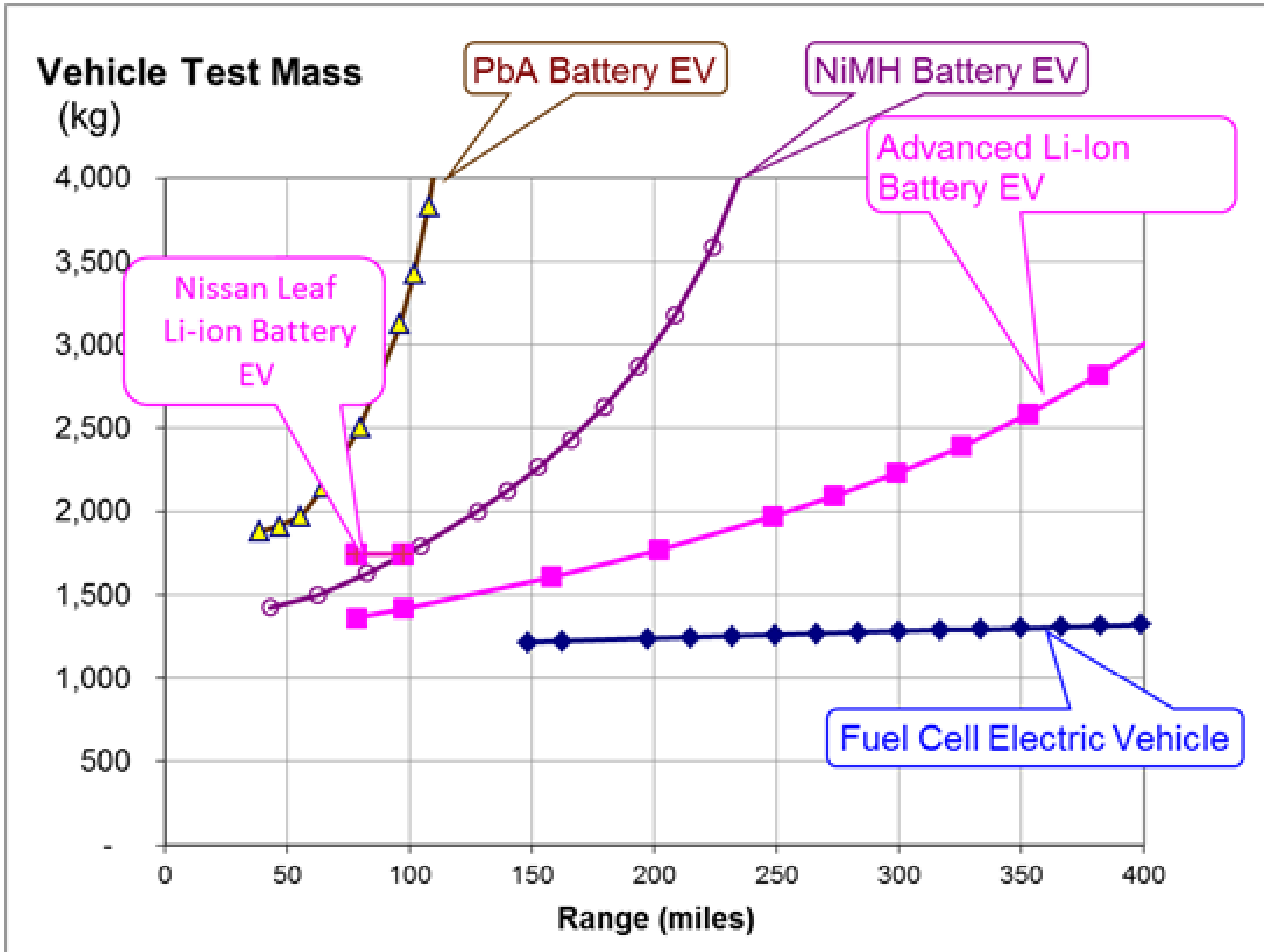


- 62% increase in truck counts vs 14% growth in population
- Short-haul: 69% increase
- Long-haul: 59% increase

UCPRC/Caltrans WIM data

Electric vehicles and weight

- Eurrently about 30% heavier for about 30% of the range
- Trucks use same technologies as cars, more range = add more batteries
- Fuel cells questionable



http://www.cleancaroptions.com/html/ev_weight.html
DeMorro, 2015, https://cleantechnica.com/2015/03/17/lighter-batteries-may-prove-tipping-point-electric-vehicles/

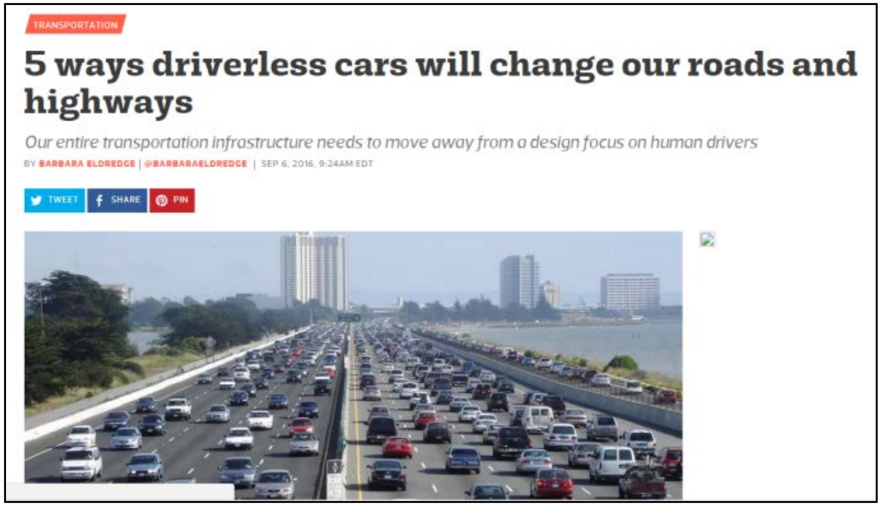
Long and short haul trucks available now

WAZE. OUTSMARTING TRAFFIC, TOGETHER.

What is wrong with this image if trucks use Waze and you are a local government?

Autonomous Vehicle Technology

- Fully automated truck platooning expected to deploy starting 2020 and broad implementation by 2030
  - 3 to 13% fuel savings
- Asphalt surfaced pavement
  - Channelized traffic if wander is not programmed into guidance, = faster rutting and fatigue
  - Truck platooning will reduce thixotropic recovery times at high speeds, larger strains
- Automated Vehicles Symposium 2017 and 2018
  - No discussion of effects on pavement


TRANSPORTATION

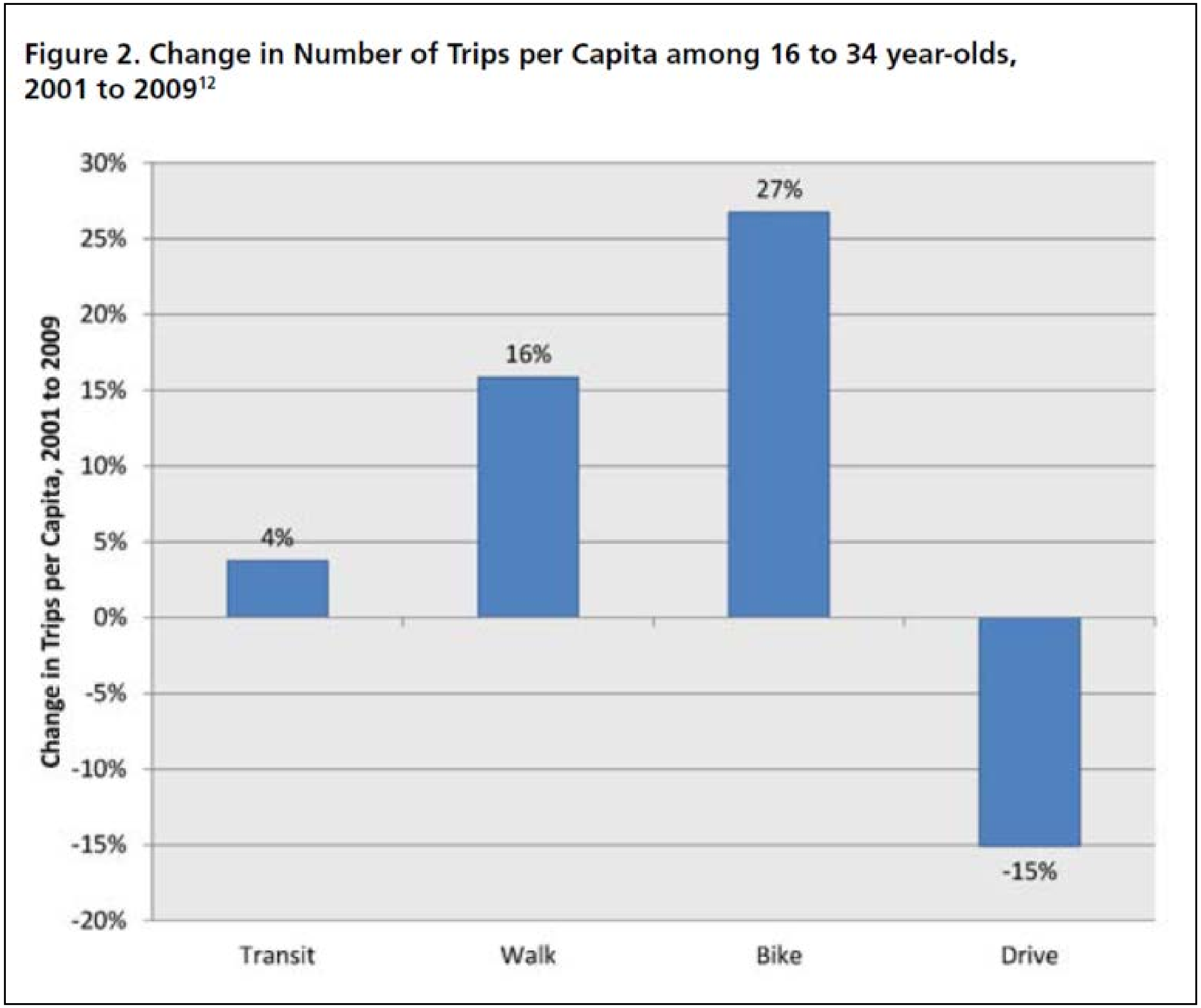
5 ways driverless cars will change our roads and highways

Our entire transportation infrastructure needs to move away from a design focus on human drivers

BY BARBARA ELDREDGE | @BARBARAELDREDGE | SEP 6, 2016, 9:24AM EDT

TWEET SHARE PIN

What kind of pavement will we need in the future?



Millennials driving the trend; may not just be recession

Less interested in cars; use of technology to connect instead of travel; more interested in walkable, bikeable cities; fewer or more vehicles

NCST white paper, Feb 2016, What affects US passenger travel? Current trends and future perspectives;
US PIRG, Oct 2014, Millennials in Motion

Summary of Sustainability Goals

- Respond to changes in vehicle technology
- Save the planet from excessive global warming
  - Reduce greenhouse gas emissions from pavement and interactions of pavement with other systems
- Reduce local emissions harming people
  - Air pollution, water pollution, etc
- Do not use finite resources too quickly
- Maintain economic competitiveness
- Improve pavement effects on human quality of life
- Achieve equity to all people in access to opportunities provided by pavement
  - Access to education, health care, jobs, recreation

Tools for Measuring Sustainability

- Life Cycle Cost Analysis (LCCA)
  - Economic
- Life Cycle Assessment (LCA)
  - Range of environmental impacts, quantitative
- Social Life Cycle Assessment (S-LCA)
  - Indicators for social outcomes and equity

Reasons to Measure

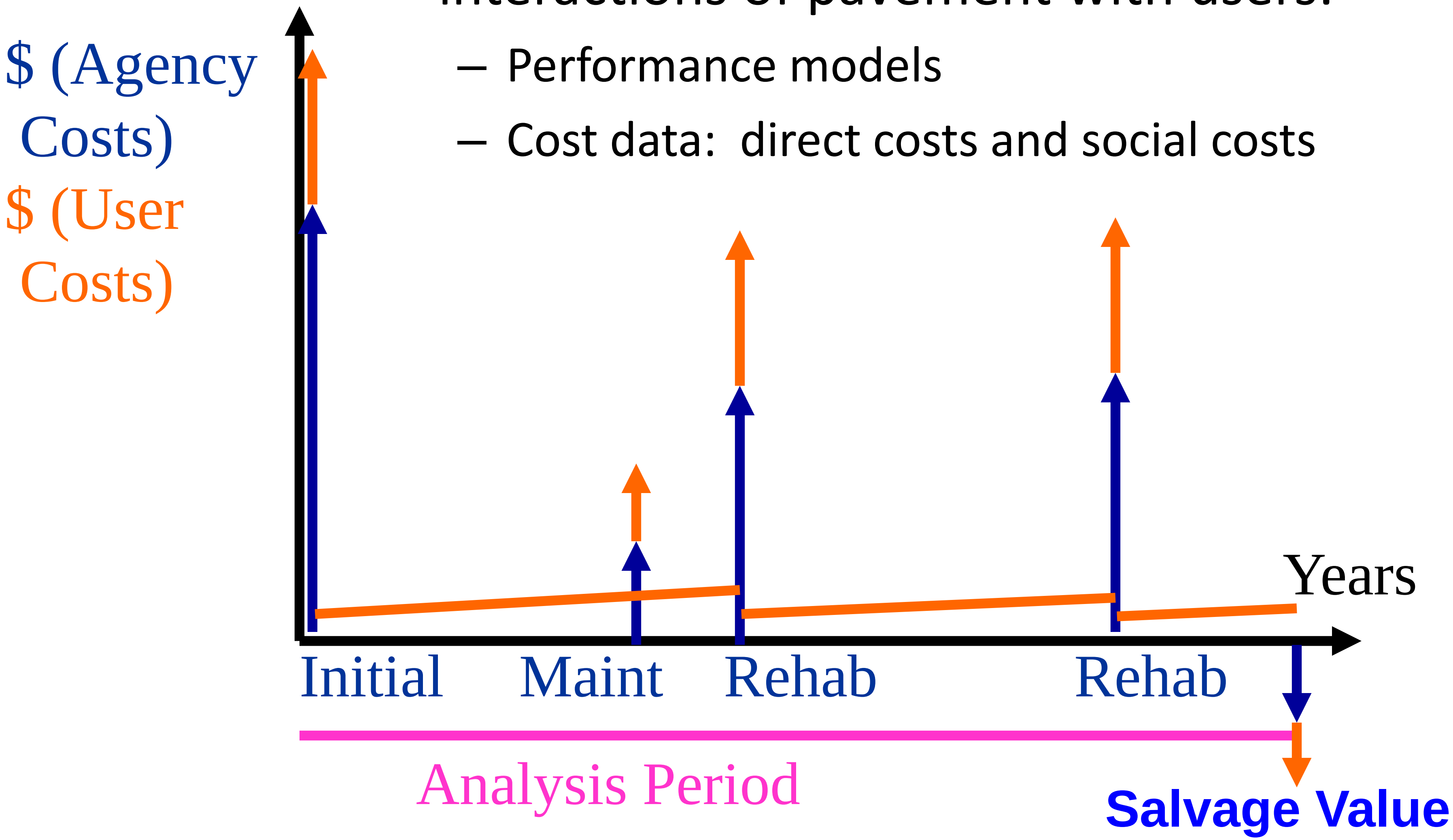
Decision support

Establish baselines for process improvement

Reporting for public, industry and government

Life Cycle Cost Analysis (LCCA)

- Need for both pavement and interactions of pavement with users:
  - Performance models
  - Cost data: direct costs and social costs



Four Key Stages of Life Cycle Assessment

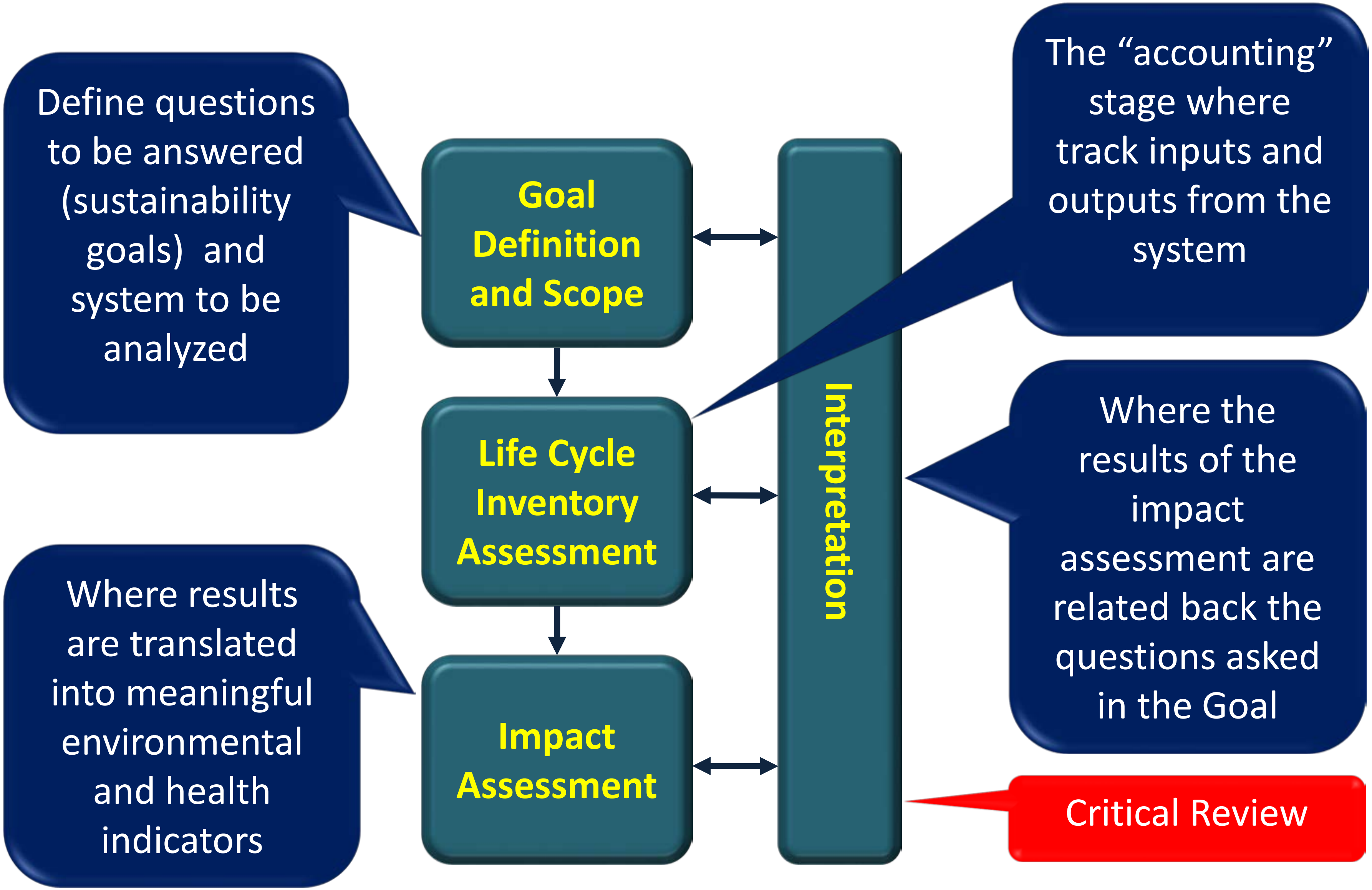
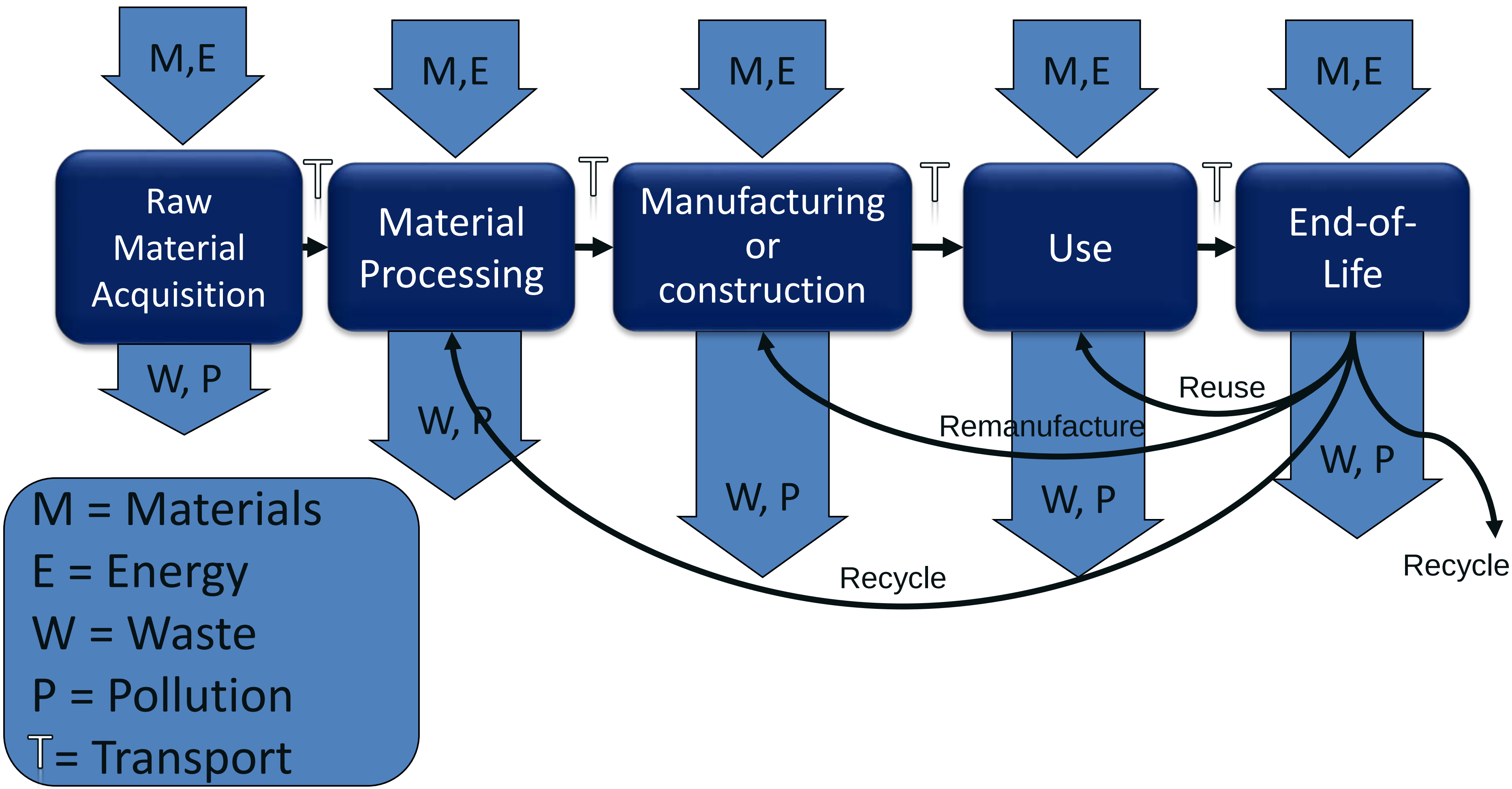


Figure based on ISO 14040, adopted from Kendall

Inventories of flows needed for all life cycle stages

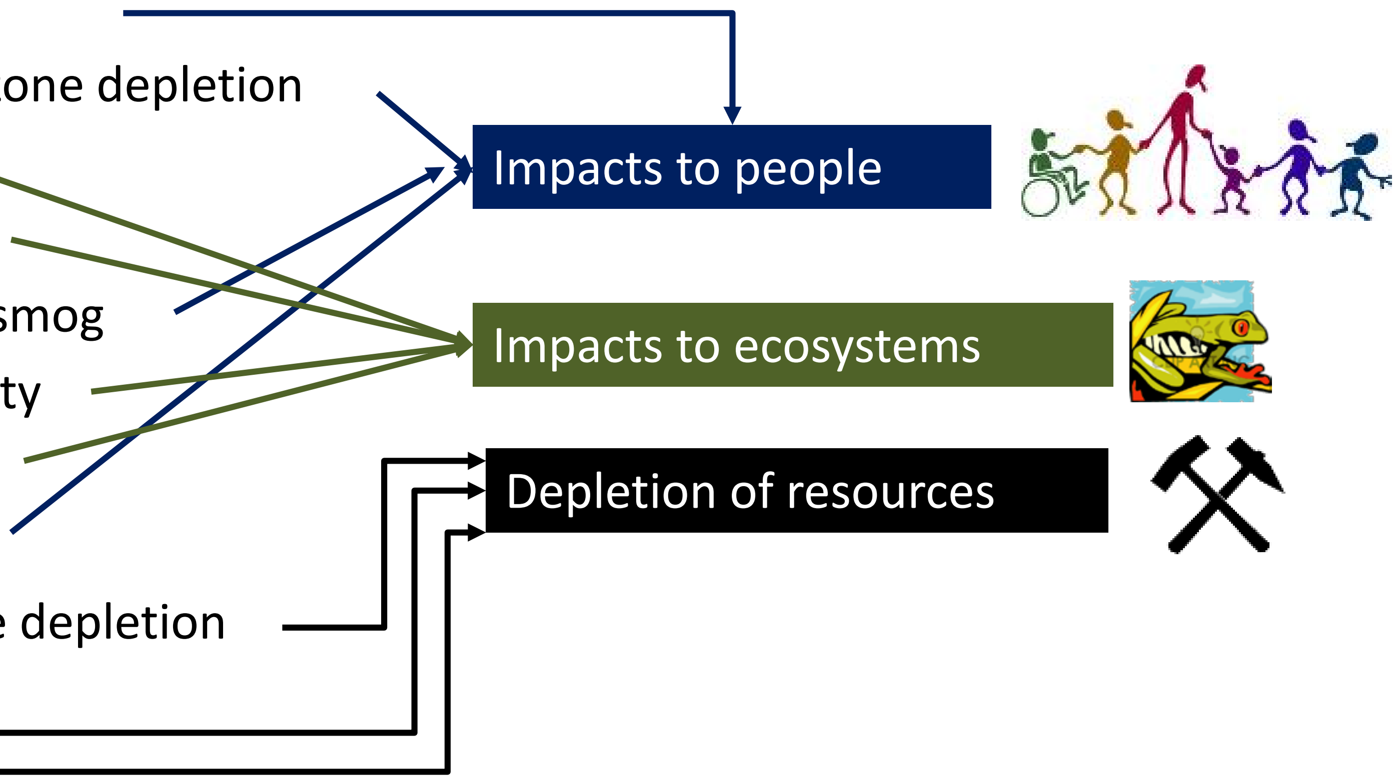


Kendall, A., Keoleian, G. A., 2009

US EPA Impact Assessment Categories

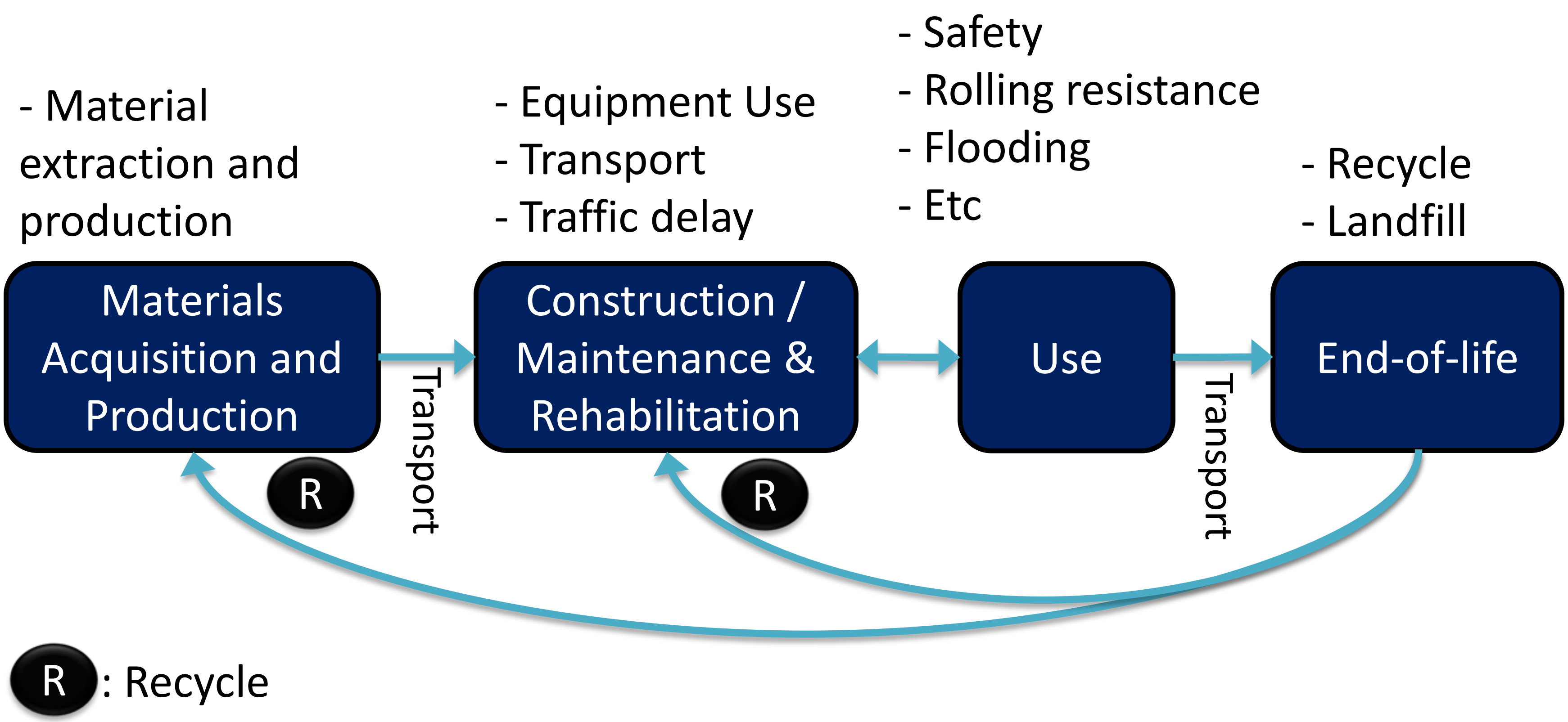
(TRACI – Tool for the Reduction and Assessment of Chemical and other environmental Impacts)

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



From Saboori   *Image sources: Google*

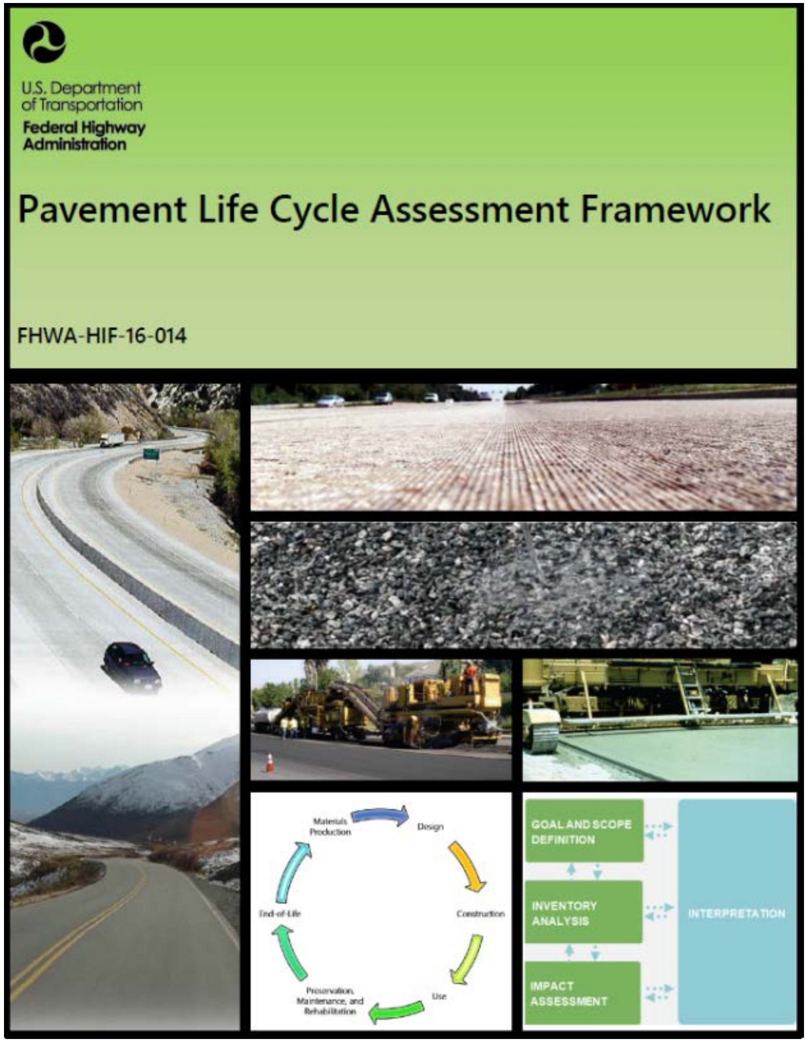
Pavement Life Cycle Stages data and performance models needed for each stage



From: Kendall et al., *2010*

ISO Standards and FHWA Pavement LCA Framework Document

- Search "FHWA pavement LCA framework"
- International Standards Organization (ISO) standards for LCA are generic for all materials
- FHWA guidance specific to pavements published in 2016



Social-LCA for transportation

- Indicators and models being developed
- All indicators being reviewed for equity of transportation investment between poor and rich neighborhoods

Selected S-LCA Indicator Category	Selected performance measures
Jobs	Access to Jobs
	Job Creation
Accessibility/ Equity	Access to Community Destinations
	Access to School
Mobility/ connectivity	Average Travel Time
	Average Trip Length
	Connectivity Index
	Bike/Pedestrian Delay
Safety/ public health	Level of Service (bicycle and pedestrian)
	Crashes
	Physical Activity and Health
Livability	Green Land Consumption
	Street Trees

Pavements = urban hardscape not just roads and streets

- Stormwater management, groundwater infiltration
- Tire pavement noise
- Human thermal comfort
- Pedestrian and bicycle functionality
- Better interaction with urban forestry

Getting to Sustainable Streets

From Janet Attarian, 2017

Where can LCA and LCCA be implemented now?

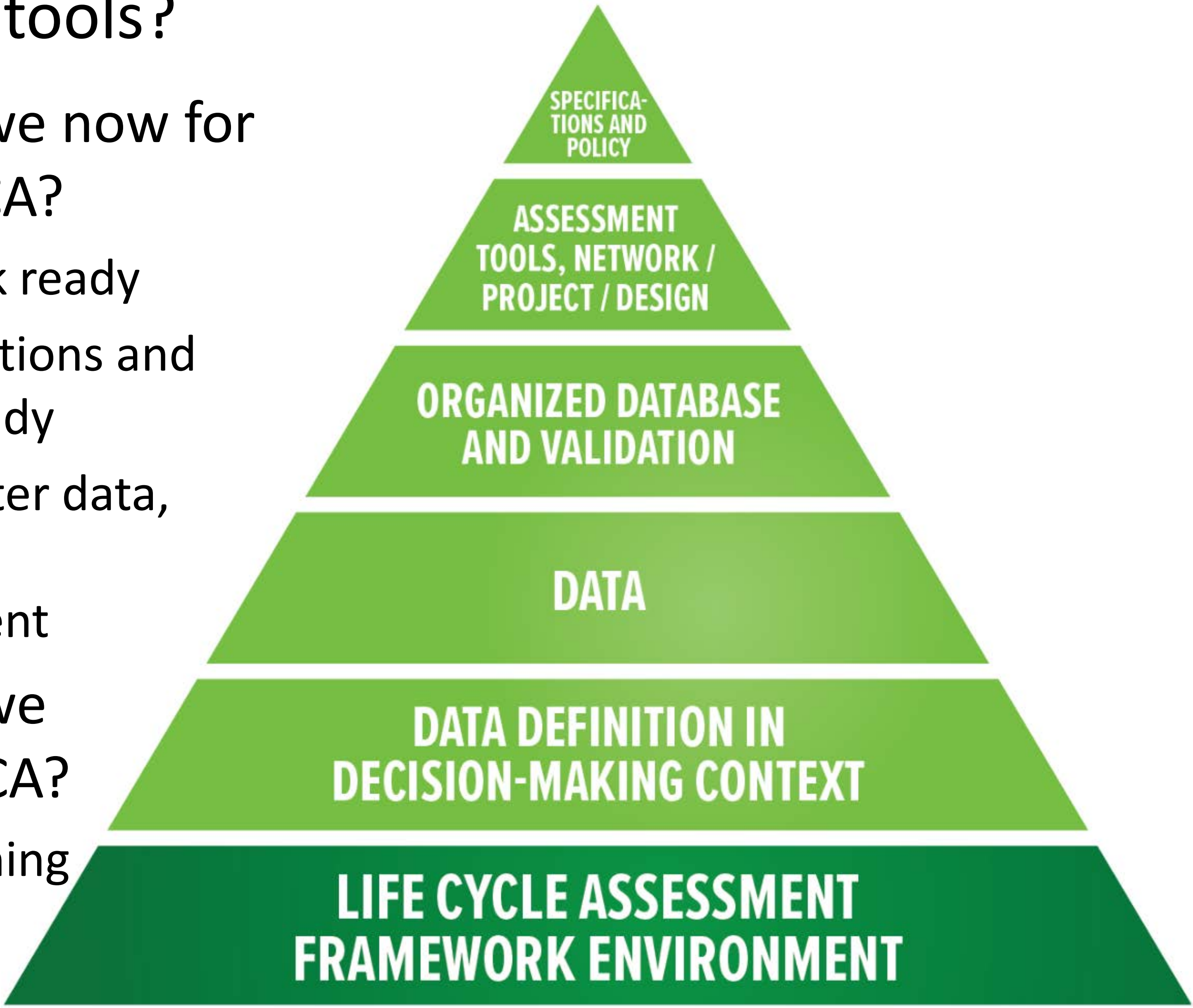
- Pavement management system optimization
  - Condition trigger levels for treatment (timing)
  - Treatment selection
- Pavement planning and design
- Policy evaluation
  - Funding planning for maintenance, rehabilitation
  - Materials changes
  - Construction quality specifications
  - Design methods

Implementation Fundamentals

- Implementation of new technology has not occurred until it is used in every day standard practice
- To achieve implementation requires about:
  - $ 1 of research
  - $ 3 of development
  - $ 6 of support for implementation
    - Tools
    - Piloting
    - Training
    - Support
- All of these are required

Steps in development of pavement LCA, LCCA and S-LCA tools?

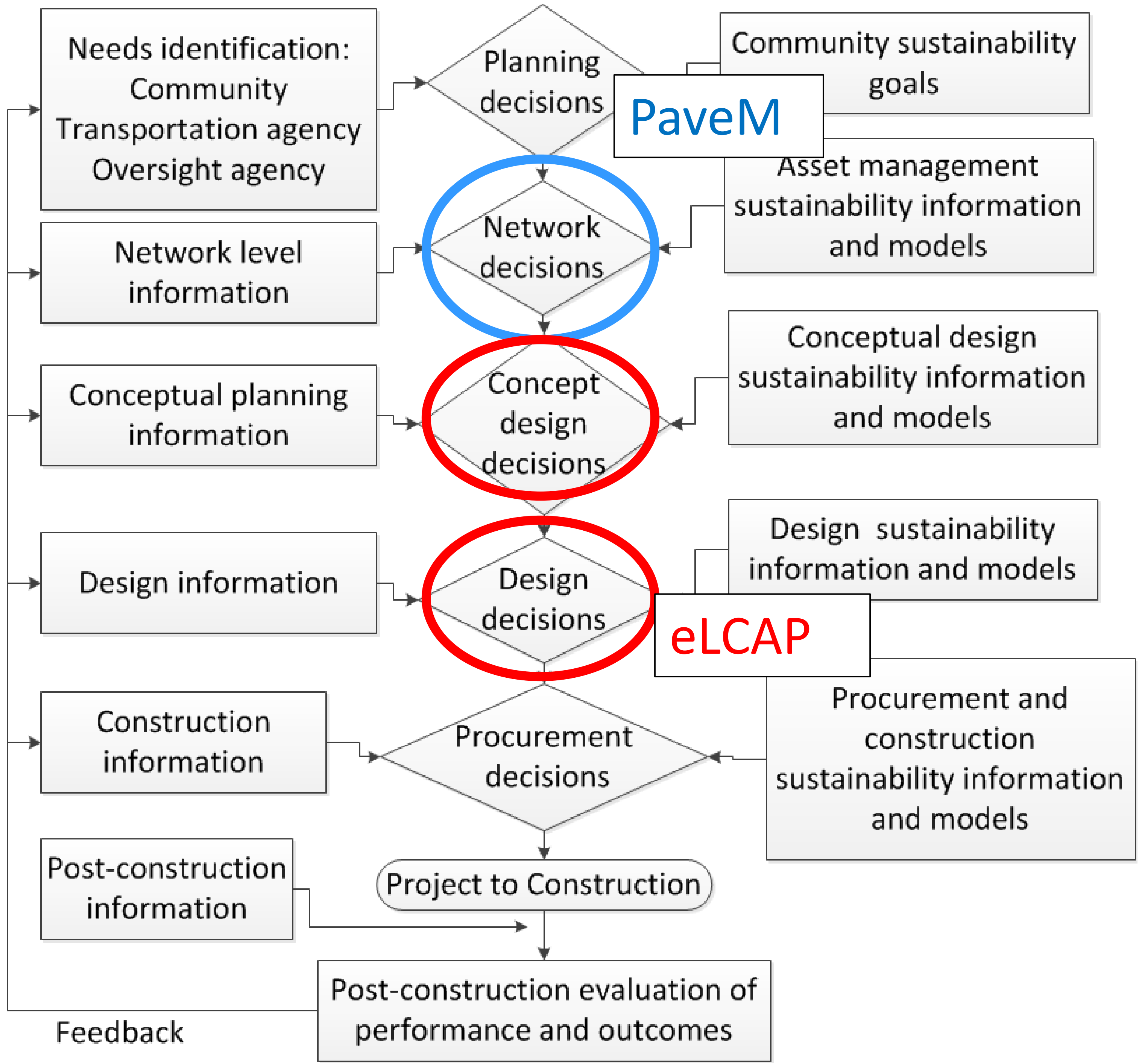
- Where are we now for LCCA and LCA?
  - Framework ready
  - Data definitions and models ready
  - Need: better data, more tool development
- Where are we now for S-LCA?
  - Just beginning



Objective: web-based integrated tools for:

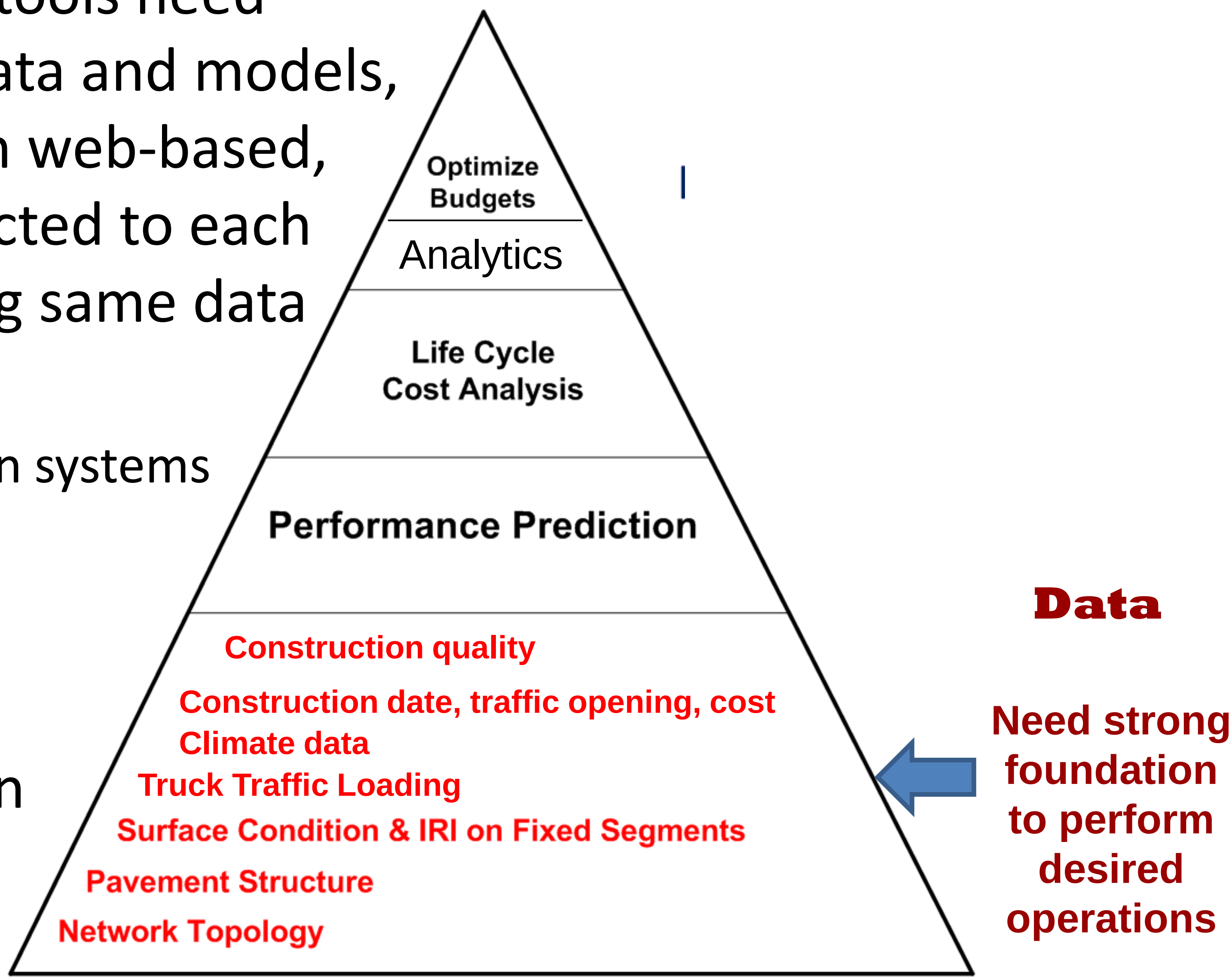
- Network
- Concept
- Design

With complete life cycle and regionally applicable data



PMS, LCCA, LCA all need some common data

- Pavement tools need updated data and models, make them web-based, and connected to each other, using same data
  - PMS
  - ME design systems
  - LCCA
  - LCA
- Update information routinely



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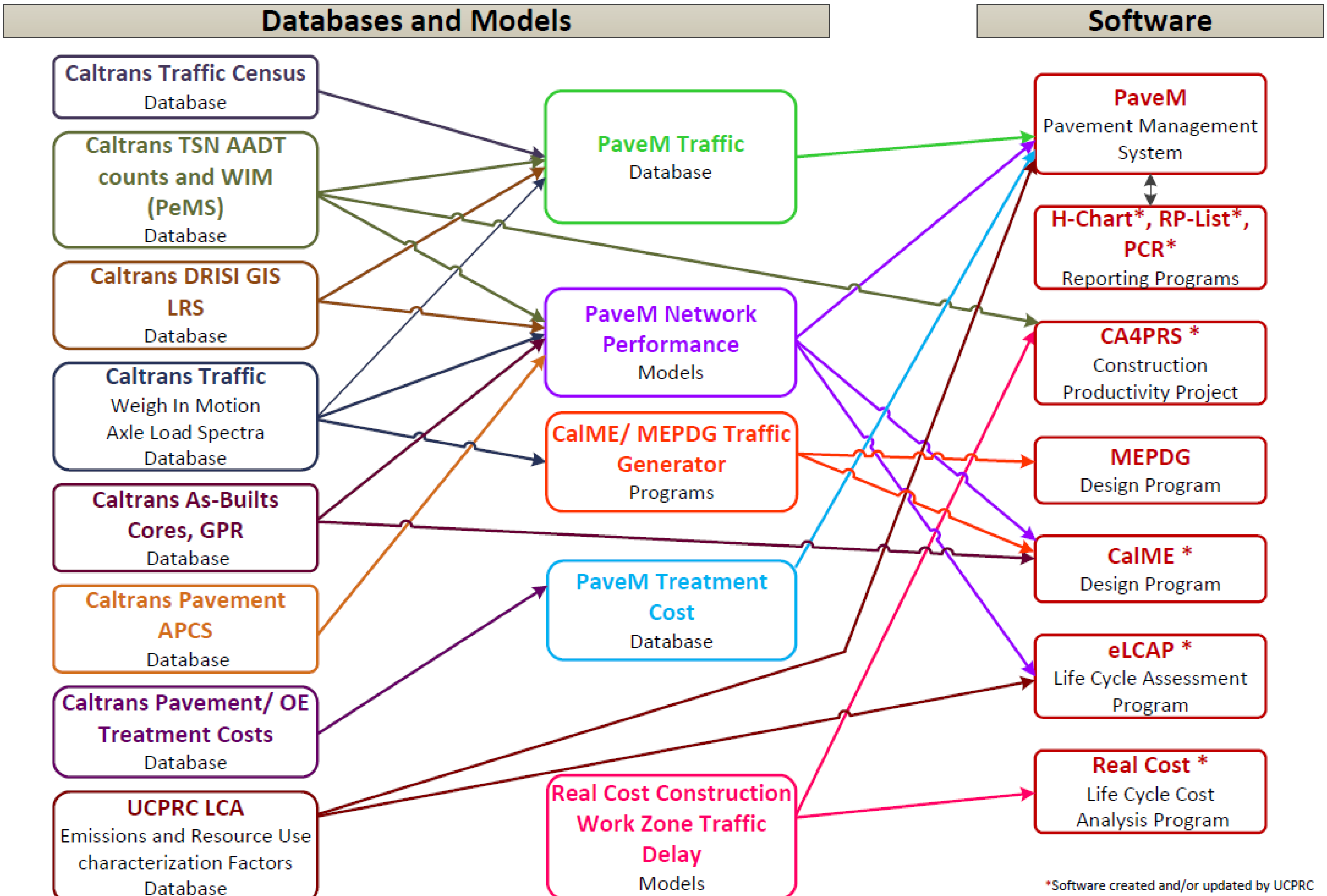
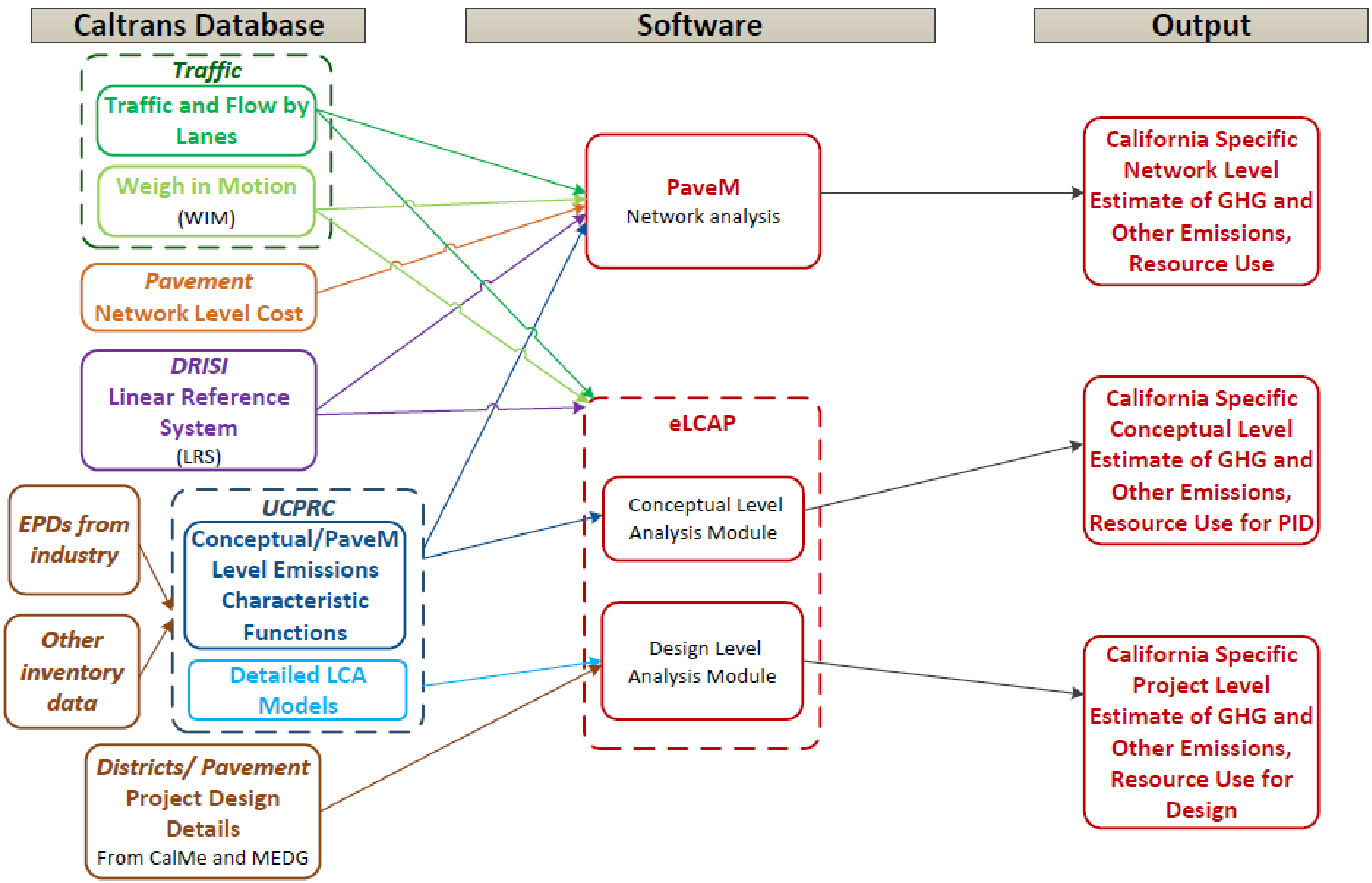
Caltrans Pavement Engineering and Database/Software Interactions



eLCAP and PaveM Functionality and Data Sources



How to get better regional data for materials: Environmental Product Declaration (EPD)

Adapted from Pavement Interactive

Environmental Facts

Functional unit: 1 metric ton of asphalt concrete

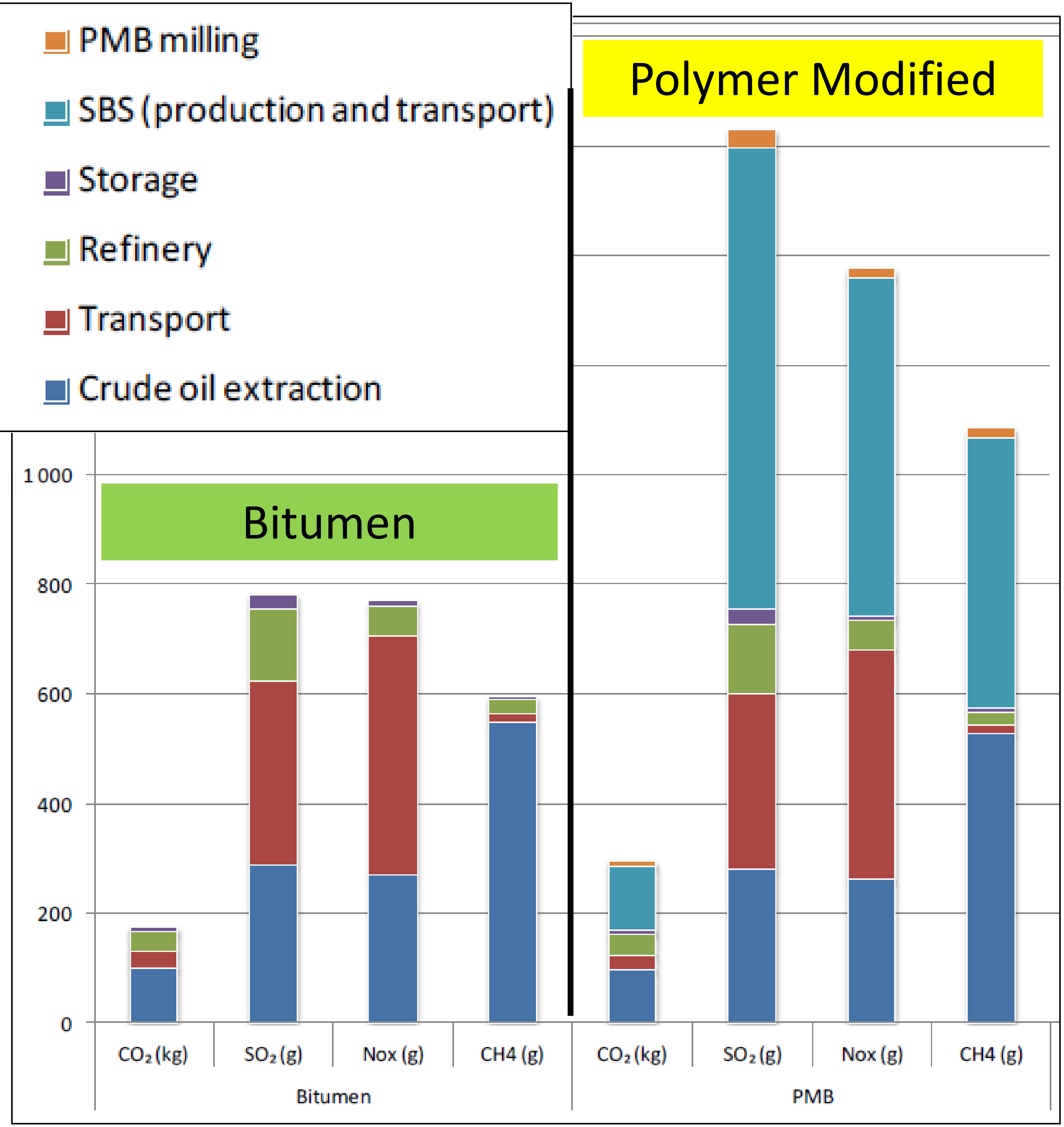
Primary Energy Demand [MJ]	4.0×10^3
Non-renewable [MJ]	*3.9×10^3*
Renewable [MJ]	*3.5×10^2*
Global Warming Potential [kg CO_2-eq]	79
Acidification Potential [kg SO_2-eq]	0.23
Eutrophication Potential [kg N-eq]	0.012
Ozone Depletion Potential [kg CFC-11-eq]	7.3×10^{-9}
Smog Potential [kg O_3-eq]	4.4

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

Example LCA results

Recommended 3 Stage Approach for Implementing EPD Requirements

1. Develop rules and then require reporting, move towards standardization of EPDs (1-2 years)
   - Caltrans will begin requiring EPDs for pavement materials in 2018
2. Develop standardization, rigor, review process, level playing field, appropriate applications (3 to 5 years)
   - Most of Europe has standardized EPD requirements
3. If desirable and have made sufficient progress, consider using for procurement
   - Defining principle: Must take into account equivalent performance
   - Netherlands, France, Sweden are using for selecting contractors



PMB manufacture causes about 60% more air emissions than straight bitumen in Europe;

True in US? Can modified asphalt show more than 60% increase in life?

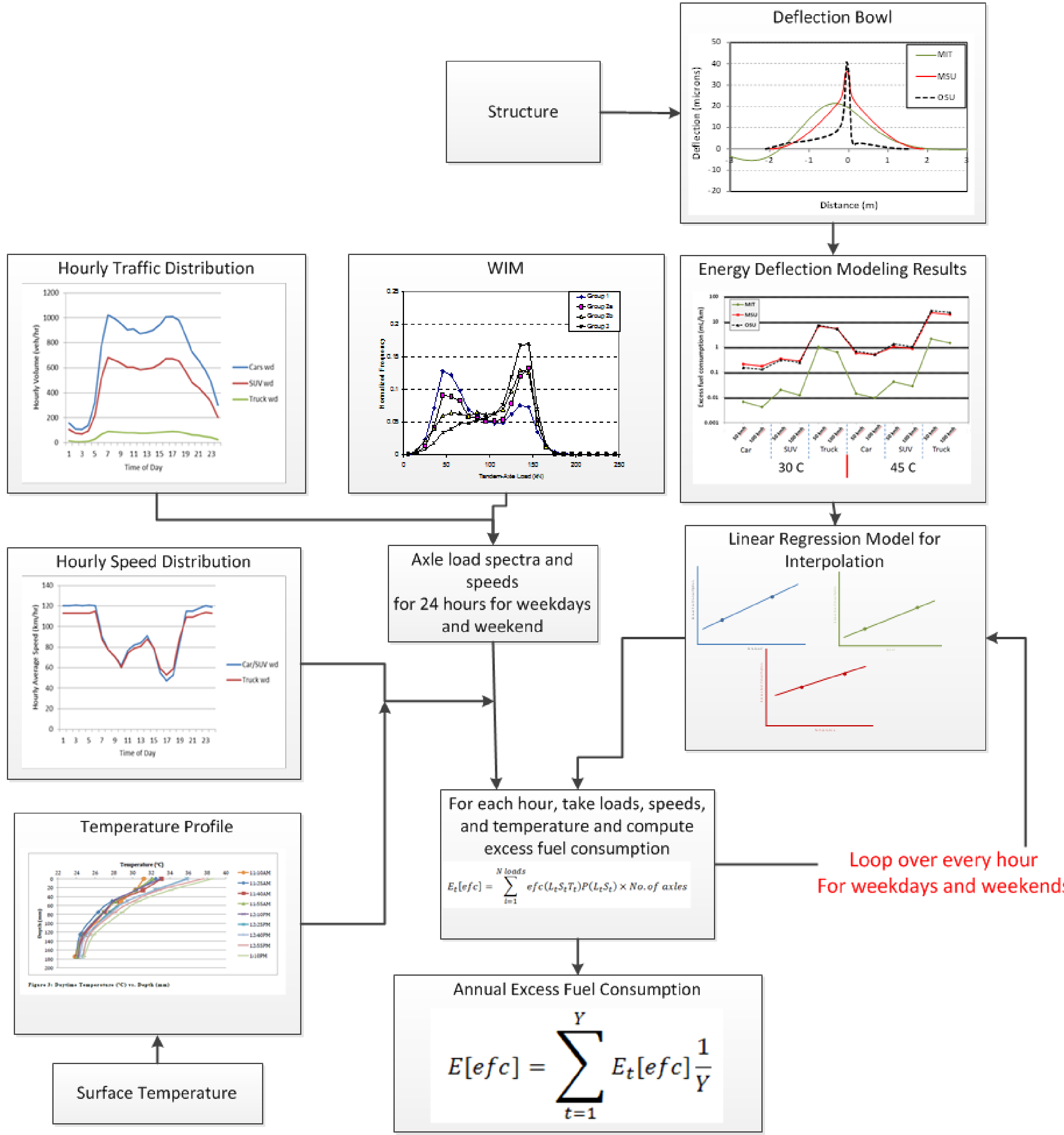
Eurobitume LCI
Bernard et al. Nantes LCA 2012

Caltrans Network: Optimal IRI to trigger treatment for GHG by traffic group

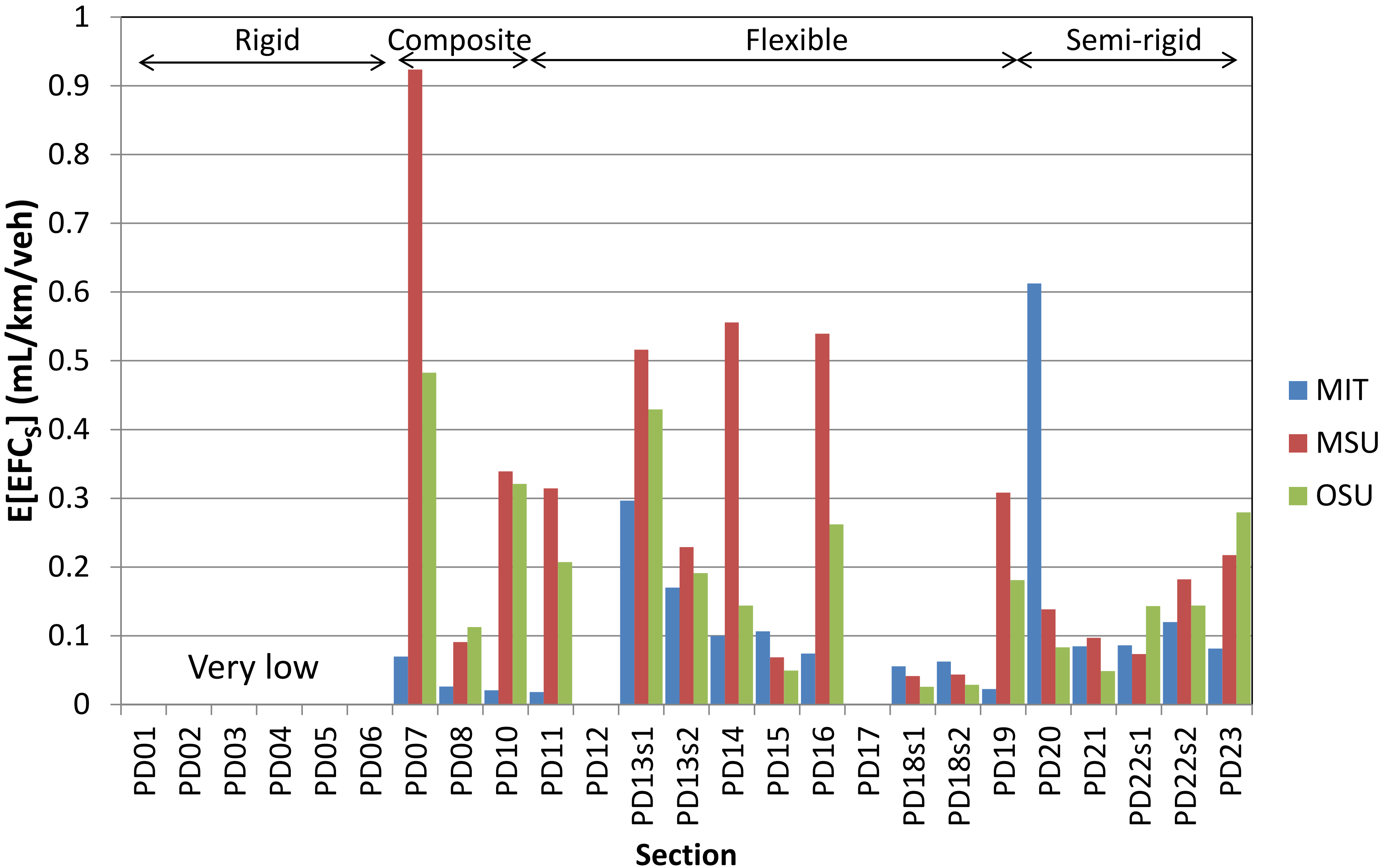
Daily equivalent vehicles of lane-segments range	Total lane-miles	Percentile of lane-mile	Optimal IRI triggering value m/km, (inch/mile)	Annual CO_2-e reductions (MMT)	Modified total cost-effectiveness ($/t$CO_2$-e)
<2,517	12,068	<25	-----	0	N/A
2,517 to 11,704	12,068	25-50	2.8 (177)	0.141	1,169
11,704 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

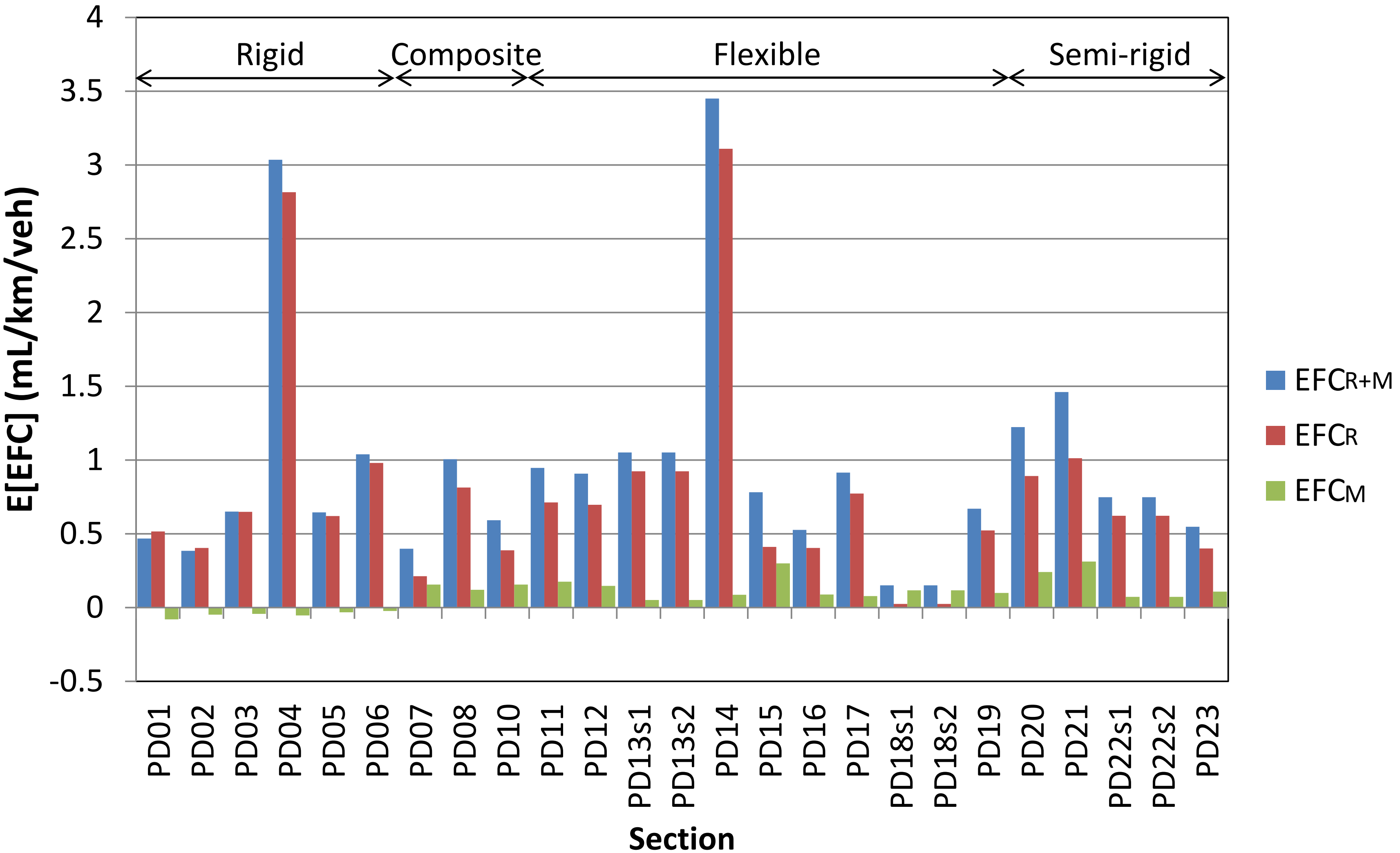
Annual Excess Fuel Consumption from Asphalt Viscoelastic Response Simulation flowchart



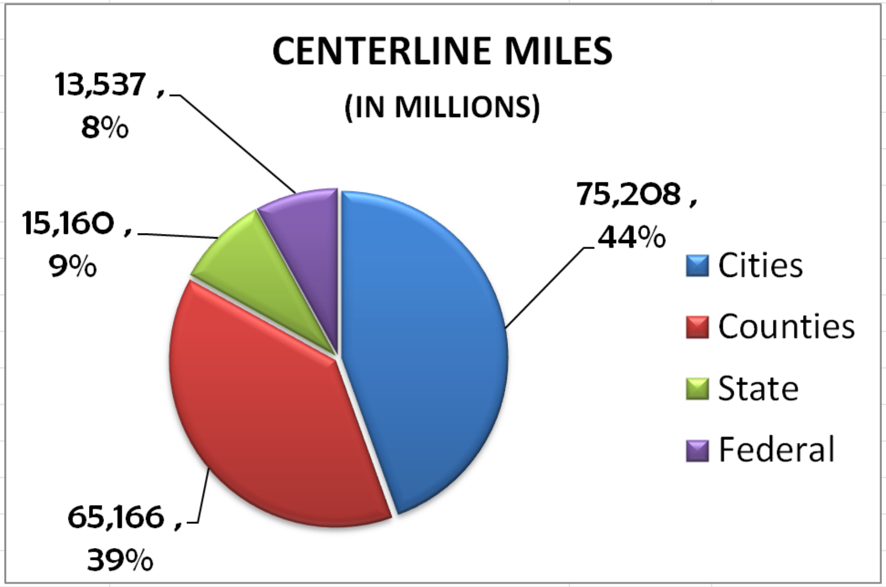
Structural Response Simulation Results by factorial traffic/climate (avg ml/km/veh EFC)

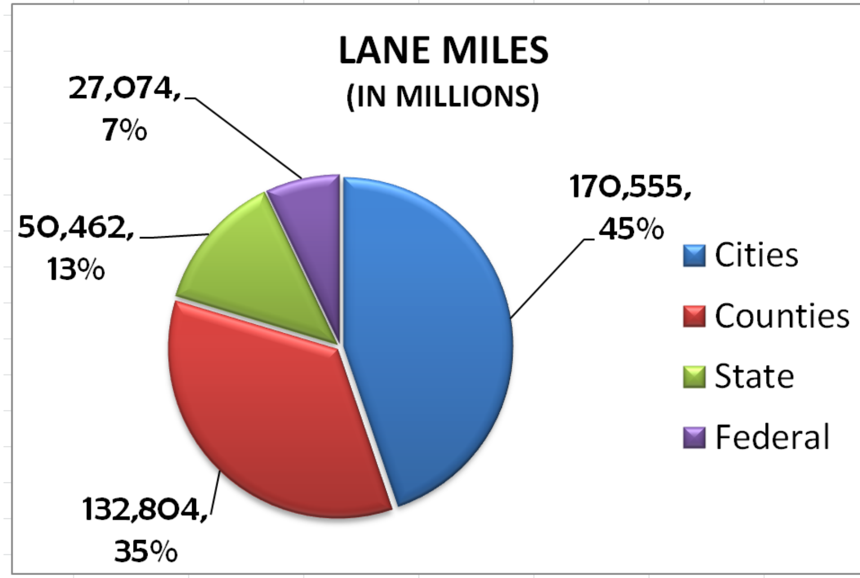


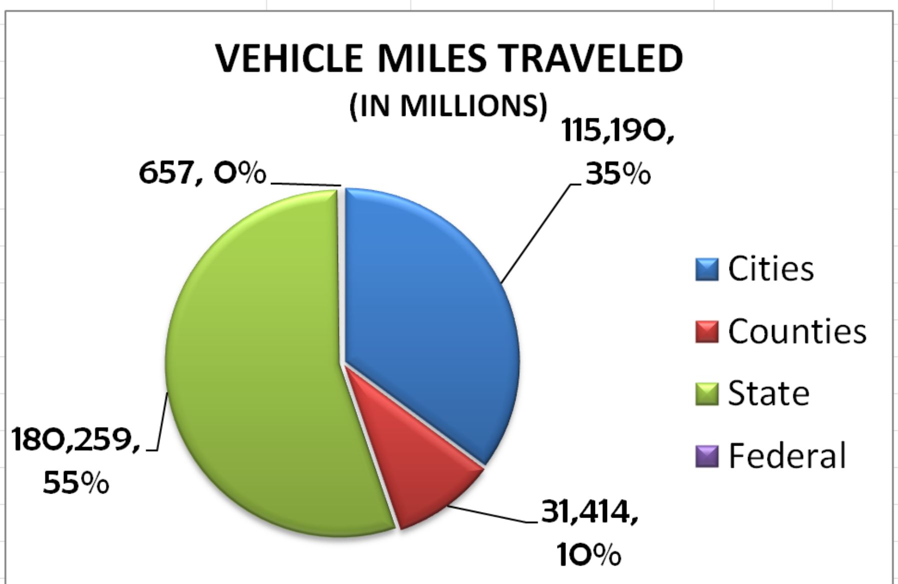
Roughness (R) and Macrotexture (M) Simulation Results by Section Specific Data relative to 0.6 m/km and 0.5 mm (avg ml/km/veh EFC)



The Forgotten 80% of Our Pavements







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

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

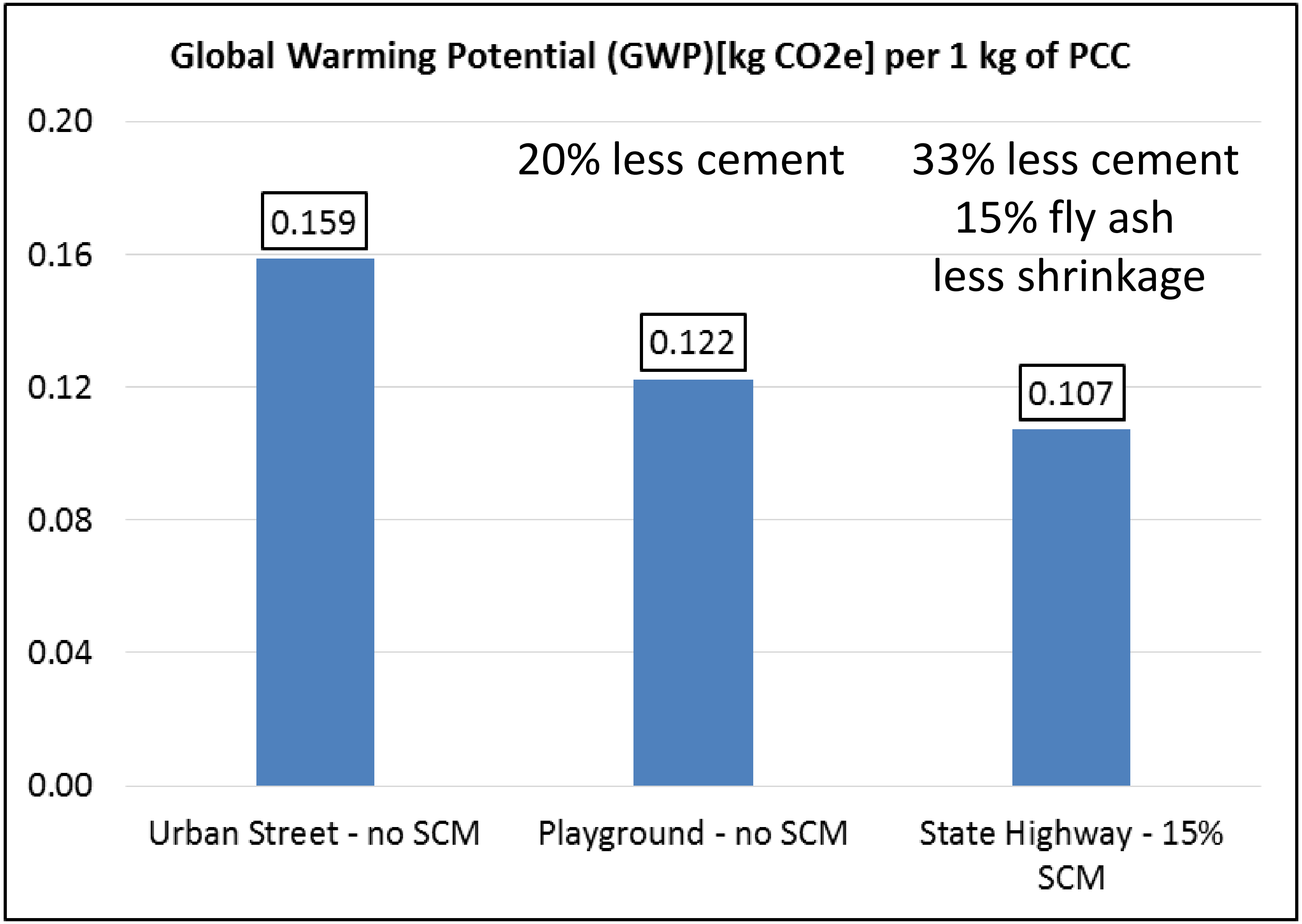
County LCCA and LCA example: 8% vs 12% air-voids

- Assumptions:
  - Rural pulverize HMA, compact, 4 in. HMA
  - $31/m^2
  - 12% air-voids = 12 year life
  - 8% air-voids = 18 year life
- Net present cost* per ln-mi over 50 year period:
  - 12% air-voids = $2.6 million
  - 8% air-voids = $1.9 million = **29 % less cost**
- Greenhouse gas emissions are **34% less**

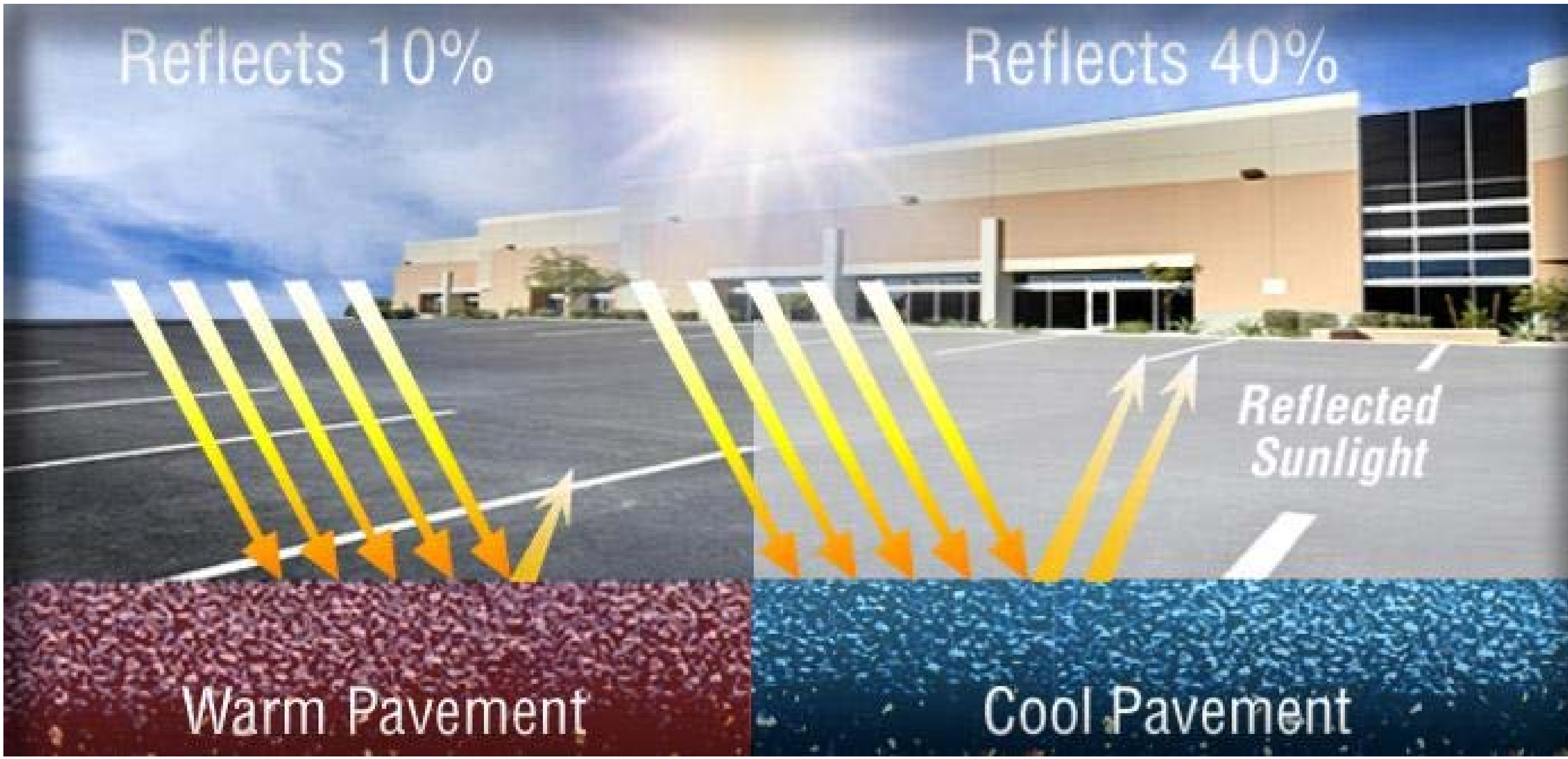
*2% discount rate

Effects on greenhouse gas emissions of concrete specifications for concrete cement & SCM content

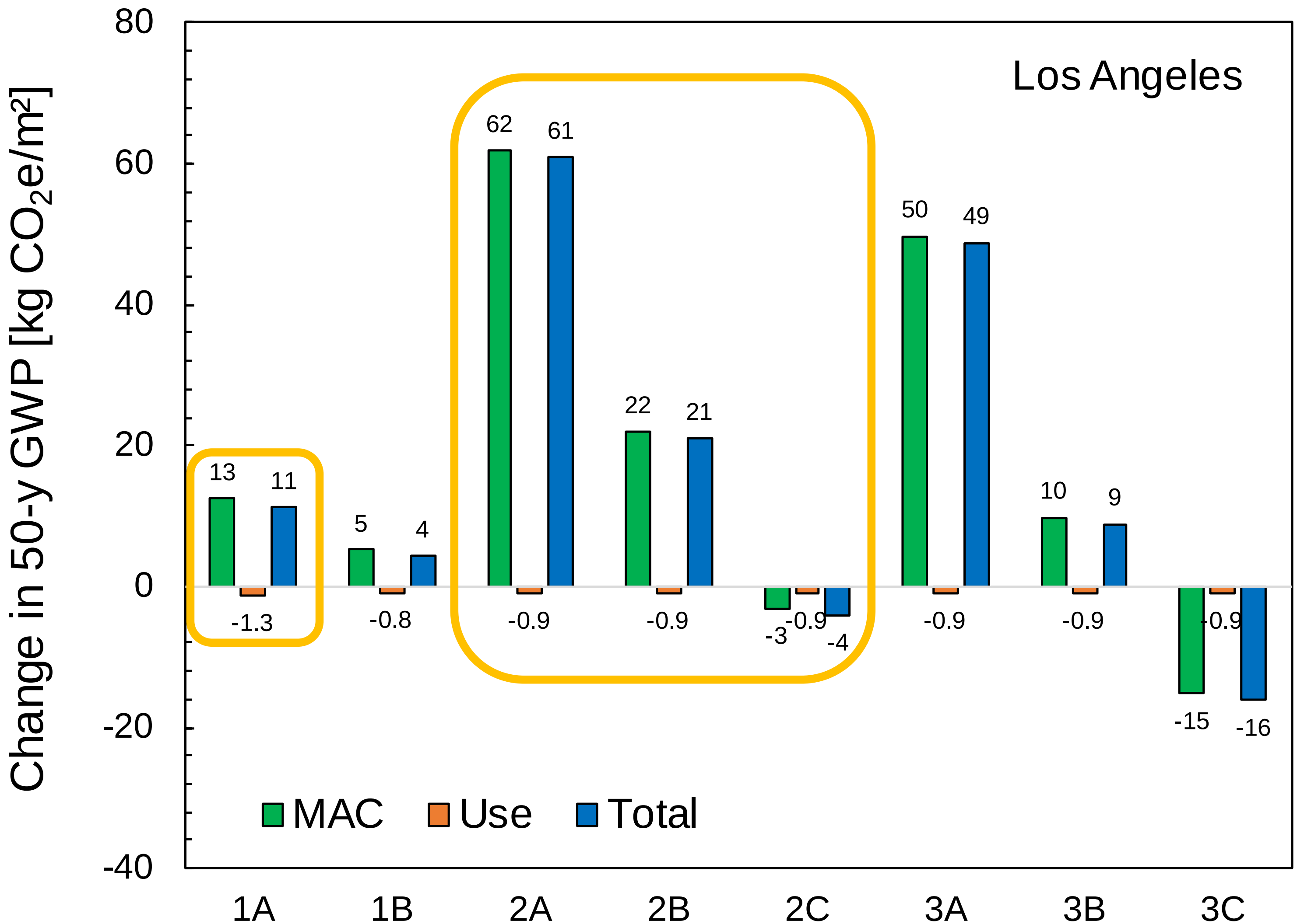
- Mix designs from a city that hasn't reviewed specifications and Caltrans heavy duty highway



To reduce greenhouse gases California passed a law to make pavements more reflective, was it the right thing to do? LCA can be used to check policy



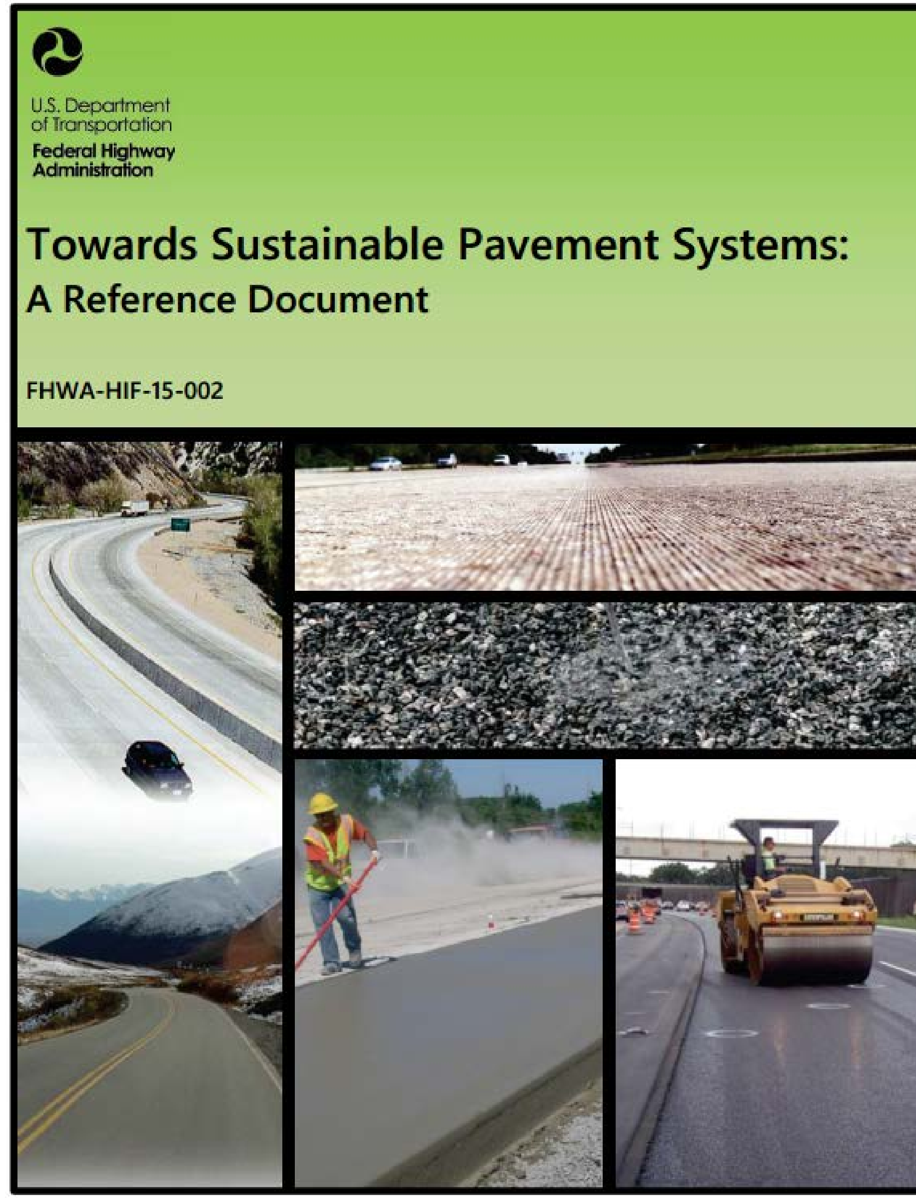
Difference in greenhouse gases for: asphalt inlay vs thin concrete, slurry vs reflective coatings



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

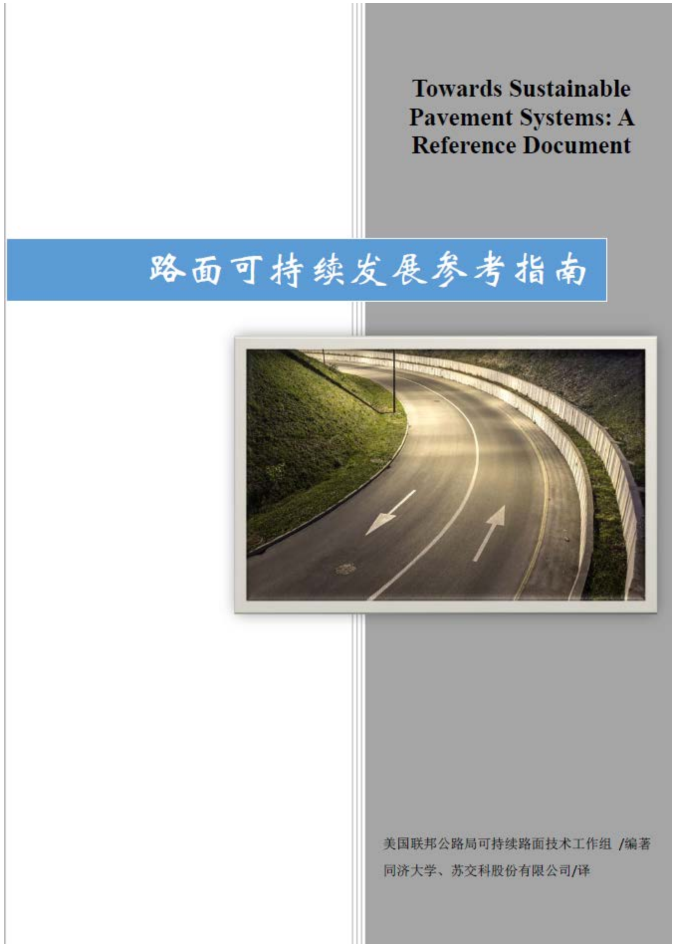
So what can be done to make pavements more sustainable?

- FHWA Sustainable Pavements Task Group
  - More sustainable pavement reference document (2015)
  - Covers everything about pavement and sustainability
  - Tech briefs and webinars



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

路面可持续发展参考指南



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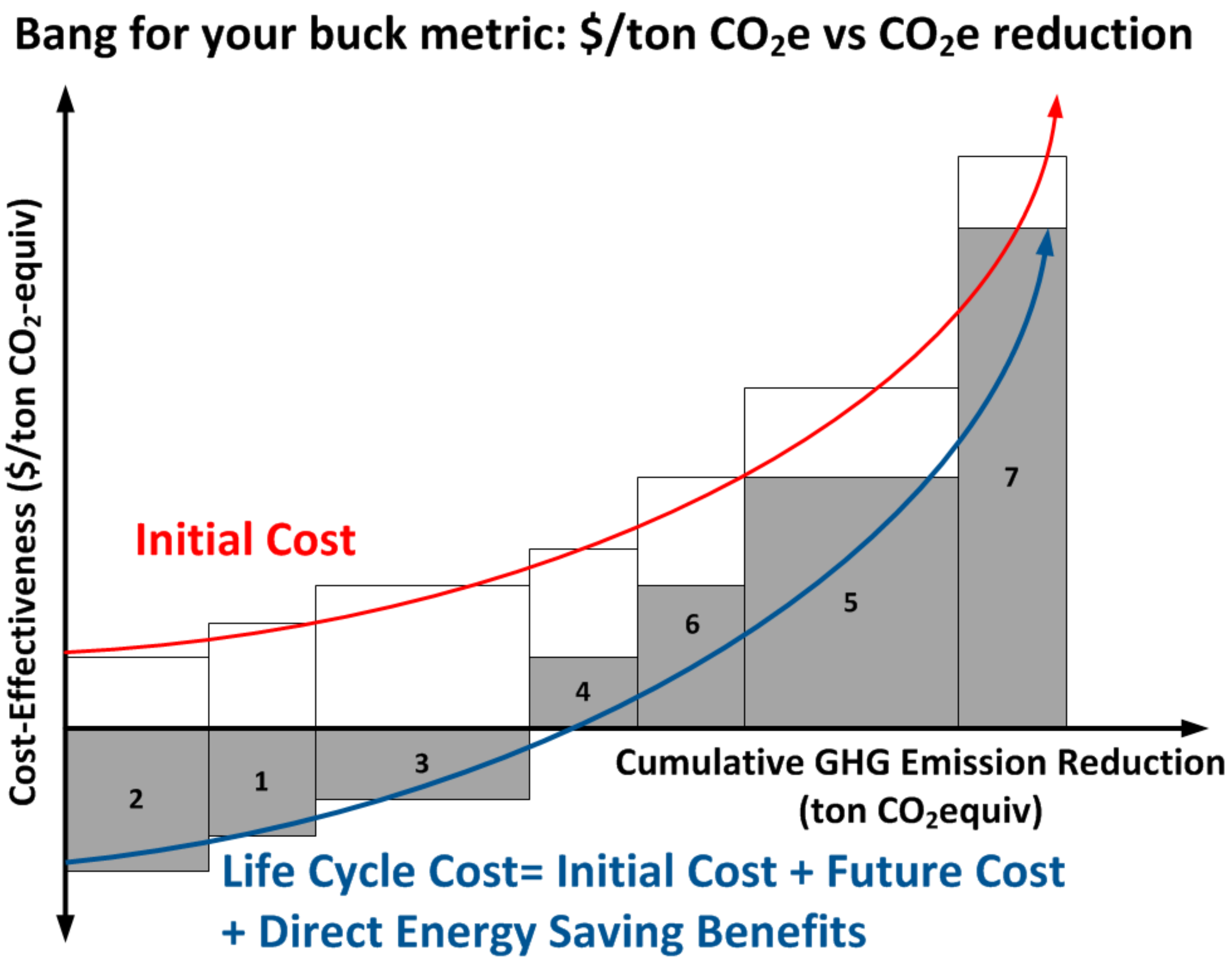
http://www.gowisdom.org/images/可持续铺面研究-V1206.pdf

How to prioritize what to do?



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
- Cost from Life Cycle Cost Analysis (LCCA)
- Environment from Life Cycle Assessment (LCA)

New Caltrans project beginning in 2018

- Calculation of Benefit/Cost for Alternative Strategies to Reduce GHG
  - Evaluate all potential strategies that Caltrans could undertake to improve sustainability, for example
    - Planning
    - Pavement and bridges
    - Equipment
    - Traffic operations
    - Land use for solar, other energy generation
  - Primary focus on greenhouse gases, but also on important local issues: air pollution

All new Caltrans pavement initiatives required to have LCA and LCCA

- Asphalt rubber
  - All Caltrans surfaces must be rubberized, top 60 mm
  - Next: deeper use of gap-graded rubber mixes
- Thin bonded concrete overlay on asphalt
  - 100 to 175 mm concrete overlays bonded to existing asphalt
- PG+X
  - All binders used in dense-graded hot mix to have 5 to 10 percent tire rubber
- High RAP mix
  - 16 to 40 %
  - Interaction with warm mix asphalt

Conclusions

- We must deliver more in terms of sustainability:
  - Cost, safety, smoothness, construction delay, small environmental impacts, local pollution
  - Asphalt paving: compaction,, recycling as long as equal or better performance, smoothness
- Deliver innovation that can be used
  - $9 on development, implementation for each $1 of research
- Be using LCA and LCCA now!
  - Optimize pavement management system decision trees
  - Evaluate <u>all</u> new materials and pavement structures as part of research & development process before implementation
  - Evaluate changes in policy, specifications
  - Review and respond to new and automated vehicles

Conclusions

- Put LCA, LCCA and later Social LCA tools into standard practice; next 5 years
  - Finish filling data and model gaps
  - Require EPDs
  - Deliver first generation tools
- Require training in LCA and LCCA for all undergraduate pavement students, starting now
  - Practice as part of their materials design classes
- Train all practicing engineers, pavement mangers, decision makers in LCA and LCCA, starting now
- Educate policy-makers on basics of LCA and LCCA and prioritization of policy using them, starting now

www.ucprc.ucdavis.edu

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Thanks to Caltrans and other sponsors