Environmental Sustainability of Pavement Materials: *Some thoughts to initiate discussion*

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Key Issues

- What does sustainable mean?
- What is the incentive?
- Who decides and how do they decide?
- What are the technical and human barriers?
- What are the institutional and legal barriers?
- What are the possible unintended consequences?
- What should we be doing now?

What does sustainable mean? My (own biased) perspective

- Currently "sustainability" is primarily a marketing theme for different products to capture market share from their rivals
- Our approach to date has often been:
  - Confusing to engineers and decision-makers
  - Unscientific
    - Biased
    - Incomplete
    - Not peer-reviewed by experts in the area of LCA
    - Not followed any established principles
    - Focused on wrong question: concrete vs asphalt for new pavement (see first bullet above)
  - Irrelevant by not addressing how decisions are made
  - Ignored the pavement environmental impact Hippocratic oath: "First, do no harm"

Where are we with regard to definition of sustainability?

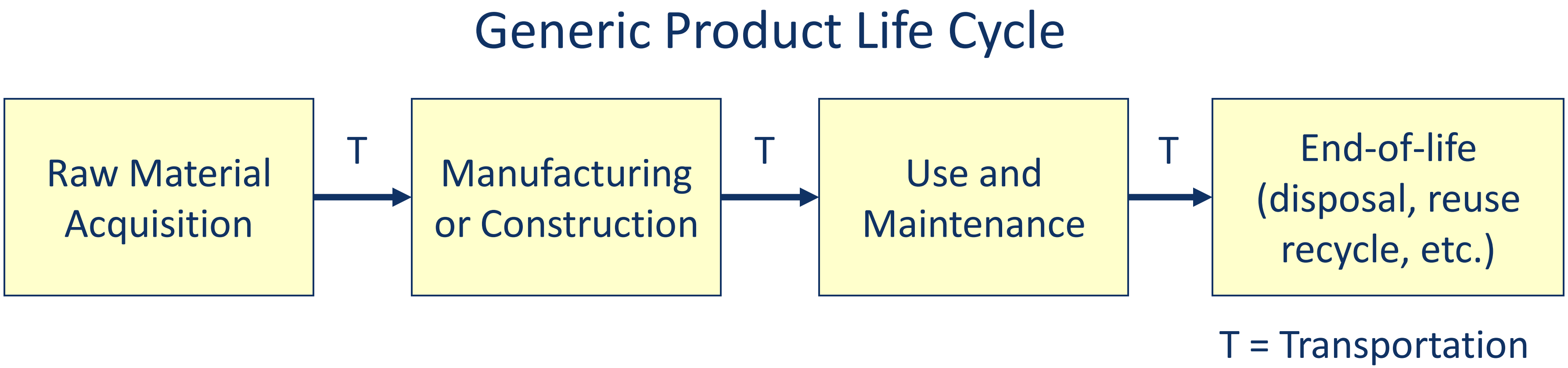
- We are just beginning to develop the science to really analyze sustainability
  - Agreement on sustainability performance parameters
    - Energy use, GHG production, category pollutant production (air, water, land), use of finite non-renewable resources, noise, water use, heat island effect, land use, environmental justice (distribution of exposure) and <u>cost</u>
    - Comparison across all of these
  - Ability to consider complete life cycle
  - Agreed upon assumptions, system boundaries
  - Data sets that are
    - Complete
    - Regionally applicable
  - Understanding of context sensitive determination of sustainability

Some more interesting questions, (all from an LCA point of view!)

- What is the optimal rehabilitation?
  - For an existing low-volume asphalt road
  - For an existing asphalt freeway
  - For an existing concrete pavement
- What is the optimal pavement preservation treatment and timing for the above?
- What is the optimal design life?
- How do I optimize surface characteristics to minimize environmental impact of above? Where is this important?
- How can I reduce environmental impact of the material I want to use? And can I lower the (agency and/or user cost also?)
  - Materials sourcing, design, manufacture, construction
  - Traffic handling
  - Integration of materials into a pavement structure

Life cycle assessment

- Evaluates a product or system throughout its entire ***life cycle***



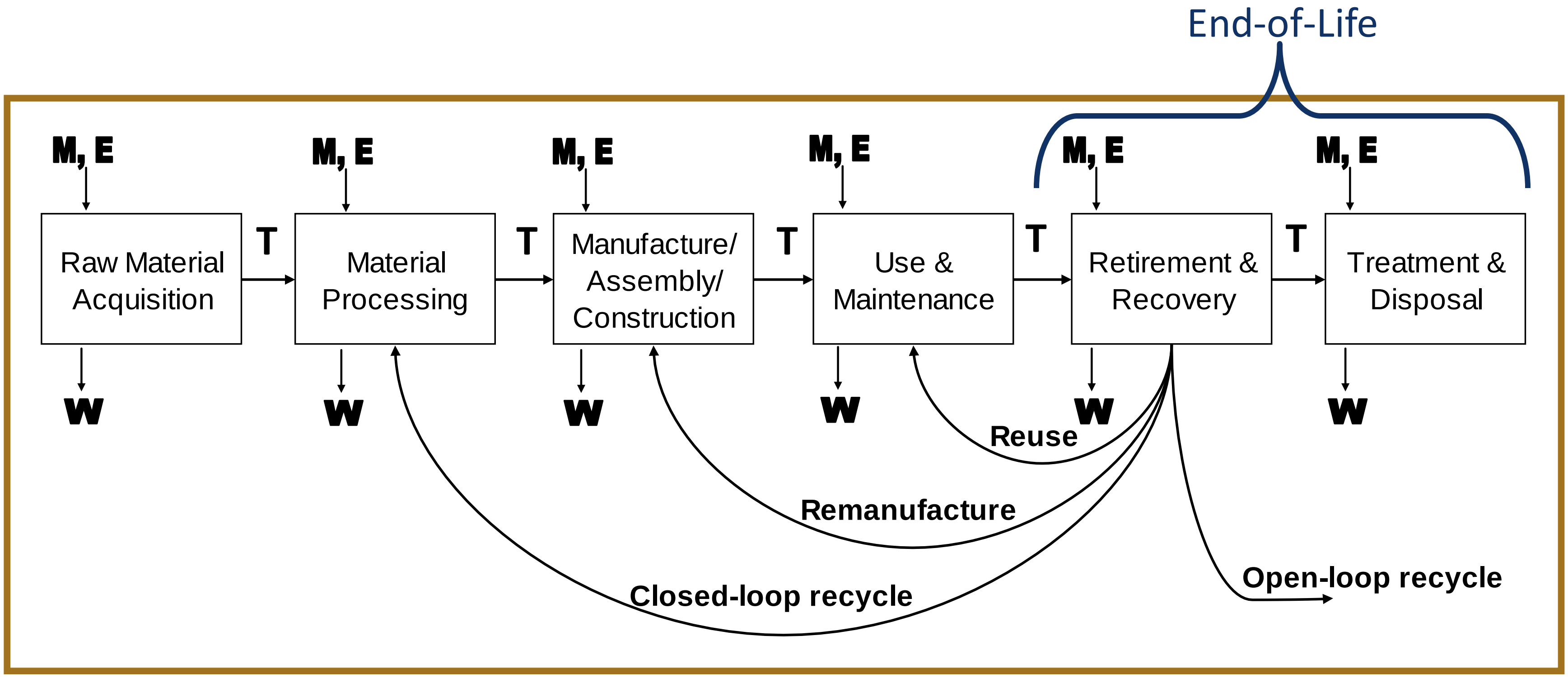
Generic Product Life Cycle

Raw Material Acquisition → T → Manufacturing or Construction → T → Use and Maintenance → T → End-of-life (disposal, reuse recycle, etc.)

T = Transportation

Kendall, Harvey, Lee, A Critical Review of Life Cycle Assessment Practice for Infrastructure Materials, Proceedings of US-Japan Workshop on Life Cycle Assessment of Sustainable Infrastructure Materials Sapporo, Japan, October 21-22, 2009

Product or System Life Cycle



M, E material and energy inputs for process and distribution

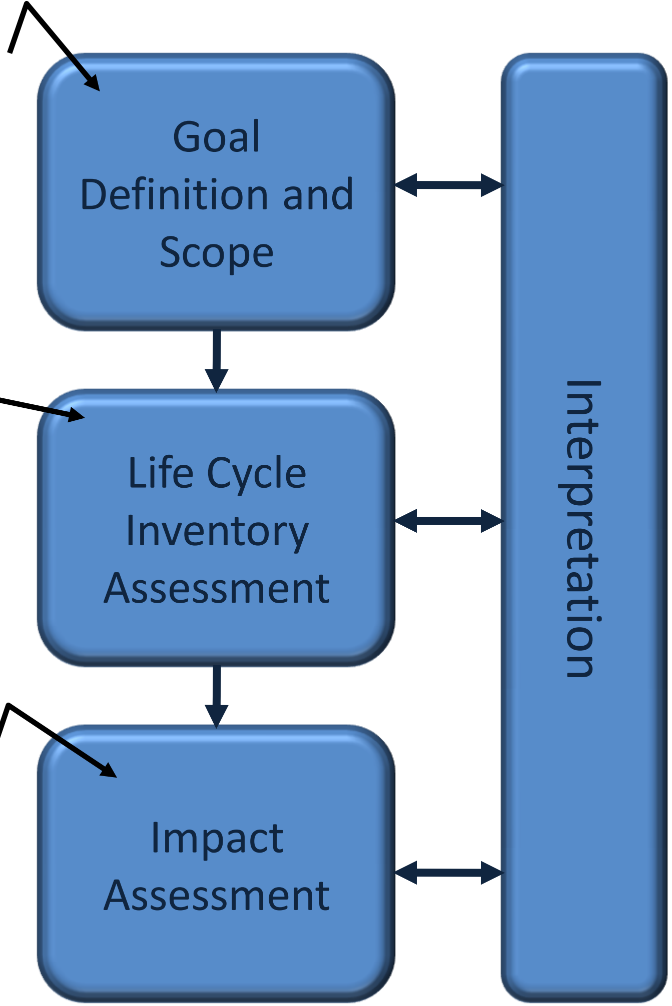
W waste (gaseous, liquid, solid) output from product, process and distribution

T transportation between stages

→ material flow of product components

Adapted from Dr. Gregory Keoleian's *Industrial Ecology* lectures, 2007

Three Key Elements of Life Cycle Assessment



Establish the system to be evaluated (design, location, etc.) and the boundaries of the study.

inputs to and outputs from the system are assessed and assembled

LCI are translated into relevant impacts on humans and the environment

At each stage sources of uncertainty and variability are introduced.

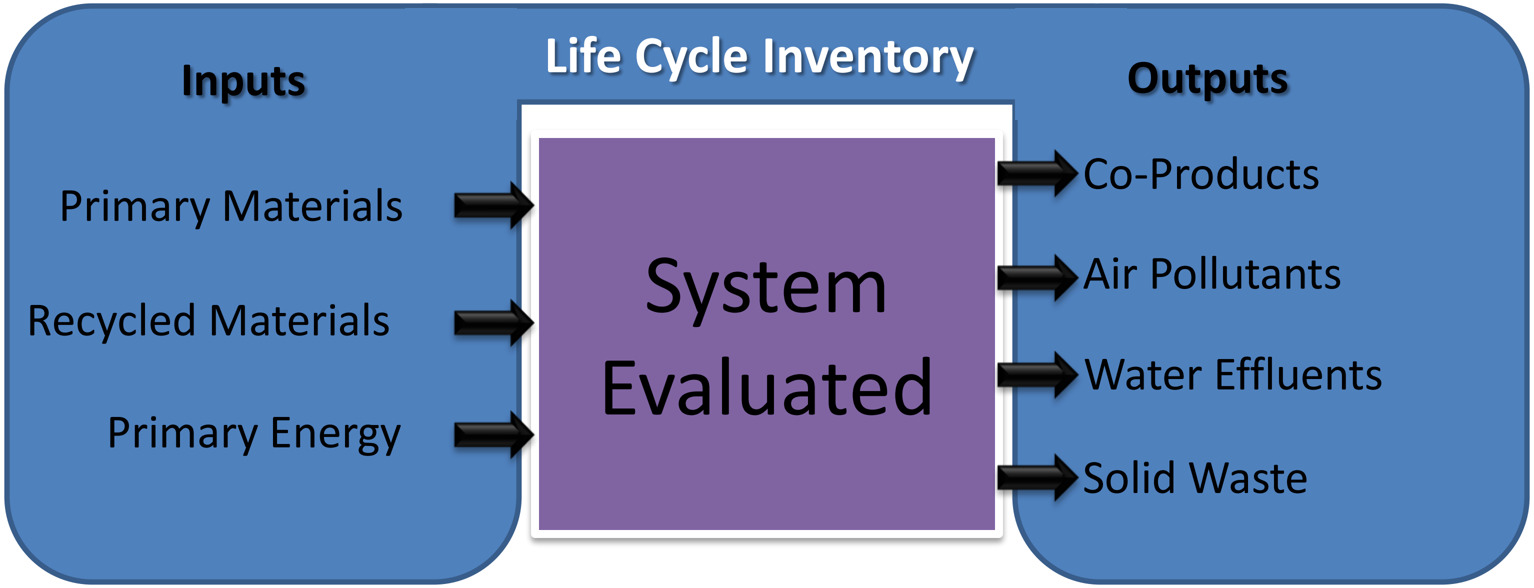
Figure based on ISO 14001

Goal Definition and Scope

- Defines the audience and level of detail of the study
- Includes the system boundary definition
  - Defines the processes to be included in the LCA
- The scope includes
  - Definition of the study time horizon and geography
  - Functional unit, which is the basis for comparing across products or systems
- All of these steps can influence the study outcome and the relevancy of the study

Life Cycle Inventory

- The “accounting” stage for LCA



Impact Assessment

- At this stage, the LCI is translated into meaningful metrics and indicators
- Usually we want to understand the impact of a product or system on human health and the environment
- Most of the time we rely on aggregate numbers which means we understand little about the fate and transport of emissions, the location of emissions, and the expected intake fraction for emissions.

Comparison of Scope for Five Pavement LCA Studies

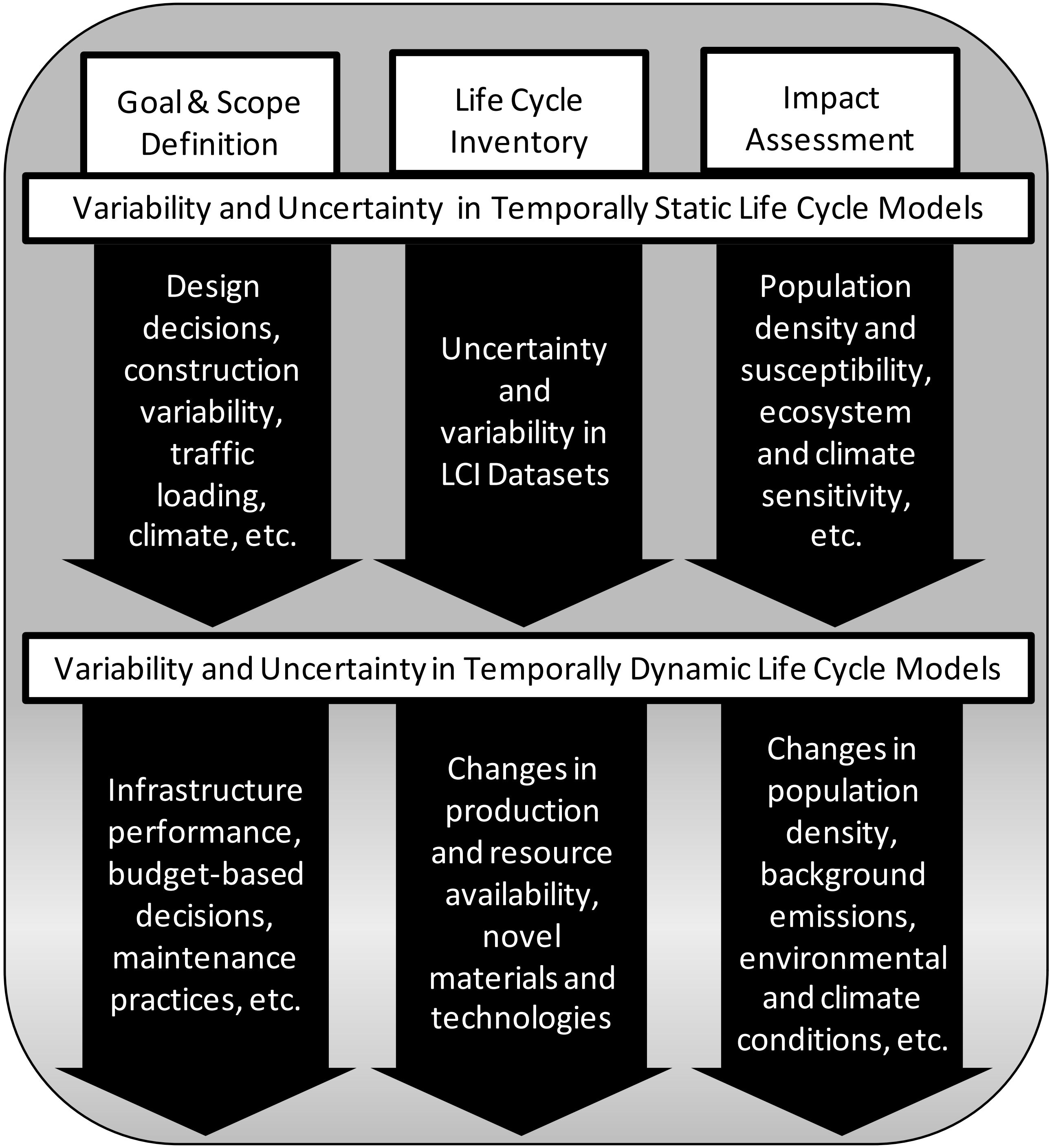
Author	Year	Scope	Key Findings for GHG emissions	Tr
Stripple	2001	P s comp 40- ye a	Asphalt better for CO_2 emissions, and results are dominated by construction emissions. Lighting and traffic control are important.	S c sc flow.
Park et al	2003	Asphalt pavement system that considers earthwork along with other construction anc rehabilitation activities, 20-year time horizor		None
Athena Institute	2006	Com e anc asp base	For 20% recycled asphalt content, asphalt slightly better	Scenario analysis for different roadway types and capacities, also 0% and 20% recycled asphalt content in asphalt mixes
Zhang et al	2007	Ov raffic over a 40-year service life for asphalt, concrete and ECC	ECC best, then concrete, then asphalt for CO_2e emissions	Sensitivity to traffic growth rate
Chiu et al	2008	Asphalt pavement and concrete pavement (40-year life cycle), materials, construction	Asphalt pavement performs better on CO_2 emissions as well as all other energy and emissions categories	Evaluated low-emission and normal vehicles

4 of 5 studies compare asphalt and concrete

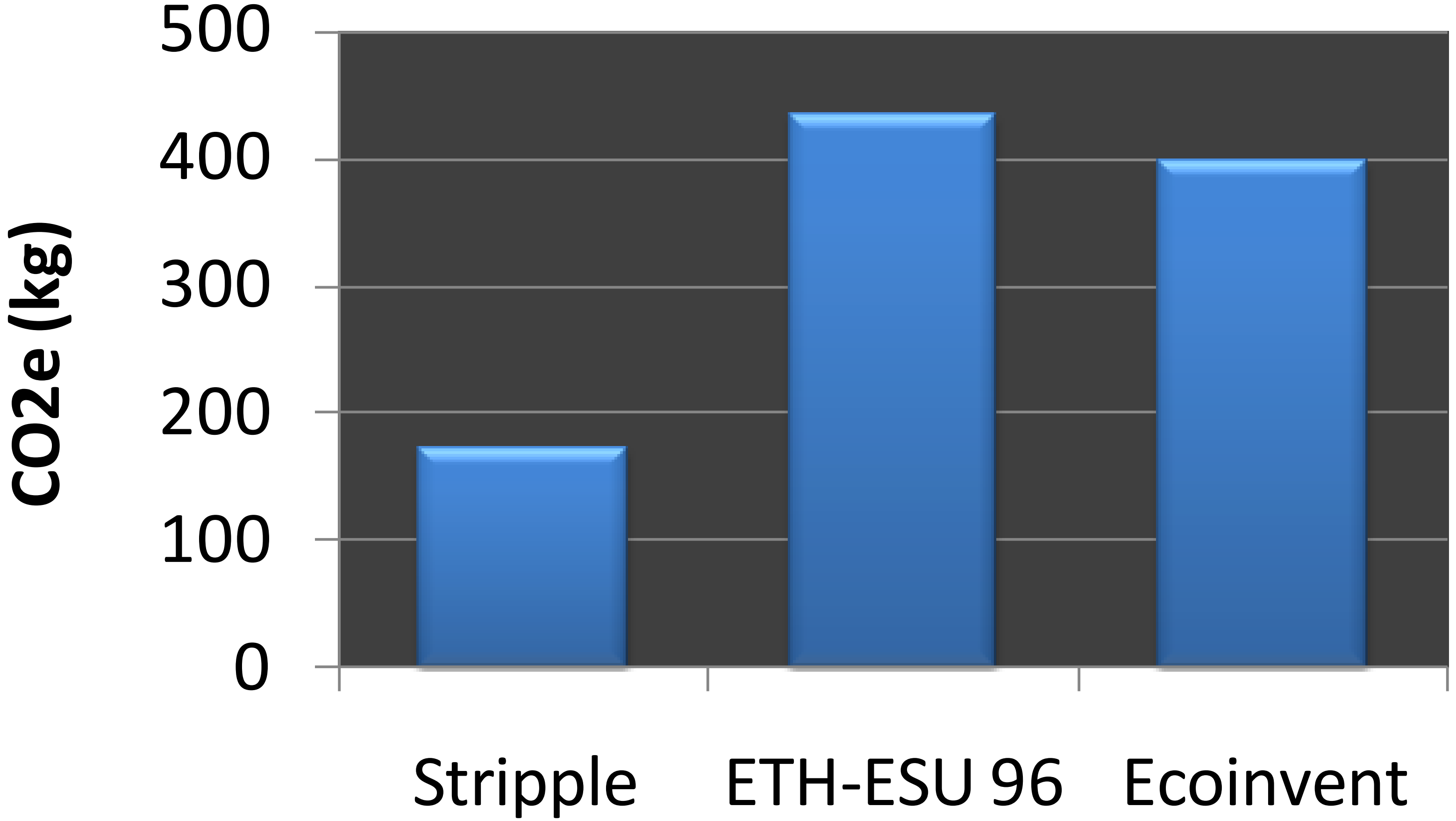
Asphalt better for Greenhouse gas (GHG) emissions

Only two that consider use-phase. But they don't consider the same use-phase process

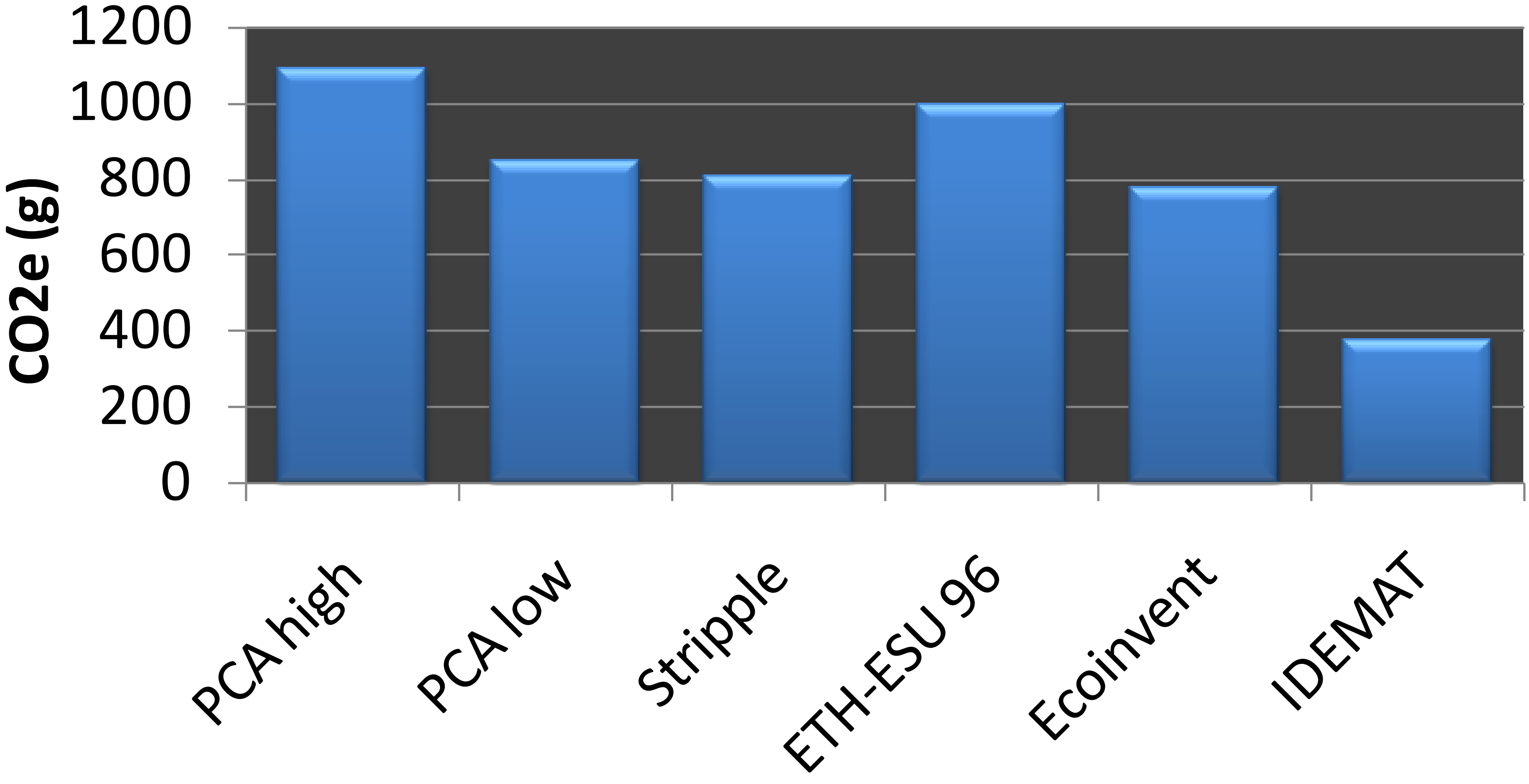
Concrete better for Greenhouse gas (GHG) emissions


Goal & Scope Definition
Life Cycle Inventory
Impact Assessment
Variability and Uncertainty in Temporally Static Life Cycle Models
Design decisions, construction variability, traffic loading, climate, etc.
Uncertainty and variability in LCI Datasets
Population density and susceptibility, ecosystem and climate sensitivity, etc.
Variability and Uncertainty in Temporally Dynamic Life Cycle Models
Infrastructure performance, budget-based decisions, maintenance practices, etc.
Changes in production and resource availability, novel materials and technologies
Changes in population density, background emissions, environmental and climate conditions, etc.

GHG emissions per kg bitumen



GHG emissions per kg cement



Recommendations for assessing environmental impact of pavement materials

- Develop common approach for LCA goals and scope definition
  - Be sure to include use and operations phases (vehicle interaction with pavement, particularly for high volume roads)
  - Clearly state the goal and scope
- Consider uncertainty and variability in analysis
  - Temporal changes
  - Regional relevance
  - Infrastructure use relevance (high/load speed, high/low volume)
  - Clearly discuss temporal and geographic data shortcomings and uncertainties, and relevance to project context
- Focus on the relevant questions (not you know what!)
  - Rehab and preservation in developed world
  - How to reduce the environmental impact of the most cost effective strategy

What is the incentive for reducing environmental impact?

1. Costs less
   - Contractor/supplier
   - Owner
   - Road user
2. Reduces traffic delay
3. Makes construction easier
4. Makes permitting easier
5. There is a regulation or law
6. Good publicity

Who decides and how do they decide?

- Life Cycle Cost (or initial/entry cost) will always be first incentive
  - Mostly owner/financier cost
  - With or without considering road user cost, external monetary costs
- Environmental Life Cycle Assessment will be secondary decision criterion
- Unless
  - Unconstrained budget
  - Changes in rules change the costs

What are the technical and human barriers?

- Compatibility with other processes
- Expertise to start
- Training and expertise to operate
- Safety
- Uncertainty
  - Variability of product quality
  - Applicability
  - Knowledge
  - Experience

What are the institutional and legal barriers?

- Protection of existing industries, organizations, products
- Unintentional effects of existing rules, regulations, permitting
- Low-bid project delivery laws that cannot consider criteria other than cost
- Lack of knowledge on part of purchasers or providers
- Early failures in an extremely risk-averse industry
- Sustained change usually requires top-down understanding and support
  - Do they understand?
  - Will they take the risk?
  - Will they be around long enough?

What are the possible unintended consequences?

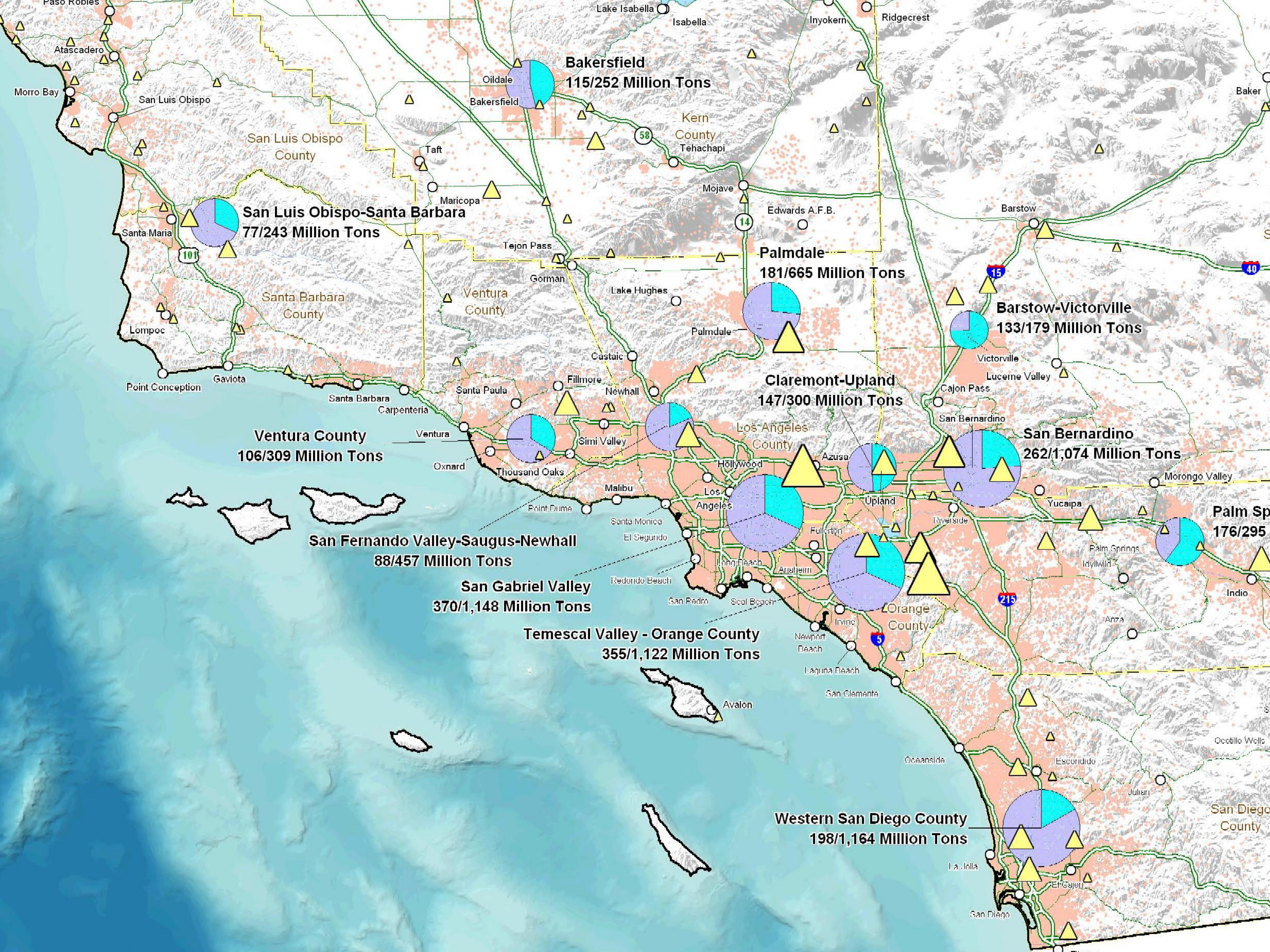
- Haphazard or biased LCA can lead to decisions that are worse for the environment
- Not identifying technical and human risks, and following a clear path of research and development can lead to early death of promising technologies
  - Need to balance risks with potential benefits
- Not solving institutional and legal barriers can lead to inertia

What should we be doing?

- Develop better LCA
  - Create a funding pipeline for LCA for pavement
  - Align LCA for all pavements with the broader LCA field, including international standards and the current consensus of the scientific community.
  - Maintain a strict commitment to quantitative assessment and scientific best-practices.
  - Identify and communicate best practice of LCA for pavements, gaps and uncertainties in knowledge, recent research and development
  - Provide a forum for discussions, exchange of ideas and information, and creation of new research and development initiatives.
  - Up-to-date and regionally applicable data sets
  - Identify and quantify fundamental surface characteristics controlling rolling resistance

What should we be doing?

- Once LCA tools are sufficiently mature (2-3 years): assess materials and technology alternatives within generic technologies
- When LCA is more mature (3 to 8 years): compare across technologies
- Consider implementation requirements, do the research & development work to identify and resolve risk
- Identify and solve institutional and legal barriers that are stopping clear winners
  - Include environmental impact in decision-making processes once science-based decisions can be made
  - Understand the incentives and use them


Paso Robles
Lake Isabella
Isabella
Inyokern
Ridgecrest
Atascadero
Bakersfield
115/252 Million Tons
Oildale
Bakersfield
Morro Bay
San Luis Obispo
Baker
Kern County
Tehachapi
58
San Luis Obispo County
Taft
Mojave
Maricopa
San Luis Obispo-Santa Barbara
77/243 Million Tons
Santa Maria
101
Edwards A.F.B.
14
Barstow
Tejon Pass
Palmdale
181/665 Million Tons
15
40
Gorman
Lake Hughes
Santa Barbara County
Ventura County
Barstow-Victorville
133/179 Million Tons
Lompoc
Palmdale
Castaic
Victorville
Lucerne Valley
Point Conception
Gaviota
Fillmore
Claremont-Upland
147/300 Million Tons
Cajon Pass
Santa Barbara
Santa Paula
Newhall
Carpenteria
San Bernardino
Ventura
Ventura County
106/309 Million Tons
Simi Valley
Los Angeles County
San Bernardino
262/1,074 Million Tons
Azusa
Hollywood
Oxnard
Thousand Oaks
Morongo Valley
Malibu
Los Angeles
Upland
Yucaipa
Point Dume
Santa Monica
Riverside
Palm Sp
176/295
Fullerton
El Segundo
San Fernando Valley-Saugus-Newhall
88/457 Million Tons
Palm Springs
Idyllwild
Long Beach
Anaheim
Indio
Redondo Beach
San Gabriel Valley
370/1,148 Million Tons
215
San Pedro
Seal Beach
Orange County
Irvine
Anza
Newport Beach
5
Temescal Valley - Orange County
355/1,122 Million Tons
Laguna Beach
San Clemente
Avalon
Ocotillo Wells
Oceanside
Escondido
Julian
San Diego County
Western San Diego County
198/1,164 Million Tons
La Jolla
El Cajon
San Diego

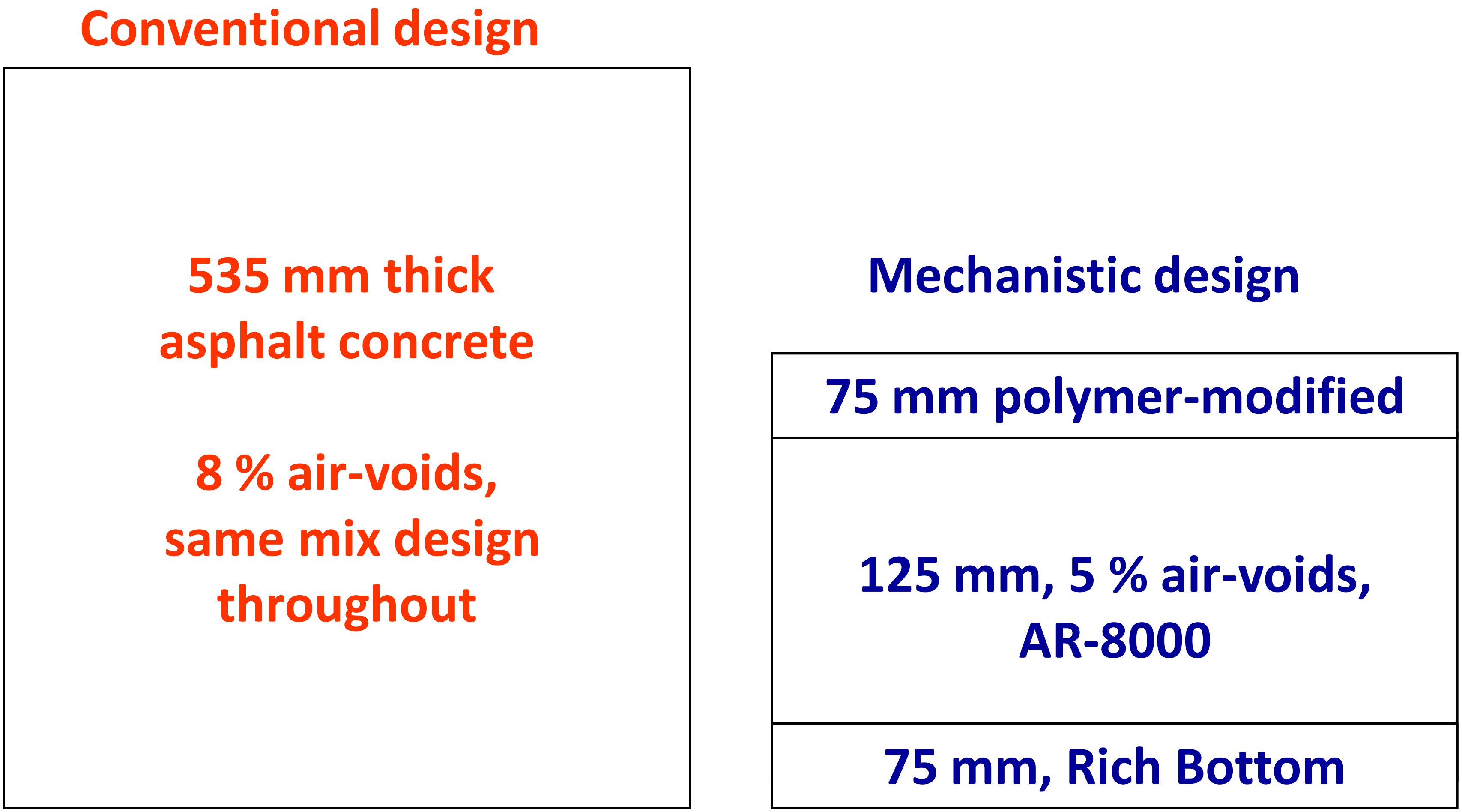
Some basic good practices

- Minimize the annual use of new materials
  - Perpetual reuse
  - Make materials/pavements last longer
  - Thinner pavements for same design life
- Reduce the environmental impactss of new materials and recycling
  - Local materials
  - Reduce energy needs
  - Low-impact materials
- Reduce the traffic delay associated with construction
- Reduce rolling resistance on high volume roads

CA4PRS: Case Study on I-15 Devore Reconstruction Project

Construction Scenario	*Schedule Comparison*		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closures	Closure Hours	User Delay	Agency Cost	Total Cost	
One Roadbed Continuous (24/7)	*2*	*400*	*5.0*	*15.0*	*20.0*	80
72-Hour Weekday Continuous	*8*	*512*	*5.0*	*16.0*	*21.0*	50
55-Hour Weekend Continuous	*10*	*550*	*10.0*	*17.0*	*27.0*	80
10-Hour Night-time Closures	*220*	*2,200*	*7.0*	*21.0*	*28.0*	30

I-710 Reduction of Pavement Thickness Using Mechanistic Design



Conventional design

535 mm thick asphalt concrete

8 % air-voids, same mix design throughout

Mechanistic design

75 mm polymer-modified

125 mm, 5 % air-voids, AR-8000

75 mm, Rich Bottom

Some materials technologies with promise

- Perpetual recycling of pavement materials back into pavements
- Alternative cementitious materials
- Rubberized asphalt overlays
- Warm mix asphalt
- Integration of design/construction/materials to reduce thickness and increase life
- Integration of construction productivity and traffic delay

And let’s remember that not all roads are paved