Sustainable Geotechnical Construction with Recycled Materials

Craig H. Benson, PhD, PE, DGE
Wisconsin Distinguished Professor
Director, Recycled Materials Resource Center
University of Wisconsin-Madison

chbenson@wisc.edu

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Why is Sustainability Important?

- Nexus of major issues caused by rapidly growing global economy:
  - Global warming
  - Energy constraints
  - Resource availability (metals, cement, oil etc.)
- World population is 6 billion (B) → 12 B projected by 2100. US at 0.5B by 2050.
- US and EU (combined population = 0.75 B) consume most of world resources. China catching up fast.
- Remaining 5.25 B want everything we have. Not enough to go around if we do business as usual.

How Can We Make Infrastructure Construction More Sustainable?

1. Reduce energy consumed in construction and rehabilitation.
2. Reduce emissions emitted in construction and rehabilitation.
3. Reduce consumption of natural resources.
4. Increase service life and lower cost.

Triple Bottom Line: Environment, Economics, Society

How Do Recycled Materials Fit In?

1. Avoid energy and emissions associated with mining and processing construction materials. Energy has already been expended in first life of recycled material.

2. Avoid use of a natural resource (sand and gravel, limestone, oil).

3. Increase service life. Not an "infrastructure landfill," but comparable or better/longer lasting infrastructure

4. Capital and life cycle costs can be lower (economic sustainability).

Safe and Wise Principle

- Promote the safe and wise use of recycled materials in construction of transportation infrastructure through education, technology transfer, and applied research.

- Wise … ensure that the recycled material is suitable for the highway environment and provide procedures for appropriate use.

- Safe …. ensure that material will not have an adverse impact on the environment or users.

Recap Poll # 1 – True or False

- Climate change is the biggest driver behind sustainability considerations infrastructure: T/F

- Energy savings is a primary advantage of using recycled materials in construction: T/F

- Sustainability triple bottom line is social, economic, and political issues: T/F

- Safe and wise principle is ensuring recycled materials do not adversely impact environment and make sense from civil engineering perspective: T/F

Coarse-Grained Recycled Materials

- Recycled concrete aggregate
- Recycled asphalt concrete
- Foundry sand from iron casting (low bentonite)
- Bottom ash from coal combustion
- Crushed and mixed glass
- Wood chips
- Shingle shreds
- Tire shreds
- Shredded plastics and crushed thermoset plastics
- Polystyrene foam

Recycled concrete aggregate (RCA) from building demolition – note brick fragments, reddish color, and high fraction of finer particles. More sensitive to water softening.

Recycled concrete aggregate (RCA) from pavement – clean and angular particles. Stiff material compared with RCA with brick. Residual cements bind particles together when moistened.

Bottom ash – looks like sand, but has lower specific gravity and particles more prone to crushing. Can have contaminants (see chunk at upper left).

Grey-iron slag – looks like pea gravel. This slag is porous, like tuff, because it was quenched in water. More prone to particle crushing than natural aggregate. Air-cooled slags not as porous.

RAP – residual asphalt coating particles. Stick from asphalt brings up strength and stiffness, but also creep. For example, will rut more readily than conventional aggregate.

RAP and some RCA. Blend probably from milling of HMA overlay over a concrete pavement.

Shredded “tear-off” shingles contaminated with wood chips. Lightweight, but compressible, creeps, and temperature sensitive

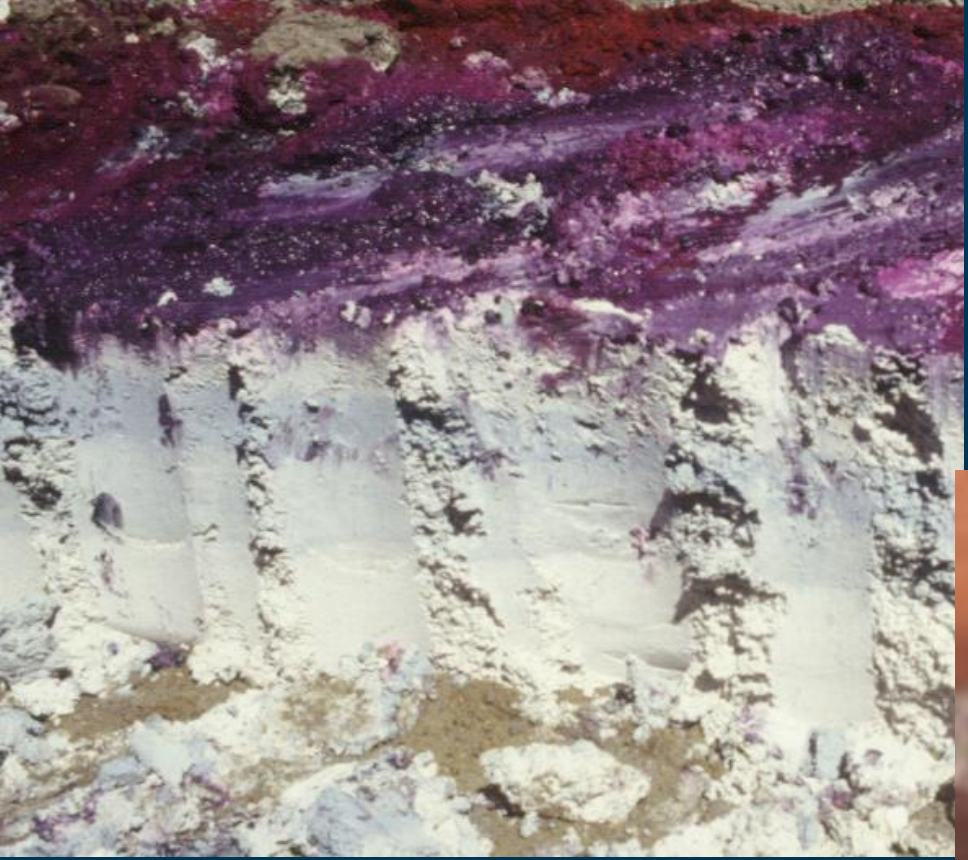
Grey-iron foundry sand with low bentonite content. Black color from sea coal used as reducing agent. More moisture sensitive when higher bentonite content.

Applications

- Structural fill for slabs and retaining walls
- Lightweight fill (tires, foams, crushed thermosets)
- Embankments
- Base and sub-base for pavements
- Drainage media

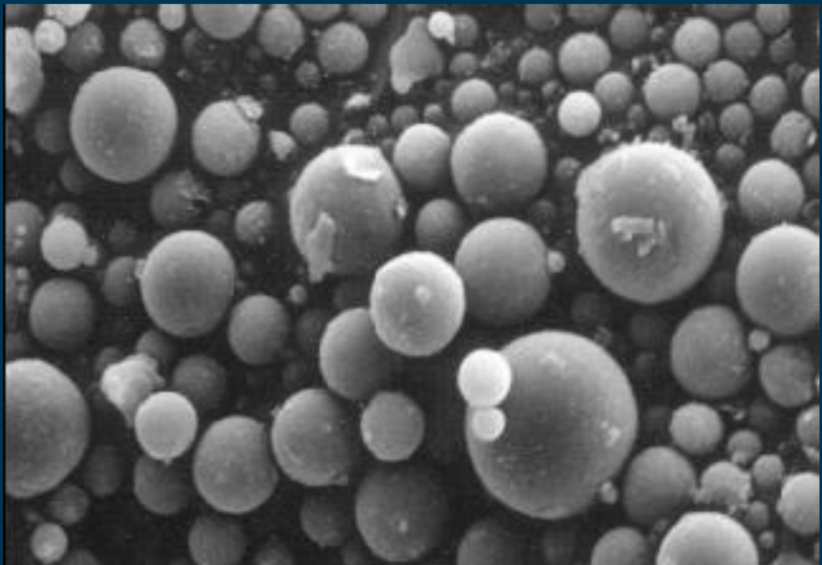
Fine-Grained Recycled Materials

- Fly ash (self-cementing & non-cementing)
- Flue-gas desulphurization (FGD) sludges
- Foundry slag from iron casting (higher bentonite content)
- Papermill residuals (“sludges”)
- Dredge spoils



Soft paper sludge used as barrier.

Powdery fly ashes and close up of fly ash particles.



FGD gypsum – may be used to address plasticity, but problems with ettringite. Used as agricultural amendment or for drywall production.

FGD filter cake. Not useful alone, but may be blended with cementitious fly ashes.

Applications

- Fill in applications where lower strength and higher compressibility are acceptable.
- High strength fill when blended with other materials (e.g., with cementitious fly ash).
- Cementing and stabilization of soils.
- Hydraulic barriers

Other Examples of Recycled Materials in Geotechnical Construction

- Piling manufactured with recycled plastic
- Recycled plastic pins for slope stabilization
- Geosynthetics from recycled polymers.
- Strength enhancement using shredded reclaimed plastics or fibers

Design with these materials generally follows conventional methods, but with consideration of different material source (e.g., stiffness, durability, creep).

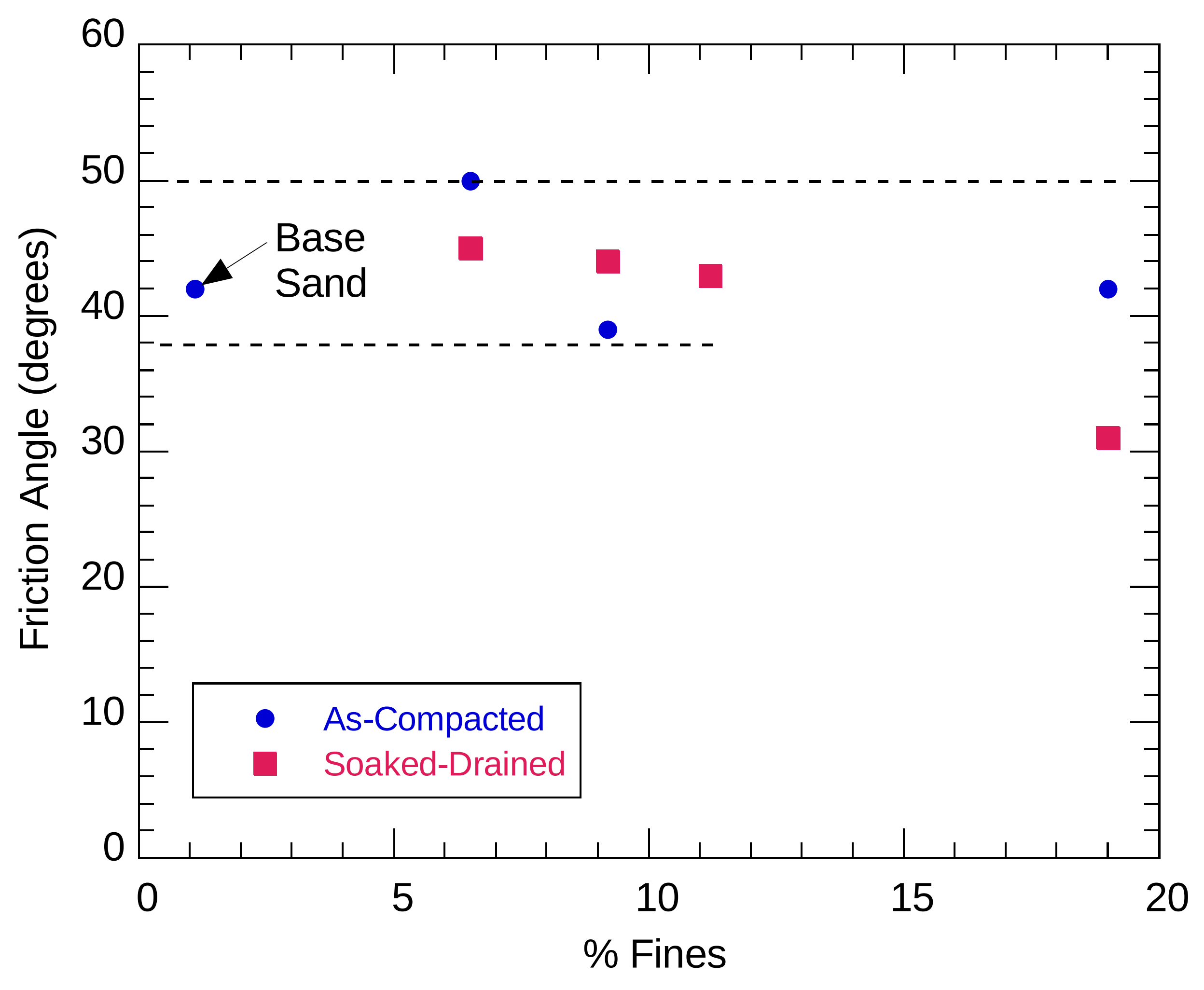
Practical Factors to Consider

- Volume availability, source, & delivery price
- Consistency – varies between materials & suppliers
- Special handling needs – Dusting? Moisture?
- Regulatory permitting
- Engineering properties – available? Measured?
- Past experience

Geotechnical Considerations

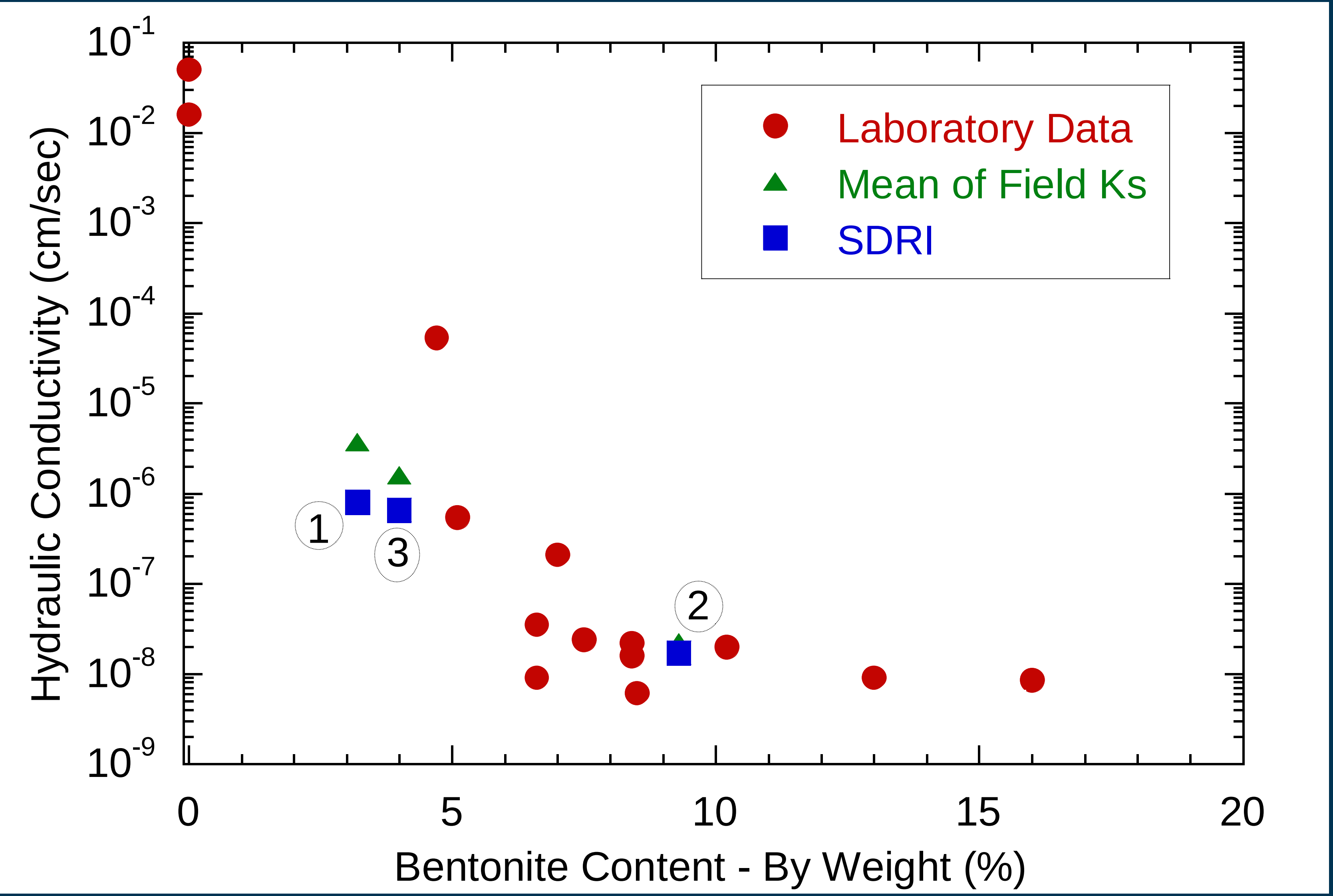
- Shear strength
- Compressibility
- Hydraulic conductivity
- Durability – wetting & drying, freezing & thawing, handling
- Reactivity – cementing, heating, swelling
- Leaching – release of trace elements, organic compounds
- Coarse vs. fine materials
- Test scale, drainage conditions

Shear Strength of Foundry Sands

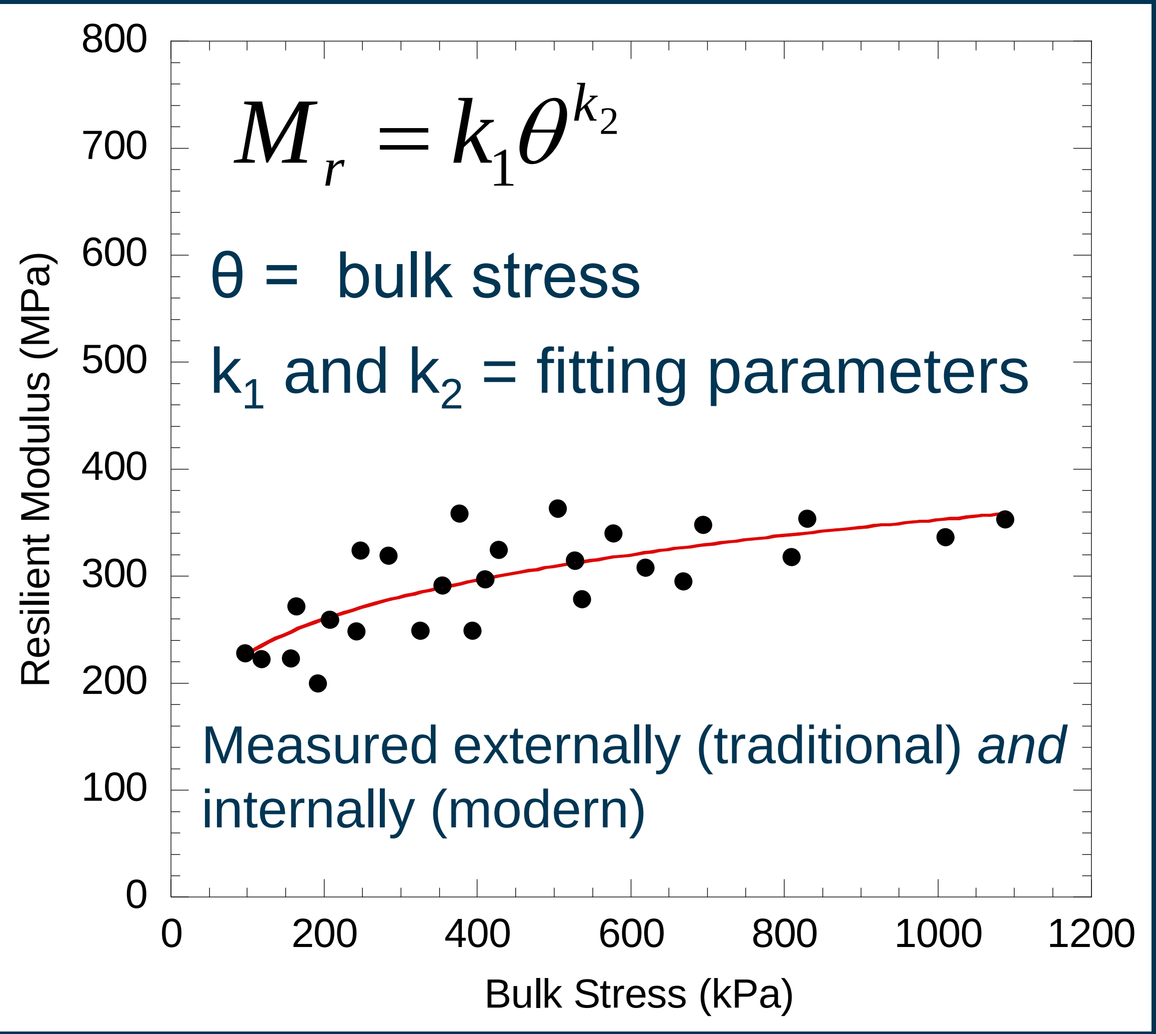


- Friction angle not sensitive to fines or bentonite content, except when bentonite content gets higher.
- Reasonable to use 36º for many sands, except high bentonite content.

Hydraulic Conductivity of Foundry Sands

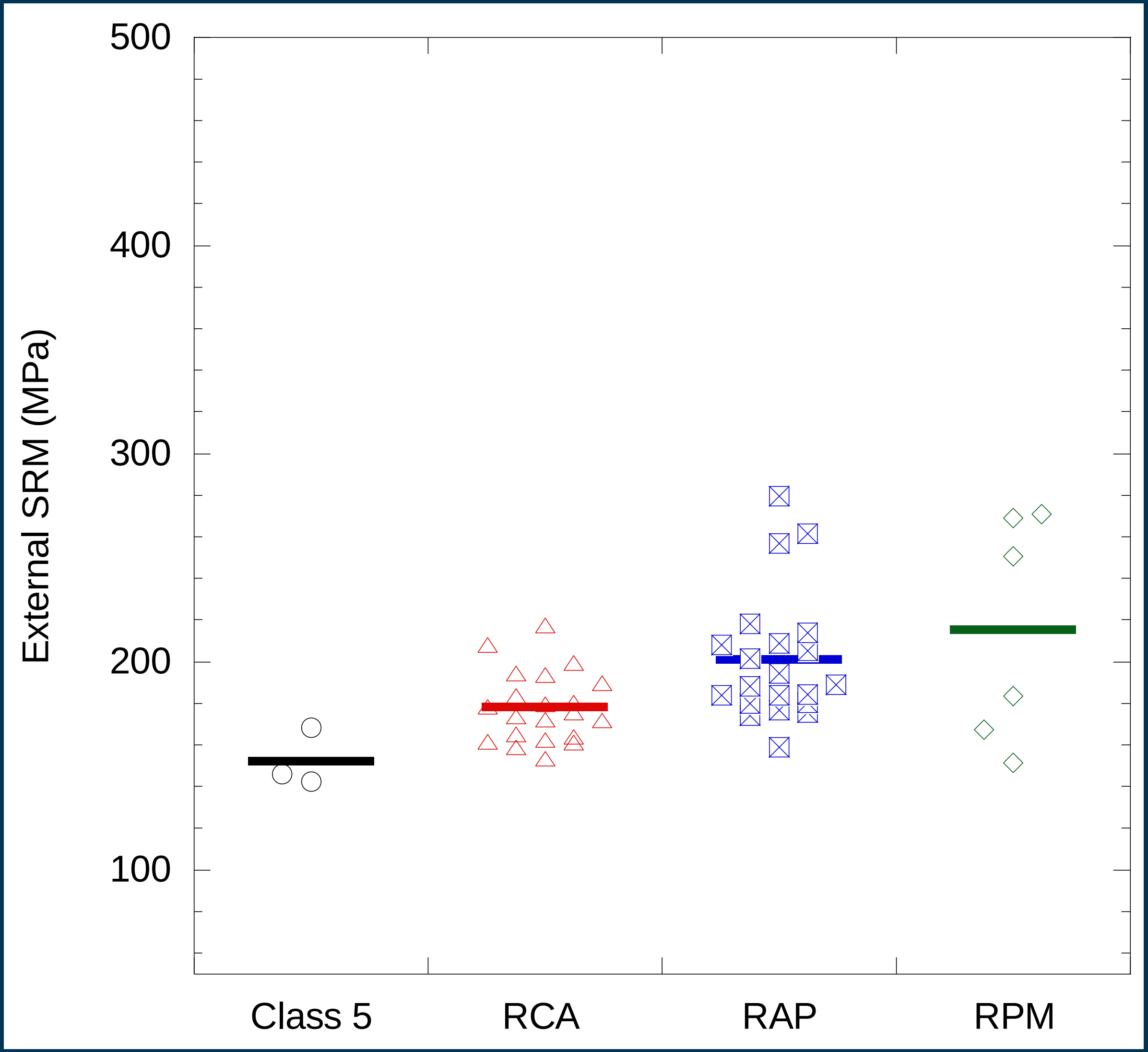


Resilient Modulus of RAP and RCA



Summary resilient modulus (SMR) at bulk stress = 208 kPa.

Summary External Resilient Modulus



- RCA, RAP, RPM all have ***higher*** SRM than Class 5.
- Not sensitive to gradation. Similar for each RAP, RCA, or RPM
- Recommended SRM:
  - RCA = 180 MPa
  - RAP = 150 MPa
  - RPM = 150 MPa

Large-Scale Testing Equipment

- Large-scale testing equipment may be required for recycled materials with large particles.
- Analogous to large-scale testing of gravels and cobbly materials for dams.
- Use caution when scalping materials and testing residual in conventional test cells.

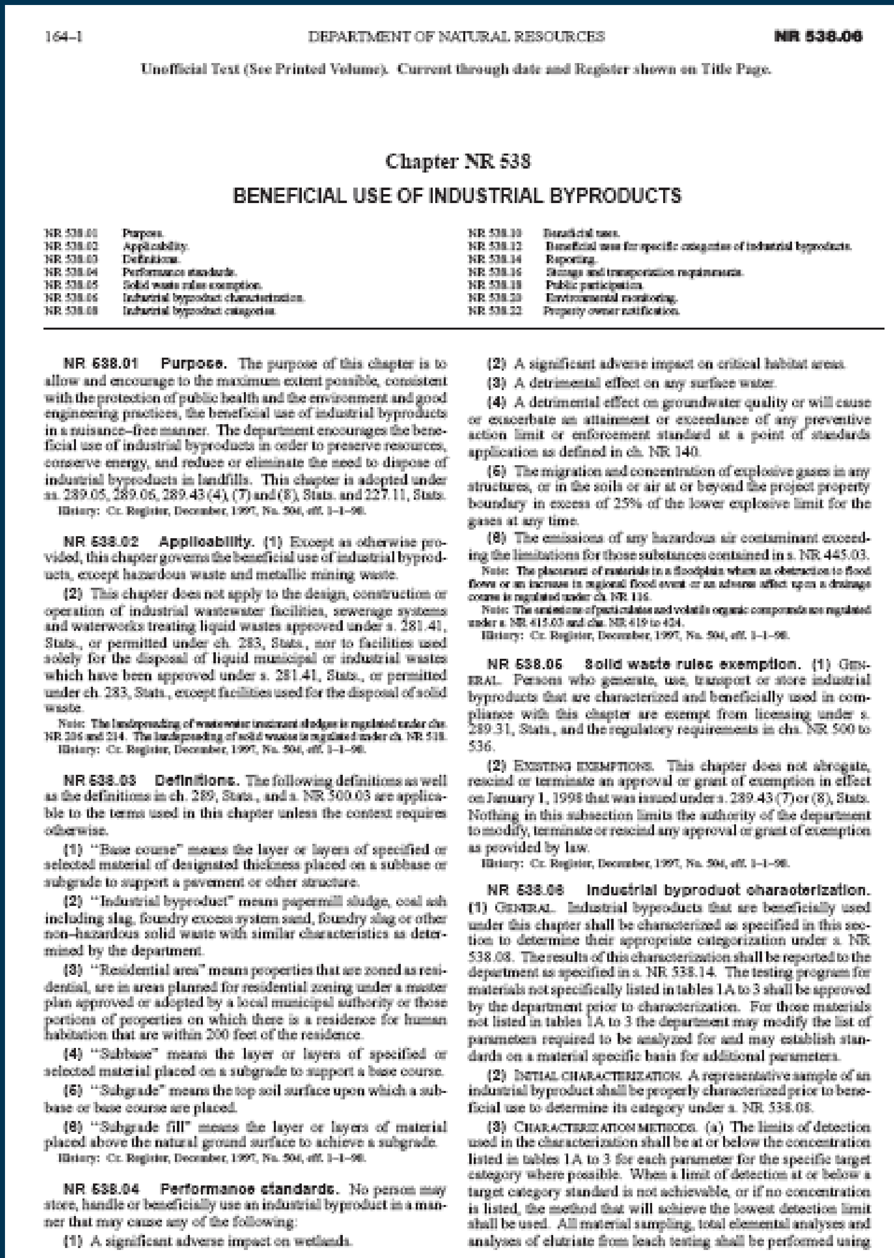
Recap Poll # 2 – True or False

- RCA from buildings and pavements is the same: T/F
- Shredded shingles can be used as light weight fill, but are compressible prone to creep: T/F
- Foundry sands have essentially the same engineering properties regardless of source: T/F
- Papermill residuals (sludges) can be used as hydraulic barrier materials: T/F

Environmental Considerations

- Ground water is the most common environmental consideration – leaching of constituents that may impair drinking water.
- Surface water can be an issue for embankments and other earth structures above grade if side seeps occur or internal drainage provided.
- Air quality can be a concern for fine-grained non-plastic materials – fly ash.
- No federal regulations or guidance. Some states have rules or 'beneficial use determinations' (BUDs).

Wisconsin NR 538 Code



164–1 DEPARTMENT OF NATURAL RESOURCES **NR 538.06**

Unofficial Text (See Printed Volume). Current through date and Register shown on Title Page.

Chapter NR 538

BENEFICIAL USE OF INDUSTRIAL BYPRODUCTS

NR 538.01	Purpose.	NR 538.10	Beneficial uses.
NR 538.02	Applicability.	NR 538.12	Beneficial uses for specific categories of industrial byproducts.
NR 538.03	Definitions.	NR 538.14	Reporting.
NR 538.04	Performance standards.	NR 538.16	Storage and transportation requirements.
NR 538.05	Solid waste rules exemption.	NR 538.18	Public participation.
NR 538.06	Industrial byproduct characterization.	NR 538.20	Environmental monitoring.
NR 538.08	Industrial byproduct categories.	NR 538.22	Property owner notification.

NR 538.01 Purpose. The purpose of this chapter is to allow and encourage to the maximum extent possible, consistent with the protection of public health and the environment and good engineering practices, the beneficial use of industrial byproducts in a nuisance–free manner. The department encourages the beneficial use of industrial byproducts in order to preserve resources, conserve energy, and reduce or eliminate the need to dispose of industrial byproducts in landfills. This chapter is adopted under ss. 289.05, 289.06, 289.43 (4), (7) and (8), Stats. and 227.11, Stats.

History: Cr. Register, December, 1997, No. 504, eff. 1–1–98.

NR 538.02 Applicability. (1) Except as otherwise provided, this chapter governs the beneficial use of industrial byproducts, except hazardous waste and metallic mining waste.

(2) This chapter does not apply to the design, construction or operation of industrial wastewater facilities, sewerage systems and waterworks treating liquid wastes approved under s. 281.41, Stats., or permitted under ch. 283, Stats., nor to facilities used solely for the disposal of liquid municipal or industrial wastes which have been approved under s. 281.41, Stats., or permitted under ch. 283, Stats., except facilities used for the disposal of solid waste.

Note: The landspreading of wastewater treatment sludges is regulated under chs. NR 206 and 214. The landspreading of solid wastes is regulated under ch. NR 518.

History: Cr. Register, December, 1997, No. 504, eff. 1–1–98.

NR 538.03 Definitions. The following definitions as well as the definitions in ch. 289, Stats., and s. NR 500.03 are applicable to the terms used in this chapter unless the context requires otherwise.

(1) "Base course" means the layer or layers of specified or selected material of designated thickness placed on a subbase or subgrade to support a pavement or other structure.

(2) "Industrial byproduct" means papermill sludge, coal ash including slag, foundry excess system sand, foundry slag or other non–hazardous solid waste with similar characteristics as determined by the department.

(3) "Residential area" means properties that are zoned as residential, are in areas planned for residential zoning under a master plan approved or adopted by a local municipal authority or those portions of properties on which there is a residence for human habitation that are within 200 feet of the residence.

(4) "Subbase" means the layer or layers of specified or selected material placed on a subgrade to support a base course.

(5) "Subgrade" means the top soil surface upon which a subbase or base course are placed.

(6) "Subgrade fill" means the layer or layers of material placed above the natural ground surface to achieve a subgrade.

History: Cr. Register, December, 1997, No. 504, eff. 1–1–98.

NR 538.04 Performance standards. No person may store, handle or beneficially use an industrial byproduct in a manner that may cause any of the following:

(1) A significant adverse impact on wetlands.

(2) A significant adverse impact on critical habitat areas.

(3) A detrimental effect on any surface water.

(4) A detrimental effect on groundwater quality or will cause or exacerbate an attainment or exceedance of any preventive action limit or enforcement standard at a point of standards application as defined in ch. NR 140.

(5) The migration and concentration of explosive gases in any structures, or in the soils or air at or beyond the project property boundary in excess of 25% of the lower explosive limit for the gases at any time.

(6) The emissions of any hazardous air contaminant exceeding the limitations for those substances contained in s. NR 445.03.

Note: The placement of materials in a floodplain where an obstruction to flood flows or an increase in regional flood event or an adverse effect upon a drainage course is regulated under ch. NR 116.

Note: The emissions of particulates and volatile organic compounds are regulated under s. NR 415.03 and chs. NR 419 to 424.

History: Cr. Register, December, 1997, No. 504, eff. 1–1–98.

NR 538.05 Solid waste rules exemption. (1) GENERAL. Persons who generate, use, transport or store industrial byproducts that are characterized and beneficially used in compliance with this chapter are exempt from licensing under s. 289.31, Stats., and the regulatory requirements in chs. NR 500 to 536.

(2) EXISTING EXEMPTIONS. This chapter does not abrogate, rescind or terminate an approval or grant of exemption in effect on January 1, 1998 that was issued under s. 289.43 (7) or (8), Stats. Nothing in this subsection limits the authority of the department to modify, terminate or rescind any approval or grant of exemption as provided by law.

History: Cr. Register, December, 1997, No. 504, eff. 1–1–98.

NR 538.06 Industrial byproduct characterization. (1) GENERAL. Industrial byproducts that are beneficially used under this chapter shall be characterized as specified in this section to determine their appropriate categorization under s. NR 538.08. The results of this characterization shall be reported to the department as specified in s. NR 538.14. The testing program for materials not specifically listed in tables 1A to 3 shall be approved by the department prior to characterization. For those materials not listed in tables 1A to 3 the department may modify the list of parameters required to be analyzed for and may establish standards on a material specific basis for additional parameters.

(2) INITIAL CHARACTERIZATION. A representative sample of an industrial byproduct shall be properly characterized prior to beneficial use to determine its category under s. NR 538.08.

(3) CHARACTERIZATION METHODS. (a) The limits of detection used in the characterization shall be at or below the concentration listed in tables 1A to 3 for each parameter for the specific target category where possible. When a limit of detection at or below a target category standard is not achievable, or if no concentration is listed, the method that will achieve the lowest detection limit shall be used. All material sampling, total elemental analyses and analyses of eluate from leach testing shall be performed using

- Evaluate byproducts based on total elemental analysis and water leach tests.
- Define byproduct categories based on test data.
- Define suitable application based on category.

Applications Based on Category

Lower category number provides more stringent limits on leaching characteristics.

Water Leach Test Criteria – NR 538

Category 4 ASTM Water Leach Test

Standard (mg/l)	Parameter	Ferrous Foundry Excess System Sand	Ferrous Foundry Slag	Coal Ash	Other[1]
0.03	Antimony (Sb)				X
0.25	Arsenic (As)				X
10	Barium (Ba)	X			X
0.02	Beryllium (Be)				X
0.025	Cadmium (Cd)	X	X	X	X
2500	Chloride (Cl)				X
0.5	Chromium, Total (Cr)			X	X
6.5	Copper (Cu)				X
1	Total Cyanide				X
20	Fluoride (F)				X
3	Iron (Fe)	X	X		X
0.075	Lead (Pb)	X	X		X
0.5	Manganese (Mn)				X
0.01	Mercury (Hg)	X	X		X
0.5	Nickel (Ni)				X
50	Nitrite & Nitrate (NO_2+NO_3–N)				X
30	Phenol				X
0.25	Selenium (Se)			X	X
0.25	Silver (Ag)			X	X
2500	Sulfate			X	X
0.01	Thallium (Tl)				X
50	Zinc (Zn)				X

1 As provided under s. NR 538.06 (1), the testing program for materials other than ferrous foundry system sand, ferrous foundry slag and coal ash must be approved by the department prior to characterization. For other materials the department may modify the list of parameters required to be analyzed for and may establish standards on a material specific basis for additional parameters.

Note: All testing is to be conducted on a representative sample of a single industrial byproduct prior to commingling with other materials, unless otherwise approved by the department.

- Contaminants of concern depend on byproduct being considered.
- Category 1 has the most test requirements.

Lab Methods to Assess Leaching

- Batch tests:

- solid and liquid in a vial

- tumbled to ensure local well-stirred

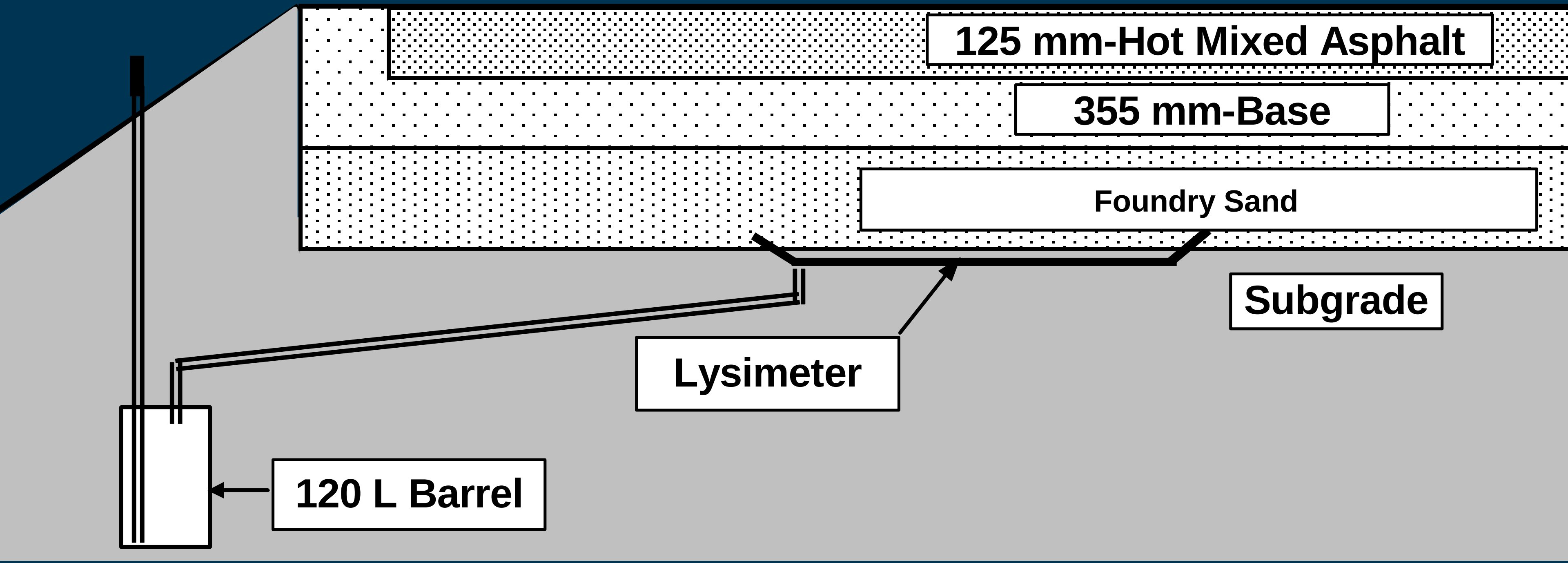
- supernatant analyzed for contaminants of concern

- Column tests:

- flow through experiment simulating field scenario

- effluent analyzed for contaminants of concern.

Field Methods – Pan Lysimeters



Leachate collected in drum analyzed for volume transmitted and trace elements.

Field Methods: Lysimeter for Direct Measurement

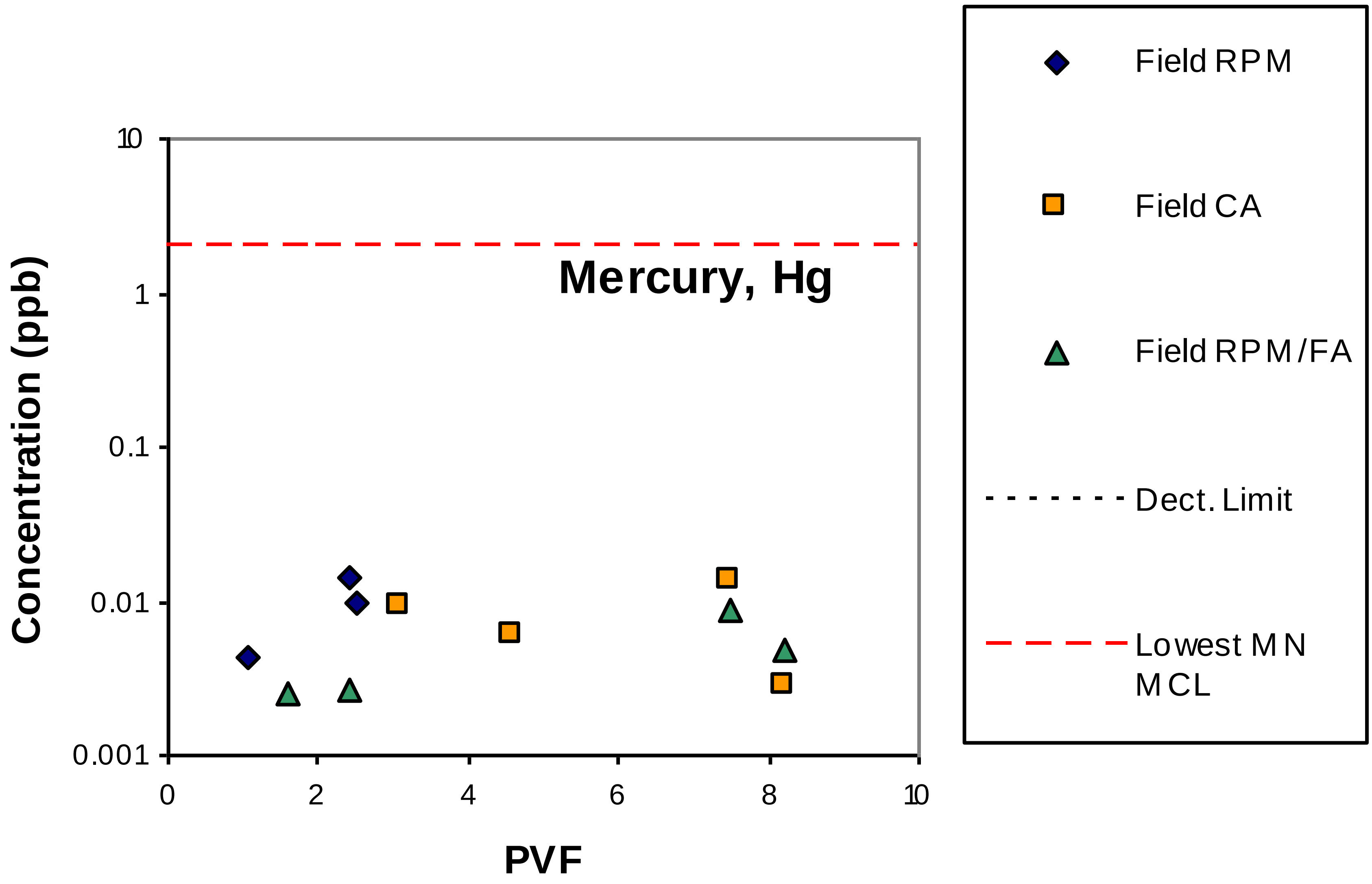
Geomembrane installation

Sump welding

Drainage layer installation

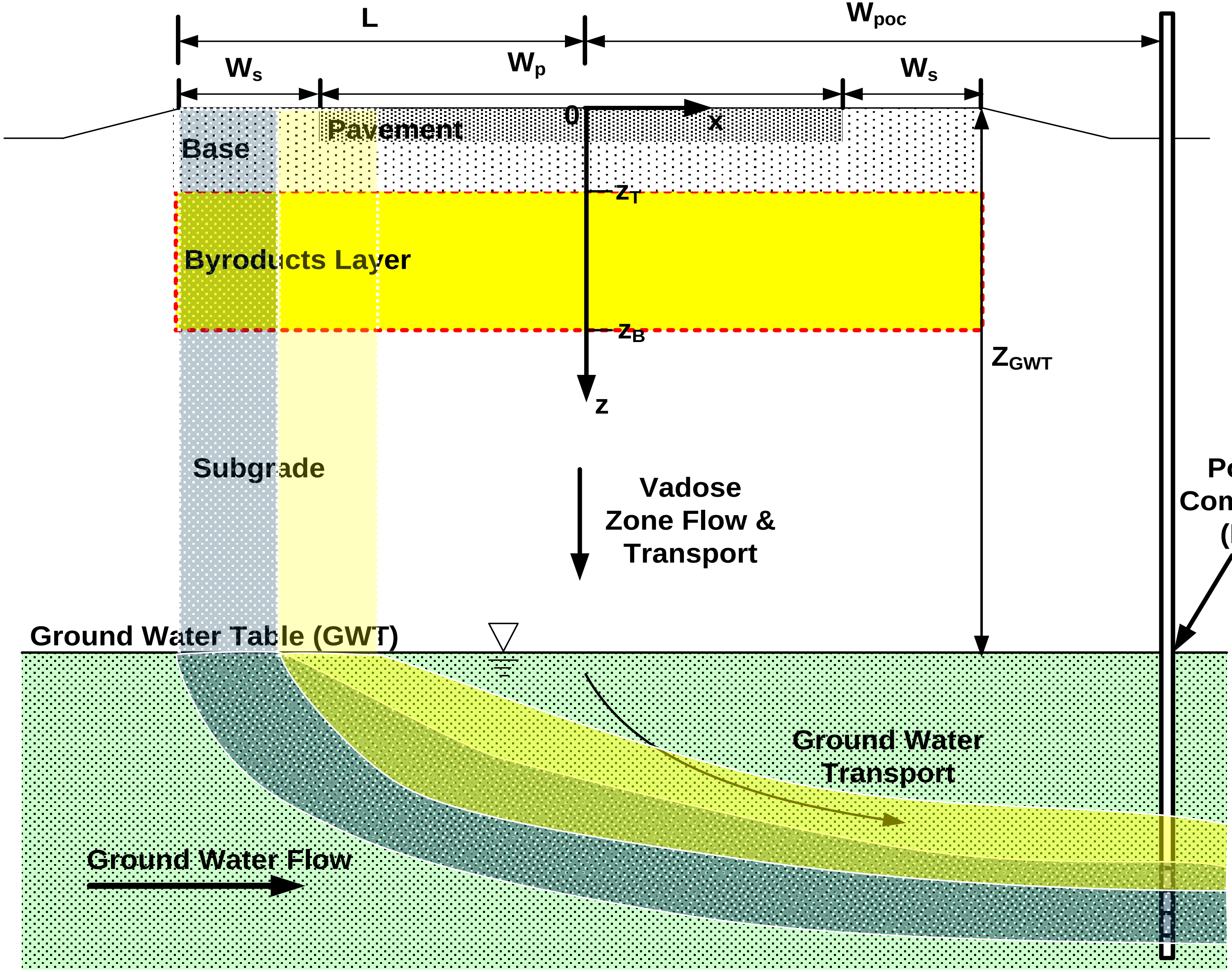
Collection tank installation

Environmental Impact and Importance of Controls



Hg is well below MCL. No difference between conventional and recycled materials.

WiscLEACH Model

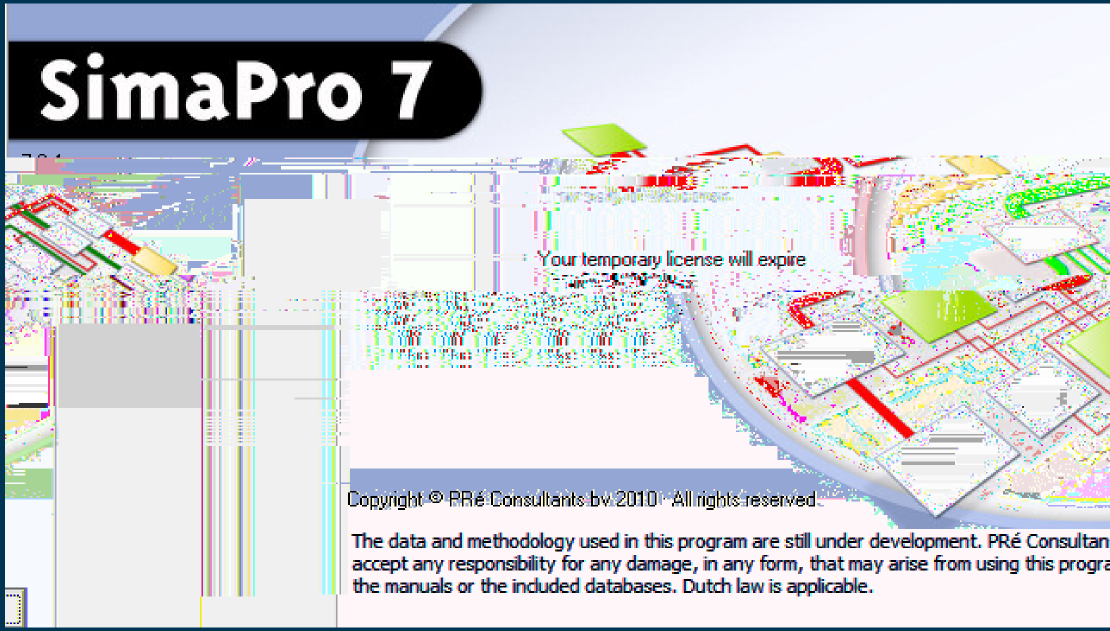


Recap Poll # 3 – True or False

- Federal regulations govern the use of recycled materials in geotechnical construction: T/F
- States have regulations to follow regarding using recycled materials in construction: T/F
- Batch tests are the most common tests to evaluate leaching from recycled materials: T/F
- Control tests are un-necessary and provide extraneous data: T/F

Sustainability Metrics & Life Cycle Assessment Tools

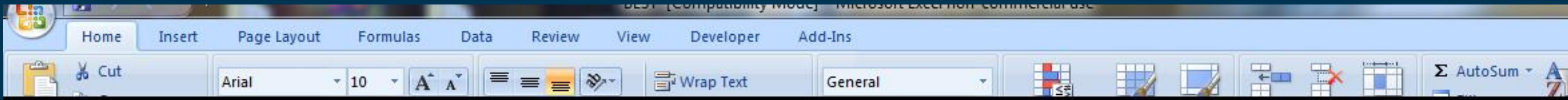
- Life cycle analysis (LCA) to assess variety of sustainability metrics (energy, GHG emissions, water use, hazardous waste generation, etc.).



- Life cycle cost analysis (LCCA) to evaluate life cycle cost of design alternatives.

- Quantitative and auditable metrics.

BE^{2}ST Highway Sustainability Rating System



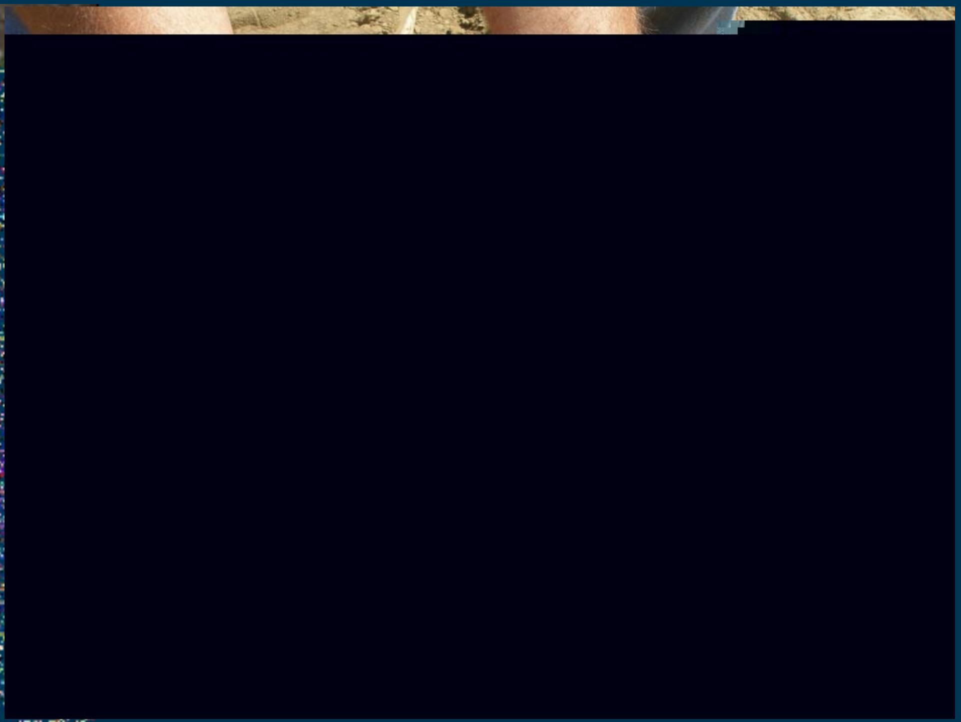
Stabilizing RPM with Off-Spec Cementitous Fly Ash at MnROAD

MnROAD is a full-scale highway test facility operated by Minnesota DOT.

Tuncer B. Edil, RMRC, PI

US DoE & RMRC

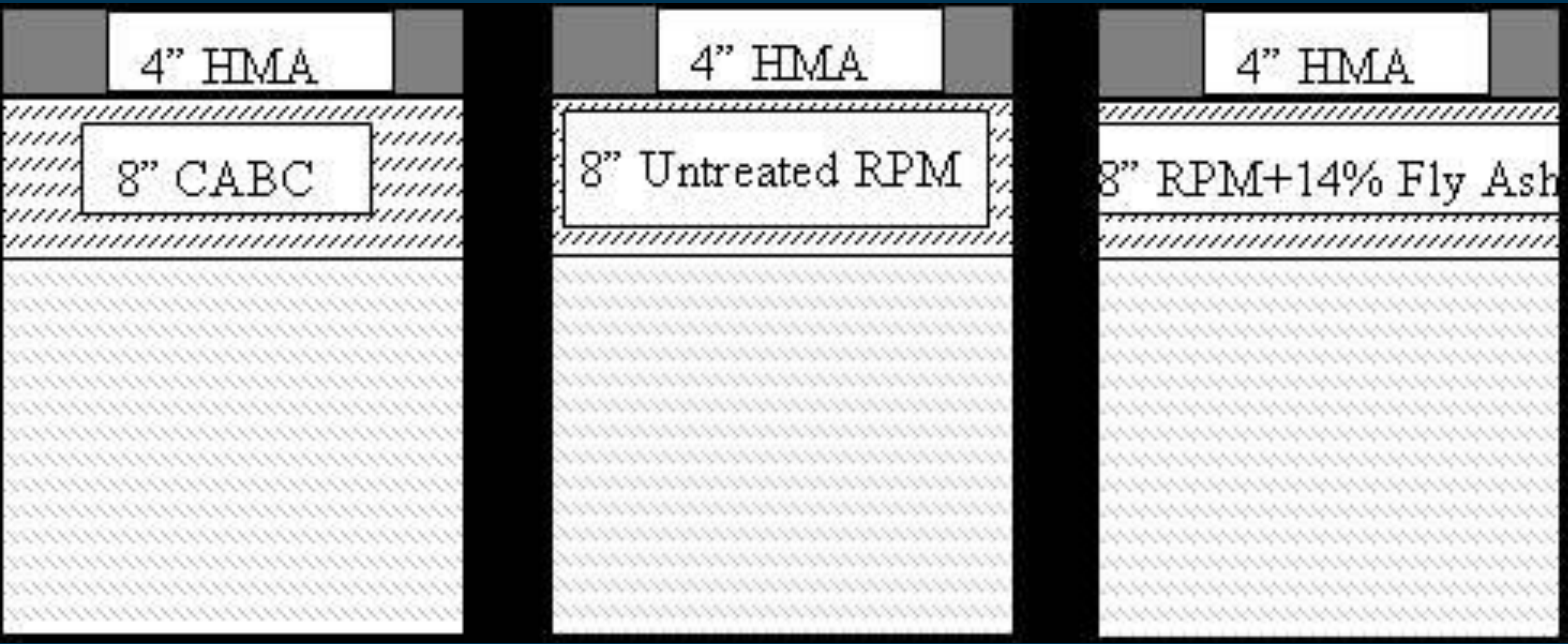
Two Byproducts → Useful Product



RPM + High Carbon Fly Ash

= high modulus and durable base

MnROAD Test Sections



Conventional Aggregate Base

RPM Base

RPM + Fly Ash Base

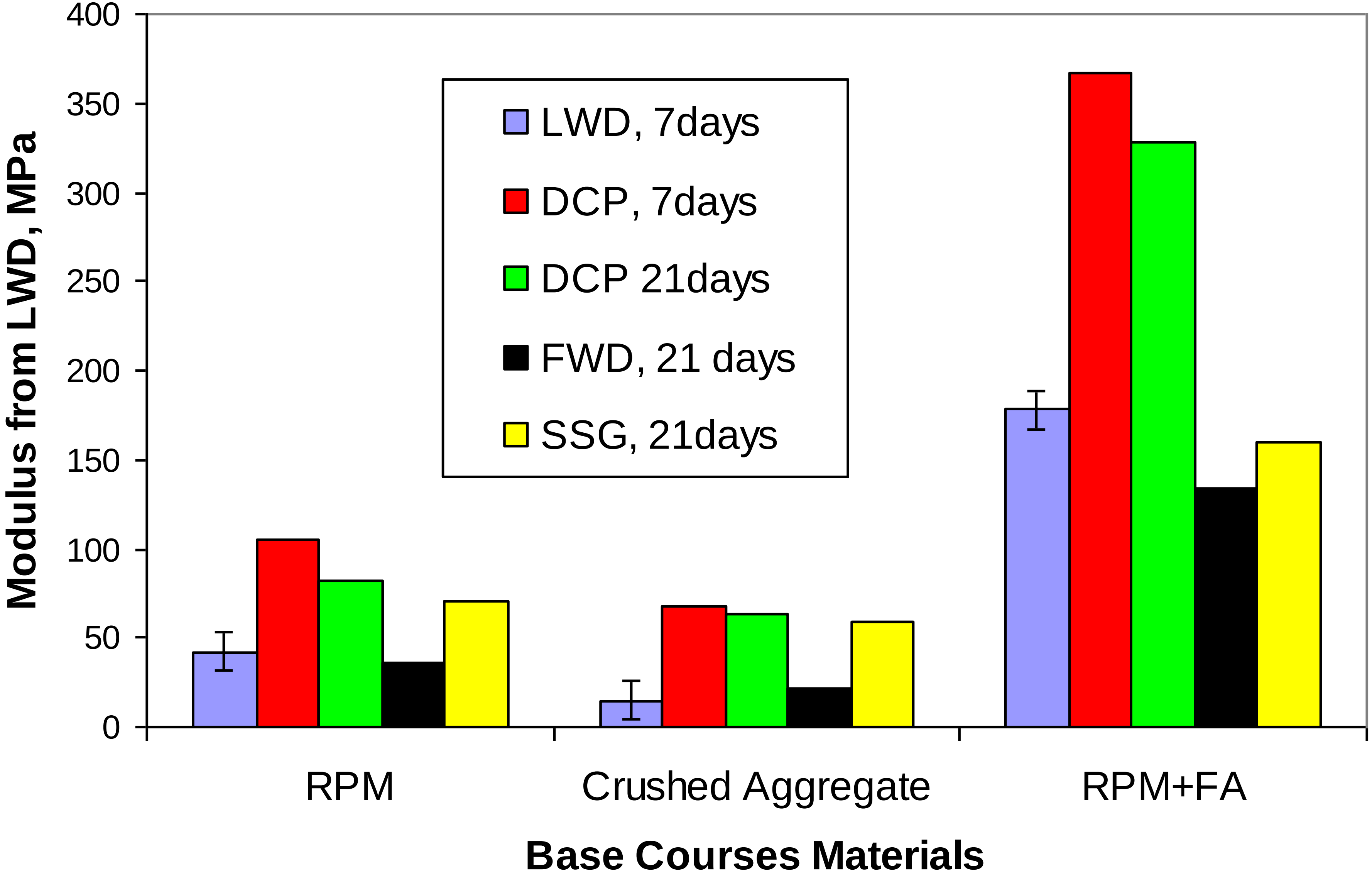
Riverside 8 Fly Ash from Xcel Energy, 14.6% LOI and 22% CaO
Non-compliant with MCPA requirements.

Placement of RPM and Fly Ash

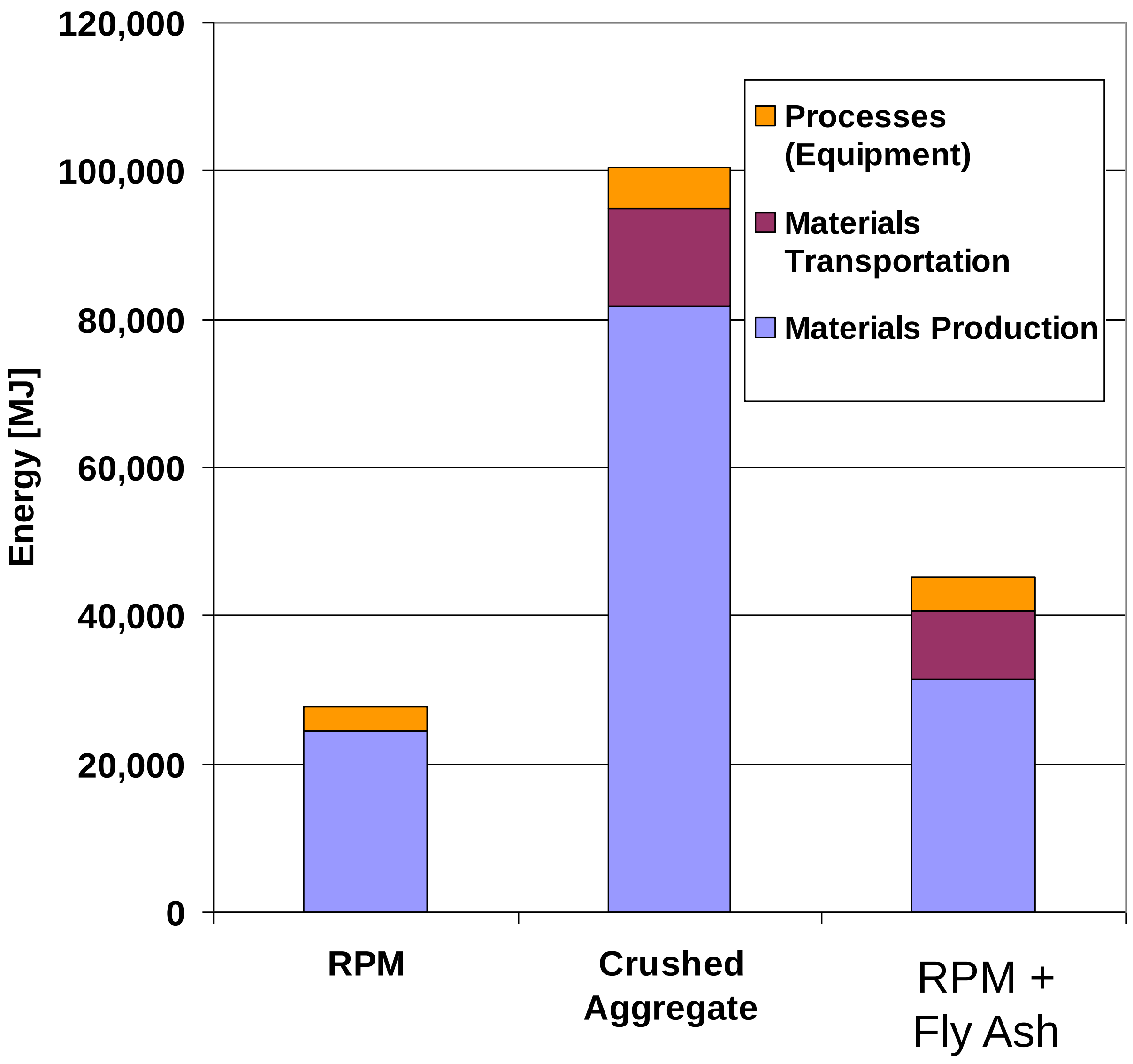
Mixing & Compaction

HMA Paving

Pavement Performance - Modulus



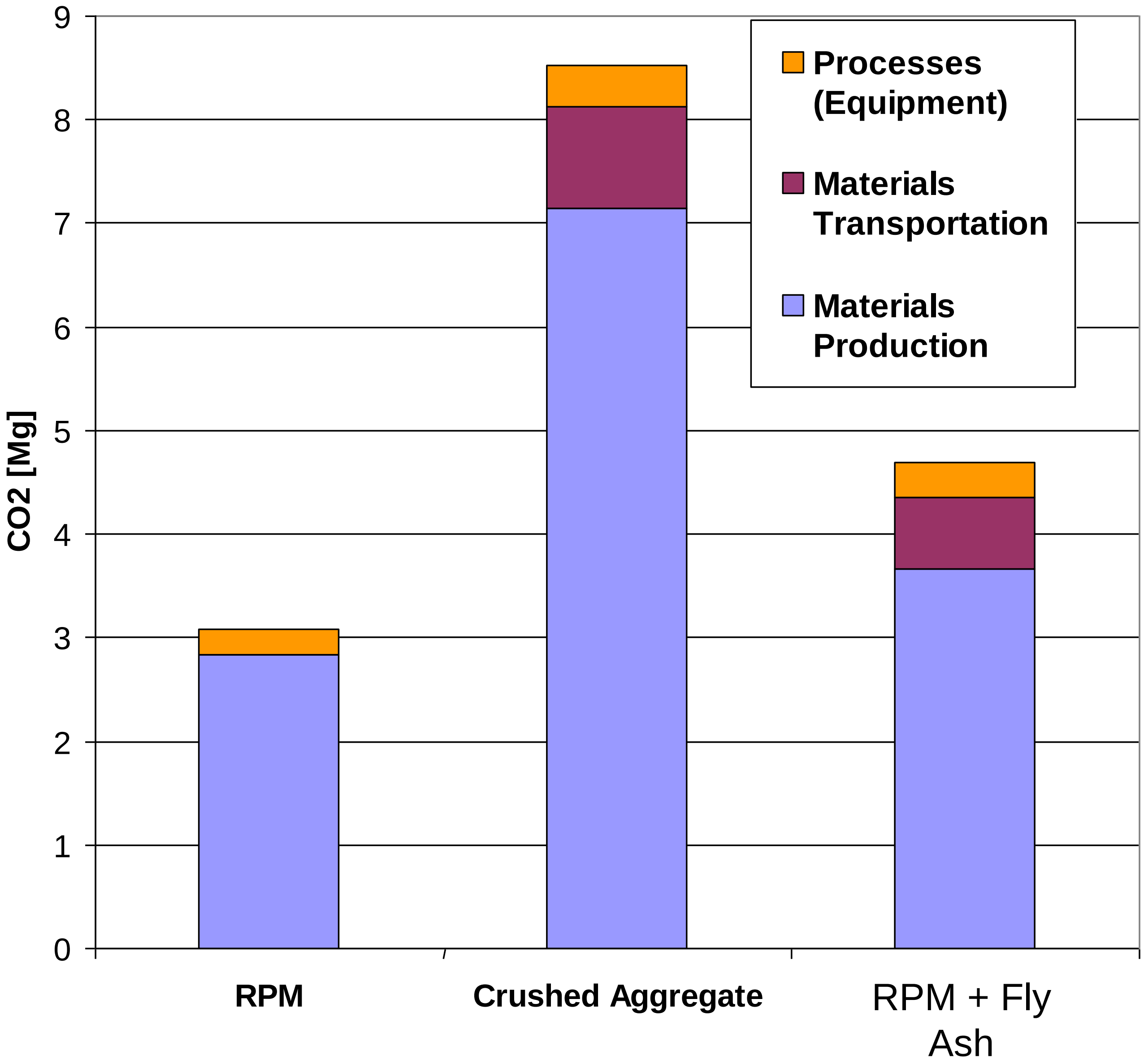
Construction Life Cycle Analysis – Energy Usage



Most energy: Conventional construction material.

Least energy: recycled pavement in place of crushed aggregate.

Construction Life Cycle Analysis – GHGs



Most emissions: Conventional construction material

Least emissions: recycled pavement in place of crushed aggregate

Recap Poll # 4 – True or False

- Life cycle analysis and life cycle cost analysis are essentially the same thing: T/F

- Sustainability metrics include energy consumption, greenhouse gas emissions, and water usage: T/F

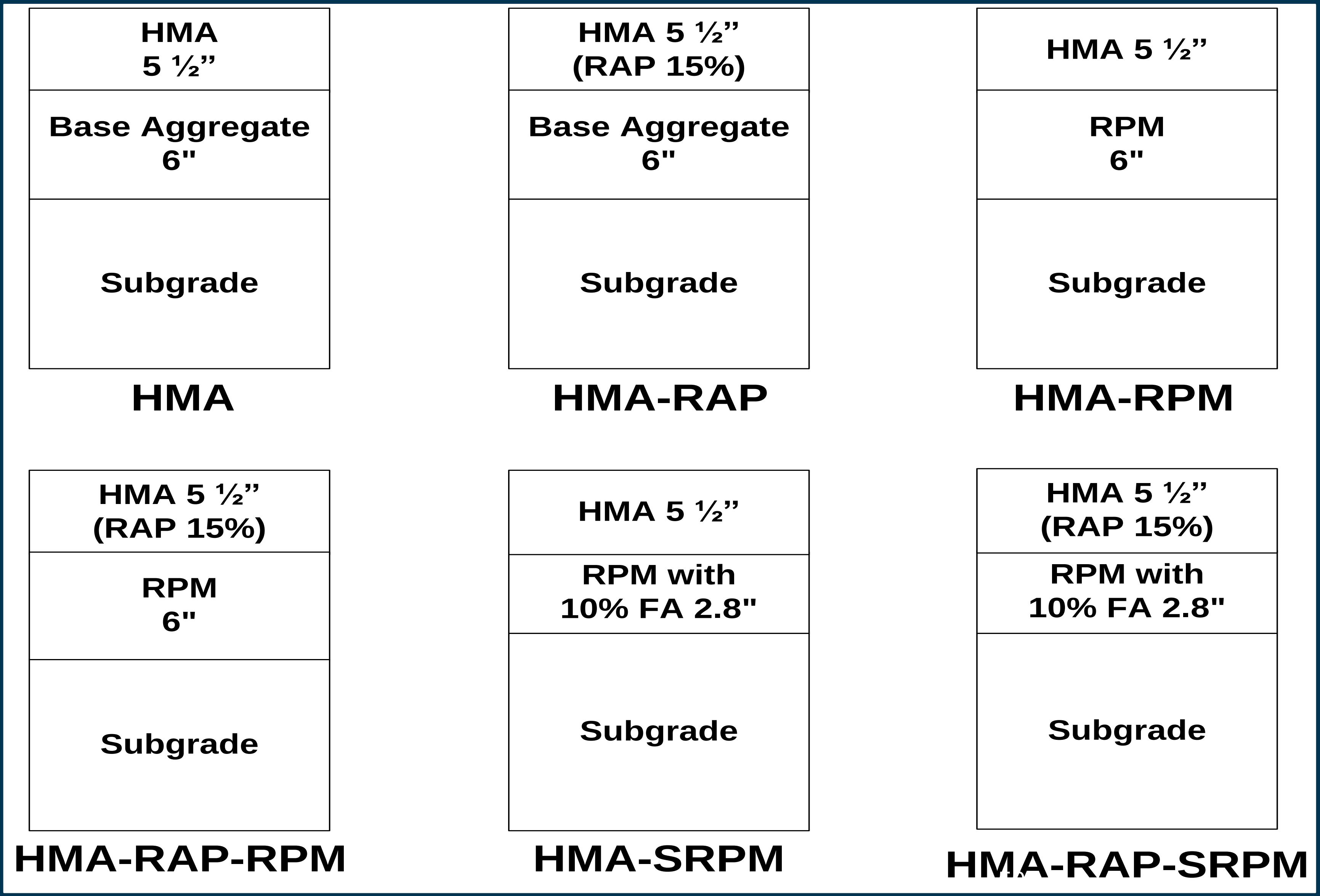
- Using recycled materials in construction can reduce energy emissions and greenhouse gas emissions: T/F

- Recycled materials always have inferior properties relative to conventional construction materials: T/F

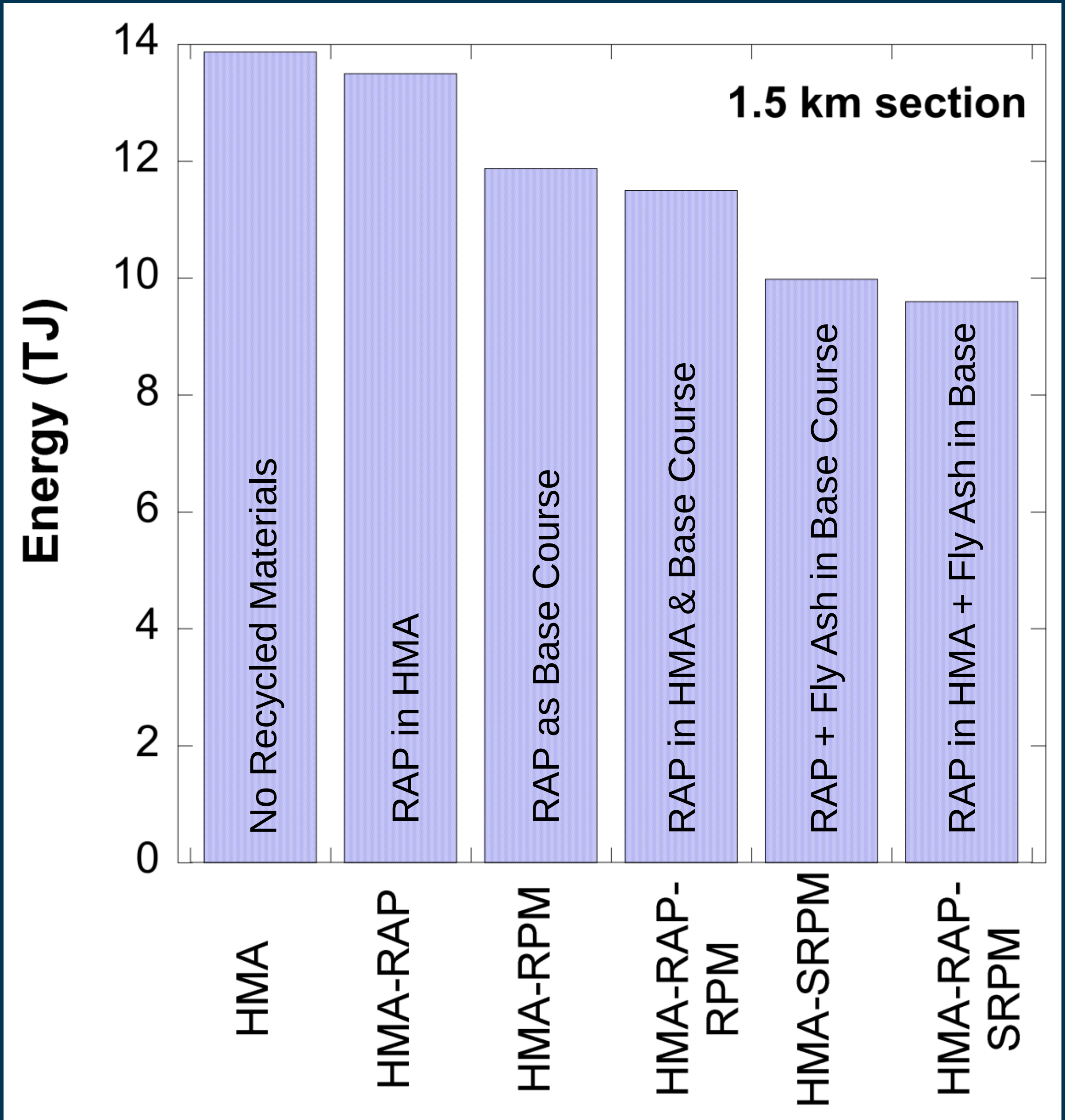
Comparison of Alternatives using BE^2ST

- HMA = hot mix asphalt
- RAP – reintroducing reclaimed asphalt into new hot mix asphalt
- RPM – using RAP as granular base
- SPRM – using RAP + fly ash binder as base.

Comparison of Alternatives using BE²ST in Highways



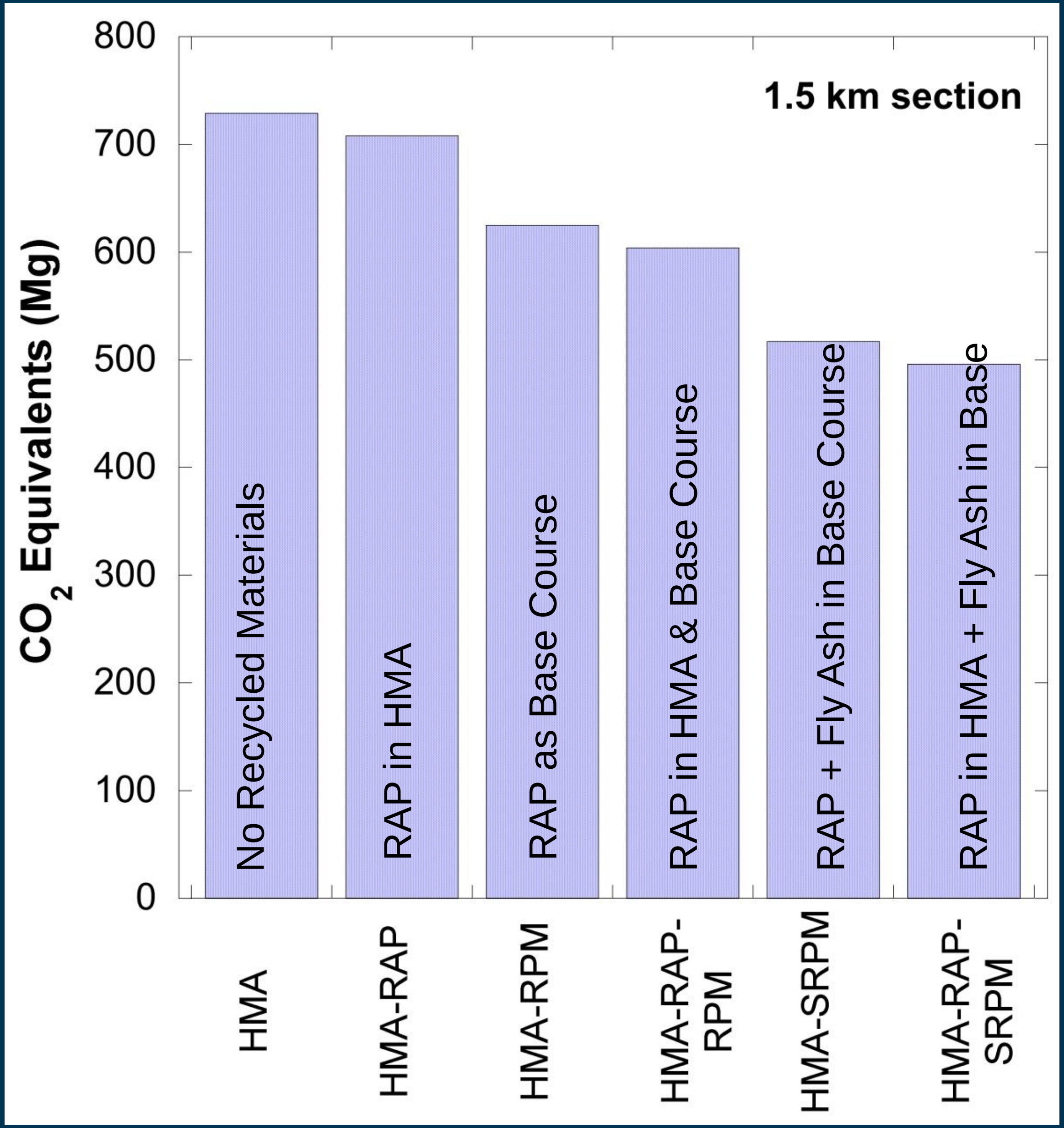
Life Cycle Energy Consumption



Most energy: reintroducing reclaimed asphalt into HMA.

Least energy: using stabilized reclaimed asphalt in base and RAP in HMA.

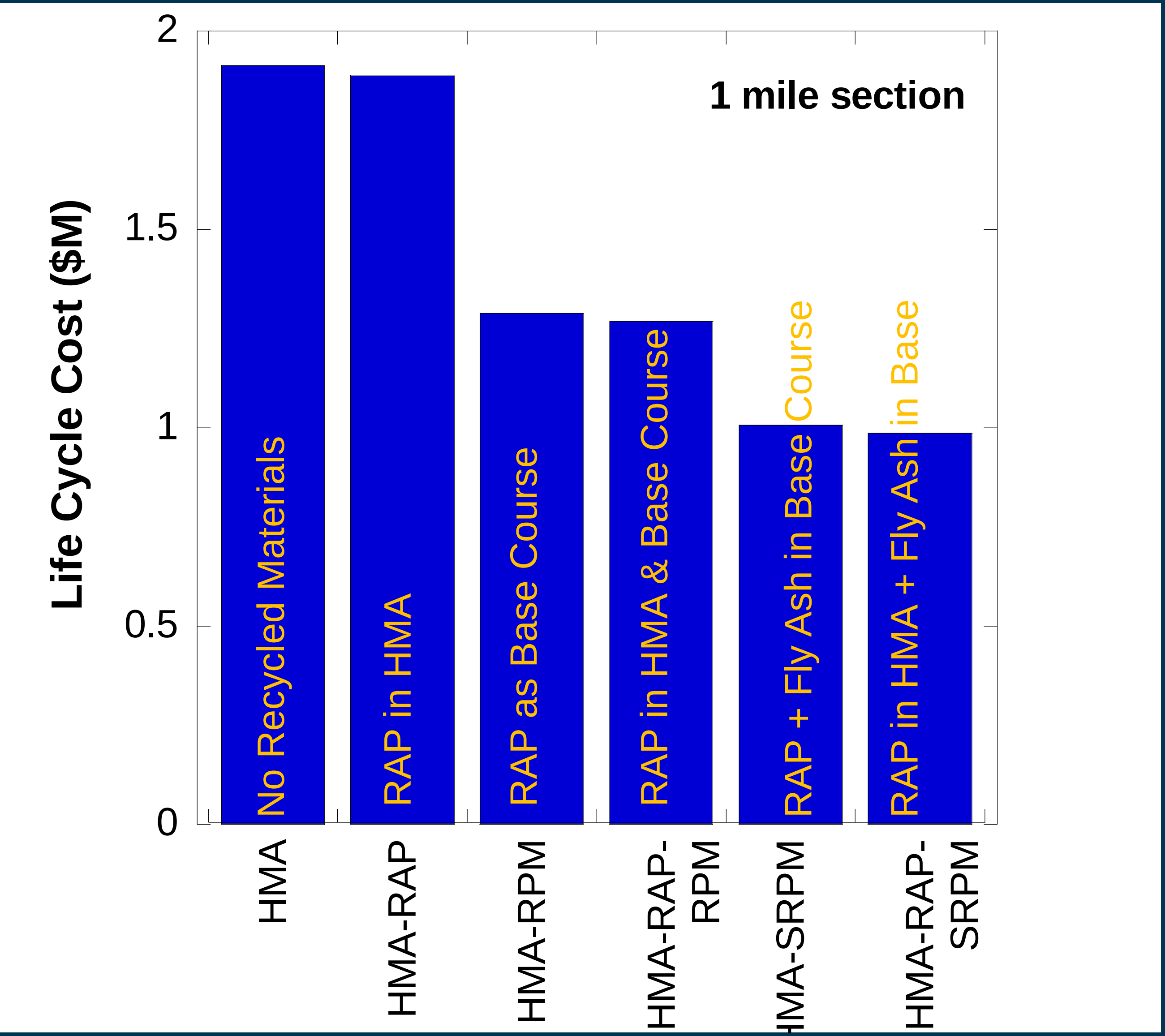
GHG Emissions



Most emissions: introducing reclaimed asphalt into HMA.

Least emissions: using stabilized reclaimed asphalt in base & RAP in HMA.

Life Cycle Cost



Least expensive: using stabilized reclaimed asphalt (SRPM) in base and RAP in HMA.

Most expensive: reclaimed asphalt in hot mix asphalt (HMA)

www.recycledmaterials.org