FHWA Sustainable Pavements Program

Towards Sustainable Pavement Systems: Webinar Series

Webinar #2:

Sustainable Strategies for Asphalt Pavements: Materials, Design, and Construction

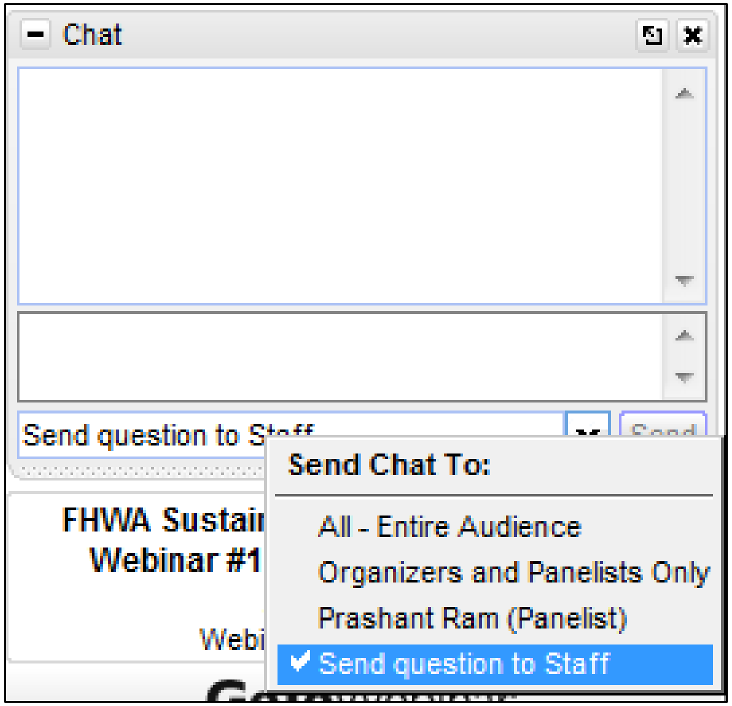
May 19, 2015

Webinar Series

- Sponsored by Federal Highway Administration
- Focuses on contents of recent publication "Towards Sustainable Pavement Systems: A Reference Document"
  - http://www.fhwa.dot.gov/pavement/sustainability/
- Total of 5 webinars from April to September
- Webinars recorded for posting on FHWA website

Housekeeping

- Formal Presentations:
  - 1 hour 40 min
- Questions:
  - 20 minutes
  - Use chat box to submit
  - Use dropdown menu to "send questions to staff"



- Professional Development Hours (PDHs) Certificates
  - 2 hours per webinar

Today's Webinar

- Topic: Sustainable Strategies for Asphalt Pavements: Materials, Design, Construction
- Speakers:
  - Gina Ahlstrom, FHWA
  - Tom Van Dam, NCE
  - John Harvey, University of California-Davis
  - Imad Al-Qadi, University of Illinois
  - Hasan Ozer, University of Illinois
- Moderators:
  - Kurt Smith, Applied Pavement Technology, Inc.
  - Tom Van Dam, NCE

FHWA Sustainable Pavements Program

Background and Overview

Gina Ahlstrom

US DOT is Committed to Advancing Sustainability

- DOT will incorporate sustainability principles into our policies, operations, investments and research through innovative initiatives and actions such as:
  - Infrastructure investments and other grant programs,
  - Innovative financial tools and credit programs,
  - Rule- and policy- making,
  - Research, technology development and application,
  - Public information, and
  - Enforcement and monitoring.

Policy Statement

Signed Secretary Anthony R. Foxx, June 2014

U.S.Department of Transportation
Federal Highway Administration

FHWA Sustainable Pavements Program

- Support the US DOT goals for sustainability
- Increase the body of knowledge regarding sustainability of asphalt and concrete materials throughout the pavement life cycle
- Increase the use of sustainable technologies and practices in pavement design, construction, preservation, and maintenance

“Towards Sustainable Pavements: A Reference Document”

- Guidelines for the design, construction, preservation and maintenance of sustainable pavements using asphalt and concrete materials
- Educate practitioners on how sustainability concepts can be incorporated into pavements
- Encourage adoption of sustainable practices

A Collaborative Effort

- Comprehensive review of current literature

- Extensive review by representative from key stakeholders groups:
  - State Departments of Transportation
  - Other Public Agencies
  - Asphalt and Concrete Industries
  - Academia

FHWA Sustainable Pavements Program

- **Materials and Consideration of Life Cycle**
- **Aggregate Materials**

Tom Van Dam

Materials and Consideration of the Life Cycle

- Must consider material choices from a life cycle perspective
  - What are the agency's sustainability goals?
  - What are the impacts of using a material once versus multiple times?
  - What are the trade-offs in increasing the use of recycled, co-product, or waste materials (RCWMs)?

Recycled, Co-Product, or Waste Materials (RCWMs)

- Recycled materials are obtained from old pavement and are included in new pavement
  - e.g. reclaimed asphalt pavement (RAP) and recycled concrete aggregates (RCA)
- A co-product is from another process (often industrial) that brings value
  - e.g. slag cement
- Waste are materials that would normally be landfilled
  - e.g. recycled asphalt shingles (RAS)

Considerations When Using RCWMs

- Does the RCWM result in equivalent or better performance?
  - What if it is just slightly worse?
- Does the RCWM have to be transported great distances?
- Does the RCWM make it more difficult to recycle in the future?

Other Considerations

- Does the use of the material increase construction variability?
- Does specifying a longer lasting material increase transportation or production-related impacts?
- Are specifications a protector or a barrier?
- Does the pavement design make best use of lower impact materials
- Are the impacts of transporting materials considered?

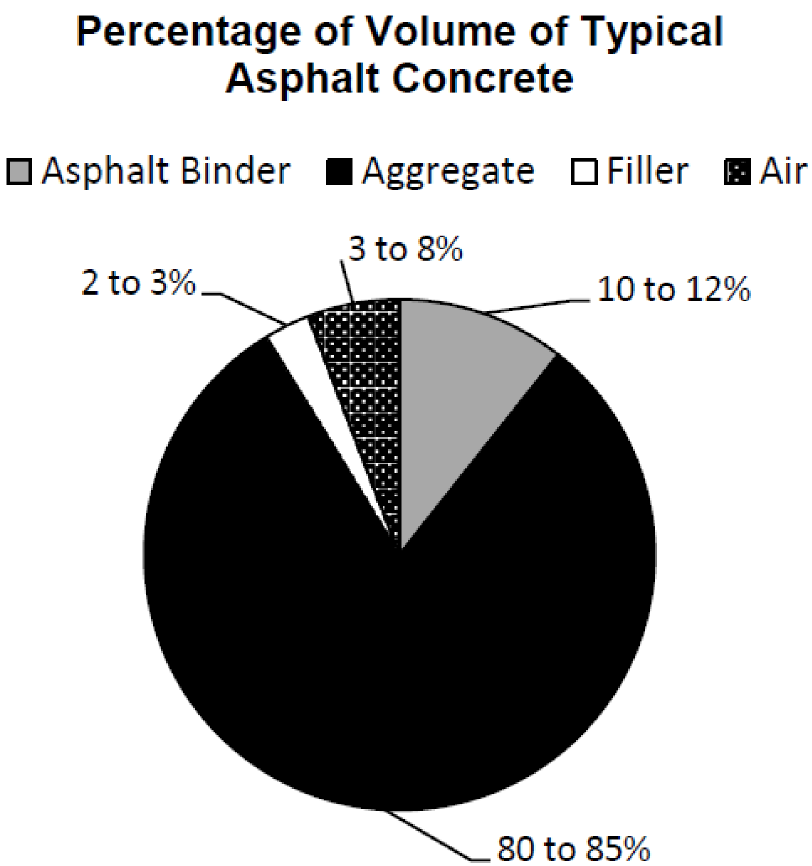
Aggregate Materials

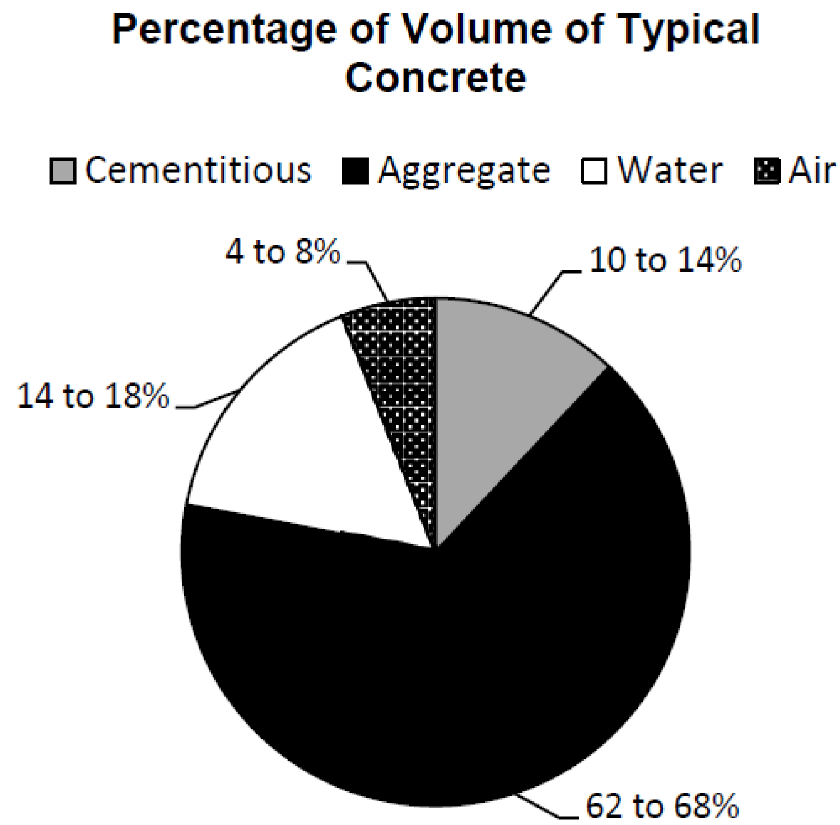
- Make up the largest share of mass and volume in a pavement structure
  - Have relatively low environmental footprint per unit mass
  - Consumed in large quantities
- Impact incurred in mining, processing, and transporting aggregates
  - Impact of transportation can be very large

Aggregates

- Used in asphalt and concrete mixtures, bound and unbound base and subbase
- Natural aggregates are classified as crushed stone or sands and gravels
- Manufactured aggregates are created to possess unique characteristic or are a co-product
  - Can also include RCWMs

Typical Volumes of Aggregate





Tayabji, Smith, and Van Dam 2010

Aggregates – The Facts (2012)

- Produced in all 50 states
- 1.324M tons of crushed stone produced, worth $12B
  - 82% used as construction materials and 10% used in cement manufacturing
- 927M tons of sand & gravel worth $6.4B
  - 93% used in road construction

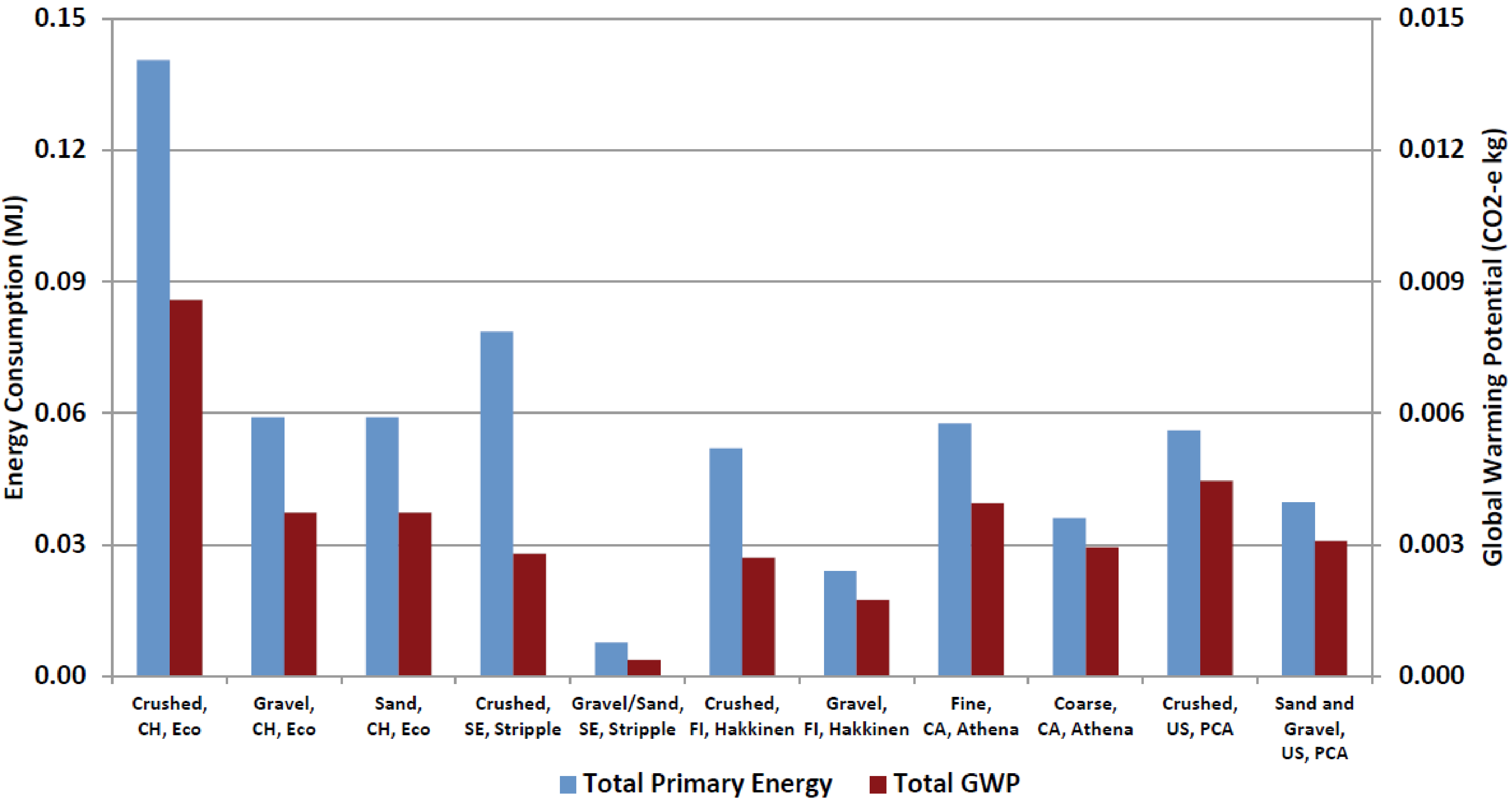
RCWMs Used as Aggregate

- Reclaimed asphalt pavement (RAP)
- Recycled concrete aggregate (RCA)
- Recycled asphalt shingles (RAS)
- Air-cooled blast furnace slag (ACBFS)
- Steel furnace slag (SFS)
- Foundry sand

Aggregates and Environmental Impacts

- Energy consumption and GHG – depends on source of electrical power and transport distance
  - Crushed stone has greater impacts
- Fugitive dust
- Water consumption
- Land-use issues
- Community impacts
- Impacts make it difficult to permit new aggregate sources

Aggregate Impacts: Energy and GHGs



Transportation Mode and Fuel Consumption

Mode	Ton-Miles/Gallon
Trucks[2]	150
Rail	478
Inland towing	616

Notes:

1. This is gross fuel use, not life-cycle fuel use.
2. Truck load assumed to be 25 tons (22.6 mt) on a 40 ton (36.28 mt) gross vehicle weight truck, loaded one way.

Strategies for Improving Sustainability

- Reduce use of virgin aggregate over the life cycle
- Reduce impact of virgin aggregate acquisition and processing
- Reduce impact of transporting aggregates
  - Use barges or rail if possible

Example: The Illinois Tollway

- Committed to recycling 100% of concrete and asphalt pavements
- Percent binder replacement in asphalt pavements is 40% to 60% using fine fractionated RAP and RAS
- Two-lift composite concrete using coarse fractionated RAP and RCA in bottom lift
- In-place recycling of existing pavements into new base/subbase common
- Decisions are firstly economic, then environmental

Aggregate Issues and Future Directions

- Proximity of aggregate sources to urban centers
  - Trade-off between transportation and local impacts
- Increasing pressures to increase use of RCWMs
  - Trade-off with regards to performance
- Increased use of marginal aggregates
- Demand for specialty aggregates increasing to meet specific sustainability goals

FHWA Sustainable Pavements Program

- Asphalt Materials and Mixtures
- Design Considerations
- Rehabilitation Options
- Example Sustainable Design Strategies

John Harvey

Asphalt Materials and Mixtures

- Includes material extraction, processing, and transportation
  - Extraction to gate of the mixing plant
- Includes mixture design and proportioning, as well as mixing plant operations
- Assess materials using life-cycle perspective



Asphalt and Asphalt Mixes – The Facts (2012)

- Produced in about 46 refineries in the US
  - The U.S. used approximately 130 million barrels in 2011, worth $7.7 billion, and 200 million barrels in 2005
  - 83 percent of asphalt binder used in the U.S. in 2011 was used for paving purposes
- More than 92 percent of all U.S. paved roads and highways are surfaced with asphalt products.
- The U.S. has about 4,000 plants producing asphalt mixtures
  - Total production of about 400 million tons in 2010
  - Value of mixtures produced in 2007 was $11.5 billion

Key issues

- *Price of petroleum and asphalt, which is a finite resource*
- *Environmental, social, and cost implications of mixture design and durability*
- *Appropriate use of polymer, rubber, and other types of binder modifiers*
- *Depletion of easily accessible high-quality aggregates needed for some type of mixtures*
- *Specialization of mixtures for safety, noise, and structural considerations and their environmental and cost implications*
- *Use of RAP and other recycled/waste materials (RCWM) including recycled tire rubber, asphalt shingles, and sulfur*
- *Future binder availability and alternatives*

Asphalt Materials and Mixtures

- Asphalt binder is produced in different forms for use in pavements
  - Asphalt cement
  - Emulsions (asphalt suspended in water)
  - Foamed asphalt (asphalt foamed with water)
  - Liquid asphalt/cutback (asphalt mixed with solvent)

Neat Asphalt Binder

Asphalt Rubber Binder

Photo Z. Alavi, UPCRC

From Crude Oil to Products

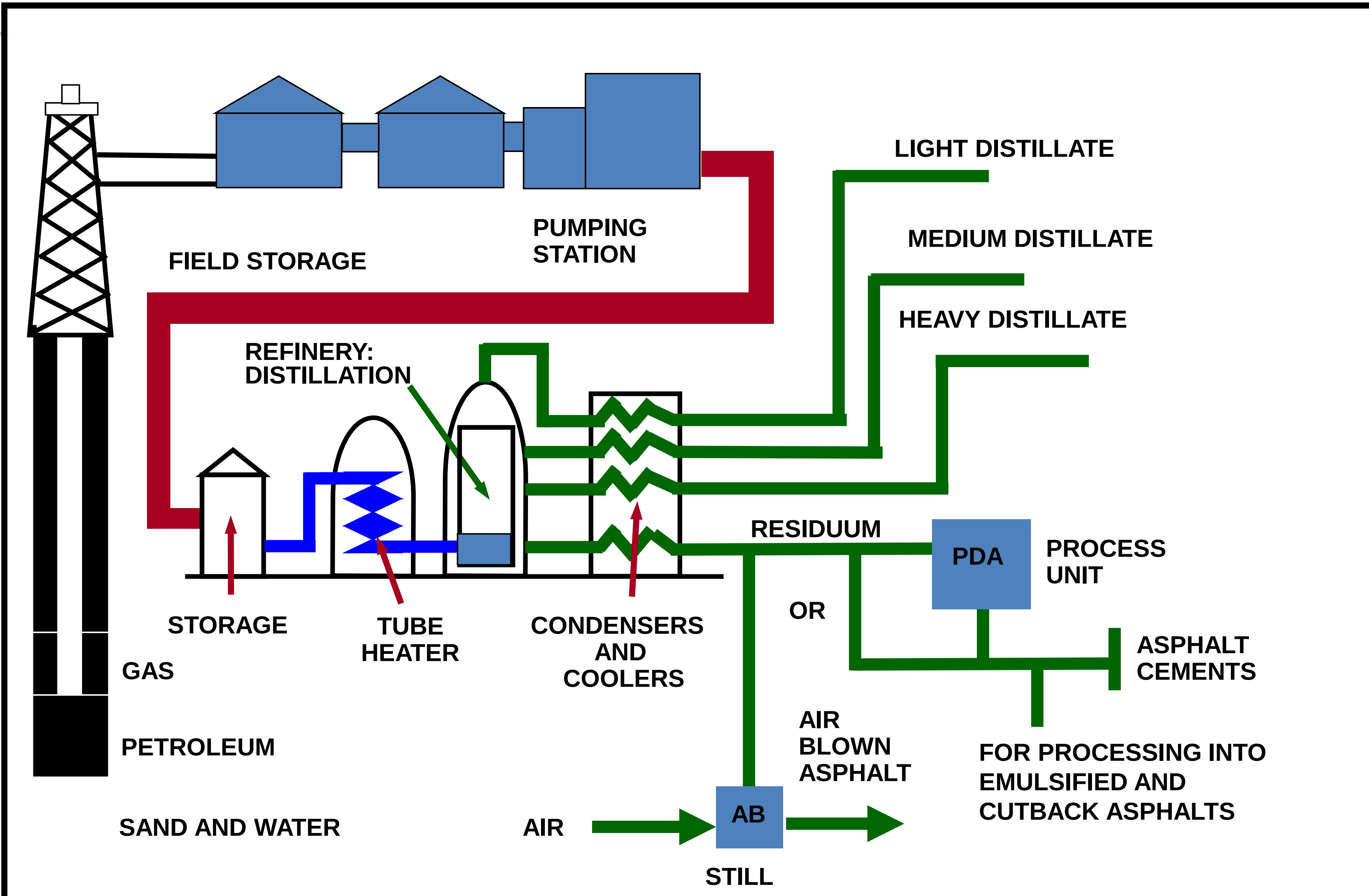
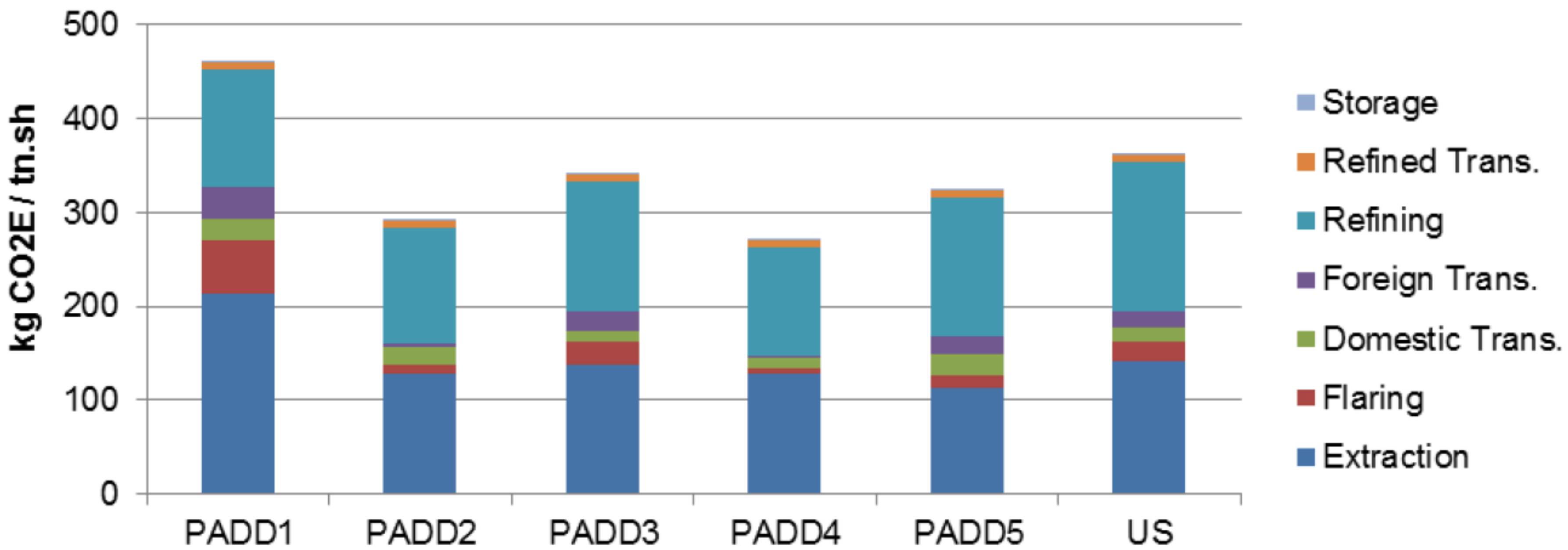


Figure Asphalt Institute

Differences in Environmental Impact of Asphalt Production

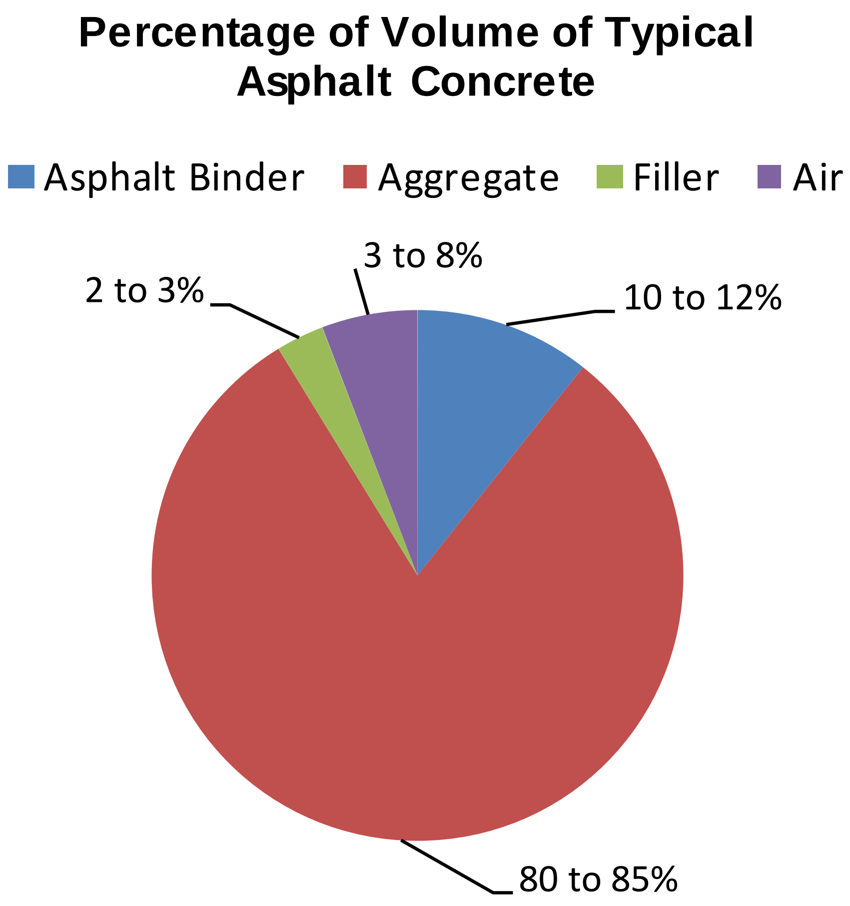


- Main sources of GHG emissions: extraction and refining
- Main sources of variability: extraction, flaring refining and transportation

Asphalt Materials and Mixtures
Hot/Warm Mix Asphalt

- Primary structural materials
  - Variety of dense and gap-graded asphalt mixtures, function in pavement:
    - wearing surface (friction, rutting resistance)
    - reduce stresses in underlying layers (stiffness, thickness)
    - resist cracking (fatigue/fracture resistance)
    - Also used as base for concrete pavement
  - Open-graded mixes, function in pavement:
    - thin wearing surface (friction, reduce hydroplaning, rutting resistance)

What is in a Dense Graded Asphalt Mix?



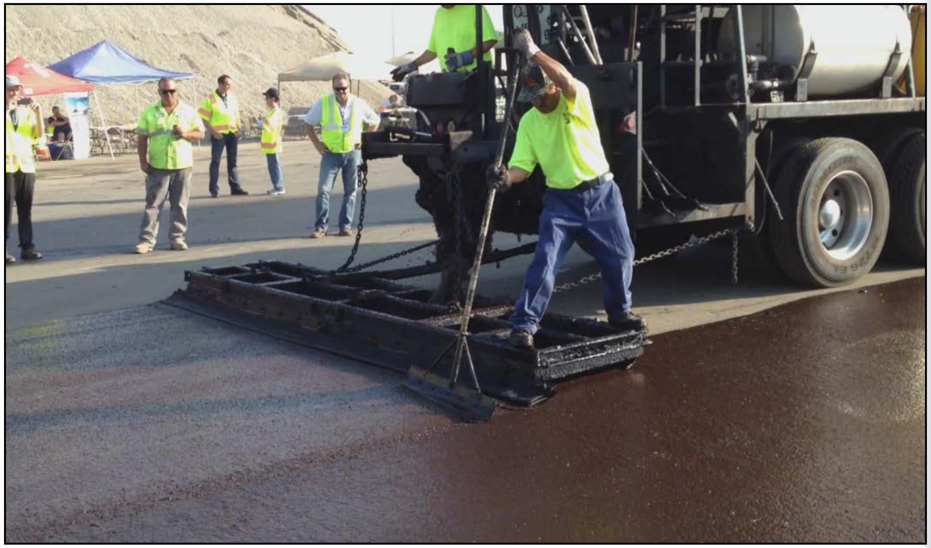
- Trends
  - Specialized mixtures for specific purposes in pavement
  - Use of polymers and crumb rubber where they enhance performance
  - Increased use of new binder replacement with Recycled Asphalt Pavement (RAP)
  - Experimentation with Recycled Asphalt Shingles (RAS)
  - Performance related testing to specify properties for each application

Dense Graded Mixture Design

- Identification of function of the pavement layer
- Identification of the appropriate asphalt binder type/grade
  - Temperatures, stresses/strains, traffic repetitions
  - Conventional, polymer-modified, rubberized
- Identification and testing of aggregate sources/gradations
- Selection of the final binder content based on volumetrics
- P*erformance-related testing*
  - Laboratory testing of stability and durability performance
  - Where project importance warrants extra cost
- Mix design should include consideration of the amount of RAP

Asphalt Materials and Mixtures
In-Place Recycling, Preservation, Other Uses

- In-place recycling
  - Partial depth recycling (CIR)
  - Full-depth reclamation (FDR)
- Maintenance and preservation seal coats
  - Chip seals
  - Microsurfacing
  - Slurry seals
  - Fog seals
- Tack and prime coats



What is Recycled Asphalt Pavement?

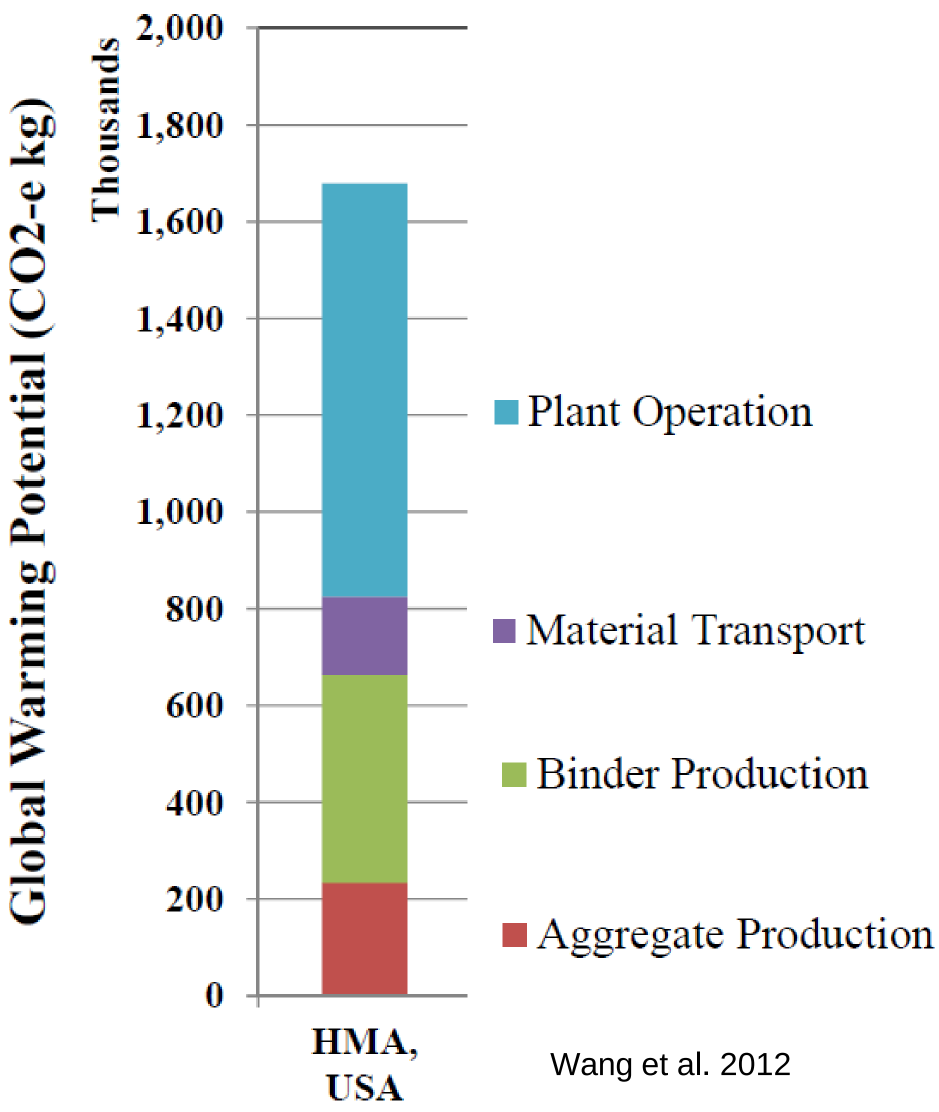
- Milled or pulverized existing asphalt pavement materials, replaces new asphalt and aggregate
- Can be recycled at plant or in-place
  - Plant produces higher quality
  - In-place reduces transportation impact

- Used in new asphalt materials:
  - Hot mix asphalt
    - Up to about 15% with no special considerations
    - Up to about 40% with consideration in mix design
  - Partial-depth recycling mixed with hot or cold asphalt
  - Full-depth reclamation mixed with various stabilizers
- Other uses

What are Warm Mix, Crumb Rubber and Polymers?

- Warm mix asphalt (WMA)
  - Various technologies that reduce the temperature needed for mixing and compacting asphalt mixes
- Polymers
  - Various petroleum derived polymer products used to change asphalt properties at different temperatures
- Crumb rubber modifier (CRM)
  - Ground recycled tire rubber, with steel removed
  - Acts as polymer
  - Can be mixed with asphalt cement, natural rubber, and other ingredients = *rubberized asphalt*
  - Used with polymers in *rubber modified binder*

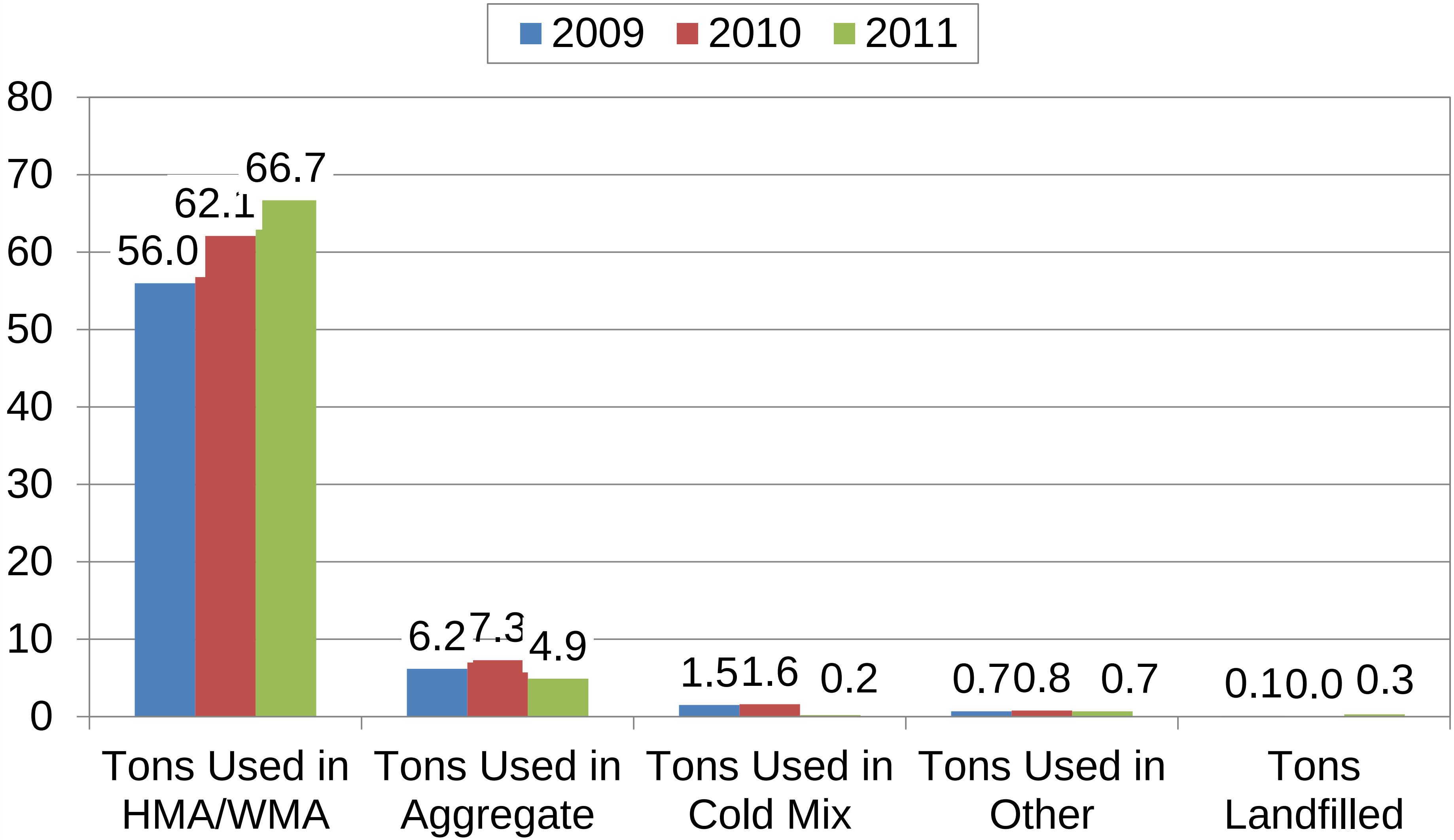
Reducing Material Global Warming Potential in an Example Large Hot Mix Asphalt Overlay Project



Wang et al. 2012

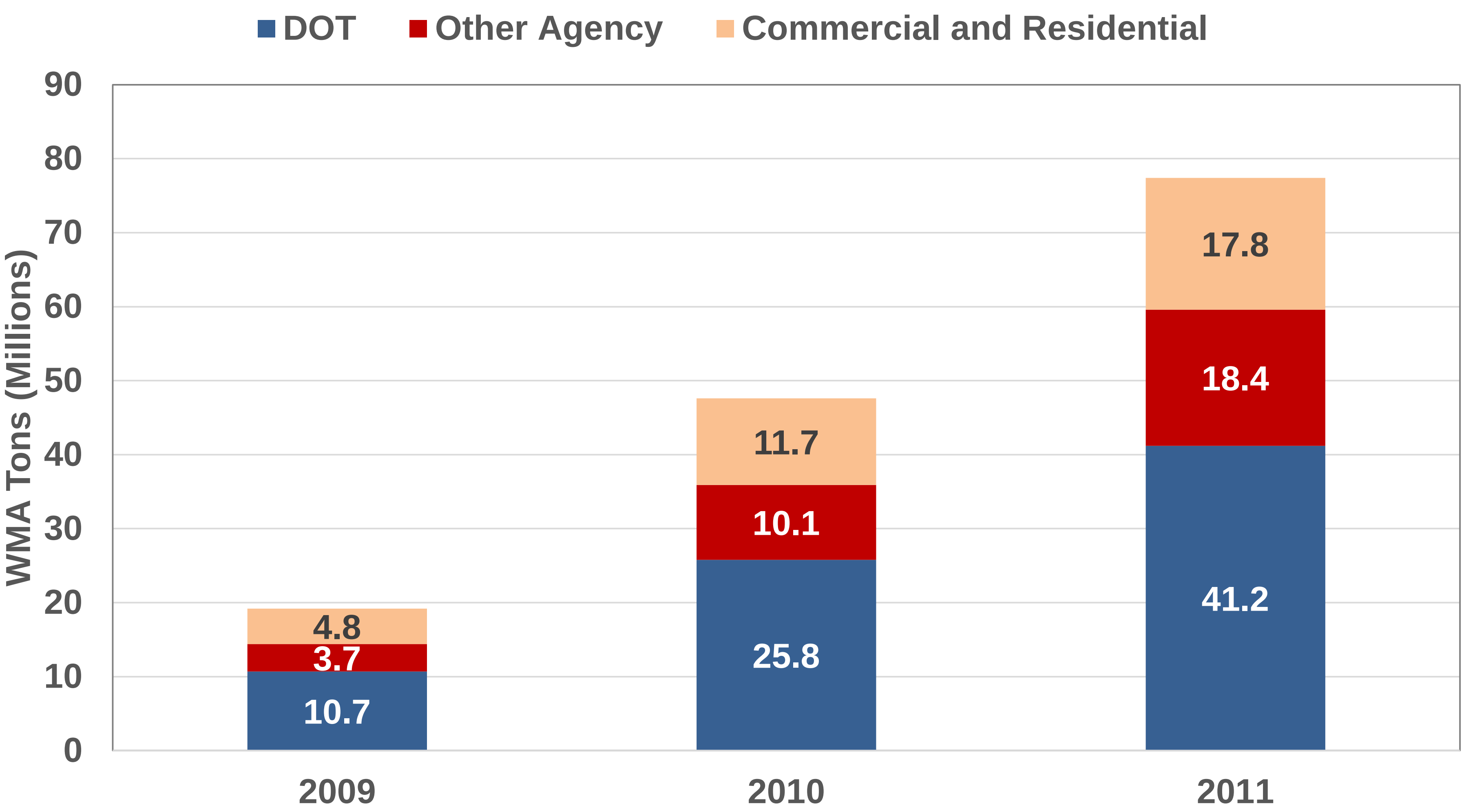
- Use of RAP
  - Reduces virgin binder content
  - Reduces virgin aggregate production
  - May increase plant operation energy
  - Effect on material transport?
- Use of WMA
  - Reduces plant operation energy

Increased RAP Usage in US



Hansen and Copeland 2013

Increased Use of WMA in US



Hansen and Copeland 2013

Highest Use of Recycled Materials?

- Depends on:
  - the project
  - what is technically feasible
  - net life cycle environmental impacts of the use on the project
  - Prioritization of impacts
- Is recycling always the best strategy?
  - Example 1: use RAP or use locally available material in new hot mix?
  - Example 2: recycling something into asphalt mixes, one-time or perpetual recycling?

Substitutes for Petroleum Asphalt

- Bio-binders from non-food plant or animal waste
  - Fermentation, enzymes convert the biomass to energy, leaving lignins
  - Fast pyrolysis, biomass heated to very high temperatures without oxygen, smaller molecules that might produce asphalt.
  - Gasification, biomass is converted to combustible gases leaving residues
- Sulphur

Strategies for Improving Sustainability

1. Increase material performance and time between future maintenance and rehabilitation treatments
   - Materials design
   - Construction quality, Topic of later webinar, but think COMPACTION
2. Reduce % of virgin asphalt binder & aggregate, polymer
   - Use more RAP, recycled tire rubber, consider RAS
   - Only use additional additives where performance increase warrants additional environmental impact
   - All above assume pavement performance is not reduced or compromised
3. Reduce materials transportation
   - Use locally available but lower quality aggregates
   - Use in-place recycling

‼ **2 and 3 assume pavement performance is not reduced**

Real World Considerations

- Sustainability goals of the organization?
- Trade-offs to reduce impact require life cycle consideration
  - Environmental impacts of material
  - Performance and replacement frequency
  - Transport distances
  - Ability to recycle in the future
- Changing standard practice (specifications and designs
  - Are specifications that limit the use of lower impact materials effective in reducing the risk of poor performance, or just do they prevent the opportunity to improve the overall sustainability of a pavement project?
  - Is the pavement designed to make the best use of lower impact materials without compromising performance?

Real World Example: Balancing Stability and Durability in Mix Design

Background: State agency with mix design procedure resulting in historically low binder content to minimize risk of rutting
Question: What is impact of changing gradation and increasing binder content in mix design to increase cracking resistance?

- Performance related testing used to evaluate
  - Stiffness
  - Fatigue cracking resistance
  - Rutting resistance
- Mechanistic-Empirical design used to evaluate effect on pavement thickness required for same performance for old and new binder contents

Real World Example: Balancing Stability and Durability in Mix Design

- Performance analysis showed:
  - Risk of rutting increased but was acceptable
  - Pavement thickness required decreased because of improved fatigue properties
  - Net amount of asphalt needed for same life? What if included RAP?

Mix Design Method	Binder Content by mass	Mix Thickness for Cracking Life (mm)	Volume of Mix Needed (m^3)	Volume of Binder Needed (m^3)
Hveem	5.0	103	555	44
Superpave	5.5	84	453	36

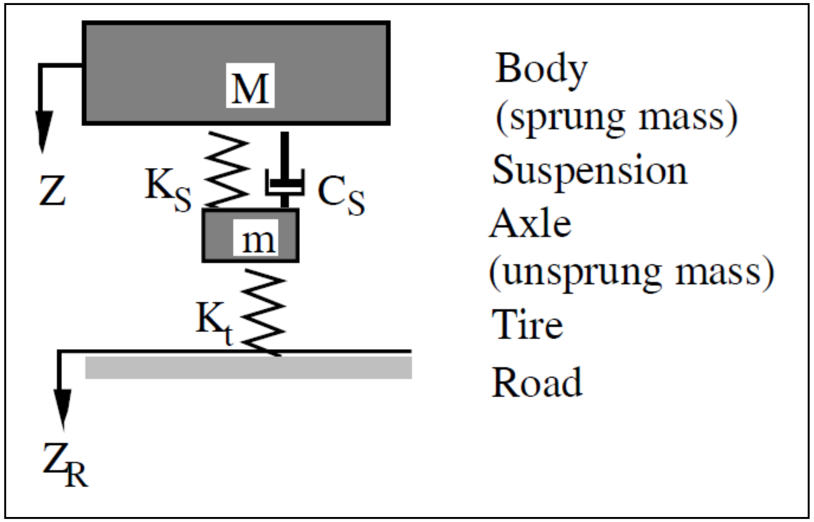
Coleri et al. 2015

Future Directions/Emerging Technologies

- Reduction in material quantities used per year
  - Improvements in mixture design, construction practices
  - New materials such as WMA
  - Use of polymers, rubber, other modifiers, where warranted by performance benefit
- Performance related testing and specifications
  - To fine tune materials for different applications
- Greater use of RCWMs, particularly RAP
- Greater use of locally available pavement materials
  - Provided benefits are not offset by reduced performance
- Alternatives binders
  - Mostly bio-based, and used as asphalt extenders in blends with RAP
  - Environmental, economic, and societal impacts must be determined

Key Issues for Pavement Design

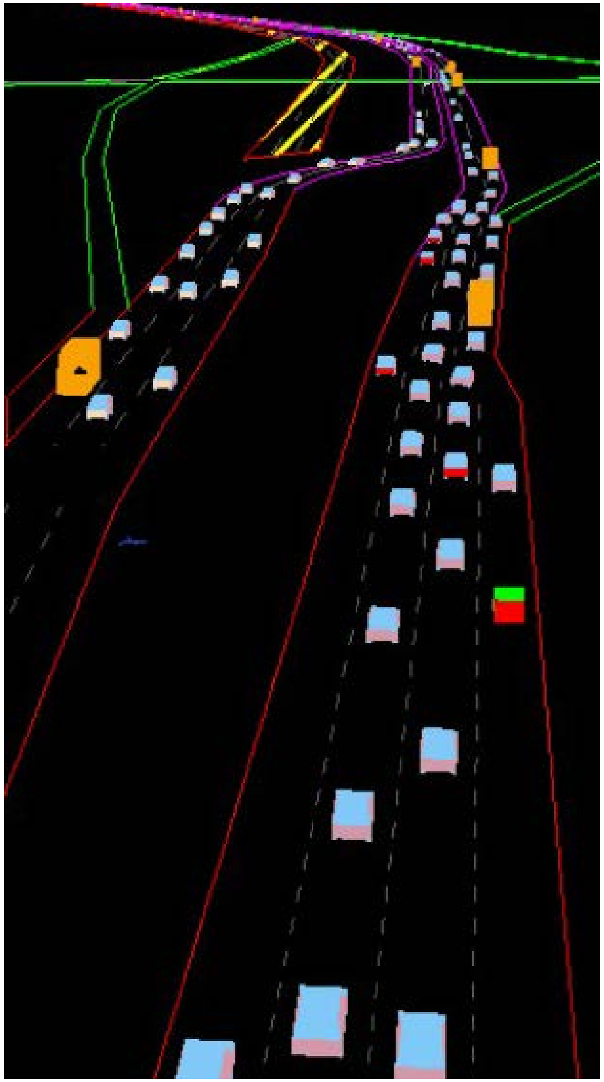
- *Surface performance*
  - *Smoothness affects vehicle fuel use and maintenance*
  - *Consider life cycle smoothness, not just initial*
  - *Importance increases with increased traffic*
- *Design life selection*
  - *Longer life usually means lower life cycle cost and impact*
  - *Also means higher initial investment (cost, environmental impact)*
  - *Should include consideration of end-of-life alternatives*



Gillespie and Sayers
Sully Miller

Key Issues for Pavement Design

- *Pavement type selection*
  - *Impacts every phase of the pavement life cycle*
  - *Relative sustainability of different types depends on location, design traffic, and available materials*
- *Construction and materials selection interaction*
  - *See discussion of asphalt materials*
  - *Consider ability to achieve high quality in construction*
  - *Consider work zone traffic delays*
- *Construction quality requirements*
- *End-of-Life recycling strategies*



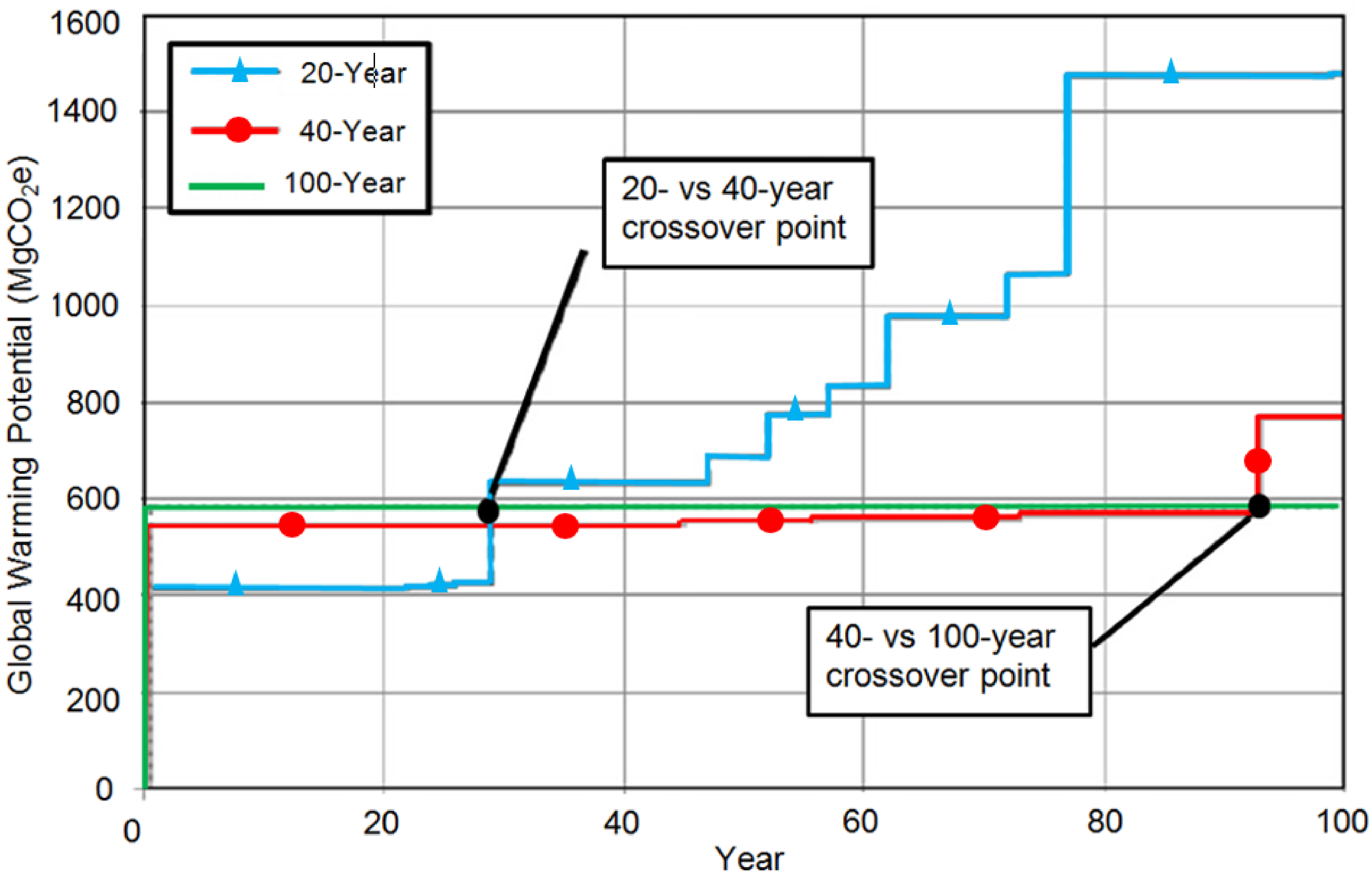
Paramics, Lee et al.

Mechanistic-Empirical Design Methods

- Permit rapid evaluation of:
  - Materials
    - Increased recycled content
    - Materials with lower environmental impact
    - Changes in mix design
    - Locally available, lower quality specifications
  - Construction
    - Improved quality (compaction in particular)
    - Less variability
    - Bonding between layers
  - Pavement structures
    - Climate, traffic and subgrade specific designs
    - With materials and construction noted above

Consideration of Payback Time

- Return time and uncertainty for high early environmental impact choices
- Design life example shown here



Santero et al.

Process for Considering Sustainability in Pavement Design

Inputs:
- Project performance, cost, and sustainability objectives
- Project traffic, climate, available materials, and construction processes
- Agency design, LCCA, sustainability practices and policies

↓

Step 1: Develop generalized pavement type or rehabilitation approach alternatives

↓

Materials	Construction Specifications	Layer Combinations	Integration of Construction and Traffic	Construction Methods (chapter 5)

↓

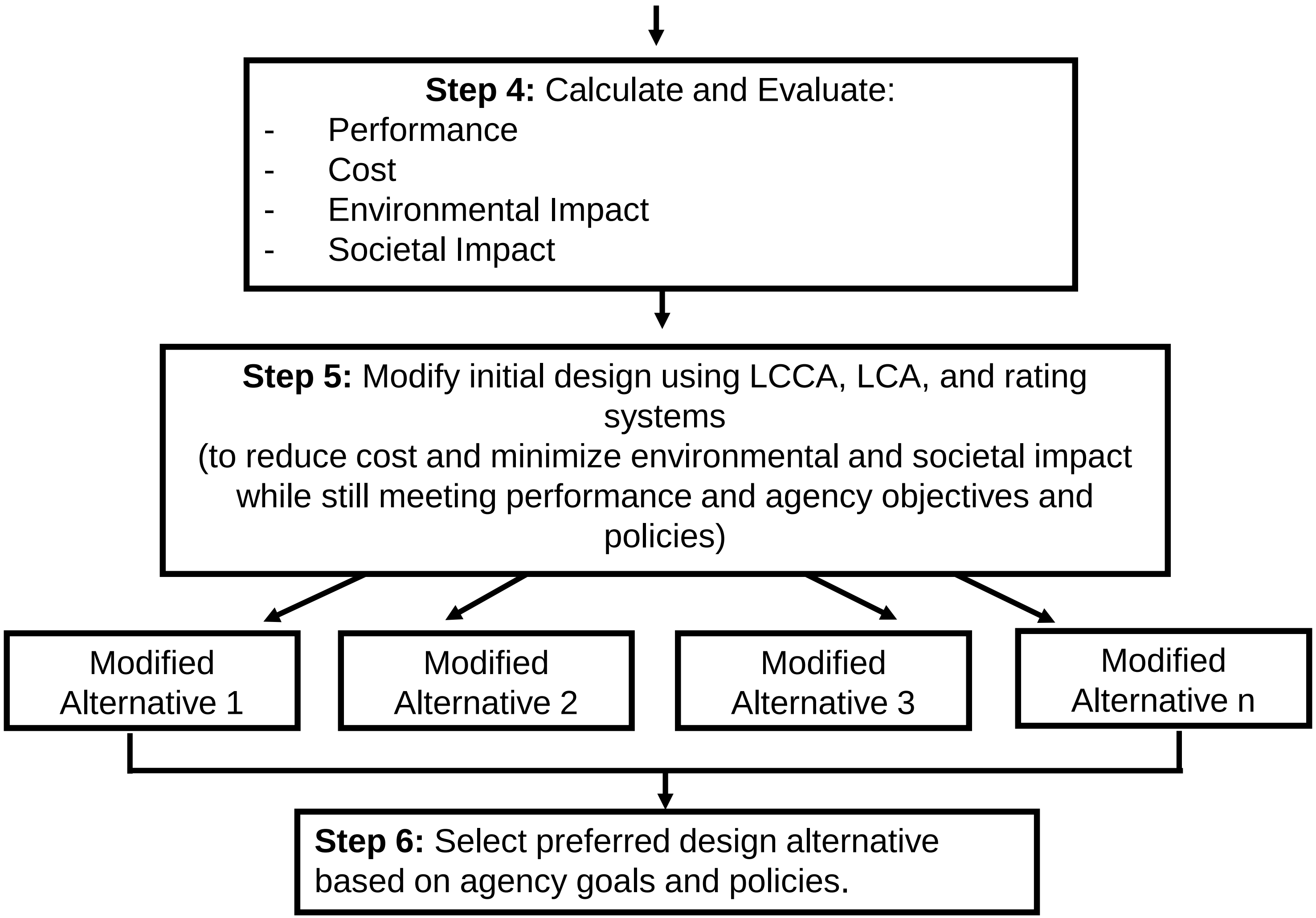
Step 2: Develop pavement designs using ME or agency design procedures

↓

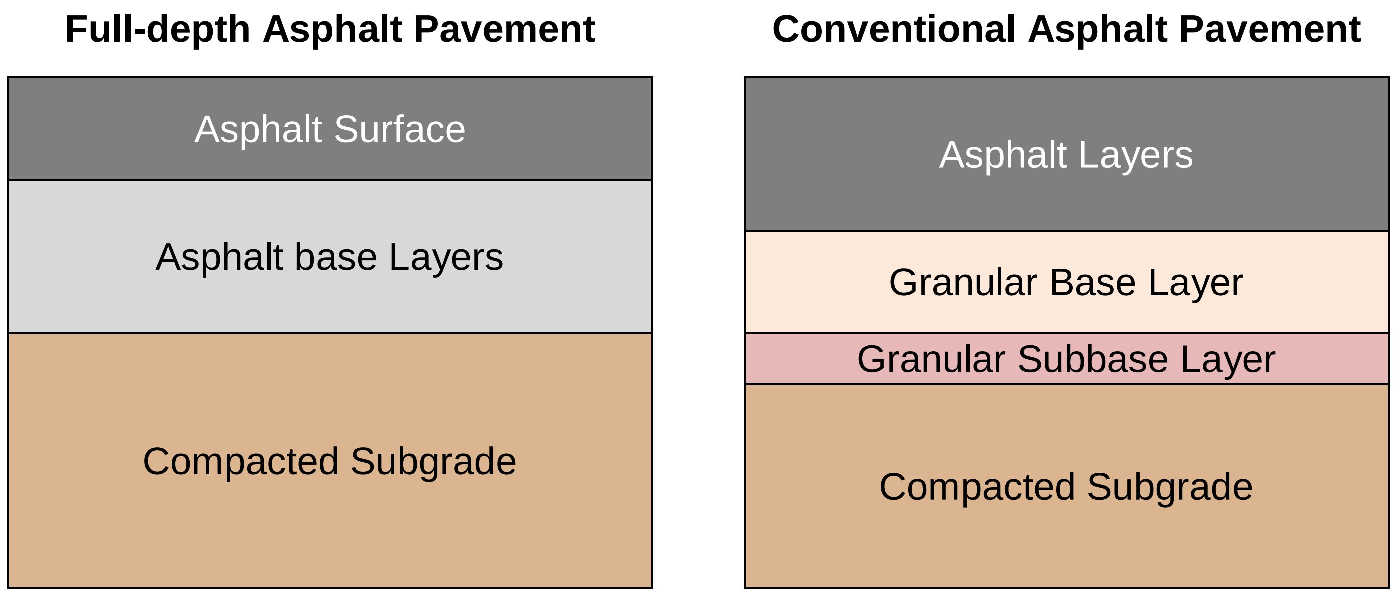
Step 3: Consider future maintenance and rehabilitation (chapters 4 & 7)

↓

Process for Considering Sustainability in Pavement Design (cont'd)



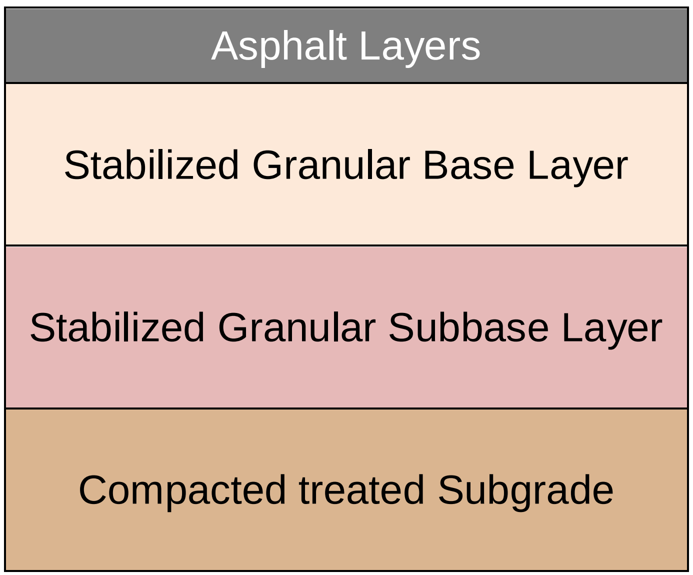
Asphalt Pavement Types



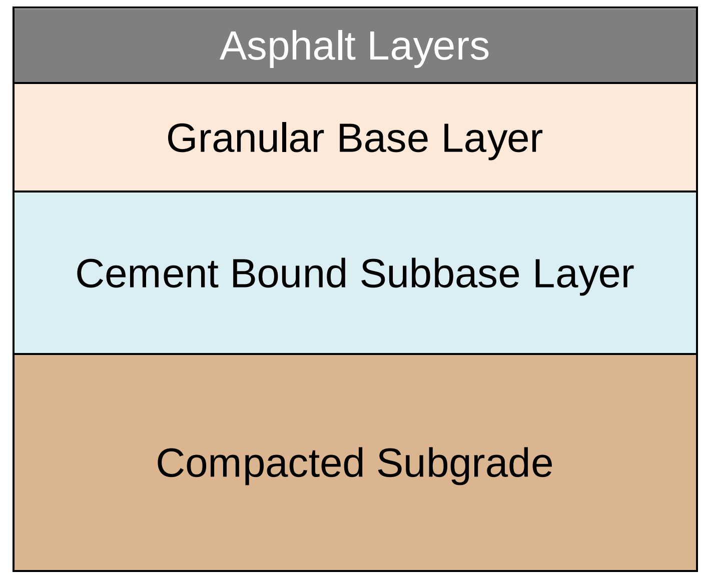
- Tradeoffs
  - Full-depth has higher impact material but overall thickness can be greatly reduced if designed well, can reduce impact for very high traffic volume routes
  - Offset higher impact if high RAP content in full-depth

Asphalt Pavement Types

Asphalt Pavement with Stabilized Subbase or Subgrade

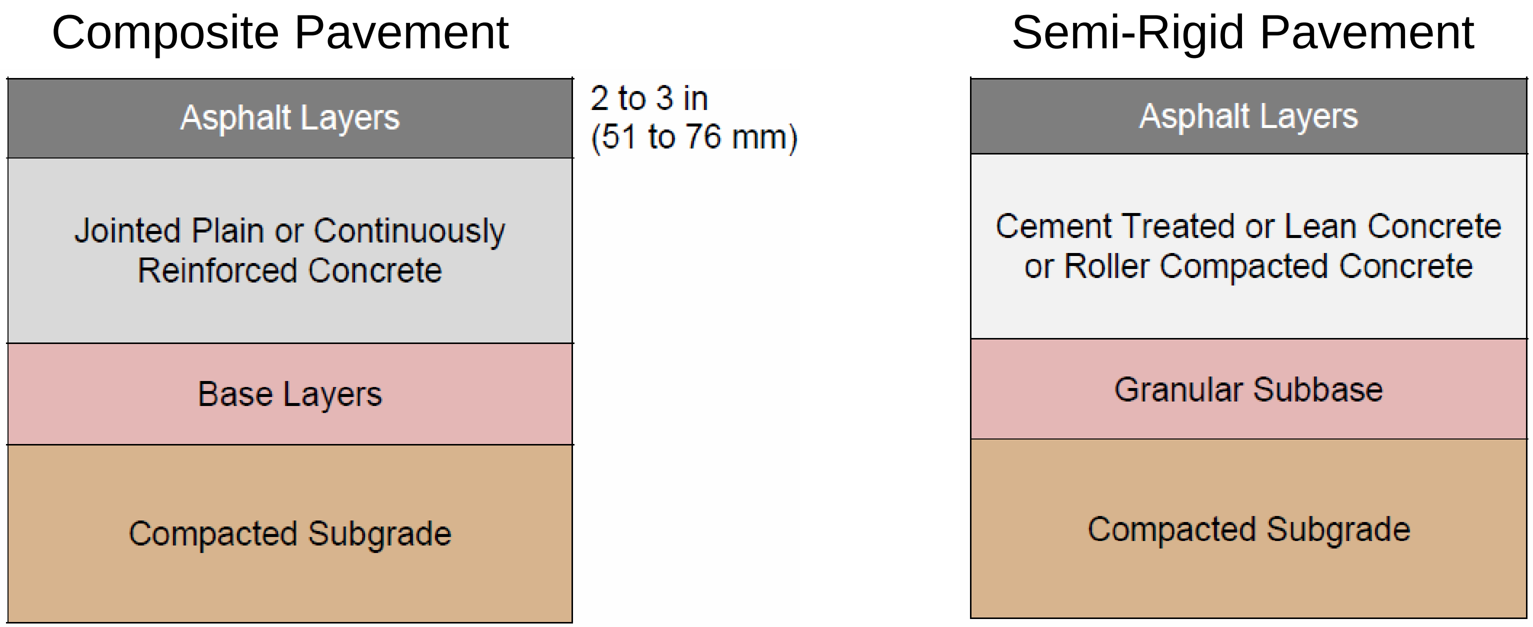


Inverted Pavement



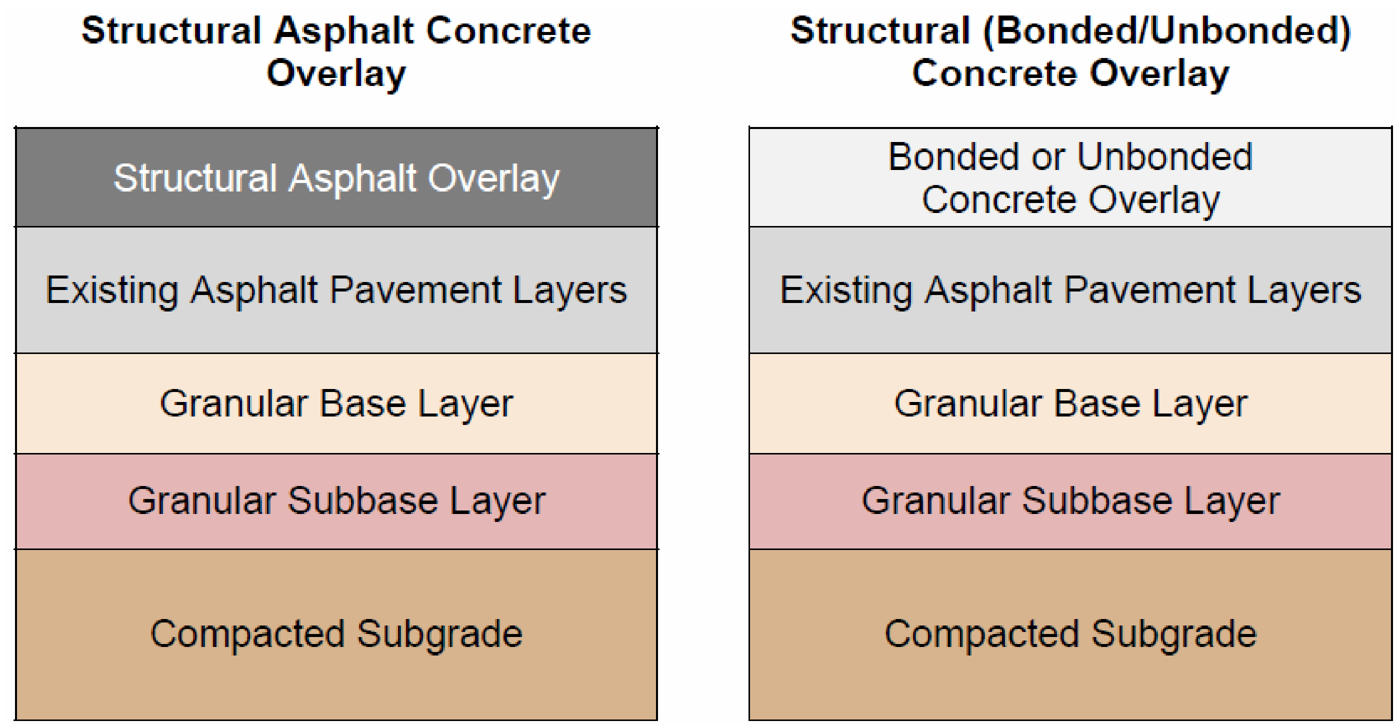
- Tradeoffs
  - Light stabilization can improve lower quality locally available granular materials (can also stabilize subgrade)
  - Inverted pavement can help minimize reflection cracking

Composite and Semi-Rigid Pavement Types



- Tradeoffs
  - Asphalt surface on composite pavement can reduce thermal stresses and allow thinner concrete, resist reflection cracking if rubberized
  - Semi-rigid pavement can help support very high axle loads

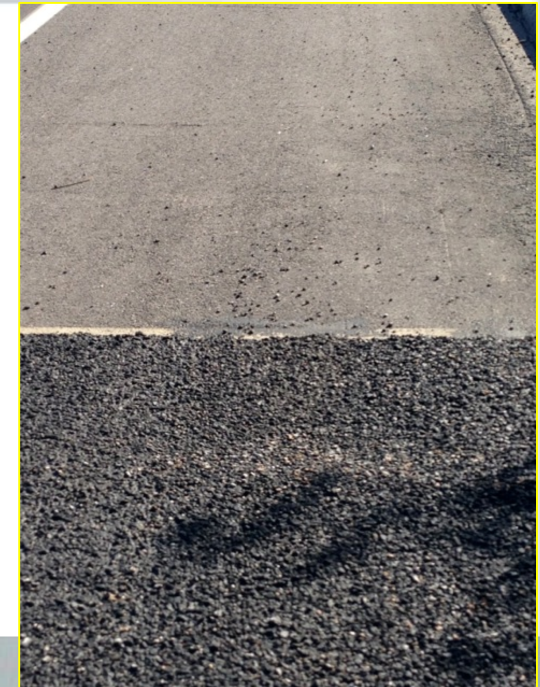
Overlays for Asphalt Pavement Structures

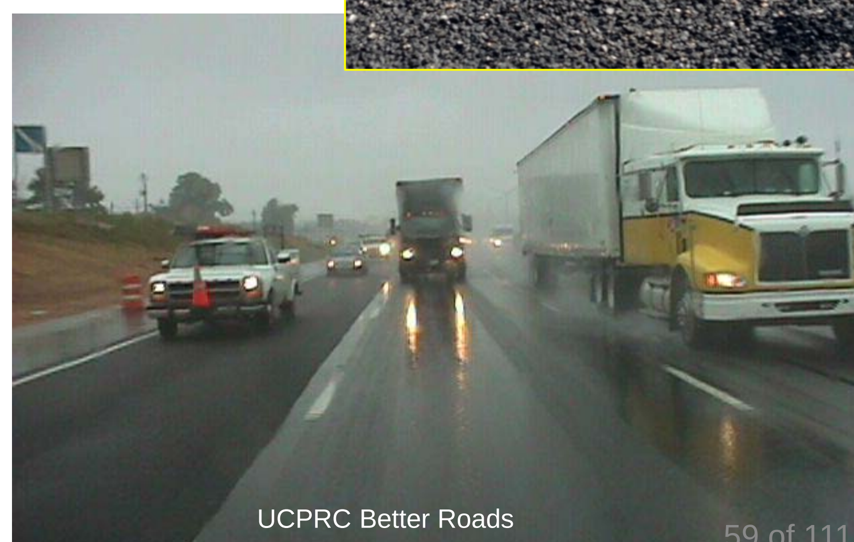


- Considerations
  - Life cycle cost will depend on relative costs of materials and ability to get good performance from alternatives
  - Environmental impact of both types of overlay can be reduced through mix design practice alternatives, improved construction quality

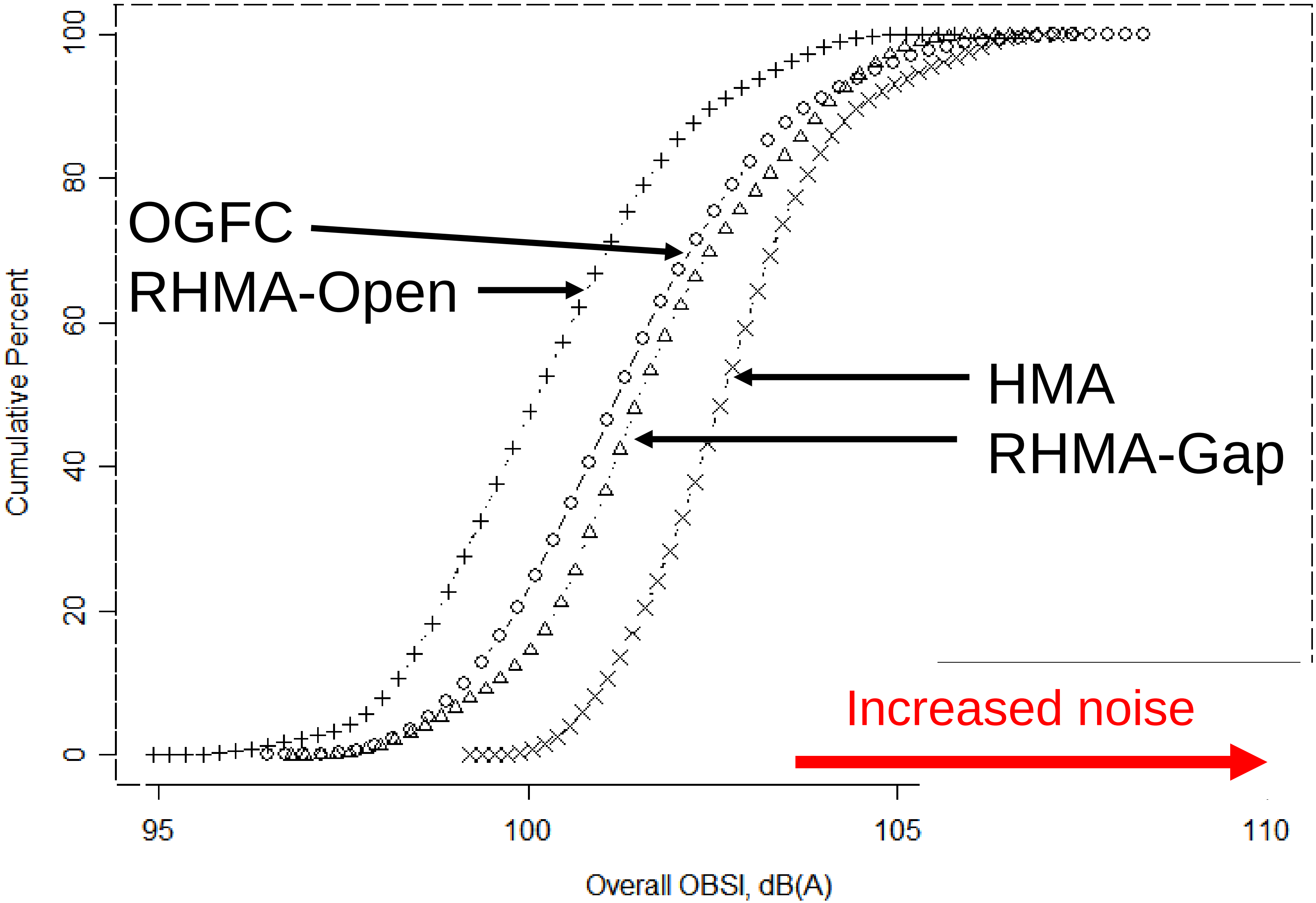
Asphalt Pavement Surface Options

- Dense-graded asphalt concrete
- High-friction materials
  - Chip seals and micro-surfacings
  - If bicycle users be aware of ride quality
- SMA for noise, durability, and friction
- Open-graded asphalt courses for noise, splash/spray, and friction





Example: Asphalt Surface Noise Performance up to 15 years of Age

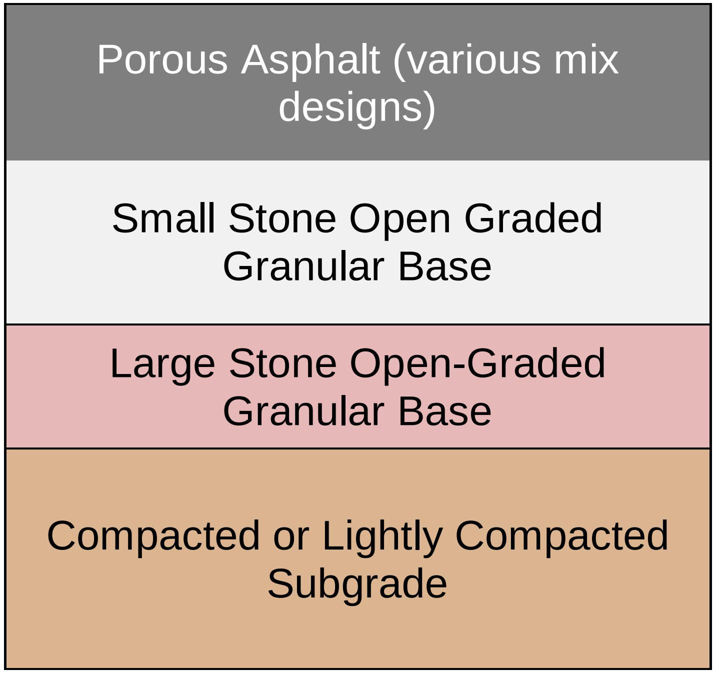


Rezaei et al. 2014

Fully Porous Asphalt Pavement

- Alternative stormwater BMP
  - Mainline pavement
  - Shoulders
  - Parking areas
- Design for hydraulic and structural performance
  - Designs for light vehicles from NAPA
  - Design method for heavy vehicles available, not yet validated

Porous Asphalt Pavement



Long Life Asphalt Rehabilitation

Existing pavement

PCC	150-300 mm AC
Base / Sub-base	150-200 mm CTB or GB

Full-Depth AC

Remove PCC or AC,
Replace with partial or full-depth AC structure

Same concept as Perpetual Pavement

Asphalt Overlay on PCC

Crack and Seat or Rubblize PCC,
Place Thick AC Overlay

Long Life AC Rehabilitation Principles and Criteria

- General Principles
  - Right material in the right place in the structure
  - Thinner pavement = faster construction
  - Materials properties specified for performance related tests
  - Design to drive distresses to occur at the surface, not in the underlying layers
- Design Criteria
  - 40 year structural design life for rutting, fatigue cracking
  - High reliability
  - Shorter design life for sacrificial surface layer

Full-Depth Asphalt Concrete Example

Layer	Thickness
Existing grade	
Sacrificial layer – safety, noise	25-50 mm
Top layer – rutting, cracking	50-100 mm
Middle layer – cracking, rutting high RAP	Varying thickness
Rich Bottom layer - cracking	50-75 mm
granular base (recycled PCC, CTB, granular)	0 or 150 mm
subgrade	

Mix Design and Compaction Specifications can Reduce Thickness Example: I-710 Long Beach Freeway

Traditional materials and ME design

535 mm thick (21 in)

8 % air-voids
same mix design throughout
AR-4000 std binder

ME design using
- Improved compaction
- Stiffer binder
- Rich Bottom

300 mm thick (12 in)

75 mm polymer 5% air-voids
150 mm AR-8000
5% air-voids
75 mm AR-8000, 2% air-voids
+0.5% binder

Local Materials/ Low-Impact Transportation

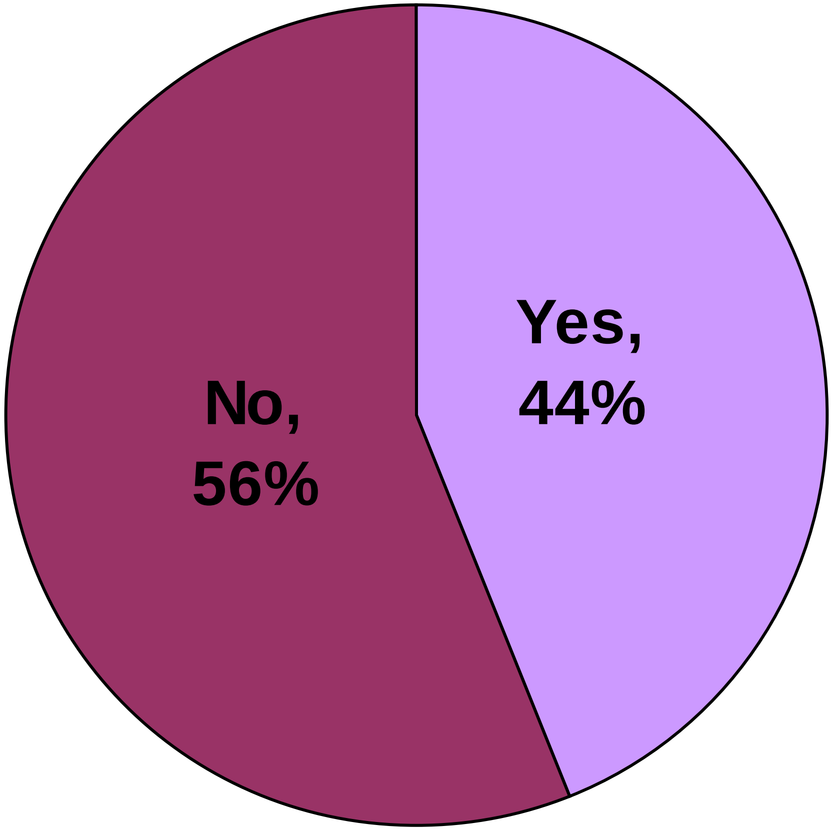
- Transporting materials has major environmental and social impacts
  - Consider materials specifications and whether designs can be developed to maximize use of local materials
- Consider adoption of a zero-waste approach that includes recycling of all pavement materials on-site or nearby
- Must not compromise pavement longevity
- Reduce environmental impact of materials over the life cycle
  - Cannot just consider initial construction

Accelerated Construction

- Can reduce cost and environmental impact
  - Less mobilization and demobilization
  - Less worker travel
  - Short intense pain vs. prolonged agony
- Techniques:
  - Designs and specifications to minimize thickness, speed construction
  - Continuous and full direction closures
  - Extensive traffic management planning, traffic monitoring and adjustments
  - Extensive public outreach
  - Provision of alternative transportation

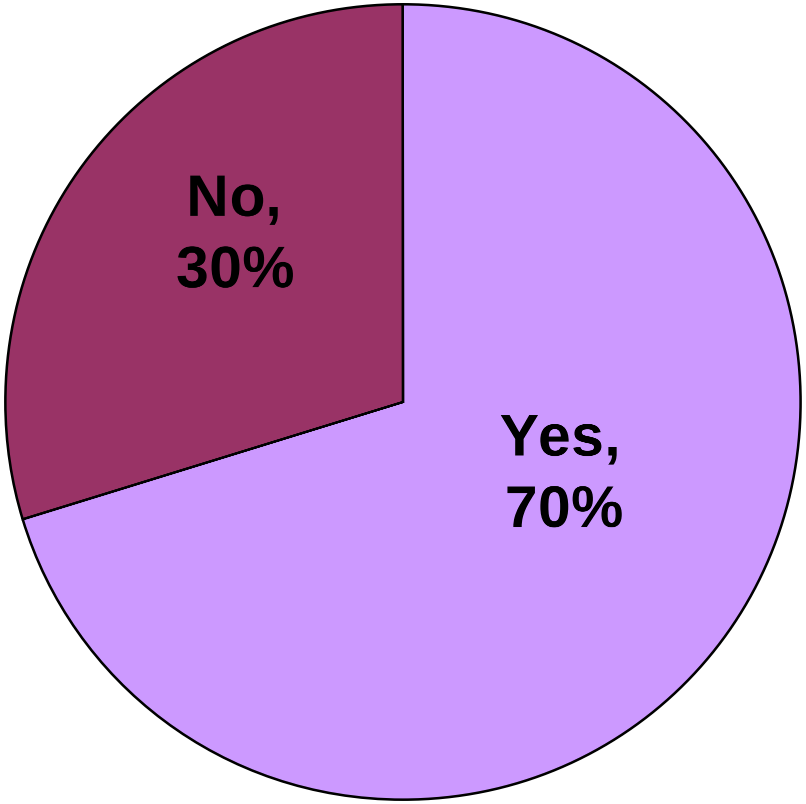
Public Perception Changes for Accelerated Construction

Before- construction



Do you support I-15 Devore "Rapid Rehab" approach?

After-construction

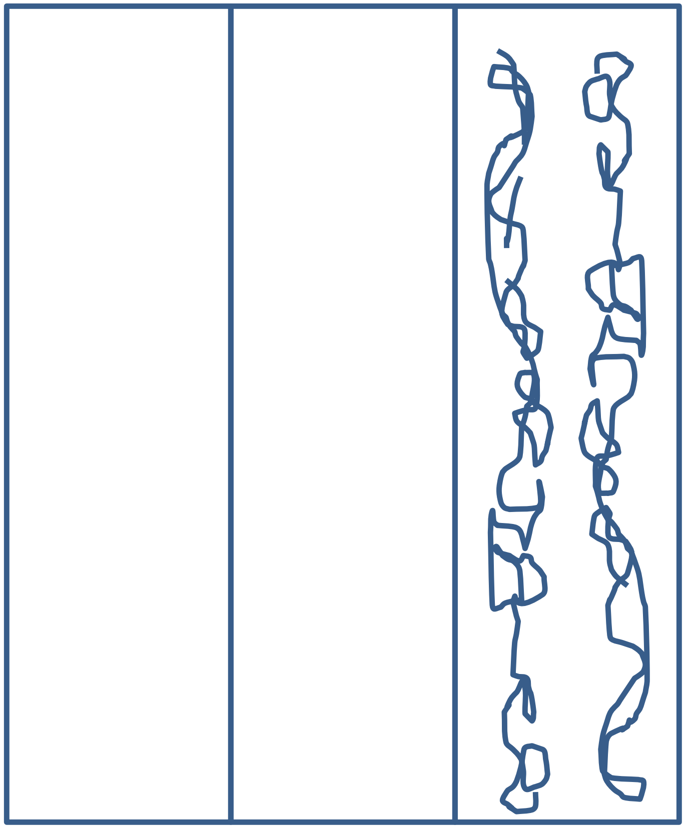


Do you support future "Rapid-Rehab" projects?

Lee et al. for Devore I-15 project

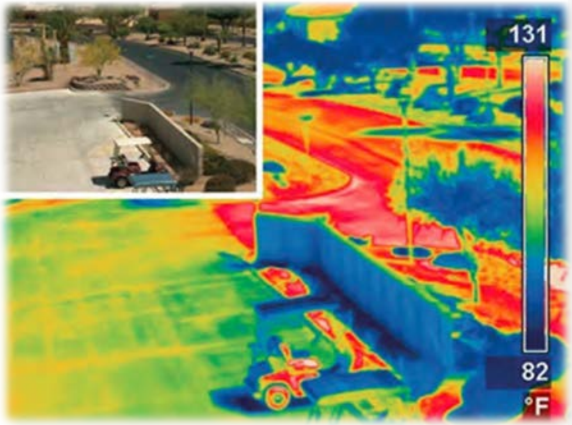
Single-Lane Rehabilitation on Multi-Lane Roads

- If truck lane is damaged and inner lanes are not
  - Consider partial reconstruction or mill & fill of outer lane
  - Leave inner intact or thin surface treatment over all lanes afterward
  - Can reduce materials and construction impact compared with overlay of all lanes



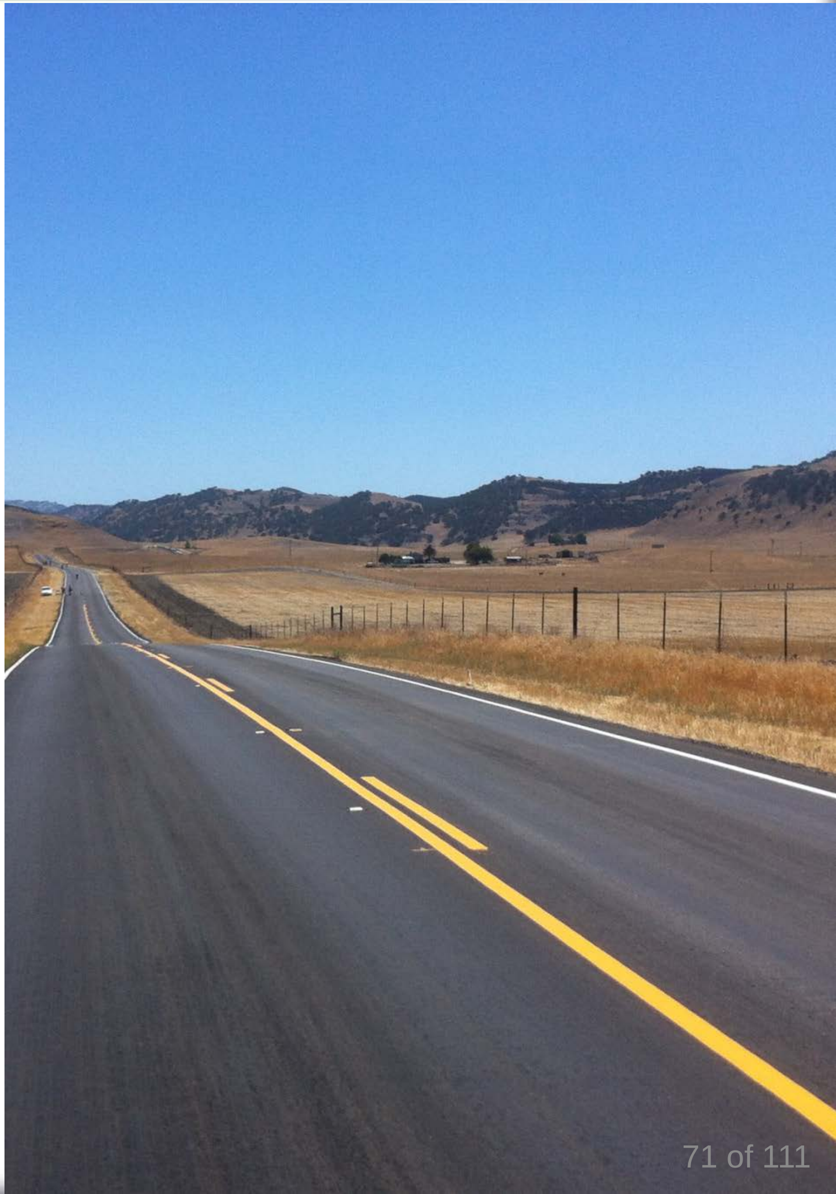
Considering the Use Phase

- Traffic
  - Fuel efficiency is correlated to smoothness
  - Also affected by texture, structural response
  - Noise, pollution, and particulates
- Stormwater
  - Urban issues include flooding and stormwater treatment
  - Safety
- Other considerations include aesthetics, urban heat island effect, artificial lighting, utility cuts, manholes



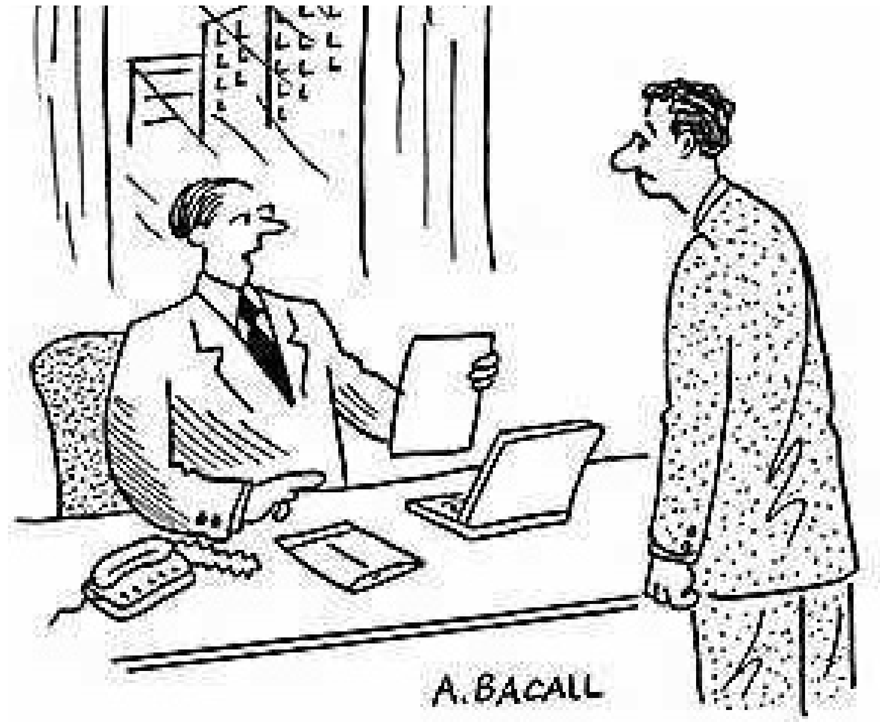
Summary of Design Considerations

- Achieve longer life or thinner pavement for same life by integrating
  - Structural design
  - Materials selection and design
  - Construction quality
- Maximize use of recycled and locally available materials
  - Consider specifications changes
- Consider
  - Use phase impacts
  - End-of-life scenarios



Sustainable Pavement Design

- Context sensitive
- Use “best” design methodology
- Consider the life cycle
- Challenge yourself and your organization to approach design differently



“Your proposal is innovative. Unfortunately, we won’t be able to use it because we’ve never tried something like that before.”

Future Directions/Emerging Technologies

- Improved ME design capabilities
- Performance related construction specifications
- New materials including more recycled materials and new binders
- Integration of cost and environment in design criteria
- More consideration of future preservation, rehabilitation and recycling in design

FHWA Sustainable Pavements Program

- Construction Considerations
- Strategies to Improve Sustainability

Imad L. Al-Qadi and Hasan Ozer

Construction Phase

- Pavement construction is the process of implementing a sustainable pavement design using appropriate sustainable materials and apply sustainable construction practices to achieve "durability" and "longevity"
- Construction activities include hauling, subgrade preparation, and base/surface layer placement and compaction

Asphalt Pavement Construction

- Every year 500 million tons of new asphalt pavement materials are produced in the U.S. at approximately 4000 asphalt mixing plants (NAPA 2013)

Subgrade preparation

Subgrade compaction

Base layer preparation and compaction

Tack coat application

Asphalt laydown

Asphalt compaction

Key Issues Related to Construction and Sustainability

1. Fuel consumption resulting from various construction activities
2. Exhaust emissions influencing local air quality and global environmental impact
3. Indirect effects such as traffic delay, congestion, and noise emissions
4. Pavement performance and overall life (affected by construction quality and pavement/material design)

1. Energy Consumption and GHG Emissions

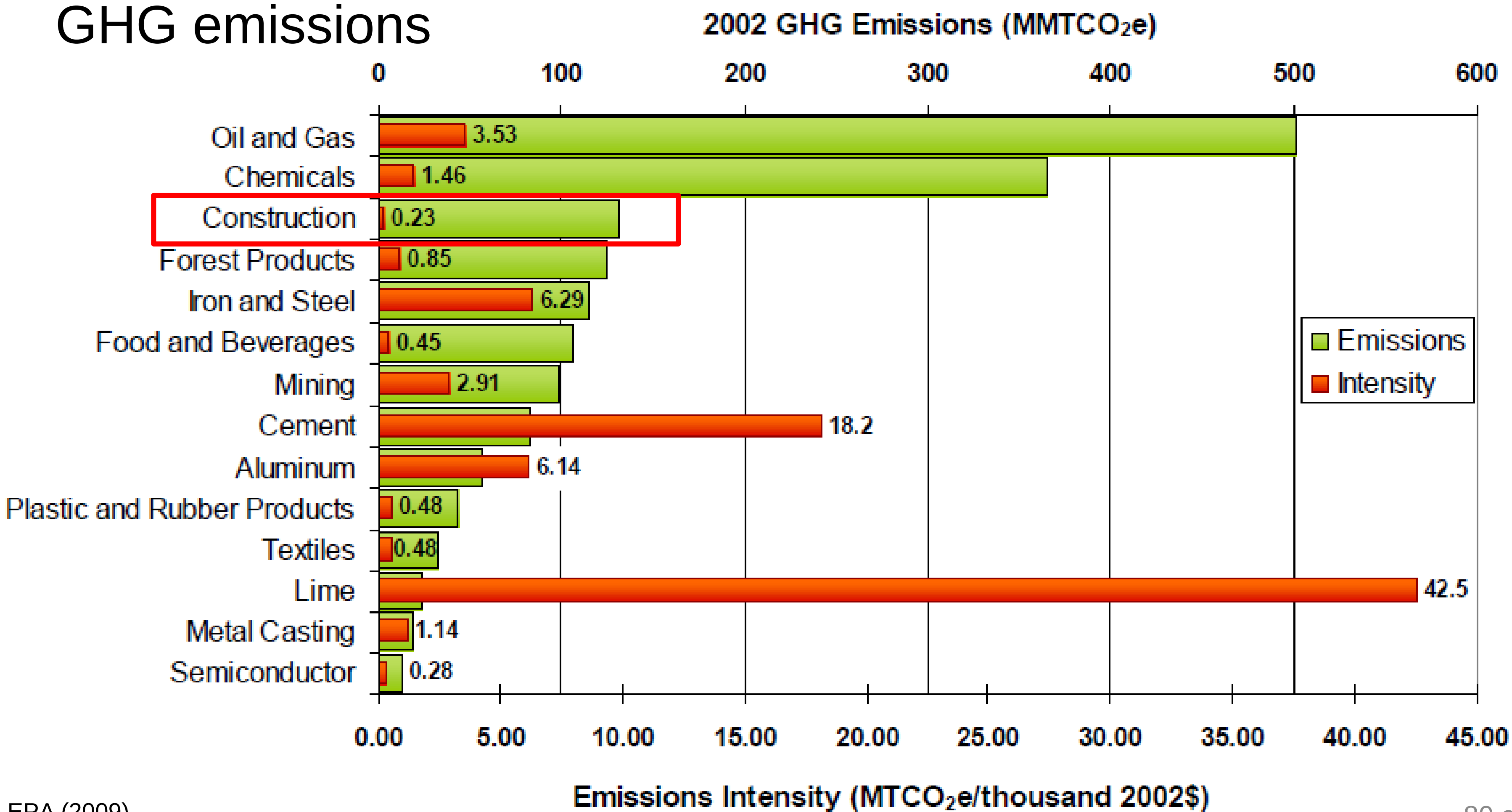
- Pavement construction is generally an energy-intensive process
  - Operation of various construction related equipment (direct energy and emissions)
- Common energy sources are gasoline, diesel, propane, purchased and generated electricity

Highway Construction Emission Intensity

- *Emission Intensity* is the ratio of the GHG emissions produced per dollar of gross domestic product (GDP); GHG per economic value added
- Provides a means for comparing sectors' emissions while considering economic output
- Introduced by EPA to characterize environmental performance of various industrial sectors including construction sector

Sector Comparisons

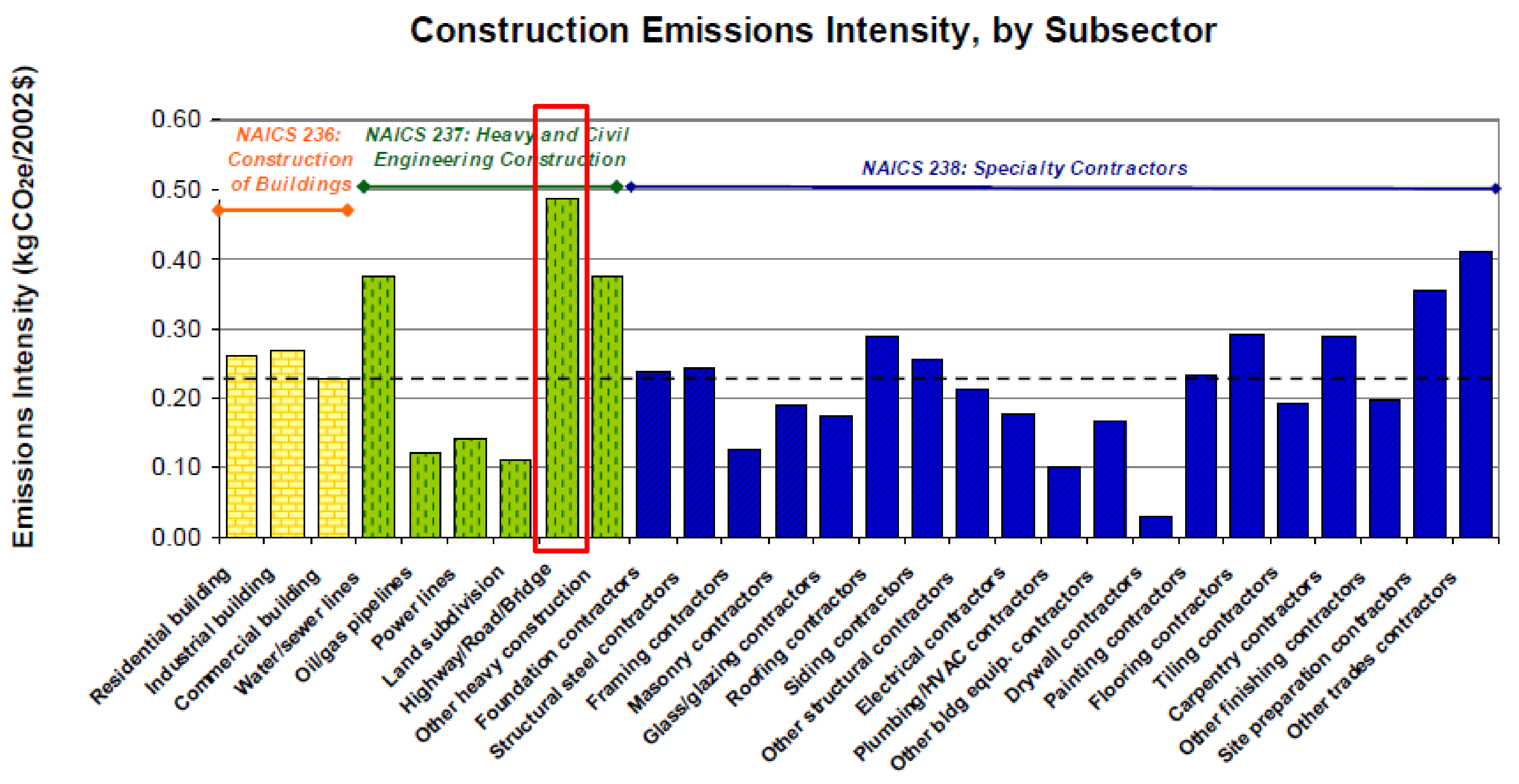
- EPA's sector strategies division has analyzed magnitude of various industrial construction sectors to find ways to reduce GHG emissions



EPA (2009)

Highway/Road/Bridge Construction

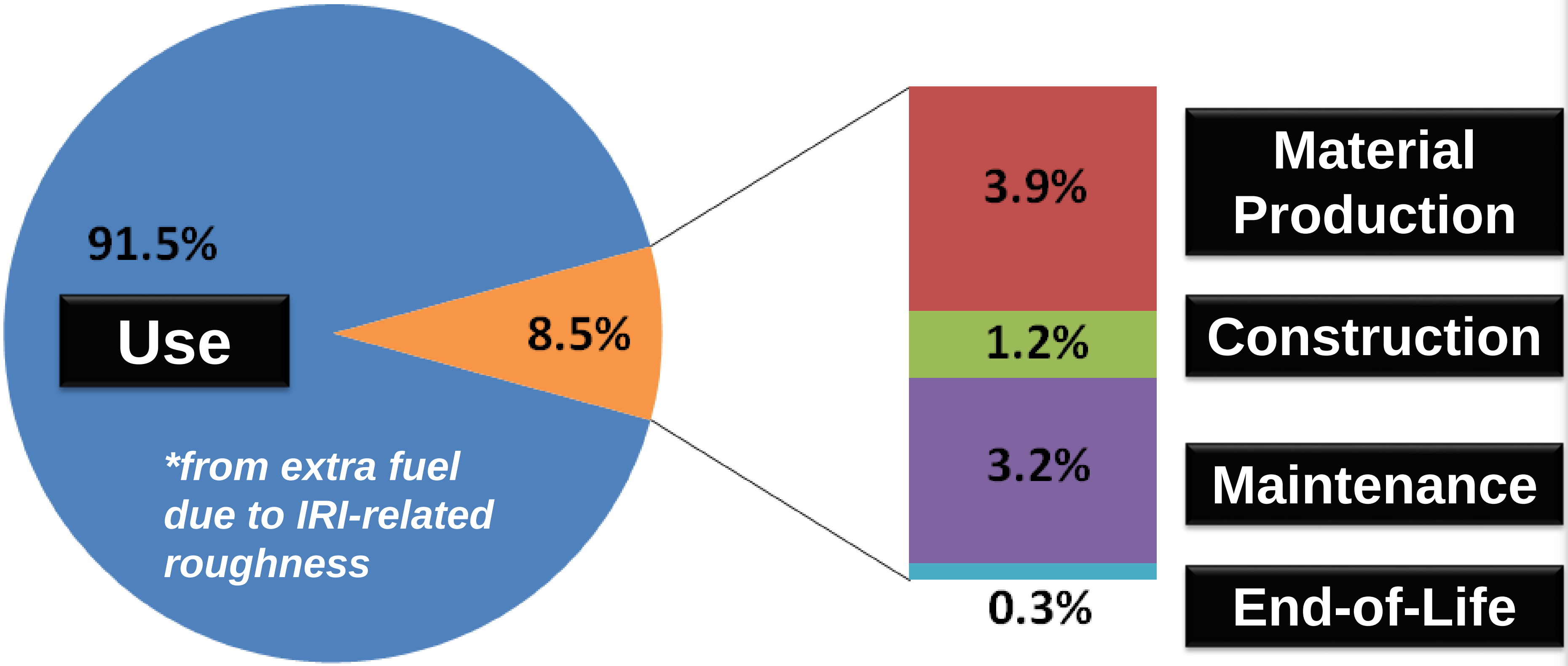
- Emission intensity: 0.49 m-ton CO_2-eq/$1000GDP (2002)



EPA (2009)

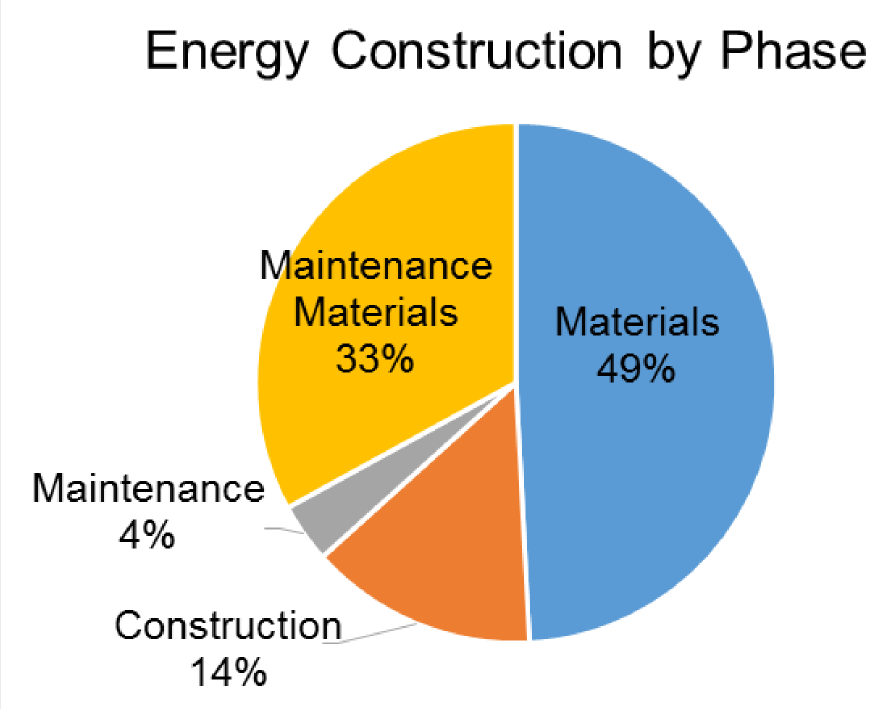
Construction Contribution to LCA

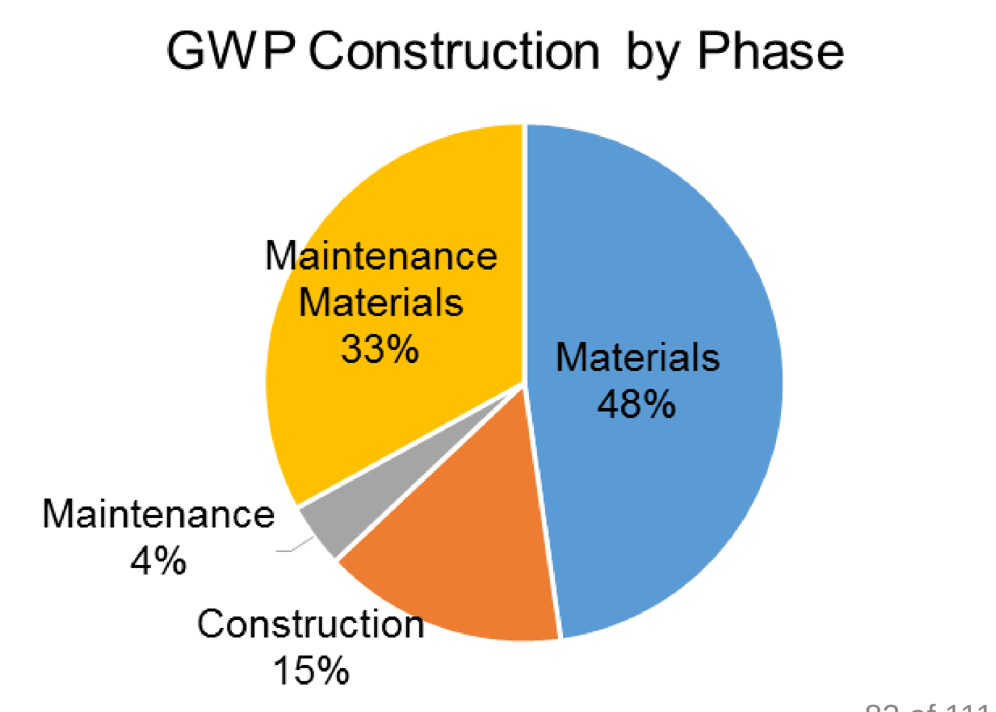
Energy Consumed in an Asphalt Pavement Life Cycle



Construction Contribution to LCA

- Construction phase contributes around 14-15% to life-cycle (excluding Use and EOL phases)



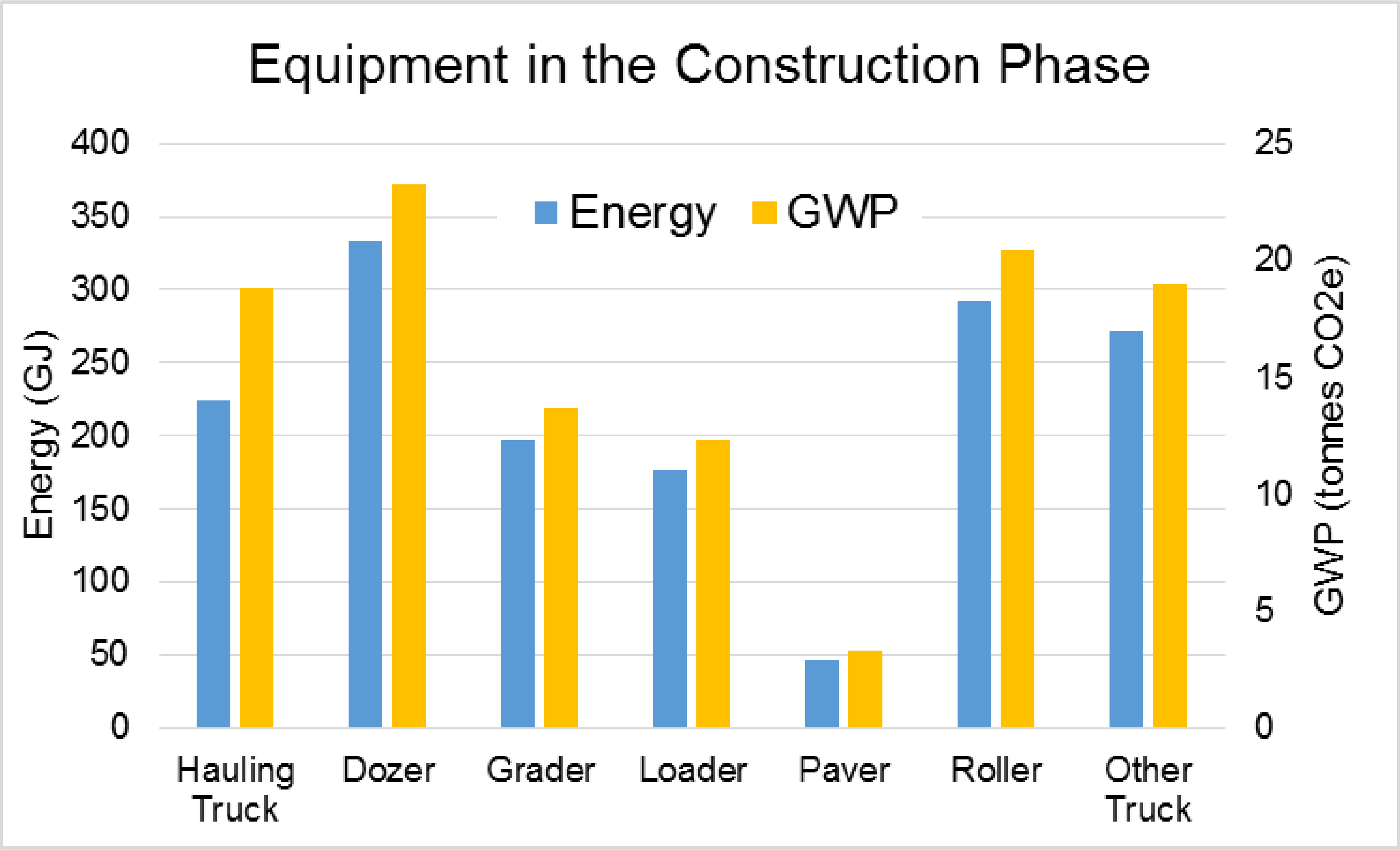


Environmental Impact of Various Tasks and Equipment

- Major equipment used in asphalt pavement construction and their contribution to energy use and GHG emissions

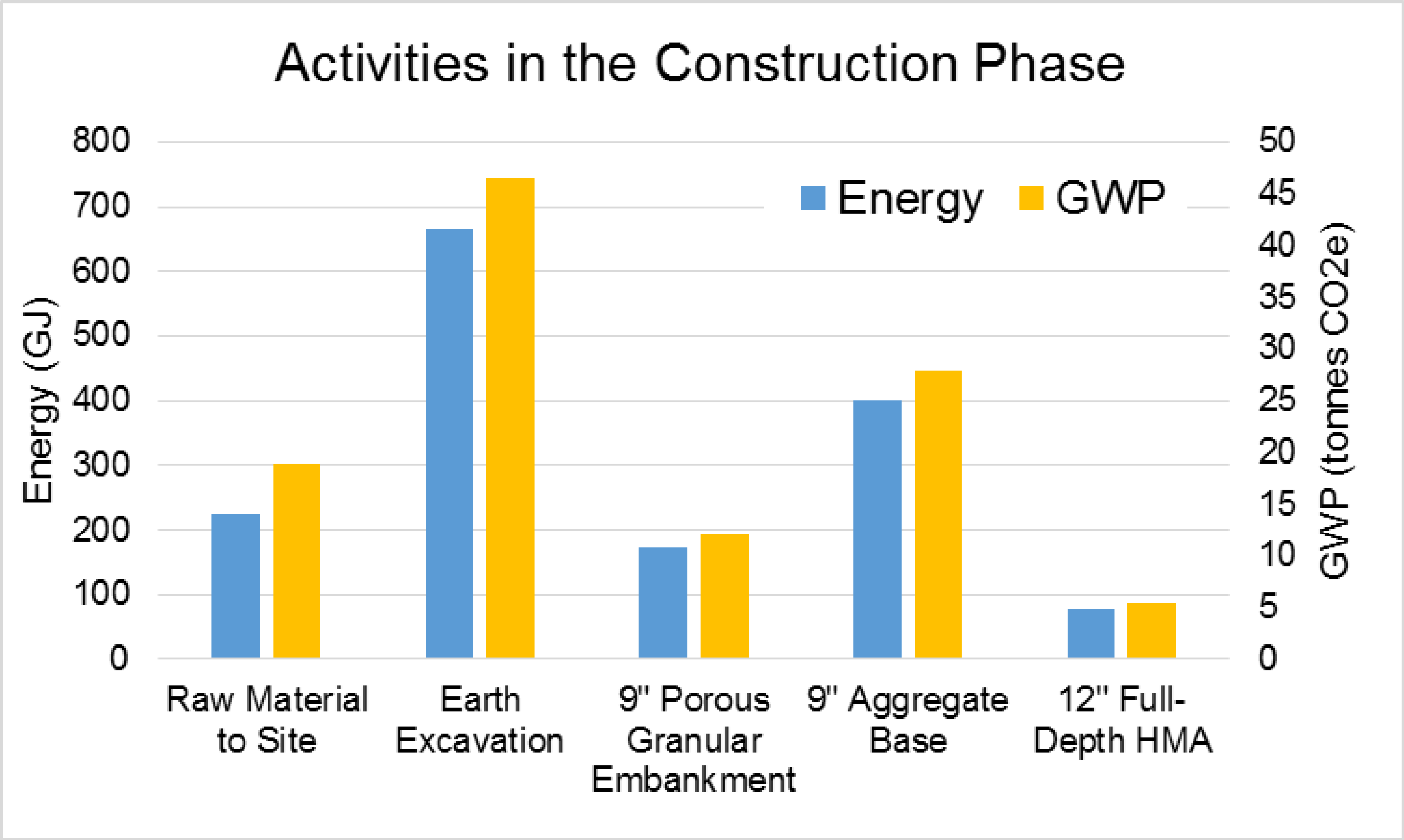
Activity	Equipment	Horsepower Range	Fuel Consumption Range (gal/hr)	CO_2 Emissions Range (lb/hr)
Asphalt Paving	Paver	125-225	35-50	90-136
	Pneumatic Roller	100-135	6-12	45-136
	Vibratory Roller	100-135	4-6	226-1130
Milling	Milling Machine	400-875	2-6	113-339
Excavation and Placing	Excavator	100-320	10-50	136-226
	Vibratory soil compactor	100-180	5-15	271-361
	Bulldozer	250-500	6-10	90-136

Example of Equipment Contribution



Case Study: Construction Activities for a High Volume Road

- Activities in the construction phase and their environmental impact in terms of GWP and energy consumption



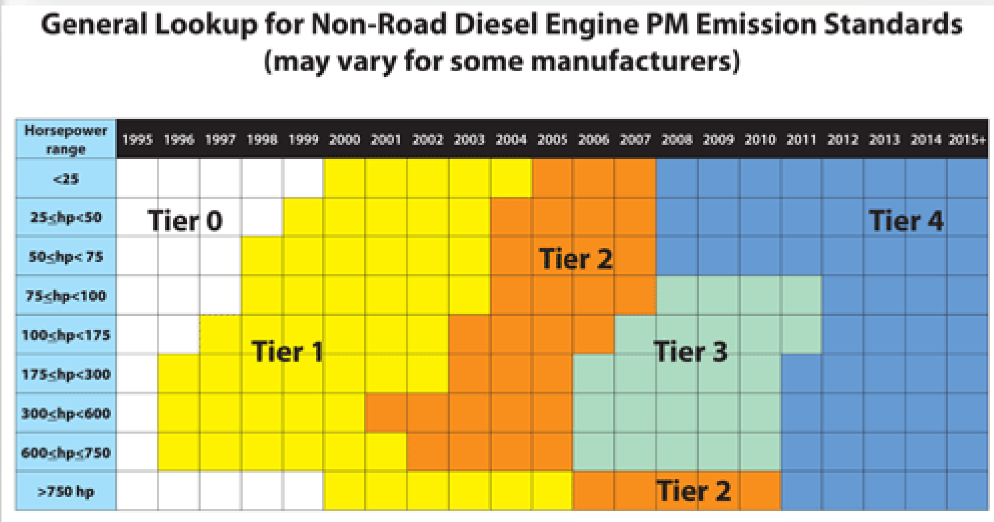
2. Impact of Construction on Surrounding Areas

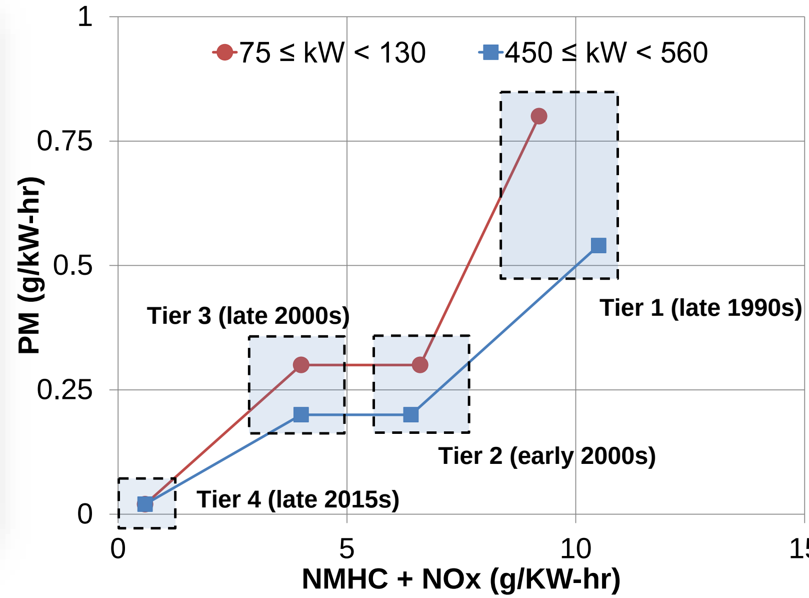
- Emissions from Equipment Exhaust
- Airborne Particulates from Construction Operations
- Noise Generated from Construction Operations
- Construction Impacts on Local Traffic, Residences, and Business Operations
- Construction in Streams, Wetlands, and Environmentally Sensitive Areas

Exhaust Emissions on Local Air Quality

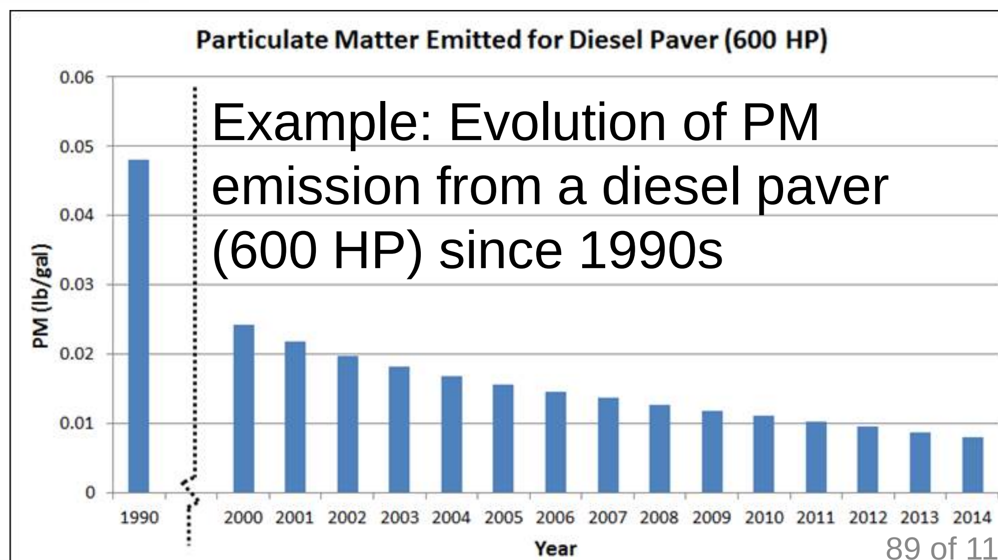
- The Clean Air Act requires EPA to set national air quality standards for particulate matter and other pollutants considered harmful to public health and the environment:
  - Carbon monoxide, nitrogen oxide, sulfur dioxide, volatile organic compounds (VOC), and particulate matter
  - Primary particles are directly emitted from a source such as construction sites, unpaved roads, etc.
  - Secondary particles are emitted from equipment/cars tail pipes combustion of fuels

EPA Standards on Engine Limits





- A tiered approach was put forward by EPA depending on the vehicles or engines' rated power and age



Example of Air Quality Implementation

- California Environmental Quality Act (CEQA) proposed construction emission thresholds to identify critical projects to calculate emissions and require mitigation

Pollutant	Threshold		
	Daily	Quarterly Tier 1	Quarterly Tier 2
VOC + NO_x (combined)	137 lbs	2.5 tons	6.3 tons
Diesel Particulate Matter (PM)	7 lbs	0.13 tons	0.32 tons
Fugitive Particulate Matter (PM_{10}), Dust		2.5 tons	
Greenhouse Gases	GHG emissions needs to be combined with other life-cycle emissions and amortized over the life of the project.		

3. Construction Management and Sustainability

- Construction work zones can cause user delay, increased fuel consumption, and compromised roadway safety
- Indirect economic and environmental impact result from construction activities due to reduction in roadway capacity and delays
  - Highway construction zones account for 24% of nonrecurring congestion equivalent to 482 million vehicle-hours per year (USDOT 2006)
  - Loss of 60 millions vehicles capacity per day based on 3,110 work zones covering 13 states (Wunderlich and Hardesty, 2003)

Construction Sequencing and Efficient Work Zone Management

- Establish performance goals and measures for work zones
  - i.e. Target work zone delay to be less than 6% of all traffic delays in Netherlands
- Incorporate lane/road closure analysis strategies during project planning
  - Project management programs such as FHWA's QuickZone, CalTrans' CA4PRS, and Dynasmart
- Implement effective road and lane closure strategies during construction
- Implement intelligent transportation systems (ITS) to provide alternative routes or modes to drivers

Quantifying Sustainability Impact of Traffic Delays

- Energy and emissions contribution of traffic delays due to construction activities are often ignored in pavement LCAs
- Impact on environment, associated with traffic delays, may be quantified using appropriate tools:
  - Traffic simulator to estimate driving schedule under changing roadway capacity
  - EPA's MOVES software to calculate additional emissions and energy consumption with changing driving schedules

Simulation Variables for MOVES

- Vehicle-related variables
  - Vehicle types
  - Fuel type
- Time & geography
  - Time-specific (i.e., year, month, hour)
  - Region-specific (i.e., state, county)
- Road-related
  - Road type (rural, urban, etc.)
  - Geometric design features

Vehicle Emissions Simulations

- EPA's MOVES
  - Emission modeling system for mobile sources
  - Energy consumption
  - Emissions to air
    - 120+ emissions

- EPA's NONROAD
  - Emission modeling system for non-road equipment
  - Energy consumption
  - Emissions to air
    - HC, CO, NOx, PM, SO2, and CO2

Vehicle Emission Simulations: LCA Inventory Database

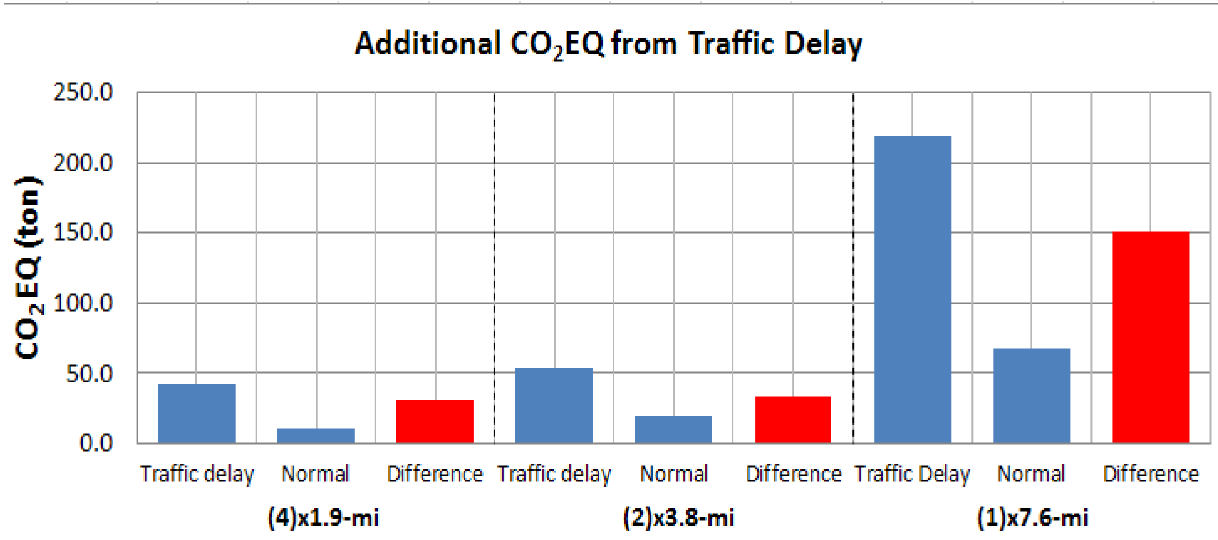
- Construction equipment
- Hauling
- Total use-phase traffic emissions
- Road related use-phase traffic emissions
- Congestion and work-zone related emission inventories

Case Study: Work Zone Scenarios and Impacts Using MOVES

- Traffic scenarios considered a 7.6 mi work zone (Kang et al., 2014):
  - Partition the project into 4 work zones and use night time closure to complete each
  - Partition the project into 2 work zones and use 16-hr closure between 10 pm and 2 pm
  - No partition with 32-hr closure starting from 9 pm and finishing 5 am

GWP due to traffic delay was 1.3 % (best case scenario) to 2.7 % (worst case scenario) of the total GWP including material and construction phases.

However , if no queue develops, there can be energy savings (Wang et al., 2014)

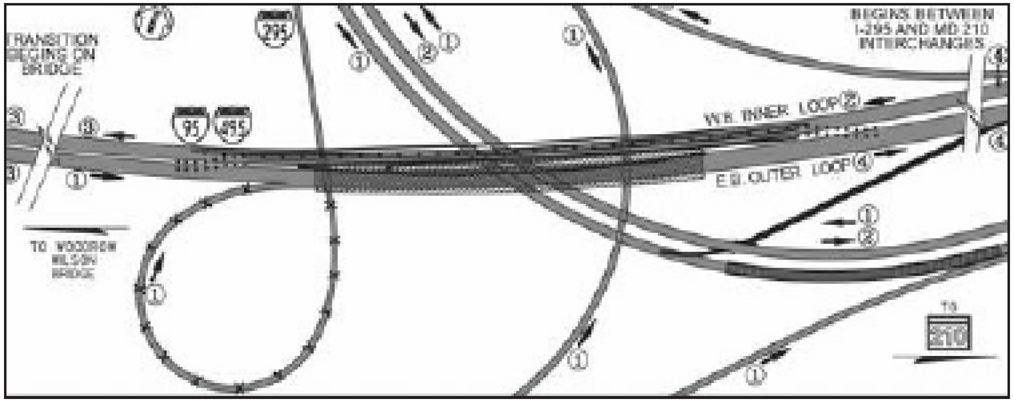


Case Study: QuickZone

- Quickzone is a software tool for traffic analysis that compares traffic impacts for work zone mitigation strategies and estimates traffic delays and cost
- Quickzone was used during the planning stage for Woodrow Wilson Bridge replacement project with an objective to minimize impact on road users

  – Duration of project was reduced from an estimated 6 months to 2 months

  – Efficient communication was created between the contractor and bridge management team



Case Study: I-15 Devore Selection of Closure Type Using CA4PRS

Construction Scenario	Schedule Comparison		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closures	Closure Hours	User Delay	Agency Cost	Total Cost	
1 Roadbed Continuous	*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

Lee et al. from I-15 Devore project

4. Quality and Performance of Constructed Pavements

- Even with the most durable materials and the most effective pavements design, the overall pavement performance expectations will go unrealized if poor construction practices or inadequate quality control are performed
- Key sustainability words are "durability" and "longevity" that can be achieved or compromised with construction practices

Key Strategies for Sustainable Asphalt Paving

- At placement and laydown
  - Achieve target density requirements
  - Meet smoothness requirements
  - Proper construction of longitudinal joints
  - Control segregation
- QC/QA control at all stages of construction
- Use of contracting alternatives and emerging technologies
  - Eco-costs; performing LCA to earn incentives
  - Warm mixes, MTV, segregation monitoring, etc.

Achieving Target Density

- Achieving uniformity and target requirements for density is critical for all layers of asphalt pavements
- A strong correlation exists between service life and in-place density
- Key factors affecting asphalt layer density:

Lift Thicknesses

Laydown Temperatures

Compaction Equipment and Procedures

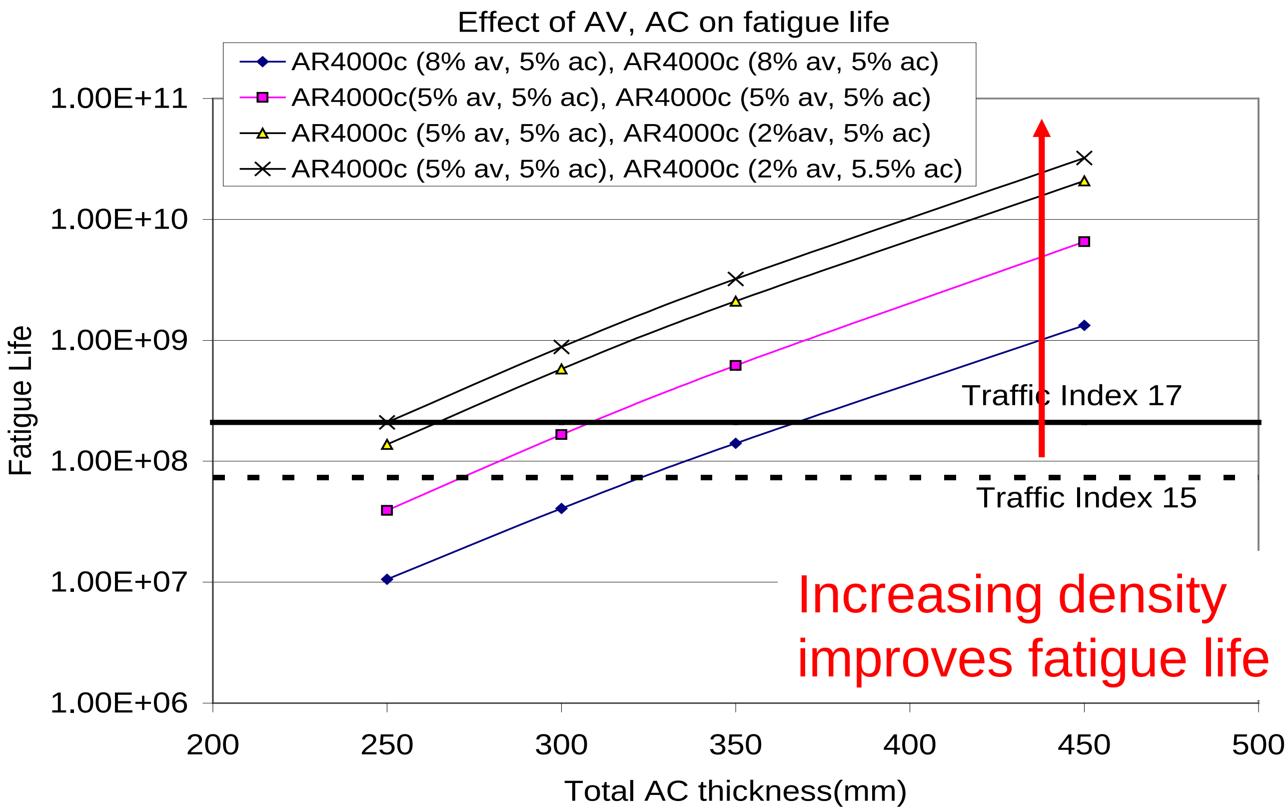
Mixture Characteristics

Environmental Conditions

Impact of Air Voids on Service Life

- Increasing density of asphalt layers up to 4% improved fatigue life in the laboratory by 50% (Kentucky Transportation Center and AI study, 2010)

An optimized mixture density reduces rutting and cracking potential (Harvey et al. 2004)

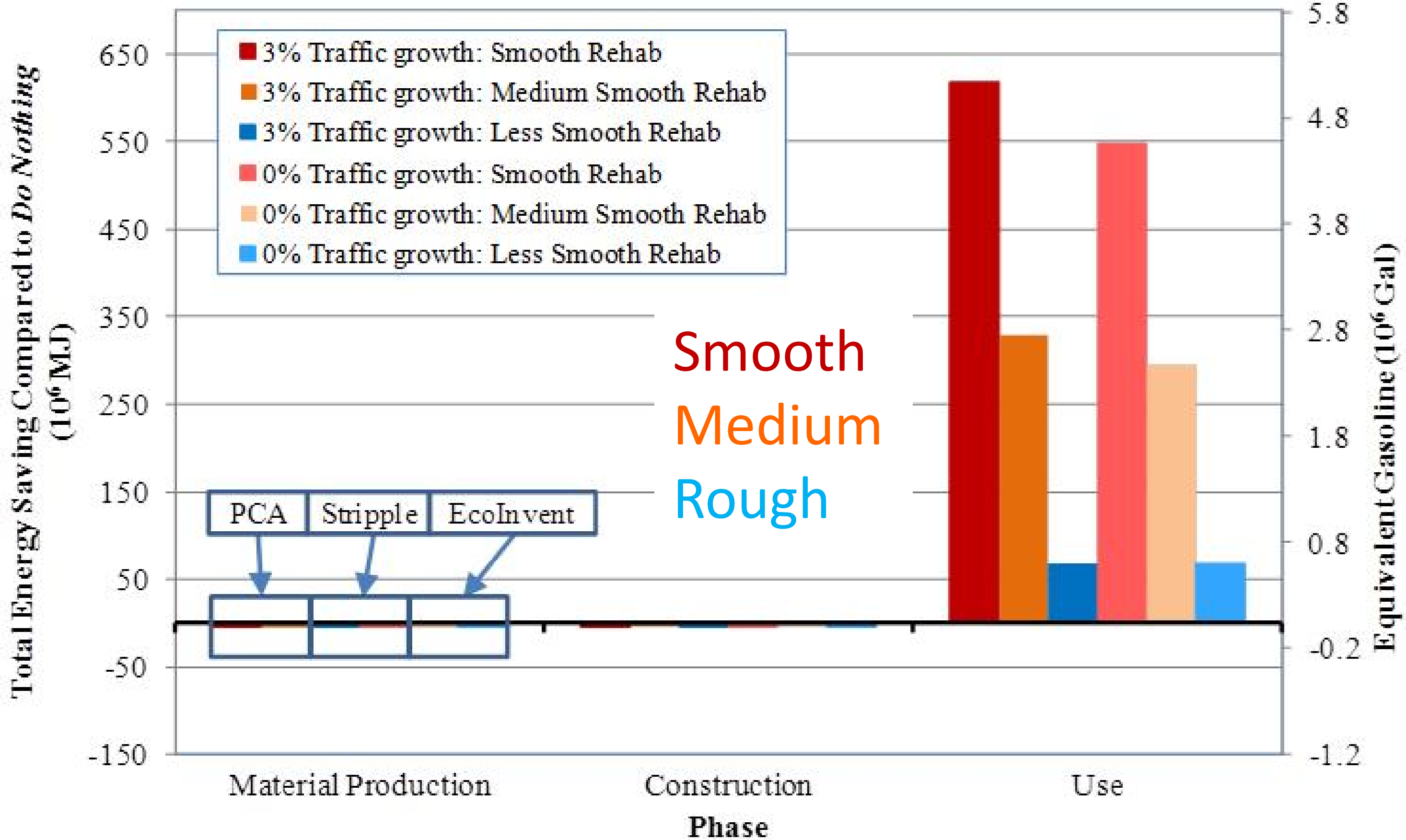


Impact of Pavement Smoothness

- Improving ride quality (user impact)
- Reducing fuel consumption (environmental impact)
- Reducing dynamic loads (economic and environmental impact)
- Reducing losses of freight damage (economic impact)
- Reducing vehicle operation costs (economic impact)

Smoothness and Fuel Consumption

- Smoother pavements directly contribute to fuel consumption during use-phase of pavements

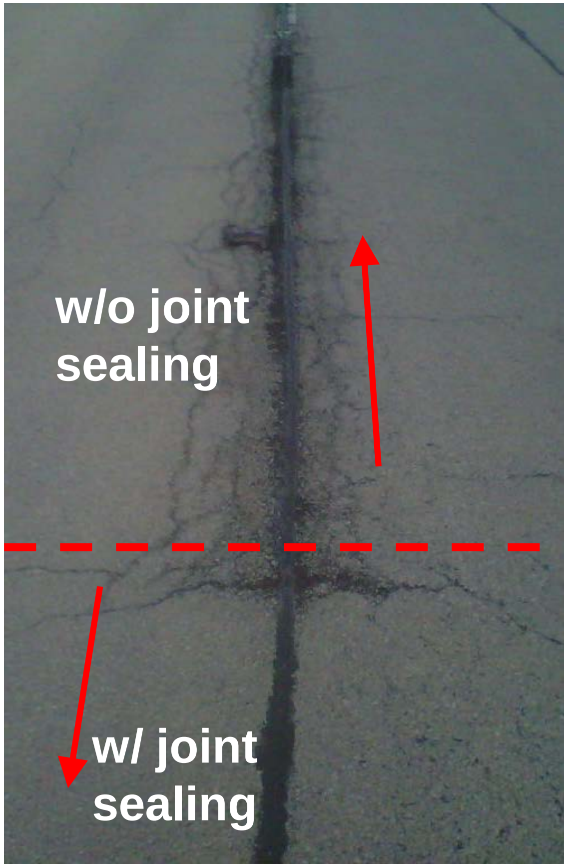


Wang et al. 2012

Impact of Longitudinal Joints

- Good longitudinal joint performance, longer life pavements
- Longitudinal joints often drive pavement rehab.
- Key strategies:
  - Achieve target density (2% < mat density)
  - Construction of notched wedge joint
  - Installing joint adhesives

After 12 years



Courtesy of J. Trepanier (IDOT)

Various Joint Adhesive Technologies

- Roll out technology

- Hot pour technology

Courtesy of J. Trepanier (IDOT)

Innovative and Emerging Technologies

- Improve construction quality using advanced technologies primarily:
  - to monitor and minimize segregation
  - to control and maintain smoothness
  - to control and achieve in-place density
- Technologies include infrared, GPR, profilers, etc.

Remarks

- Construction has an impact on energy consumed and resulted local and global environmental impacts
- Pavement construction activities offer many opportunities to adopt practices that improve pavement sustainability
- The construction phase is a phase over which engineers and contractors have a great deal of influence
- Achieving specification targets and maintaining good construction quality are keys to reduce life-cycle impact
- Tools are available for sustainable management of pavement construction

Moving Forward

- Set goals for sustainable construction practices
- Use life cycle approach
- Technical areas to consider include changes in specs, design procedures, and policies
  - Aggregate sourcing, specs, and transportation
  - Sustainable mixes: recycling, WMA, PFC, etc.
  - Construction quality standards, particularly compaction
  - Pavement structure optimization and design live

Thank You!

- Gina Ahlstrom: Gina.Ahlstrom@dot.gov
- Kurt Smith: ksmith@appliedpavement.com
- Tom Van Dam: tvandam@ncenet.com
- John Harvey: jtharvey@ucdavis.edu
- Imad Al-Qadi: alqadi@Illinois.edu
- Hasan Ozer: hozer2@illinois.edu

- **Please join us at these upcoming webinars!**

Schedule	Webinar Event
Jun 25 **1-3 pm EDT**	#3: Sustainable Strategies for Concrete Pavements: Materials, Design, Construction
Aug 20 **1-3 pm EDT**	#4: Maintenance, Rehabilitation, and End-of-Life
Sep 9 **1-3 pm EDT**	#5: Use Phase, Livable Communities, and Path Forward