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# Concrete Pavement Sustainability

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# The Sustainability Triple Bottom Line

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# Why Must We Change?

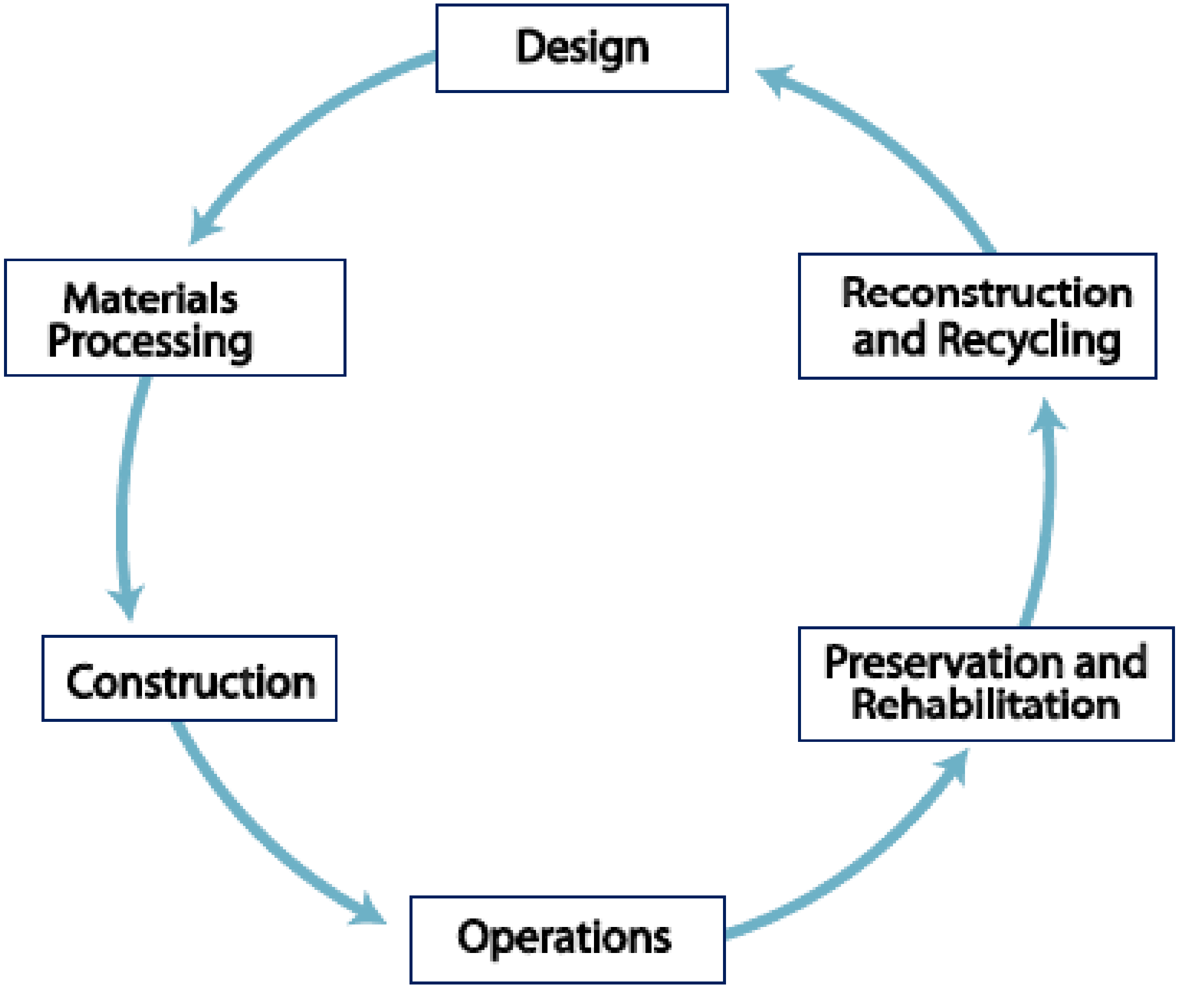
# Do We Still Need to Change?

- Politicians come and go, administrations change, but scientific facts remain
  - The Artic and Antarctica continual to melt, sea levels continue to rise, oceans are acidifying, and poison ivy is becoming more potent
- Sustainable practices are simply good engineering
  - Make sense economically, environmentally, and socially
- Likely a reduction in emphasis on GHGs

# A Sustainable Pavement is an Aspirational Goal

- Achieve engineering objectives
- Preserve and ideally restore surrounding ecosystems
- Wisely use financial, human, and environmental resources
- Meet human needs such as health, safety, equity, employment, comfort, and happiness

# Must Consider the Life-Cycle



# Basic Pavement Sustainability Concepts to be Discussed Today

- Efficiency in design
- Wise use of materials
  - Local and recycled materials
  - Low environmental impact
  - Meet design requirements
- Consider the use-phase
- Long life
- Verification

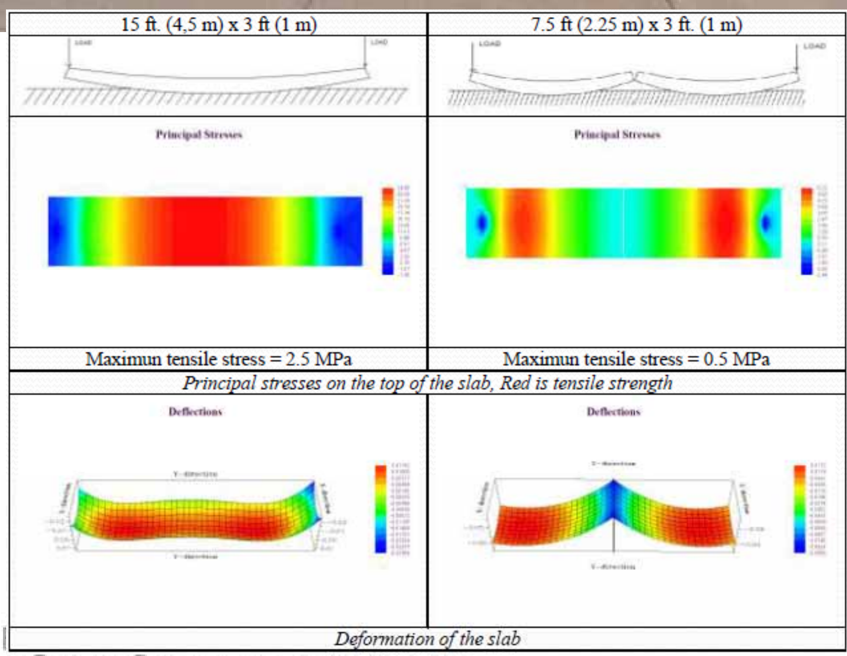
# Efficiency in Design

- Context sensitive
  - One size does not fit all
- Use "best" design methodology(ies)
  - Mechanistically-based?
- Consider the life cycle
- Embrace innovation
- Design to maintain
  - Preservation


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

# Two-Lift Concrete Pavement

# TCPavements




- A Chilean design that is a hybrid between flexible and rigid pavement
  - Thin slabs and short joints
- Uses far less material than conventional concrete pavements

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# 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



# Material Considerations

- Transporting materials has major environmental and social impacts
  - About 22 lbs of $CO_2$ from burning one gallon of diesel fuel
- Consider adoption of a zero-waste approach
- Must not compromise pavement longevity
- Reduce environmental impact of materials over the life cycle
  - Durability

# Other Material Considerations

- Does longer life justify increased material transportation or production-related impacts?
- Does the pavement design make best use of lower impact materials?
- Are the impacts of transporting materials considered?
- Are specifications protecting the owner's interest or a barrier to innovation?
- Are there impacts on construction variability?

# Aggregate Materials

- 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

# Use of Recycled and Reclaimed Aggregates

- Reclaimed asphalt pavement (RAP)
- Recycled concrete aggregate (RCA)
- Air-cooled blast furnace slag

# On-site Recycling

- Reduced project (material) costs
- Reduced haul costs
- Reduced fuel consumption
- Reduced GHG emissions
- Reduced consumption of resources
- Reduced use of landfills

# Example: The Illinois Tollway

- Committed to recycling 100% of existing pavements
- Two-lift composite concrete using RCWM in bottom lift
- In-place recycling of existing pavements
- Decisions are first economic, then environmental

Photo compliments of Steve Gillen, Illinois Tollway Authority

# Hydraulic Cement and Concrete Mixtures

- Hydraulic cement concrete is humankinds most commonly used material after water
  - Approximately 1 $yd^3$ / person / year
- Large economic, environmental, and social impacts
  - 91.3 million tons of cement manufactured in the U.S. in 2015
  - In 2013, linked to just under 0.5% of US GHGs
- About 5 percent of cement is used in paved roads

| | On-site Energy $10^6$ kJoules | On-site Energy % | $CO_2$ Emissions $10^6$ tonne | $CO_2$ Emissions % |
|---|---|---|---|---|
| ***Raw Materials – Quarrying and Crushing*** | | | | |
| Cement Materials | 3,817 | 0.7% | 0.36 | 0.3% |
| Concrete Materials | 14,287 | 2.6% | 1.28 | 1.2% |
| ***Cement Manufacturing*** | | | | |
| Raw Grinding | 8,346 | 1.5% | 1.50 | 1.4% |
| Kiln: fuels | 410,464 | 74.0% | 38.47 | 36.8% |
| Reactions | | | 48.35 | 46.3% |
| Finish Milling | 24,057 | 4.3% | 4.32 | 4.1% |
| ***Concrete Production*** | | | | |
| Blending, Mixing | 31,444 | 5.7% | 5.65 | 5.4% |
| Transportation | 61,933 | 11.2% | 4.53 | 4.3% |
| **Total** | **554,409** | **100%** | **104.50** | **100%** |

Source: Energy and Emission Reduction Opportunities from the Cement Industry, U.S. Department of Energy.

# Portland Cement in Concrete

Cement

Gravel
Sand
Water

Typical concrete at the gate:
0.26 tons $CO_2$ /$yd^3$ concrete
0.24 tons $CO_2$ from portland cement

# Sustainability is Enhanced by Using Less Portland Cement

- Reduce clinker in cementitious material
- Reduce cementitious content in concrete
  - From 564+ lbs/yd$^3$ to 500 lbs/ft$^3$ or less
  - Context sensitive
- Reduce concrete needed over the life cycle
  - Improved design – thinner structures
  - Improved durability

# Reducing Clinker Content in Cement

- Replace clinker with ground limestone and inorganic processing additions
  - ASTM C150 portland cement can have up to 5% limestone and 5% inorganic additions
  - ASTM C595 Type IL blended cement can have up to 15% limestone
- Replace clinker with supplementary cementitious materials (SCMs)
  - Added at concrete plant
  - Obtained as blended cement (ASTM C595)

# Supplementary Cementitious Materials (SCMs)

- Fly ash
  - Collected from flue gases of coal burning power plant
- Slag cement
  - From iron blast furnace
- Natural pozzolan
  - Calcined clay, volcanic ash, ground pumice, etc.

# Typical Replacement Levels for SCMs in Paving Concrete

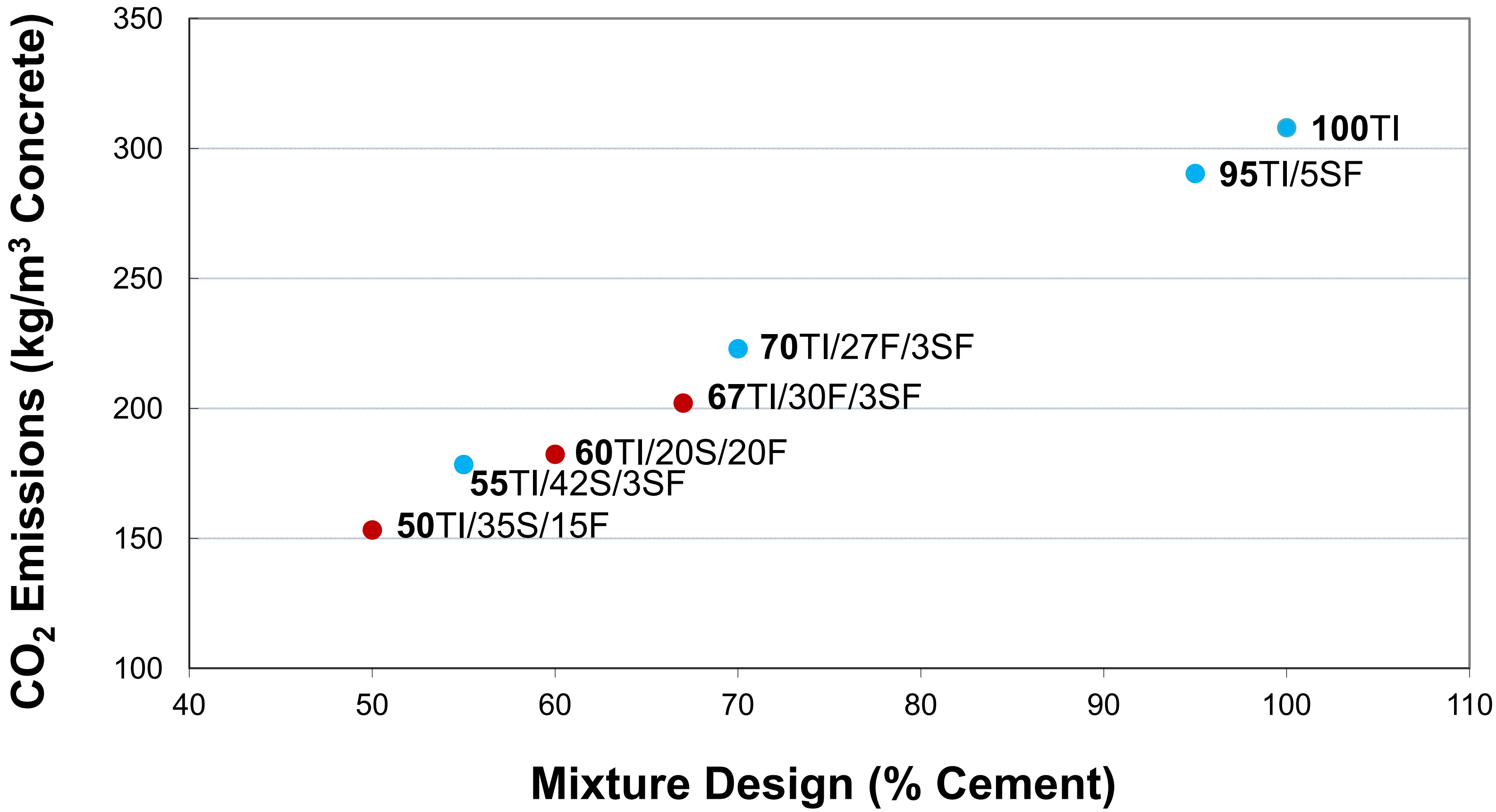
- Class F fly ash: 15% - 25%
- Class C fly ash: 15% - 40%
- Slag: 25% - 50%

Note that replacement levels can be much higher in mass concrete placements, as high as 85%

# ASTM C595 Blended Cements

- Produced by cement manufacturers
- Type IP(X), Type IS(X), Type IL(X), and Type IT (X)(Y)
  - Blended with pozzolan, slag cement, limestone or ternary blend
- Also designated as air entrained (A), moderate of high sulfate resistant (MS or HS), or moderate or low heat of hydration (MH or LH)

# SCMs and $CO_2$ Emissions




From Tikalsky (2009), "Development of Performance Properties of Ternary Mixtures"

# Reduce Cement By Increasing Aggregate Volume in Concrete

- Maximize aggregate content
  – Use of optimized aggregate grading for paving
- Ensure volume stability of aggregates
  – Porous aggregates require special handling
- Ensure aggregate durability
  – Freeze-thaw
  – Alkali-aggregate reactivity

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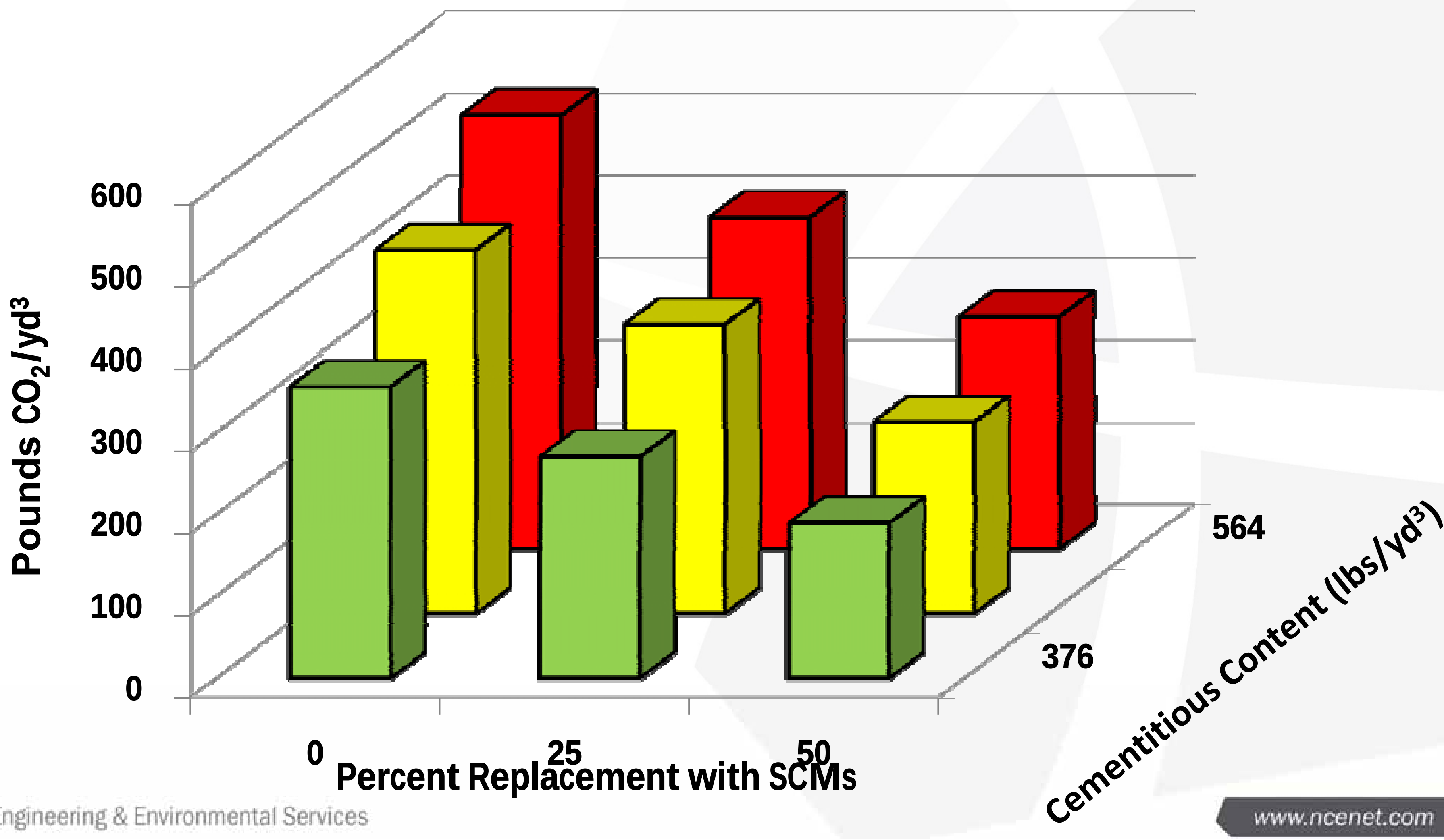
# Cement Content, SCMs, and $CO_2$

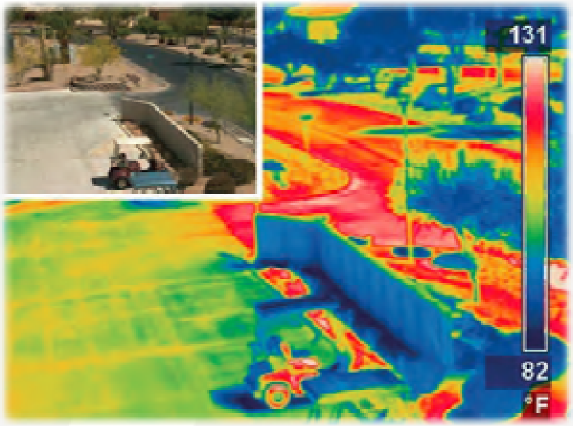


# Example: The Illinois Tollway

- Committed to recycling 100% of concrete and asphalt pavements
- 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 first economic, then environmental

# Considering the Use Phase

- Traffic
  - Fuel efficiency is correlated to smoothness
  - Noise, pollution, and particulates
- Stormwater
  - Urban issues include flooding and stormwater treatment
- Other considerations include safety, aesthetics, urban heat island effect



# IRI Trigger Values

| Traffic group | Daily PCE of lane-segments range | Total lane-miles | Percentile of lane-mile | Optimal IRI triggering value (m/km, inch/mile in parentheses) | Annualized $CO_2$-e reductions (MMT) | Modified total cost-effectiveness ($/t$CO_2$-e) |
|---|---|---|---|---|---|---|
| 1 | <2,517 | 12,068 | <25 | ----- | 0 | N/A |
| 2 | 2,517 to 11,704 | 12,068 | 25~50 | 2.8 (177) | 0.141 | 1,169 |
| 3 | 11,704 to 19,108 | 4,827 | 50~60 | 2.0 (127) | 0.096 | 857 |
| 4 | 19,108 to 33,908 | 4,827 | 60~70 | 2.0 (127) | 0.128 | 503 |
| 5 | 33,908 to 64,656 | 4,827 | 70~80 | 1.6 (101) | 0.264 | 516 |
| 6 | 64,656 to 95,184 | 4,827 | 80~90 | 1.6 (101) | 0.297 | 259 |
| 7 | >95,184 | 4,827 | 90~100 | 1.6 (101) | 0.45 | 104 |
| **Total** | | | | | **1.38** | **416** |

From Wang et al. 2012

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# Verification

- Assessment tools should be used to evaluate the economic, environment, and social impacts of alternatives over the life cycle
- Tools are currently under development

"Trust but verify"

# Assessing Sustainability

- Economics should be assessed using life cycle cost analysis (LCCA)
  - e.g. FHWA's RealCost
- Environmental and social impacts can be assessed using rating systems
  - Greenroads™, GreenLITES, INVEST
  - Gaining popularity
- Tools for environmental life cycle assessment (LCA) are emerging
  - EPDs are on the way
  - LCA guidance under development

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# Summary

- Sustainable practices are available at all phases of a pavement's life
- This is emerging field
- Sustainability requires a life cycle perspective
- Trade-offs are inevitable

# "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

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# Questions?

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