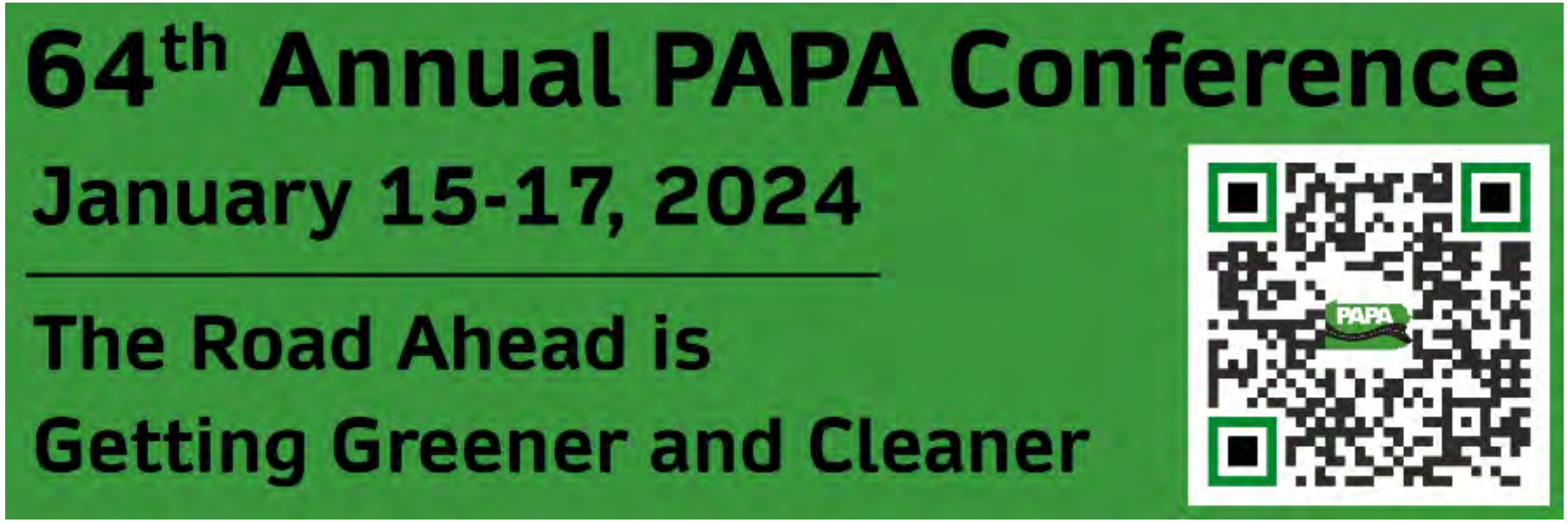
Asphalt Research & Trends from the US & Abroad

Shane Buchanan, CRH Americas Materials



PENNSY SUPPLY
A CRH COMPANY

An Interesting Fact (At Least to Me)

1. The Eagles and the Steelers once played together as the Steagles.

Wikipedia/Temple University Libraries

Who woulda thunk it, right? It's true, though. During the 1943 season, many of the Eagles and Steelers players served in World War II. The remaining players combined for a single season to play together as the Steagles.

….and a To Do for me!

HYNER
TRAIL CHALLENGE

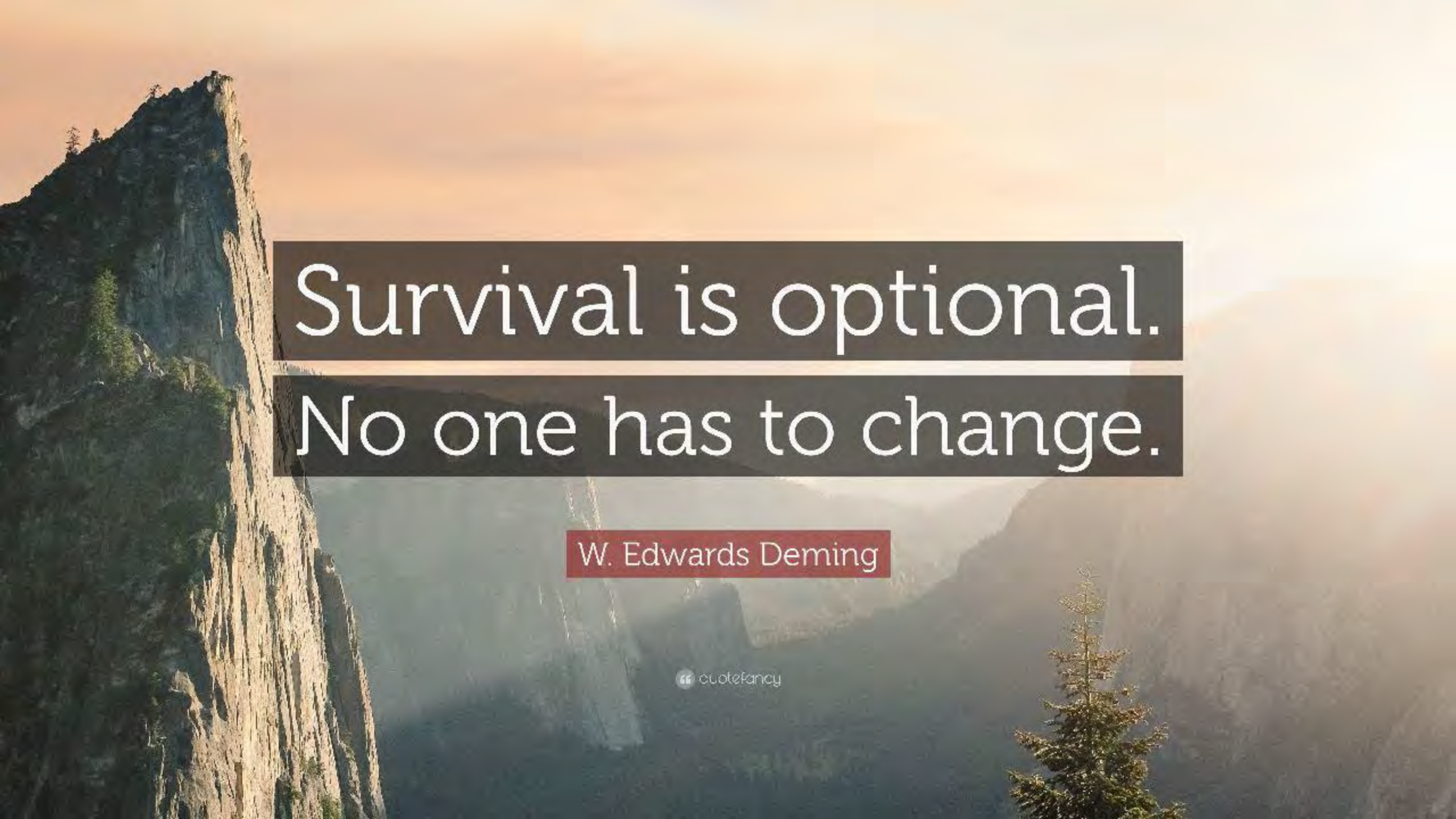
— 25k and 50k —

Where We Need to Be as an Industry?

- **<u>World Class Performance</u>** lies at the intersection of Quality (Performance), Sustainability and Economics.

- Can You Have All Three Simultaneously?
  - YES, but it requires desire and attention to detail.

- The Industry is changing ***rapidly*** and those who adapt and grow will survive and thrive.

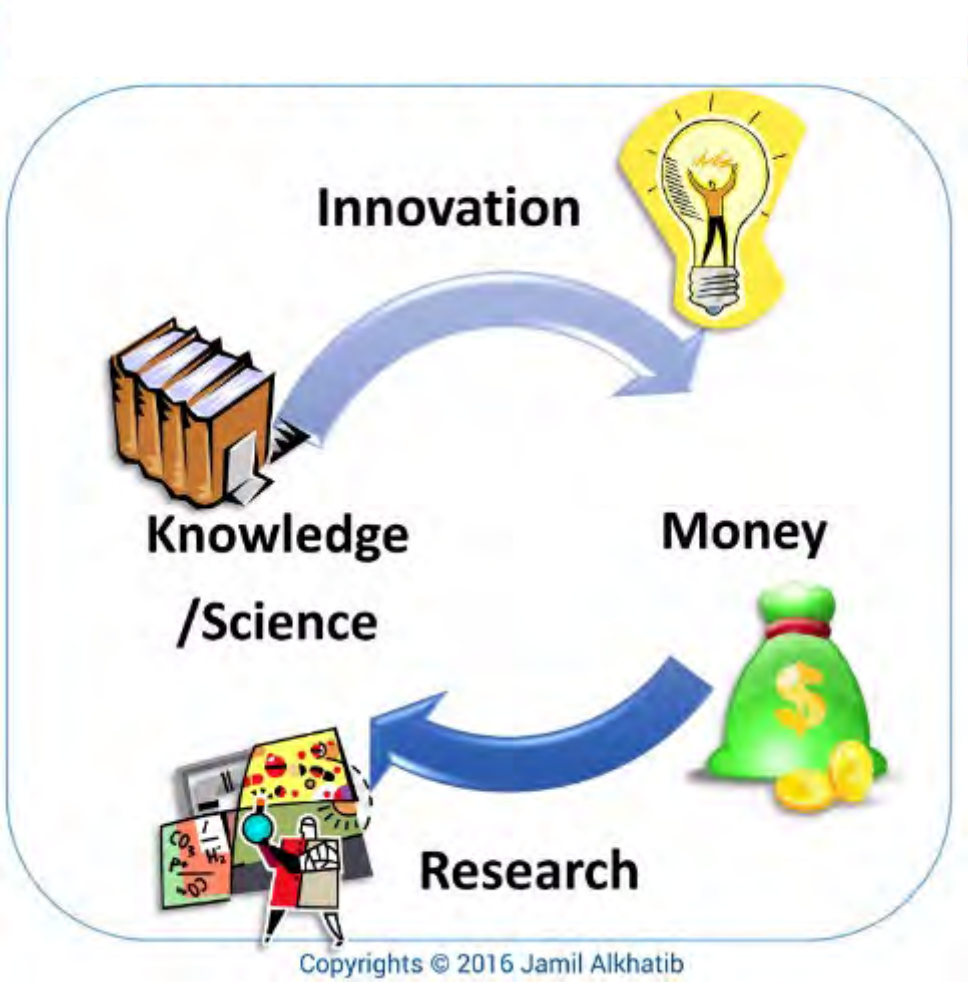

Survival is optional.
No one has to change.
W. Edwards Deming
quotefancy


RIO OLYMPIC GAMES
How past sprinting greats compare to Usain Bolt
RIO 2016
9.58"
9.74"
9.79"
9.84"
9.85"
9.86"
9.95"
10.2"
Usain Bolt (JAM) - 2009
-1.7m
Asafa Powell (JAM) - 2007
-2.2m
Maurice Greene (USA) - 1999
-2.7m
Donovan Bailey (CAN) - 1996
-2.8m
Leroy Burrell (USA) - 1994
-2.9m
Carl Lewis (USA) - 1991
-3.9m
Jim Hines (USA) - 1968
-6.5m
Jesse Owens (USA) - 1936
Source: IAAF
© AFP

Research & Innovation

- “Research is a lever that provided with money will generate knowledge whilst innovation is a lever that provided with knowledge will generate money.”

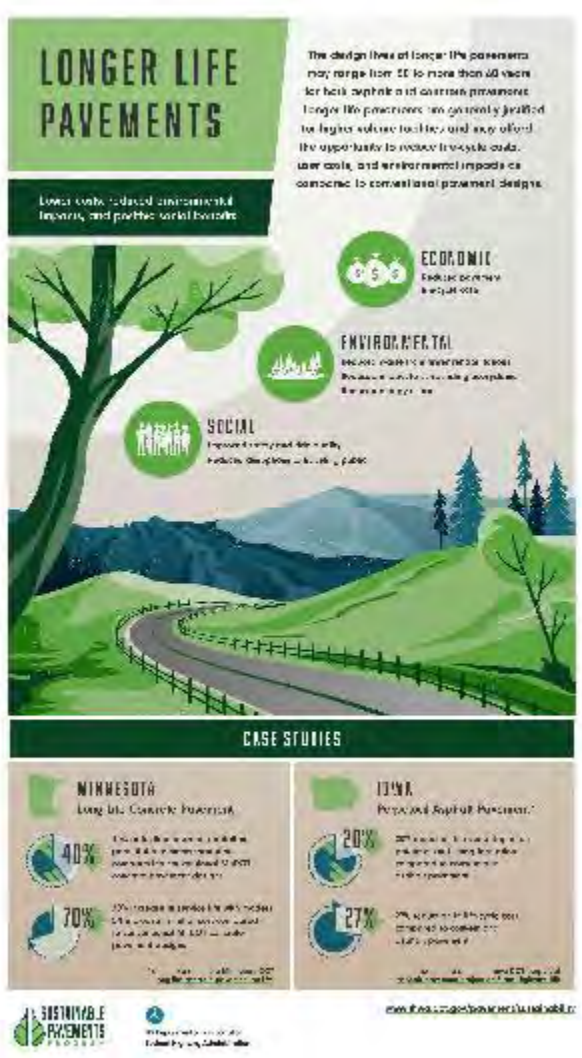
https://www.eitdigital.eu/newsroom/news/archive/the-saga-of-research-vs-innovation/

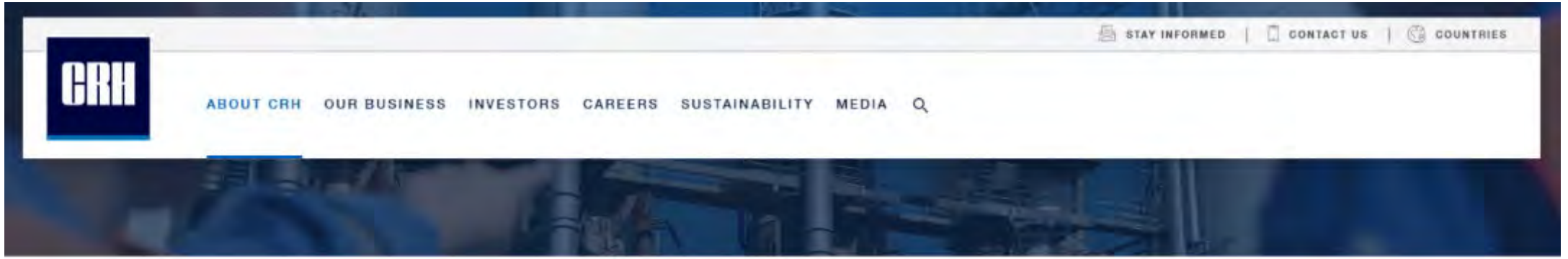


https://www.slideshare.net/ibtecar/research-innovation-62199084

What is the Key Driver of Research & Innovation Today?

- **Sustainability!**
- In recent years there has been a dramatic emphasis on pavement sustainability.
  - Development of carbon-neutral road materials and sustainable paving materials
  - Hyper focus of most companies.





Our Values

ABOUT CRH OUR PURPOSE OUR VALUES

At CRH, our Values unite us in the way we work, every day, all over the world.

People are our Priority

Character is our Strength

Performance is our Commitment

Innovation is our way Forward

Our Pillars

ABOUT CRH OUR PURPOSE OUR PILLARS

To make a real difference in the world and to ensure it is a better place for future generations, we are committed to long term sustainable business success.

Our Pillars help us win for all our stakeholders.

Empowered Talent

Customer Connected

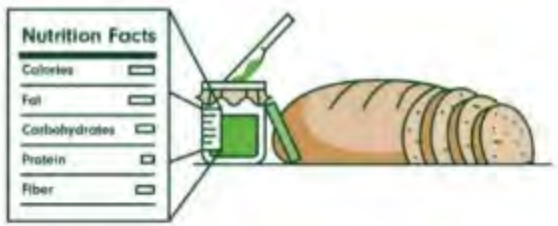
Focused Growth

Sustainability Leadership

Environmental Product Declaration (EPD)

Environmental Product Declaration (EPD)

- **Third-party verified document** that publicly discloses the environmental impacts associated with sourcing, manufacturing, use, transportation, and disposal of your product.
- **Provide** verifiable and transparent information on **life-cycle environmental impact data** for materials or products.
- **Allow meaningful comparisons of the environmental performance of materials** (if they were developed using the same product category rules, PCRs, which are industry consensus standards and guidelines used in developing and reporting EPDs).
- **Identify areas** for environmental performance **improvement,** encouraging industry efficiency.



Similar to nutrition labels for food products, EPDs communicate critical environmental information on pavement materials to the customer.

TRACI Impact Indicator	Unit	Materials	Transport	Production
Global Warming Potential	kg CO_2-Equiv.	83.4	11.8	168
Ozone Depletion	kg CFC-11-Equiv.	1.81e-08	5e-10	8.55e-11
Acidification	kg SO_2-Equiv.	0.486	0.0577	1.08
Eutrophication	kg N-Equiv.	0.0263	0.00373	0.0207
Smog Air	kg O_3-Equiv.	8.23	1.81	13.3

https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/termsandacronyms/search.do

https://www.fhwa.dot.gov/pavement/sustainability/hif19087.pdf

GWP - Carbon Dioxide Equivalent (CO2e)

- The unit used to measure the impacts of releasing (or avoiding the release of) different greenhouse gases; it is obtained by multiplying the mass of the greenhouse gas by its global warming potential.
- CO2e puts all GHG emissions in relation to carbon dioxide, which is considered to have a GWP of 1.

https://www.appropedia.org/Glossary_of_sustainability_terms

An Environmental Product Declaration for Asphalt Mixtures

TABLE 4. LIFE CYCLE IMPACT INDICATORS

ACRONYM	INDICATOR	UNIT	QUANTITY PER METRIC TONNE ASPHALT MIXTURE (PER SHORT TON ASPHALT MIXTURE)			
			MATERIALS (A1)	TRANSPORT (A2)	PRODUCTION (A3)	TOTAL (A1-A3)
GWP-100	Global warming potential, incl. biogenic CO2	kg CO2 Equiv.	24.85 (22.55)	8.61 (7.81)	27.41 (24.86)	60.87 (55.22)
ODP	Ozone depletion potential	kg CFC-11 Equiv.	1.35e-08 (1.23e-08)	5.21e-08 (4.72e-08)	2.84e-08 (2.58e-08)	9.40e-08 (8.52e-08)
EP	Eutrophication potential	kg N Equiv.	6.74e-03 (6.11e-03)	4.47e-03 (4.06e-03)	2.88e-03 (2.62e-03)	1.41e-02 (1.28e-02)
AP	Acidification potential	kg SO2 Equiv.	7.33e-02 (6.65e-02)	7.40e-02 (6.71e-02)	4.92e-02 (4.46e-02)	1.96e-01 (1.78e-01)
POCP	Photochemical ozone creation potential	kg O3 Equiv.	1.55 (1.41)	2.48 (2.25)	1.55 (1.41)	5.58 (5.07)

CO2e = GWP * GHG emission (tons)

Key Points…

<u>Regardless of your personal viewpoint,</u> leading practices that save $$$ almost always have a positive sustainability impact.

- Reduce Aggregate Moisture
- Lower Production Temperature
- Reduced Virgin Binder Demand
- Increased Recycle Use
- Using Locally Available Aggregates

Being Green Can Make you Green!

Sustainability impacts must be considered in decision making process (i.e. CAPEX)

- Cost / [Benefit ($ + Sustainability)]

Recycled Asphalt Pavement (RAP)

- 1% RAP ~ 0.35 kg CO2e / ton

Warm Mix Asphalt (WMA)

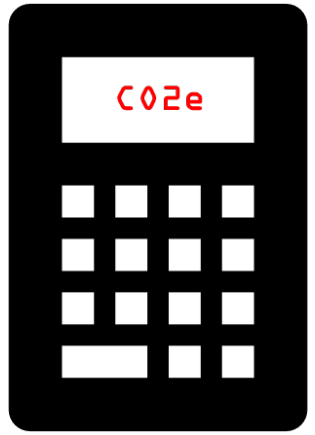
- 25F Temp. ~ 0.67 kg CO2e / ton (Natural Gas) / 0.80 (Propane) / 0.95 (RFO)

Liquid Asphalt

- 0.1% liquid = 0.25% VMA = ~ 0.57 kg CO2e / ton

Moisture

- 1% Moisture ~ 1.47 kg CO2e / ton (Natural Gas) / 1.75 (Propane) / 2.06 (RFO)



General Estimates: Local Conditions Will Drive Actual Data

U.S. vs Europe

- My experience…
- Europe (and others) is collectively outpacing the U.S. with many “innovative” technologies and processes.
- Reason…
  - Research, Innovation, and Application are being ***required and driven by procurement practices*** which have sustainability embedded.
  - Owners are requiring and paying for it!

Whatever is happening in Europe will eventually find it’s way to the U.S.

Decision Making…

Historic decision making….

- New technology
  - What's the cost?
  - What's the benefit?

Future decision making….

- New technology
  - What's the cost?
  - What's the benefit?
  - What's the sustainability benefit?
  - How do I justify expense for "sustainability" benefit?
    - Required
    - Good will

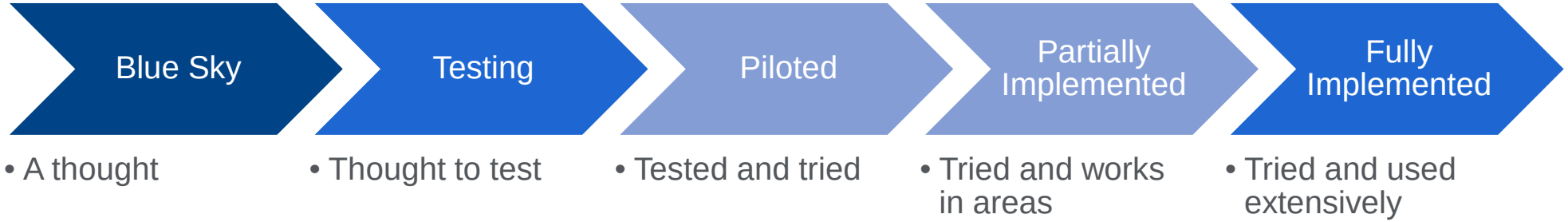
So, Let’s Talk About What’s Happening!

- **First**, there is a LOT of research and innovation taking place. Impossible to capture everything.

- Let’s bucket items into categories….
  - Materials + Mix Design
  - Production
  - Construction
  - General

Innovation Continuum

- An innovation will fall somewhere on a continuum from “blue sky” to fully implemented.



What's PennDOT Researching?

- In F.Y. 2021-2022, approximately $2.3 million were provided to fund important research projects that addressed the vital transportation needs of Pennsylvania in the areas of construction, design, maintenance, operations, and safety, planning and policy, and technology transfer.

- Active Asphalt Projects:

1. Recycled Plastics in Pennsylvania Asphalt
2. Evaluation of Asphalt Performance Testing Protocols in PA

https://www.penndot.pa.gov/ProjectAndPrograms/Planning/Research-And-Implementation/Pages/researchProjects.aspx

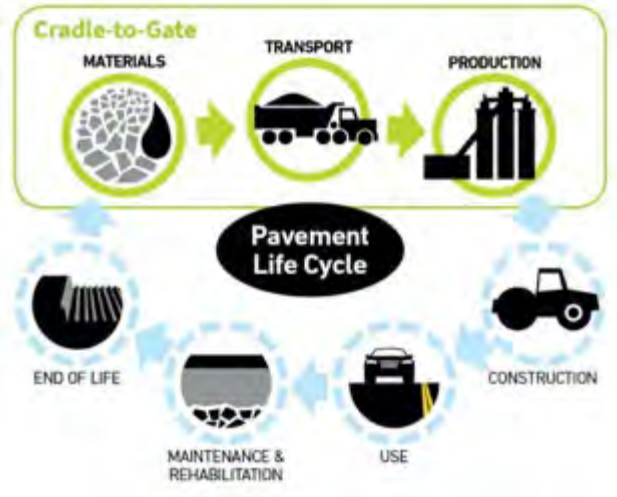
MATERIALS

+

MIX DESIGN

Materials and Mix Design

- **Extensive** research being conducted in materials area.
- Mix design research primarily focused around performance testing and balanced mix design.
- Substantial opportunity here with regards to lowering the EPD (cradle to gate) CO2e.



NCHRP

- National Cooperative Highway Research Program is the States' Research Program
- Substantial Balanced Mix Design and Recycled Materials Emphasis.

NCHRP 09-57B	Field Validation of Laboratory Cracking Tests of Asphalt Mixtures	Pending	Contract pending.
NCHRP 09-58	The Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios	Completed	
NCHRP 09-59	Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance	Final	Published as NCHRP Research Report 982
NCHRP 09-60	Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications	Active	Research in progress
NCHRP 09-61	Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures	Completed	
NCHRP 09-62	Rapid Tests and Specifications for Construction of Asphalt-Treated Cold Recycled Pavements	Completed	Publication pending
NCHRP 09-63	A Calibrated and Validated National Performance-Related Specification for Emulsified Asphalt Binder	Active	Research in progress
NCHRP 09-64	Developing Laboratory Methods and Specifications to Test Tack Coat Materials	Completed	Publication decision pending.
NCHRP 09-65	Capturing Durability of High Recycled Binder Ratio (RBR) Asphalt Mixtures	Active	Research in progress
NCHRP 09-66	Performance Properties of Laboratory Produced Recycled Plastic Modified (RPM) Asphalt Binders and Mixtures	Active	Research in progress
NCHRP 09-67	New Materials & Technology Deployment in Asphalt Pavement Structural Design	Anticipated	
NCHRP 09-68	Recycled Asphalt Materials: Binder Availability and Its Impact on Mix Performance	Active	Research in progress
NCHRP 09-69	Verifying Quantities of Materials Used in Asphalt Mixtures at Production Facilities	Active	
NCHRP 09-70	Feasibility Evaluation and Guidance Development for Implementing Practical Aging Protocols for Balanced Mix Design (BMD) Verification and Acceptance	Anticipated	In development
NCHRP 09-71	Guidance to Develop Optimized Framework of Asphalt Mixture Performance Testing for Balanced Mix Design and Acceptance (BMD&A)	Anticipated	In development
NCHRP 09-72	Sensitivity Evaluation of Balanced Mix Design Performance Tests to Binder Properties and Mix Design Variables	Anticipated	In development

Research in Progress (RIP)

- https://rip.trb.org/

RIP The Transportation Research Board's Research in Progress (RIP) Database contains information on more than 12,000 current or recently completed transportation research projects. RIP records primarily are projects funded by the U.S. Department of Transportation and State Departments of Transportation. University transportation research also is included in the database.

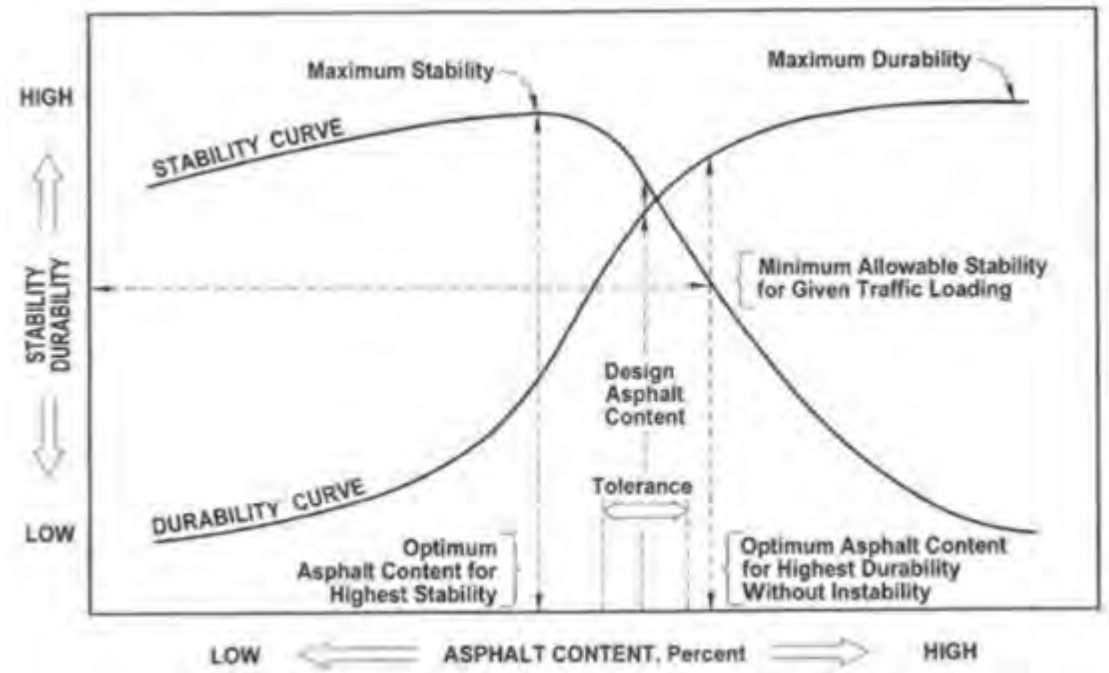
Research in Progress (RIP)

- Balanced Mix Design – Example Search
- 28 active / planned research efforts on BMD area.
- Over $7M funding.

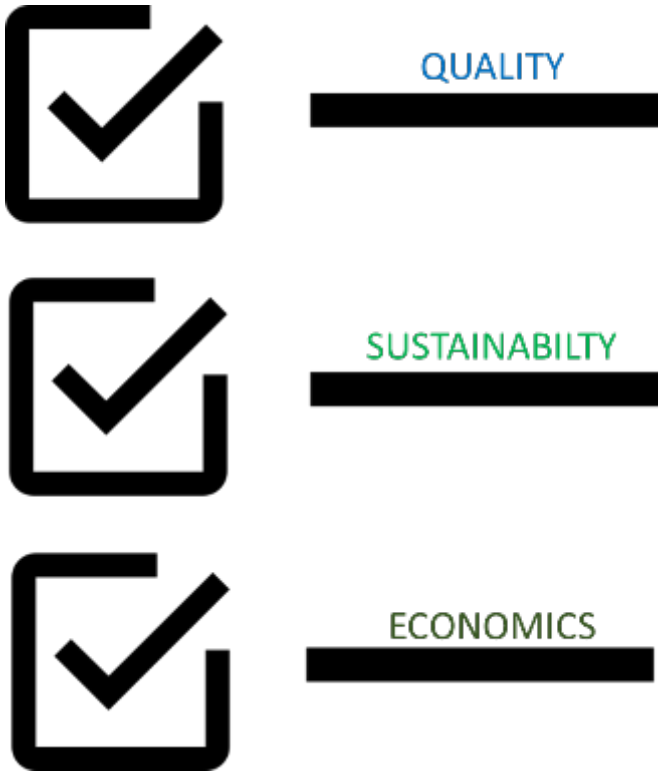
1. **Re-evaluating Asphalt Rutting Test for Balanced Mix Design and Quality Assurance Acceptance**
   Ohio Department of Transportation, $495000, Active 2024-0
2. **Ruggedness Study of Specimen Preparation and Fine-Tuning of Test Methods for IDT-C and IDT-HT**
   Virginia Department of Transportation, $241447, Active 2023-1
3. **Replacing Fossil Fuel-Based Asphalt Binder with Sustainable Lignin Binder from Waste**
   Southern Plains Transportation Center, $184933, Active 2023-1
4. **2298 Incorporating Quality Recycled Asphalt Pavement into the Balanced Mix Desig World**
   Oklahoma Department of Transportation, $293000, Active 2023-1
5. **Field Validation of Balanced Mix Design Initial Criteria**
   Virginia Department of Transportation, $250889, Active 2023-0
6. **Optimizing Asphalt Mixture Performance Testing for Balanced Mix Design**
   National Center for Infrastructure Transformation, $634918, Active 2023-0
7. **Benchmarking Study of TDOT D Mixtures for Balanced Mixed Design**
   Tennessee Department of Transportation, $225000, Active 2023-0
8. **Evaluation of Balanced Mix Design (BMD) Surface Mixtures with Conventional and High RAP Contents under Laboratory-Scale and Full-Scale Accelerated Pavement Testi (APT)**
   Virginia Department of Transportation, $15005, Active 2023-0
9. **Evaluation of Balanced Mixed Design in Kansas**
   Kansas Department of Transportation, $76660, Active 2023-0
10. **TSR Replacement and Stripping Tests River Gravel in Asphalt Mixes**
    Missouri Department of Transportation, $250000, Active 2023-0
11. **Development of Preliminary Balanced Mix Design Method for Stone Matrix Asphalt**
    National Center for Transportation Infrastructure Durability and Life-Extension, $89970, Active 2023-0
12. **Balanced Mix Design for Surface Asphalt Mixtures: Fiber-Modified Mixtures**
    Virginia Department of Transportation, $130071, Active 2022-0
13. **Assessing Cracking Test Methods to Improve the Performance of ADOT Asphalt Mixe**
    Arizona Department of Transportation, $$289,988.36, Active 2022-0
14. **Developing Long-term Aging Protocols for Cracking Performance Evaluation of Aspha Mixtures in Virginia**
    Virginia Department of Transportation, $673878, Active 2022-0
15. **Nebraska Balanced Mix Design – Phase II**
    Nebraska Department of Transportation, $141,914.00, Active 2022-07-01
16. **Inter-Laboratory Study for the Indirect Tensile Test at High Temperature and Rapid Rutting Test**
    Virginia Department of Transportation, $249311, Active 2022-05-02
17. **Validation of Loose Mix Aging Procedures for Cracking Resistance Evaluation in Balanced Mix Design**
    Minnesota Department of Transportation, $100,000, Active 2022-04-01
18. **TRC2201 - Update to ARDOT Superpave Gyratory Compaction (SGC) Specification to Increase Pavement Durability**
    Arkansas Department of Transportation, $$508,421, Active 2022-03-28
19. **Mechanistic-Based Evaluation of Performance Thresholds for Engineered Surface Asphalt Mixtures**
    Virginia Department of Transportation, $548142, Active 2022-02-02
20. **Implementation of Balanced Mix Design Methods in Oregon to Meet Long-term Performance Goals**
    Oregon Department of Transportation, $315000, Active 2021-09-20
21. **Establish Performance-Based Acceptable Lab-Molded Density Range for Mix Design and QC/QA**
    Texas Department of Transportation, $829,999, Active 2021-09-01
22. **Balanced Mix Design for Surface Asphalt Mixtures: 2021 and 2022 Plant Mix Schedule Pilots**
    Virginia Department of Transportation, $335919, Active 2021-07-12
23. **Development of a Fatigue Testing Protocol for Asphalt Mixture Using Hamburg Wheel Tracking Device**
    Center for Integrated Asset Management for Multimodal Transportation Infrastructure Systems (CIAMTIS), $139808, Active 2021-06-08
24. **Capturing Durability of High Recycled Binder Ratio (RBR) Asphalt Mixtures**
    Transportation Research Board, $750000, Active 2021-03-26
25. **2288 Long Term Performance and Benefits of Combined Balanced Mix Design and Chemical WMA Technology**
    Oklahoma Department of Transportation, $$ 300,000, Active 2021-01-22
26. **Implementation of Balanced Mix Design of Asphalt Mixtures Prepared with Reclaimed Asphalt Pavements and Rejuvenators for Enhanced Performance**
    Idaho Transportation Department, $170000, Active 2020-09-01
27. **Evaluating Recycling Agents' Acceptance for Virginia: Test Protocols and Performance-Based Threshold Criteria**
    Virginia Department of Transportation, $467438, Active 2020-07-01
28. **Impact of Production Variability on Balanced Mix Design in Virginia**
    Virginia Department of Transportation, $362921, Active 2019-10-23

Balanced Mix Design (BMD)

- An **innovative** BMD approach offers the **potential to ensure quality (performance), enhance the sustainability footprint** of mixes through optimization of binder, recycle and aggregate use, and provide a means of quantifying the overall economics.



BMD Checks All the Boxes…



With the current volumetric mix design system…

Source: Randy West, NCAT

….and no way to know if the mix is truly optimized!

National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

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Balanced Mix Design - Approaches

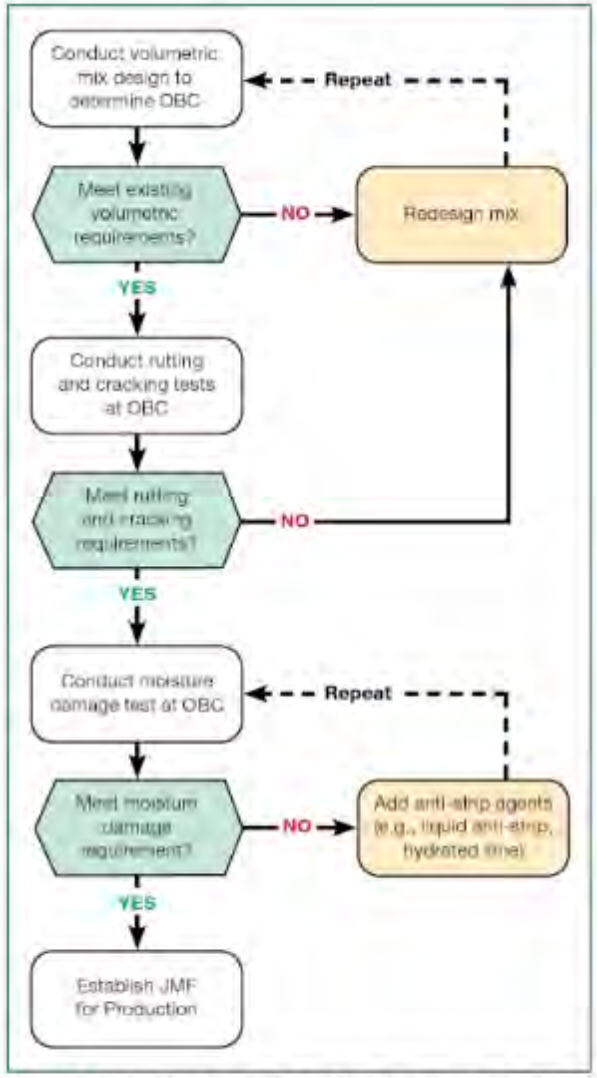


Figure 1. Graphical Illustration of the Volumetric Design with Performance Verification Approach (Approach A)

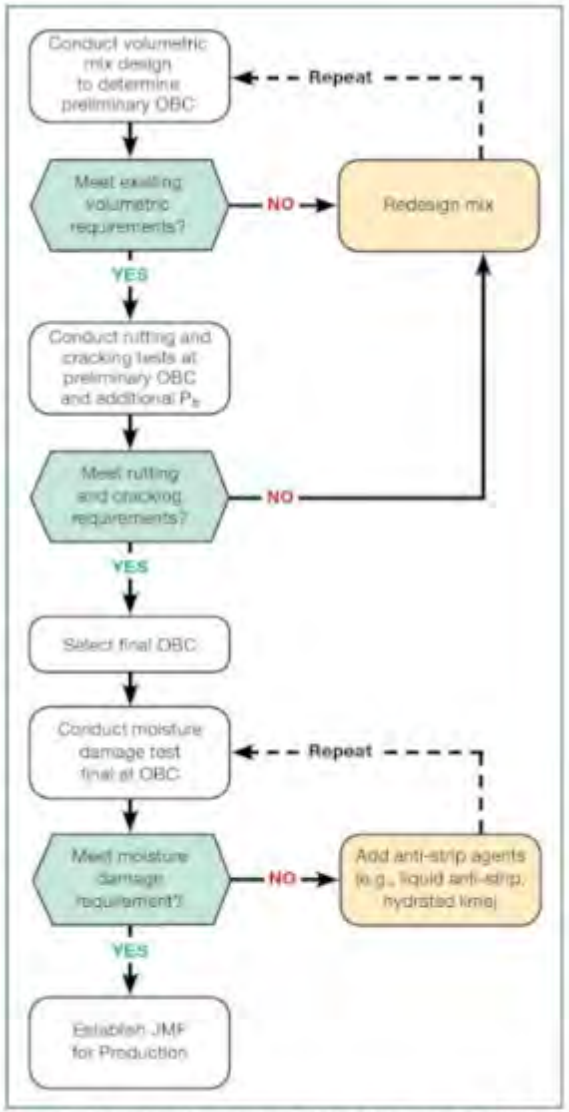


Figure 2. Graphical Illustration of the Volumetric Design with Performance Optimization Approach (Approach B)

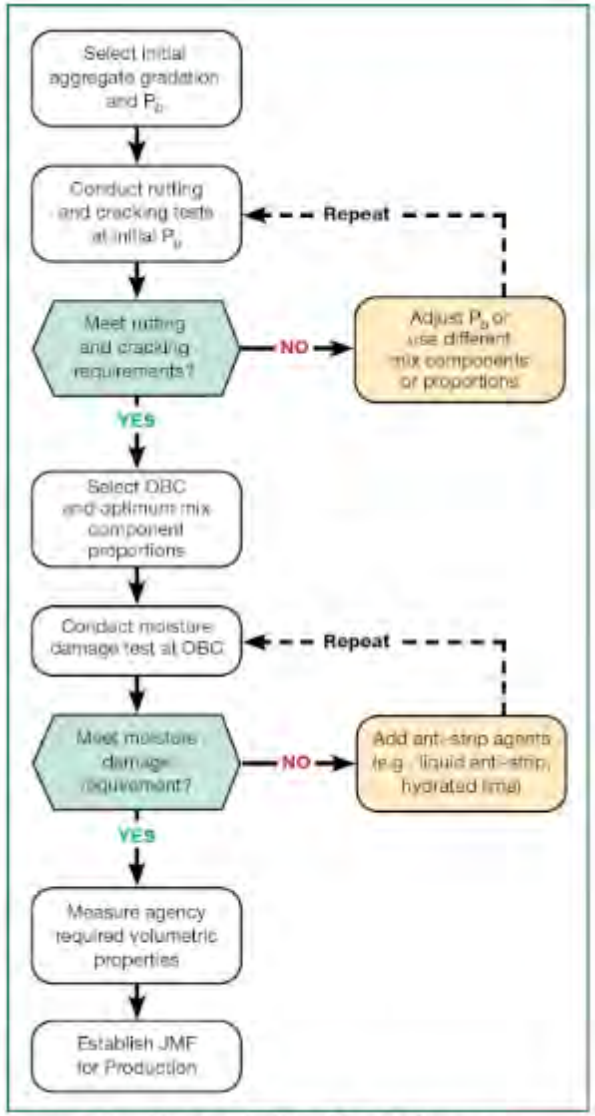


Figure 3. Graphical Illustration of the Performance-Modified Volumetric Design Approach (Approach C)

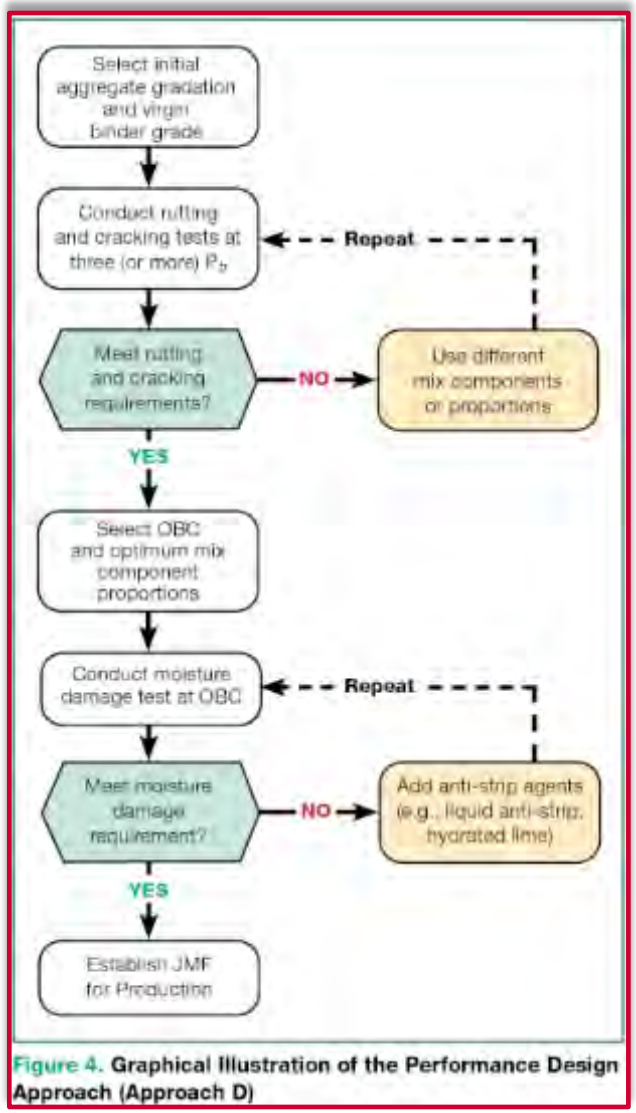
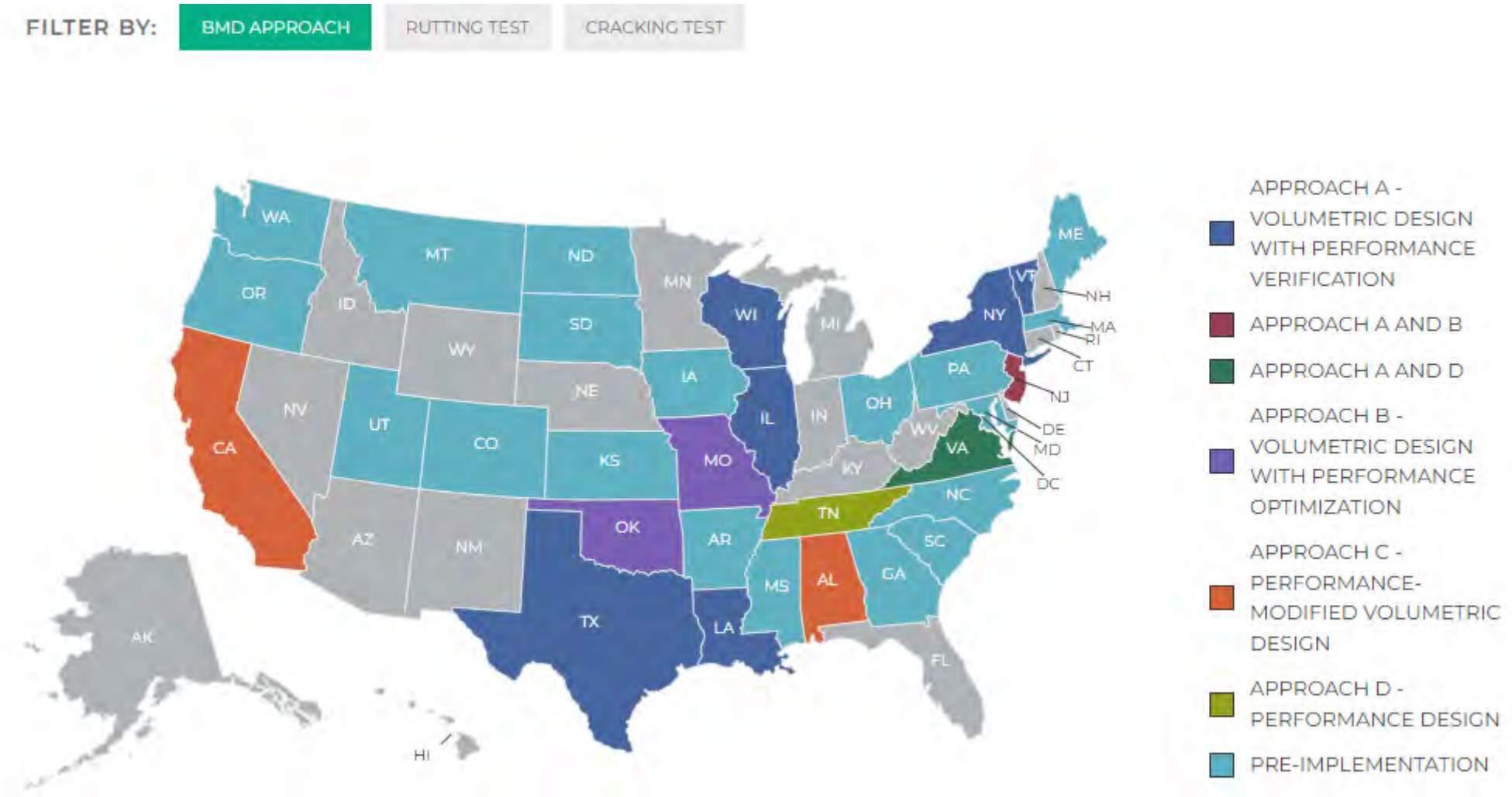


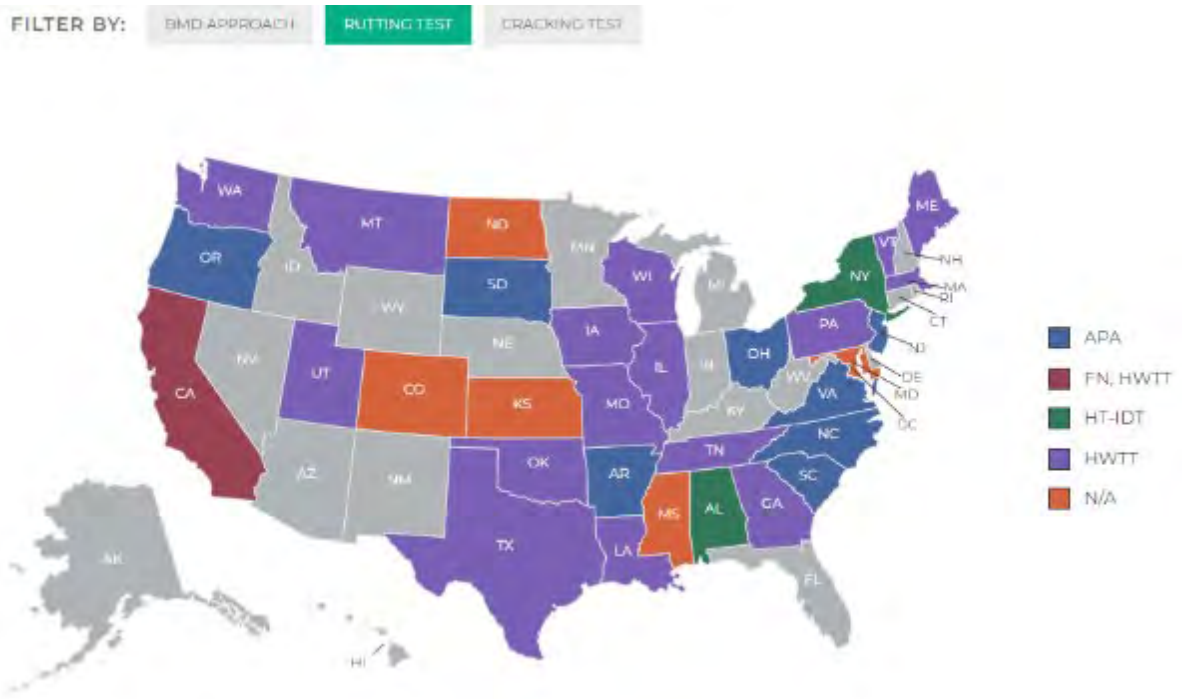
Figure 4. Graphical Illustration of the Performance Design Approach (Approach D)

BMD Implementation Status



https://www.asphaltpavement.org/expertise/engineering/resources/bmd-resource-guide

BMD Performance Tests



https://www.asphaltpavement.org/expertise/engineering/resources/bmd-resource-guide

BMD (PennDOT)

pennsylvania
DEPARTMENT OF TRANSPORTATION

Table 1. PennDOT's Preliminary Performance Test Criteria for Mix Design Approval

Traffic Level (Million ESALs)	HWTT			IDEAL-CT
	Rut Depth at 20,000 Passes (mm)	Stripping Inflection Point (SIP)	Passes to 12.5mm Rut Depth	Cracking Tolerance Index (CT_{Index})
≤ 3	≤ 15	N/A	N/A	> 70
	≤ 20	≥ 14,000	10,000	
	≤ 25	≥ 16,000	12,000	
3 to 10	≤ 10	N/A	N/A	> 80
	≤ 15	≥ 14,000	12,000	
	≤ 20	≥ 16,000	14,000	
≥ 10	≤ 10	N/A	N/A	> 90
	≤ 12	16,000	15,000	

https://www.asphaltpavement.org/expertise/engineering/resources/bmd-resource-guide

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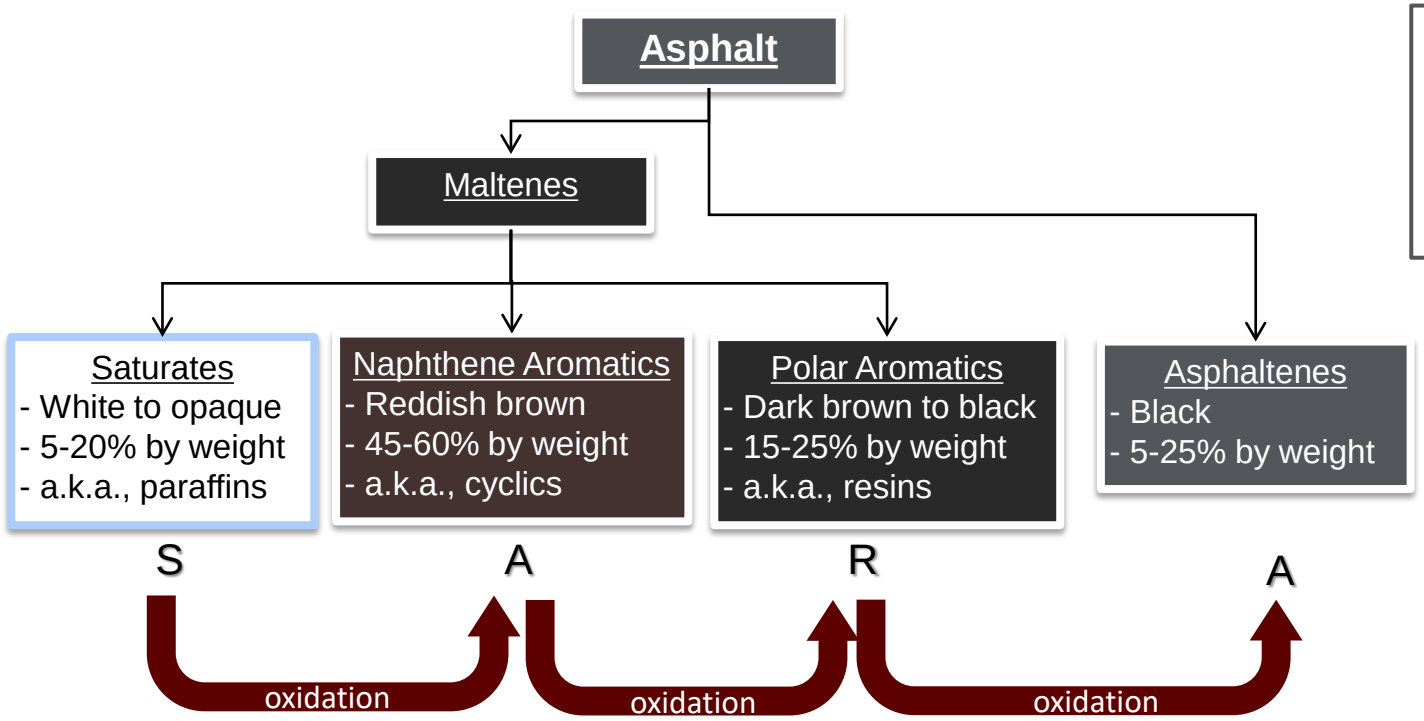
Rejuvenators (Recycling Agents)

Fully Implemented



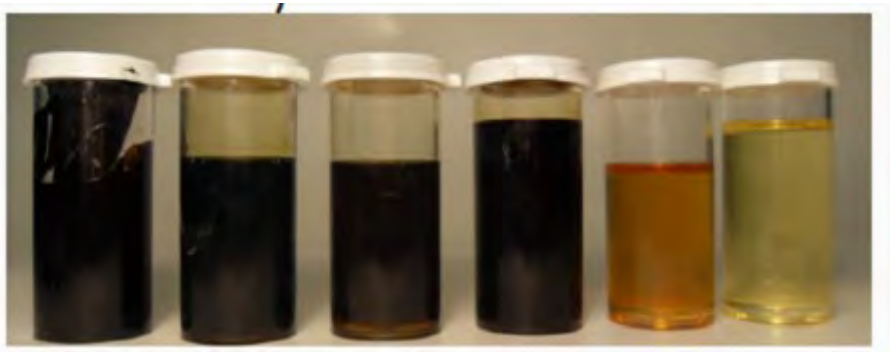
Saturates
Aromatics
Resins
Asphaltenes

http://www.tricorrefining.com/cyclogen.php

The role of rejuvenators is to restore or rebalance the portions of the asphalt that have depleted during aging

Rejuvenators (Recycling Agents)

- Rejuvenators will be a key to advancing the recycled content in asphalt mixtures.
- **Value = Higher recycle, lower CO2e, longer service life**



POET

EVOFLEX

Cargill

Delta S

SRIPATH TECHNOLOGIES, LLC
Make Asphalt Better.

ASPHALT & WAX INNOVATIONS
GREEN ASPHALT TECHNOLOGIES

ENGINEERED ADDITIVES LLC

MANCHESTER PAVEMENT SOLUTIONS

CRH

Partially Implemented

Recycled Plastic

- Research efforts continue around recycled plastics to determine their long term performance and use potential.

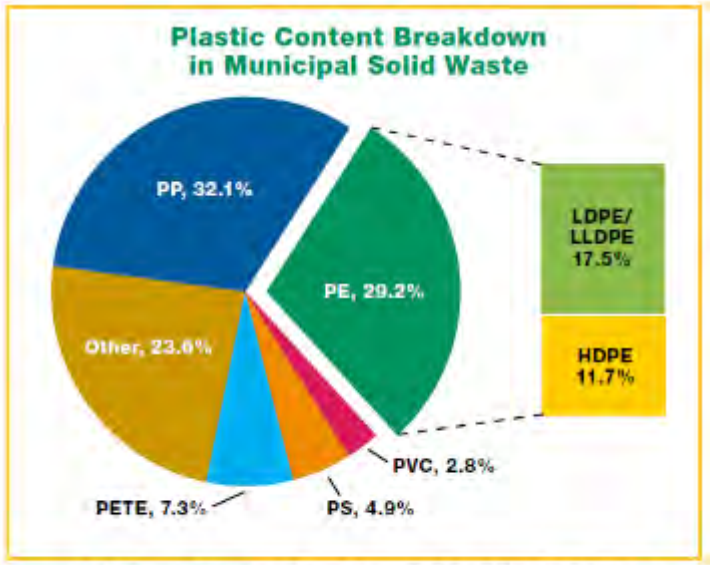


Figure 2-1. Plastic Content Breakdown in Municipal Solid Waste (DuBois, 2020; Based on EPA 2017)

SYMBOL	DESCRIPTION	
1 PETE	Clear tough plastic such as soft drink, juice and water bottles.	
2 HDPE	Common white or colored plastic such as milk containers and shampoo bottles.	
3 V	Hard rigid clear plastic such as cordial bottles.	
4 LDPE	Soft flexible plastic e.g. squeezable bottles such as sauce bottles.	
5 PP	Hard but flexible plastic such as microwave ware, takeaway containers, some yogurt/ice cream/jam containers, hinged lunch boxes.	
6 PS	Rigid, brittle plastic such as small tubs and margarine/butter containers.	
7 OTHER	All other plastics, including acrylic and nylon. Examples include some sports drink bottles, sunglasses, large water cooler bottles.	

Partially Implemented

Recycled Plastic Mix (RPM)

- Macrebur MR8 Product
- Richer appearing mix, great workability

Partially Implemented

Fibers

- Increased research on use of synthetic fibers.
- Can improve performance of mixes.
- Advanced engineering offers potential to help with recycle loadings.

Cold Central Plant Recycling (CCPR)

Partially Implemented

- Produced mostly in stand along pugmill plant

- Can be produced in asphalt plant.
  - 50/50 RAP add at RAP collar and cold feed.
  - Lower production rate around 100 to 150 tph.
  - Water added via foamers or other modification
  - Cement filler added normally
  - Successfully done at NCAT Test Track

Self Healing Asphalt

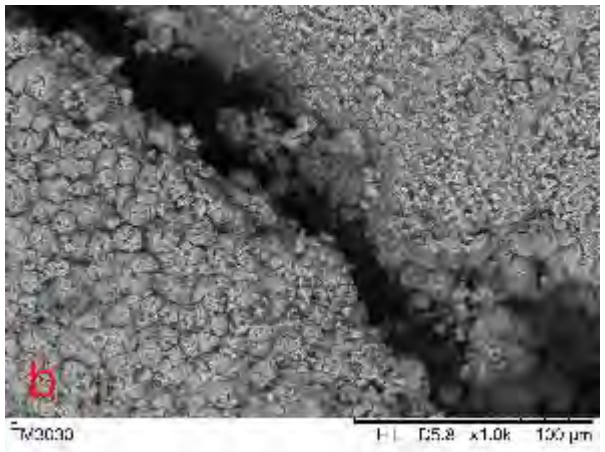
Testing

- Fischer defined self-healing property of a material as “the ability to substantially return to an initial, proper operating state or condition prior exposure to a dynamic environment by making the necessary adjustments to restore to normality and/or the ability to resist the formation of irregularities and/or defects” [1].

- Traditional methods to achieve self-healing asphalt pavements includes rejuvenation and heating. Rejuvenators are usually incorporated through capsules, hollow fibers, or vascular fibers. Upon cracking, the encapsulation breaks and the healing agent flows out and heals the crack.

- **Value = Longer service life and enhanced LCA**

https://www.sciencedirect.com/science/article/abs/pii/S0950061822000897



Alternative Binders

Blue Sky → Testing → Piloted

- Alternatives to petroleum derived asphalt binder are needed.
  - Enhance sustainability and reduce exposure to crude supply issues.

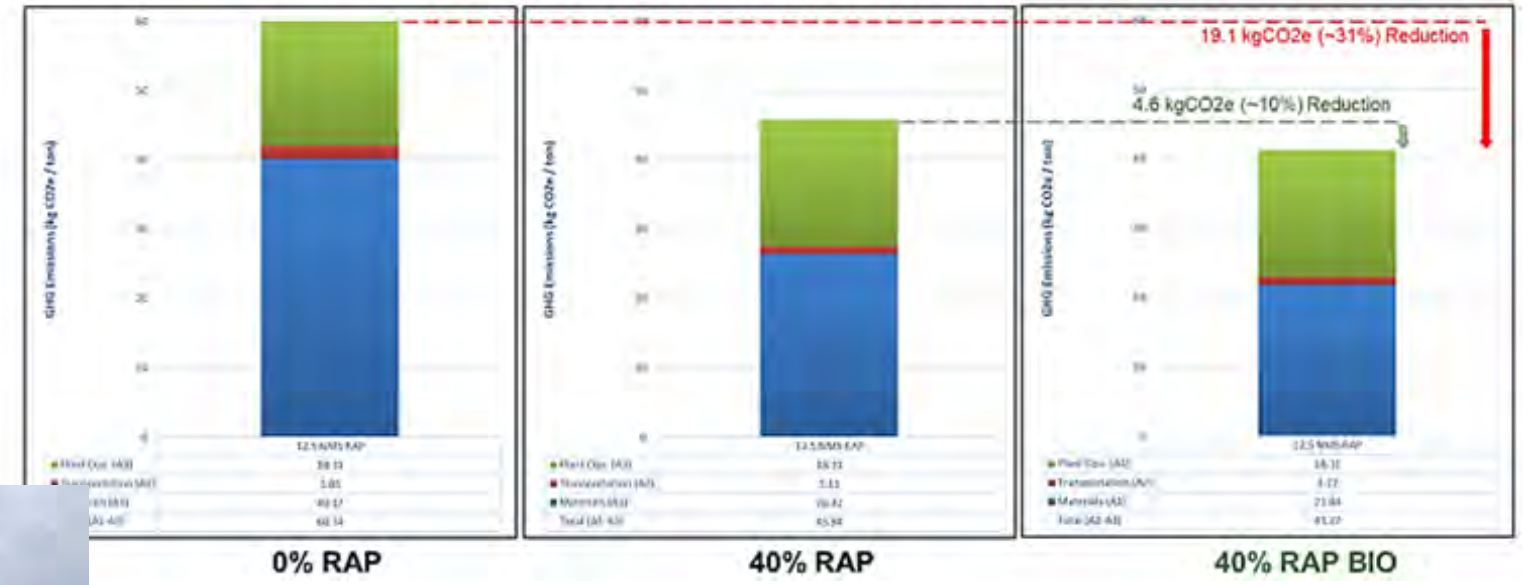
- Potential solutions…
  - Lignin
  - Biochar
  - Algae
  - Vegetable oil
  - Bio products

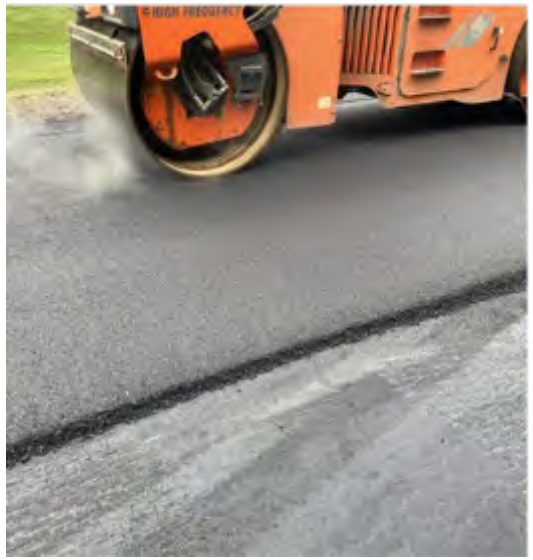
Sustainability Value of Bio-Based Products…
"Bio-based waste is used to improve properties (lifetime of the material) and environmental sustainability by shifting from fossil-based resources to bio-based resources. Bio-based resources are in favor from the sustainability point of view: they are renewable and do not contribute to climate change, as CO2 is captured from the atmosphere as a result of photosynthesis in the original vegetal source."

Alternative Binders – Successful Trial

- CRH partnered with Cargill to successfully trial a bio resin product to replace 20% of the virgin binder content.
- Research ongoing….!

- The combination of high RAP and bio-binder incorporation was estimated to provide a **31% reduction** in $kgCO_{2eq}$ emissions.

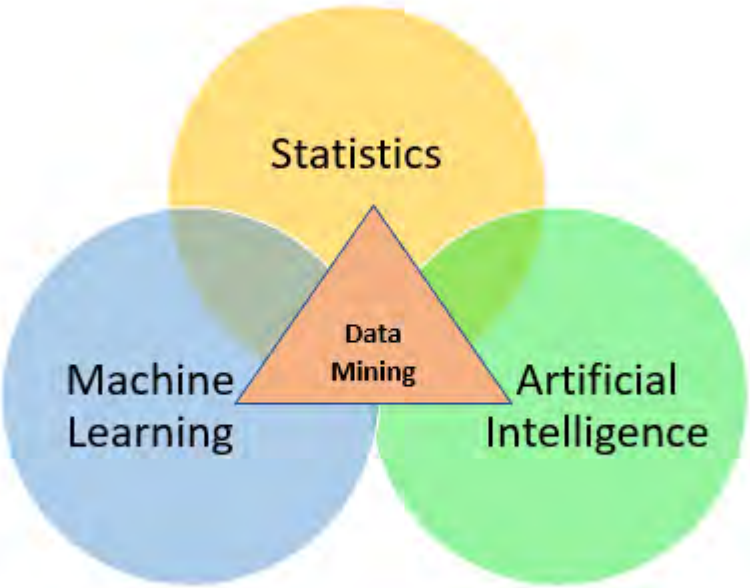




Enhanced Data Analysis and Use

Partially Implemented

- **Artificial Intelligence**
  - Leverages computers and machines to mimic the problem-solving and decision-making capabilities of the human mind.
- **Machine Learning**
  - Branch of artificial intelligence (AI) and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy.
- **Data Mining**
  - Searching and analyzing a large batch of raw data in order to identify patterns and extract useful information.
- **Statistics**
  - Collection, organization, analysis, interpretation, and presentation of data



Tremendous opportunity to USE generated data to optimize our operations.

Example

- Statistical forecasting is a way to predict the future based on data from the past.
- We have the data (or we better have it)!
- Example
  - Plant that makes 50,000 tons of a given mix w/ asphalt binder test every 500 tons
  - 100 QC tests available
- What do we do with these data? **Put your data to work for you!**

AIR VOIDS EVALUATOR - Normal (PWS)	
Air Voids Analysis	
Lower Air Voids Specification Target, %	3.5
Upper Air Voids Specifciation Target, %	4.5
Actual Air Voids, %	4.20
Number of Samples	1
Standard Deviation, %	0.30
Standard Error of Mean, %	0.30
Percent of Results Below the Lower Target Air Voids, %	0.98
Percent of Results Above the Upper Target Air Voids, %	15.87
Percent of Results Within Specification Air Voids Range, %	83.2

What If (Percent of Results Within Specification Air Voids)

Actual Air Voids, % \ Air Voids Standard Deviation, %	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
2.00	0.0	0.0	0.0	0.0	0.1	0.6	1.6	3.0	4.5	6.1	7.5	8.7	9.7	10.5	11.1
2.10	0.0	0.0	0.0	0.0	0.3	1.0	2.2	3.9	5.6	7.3	8.7	9.9	10.8	11.5	12.1
2.20	0.0	0.0	0.0	0.1	0.5	1.5	3.1	5.0	6.9	8.6	10.0	11.2	12.0	12.6	13.0
2.30	0.0	0.0	0.0	0.1	0.8	2.3	4.2	6.4	8.4	10.1	11.5	12.5	13.3	13.8	14.1
2.40	0.0	0.0	0.0	0.3	1.4	3.3	5.7	8.0	10.1	11.8	13.1	14.0	14.6	14.9	15.1
2.50	0.0	0.0	0.0	0.6	2.3	4.7	7.4	9.9	12.0	13.6	14.7	15.5	15.9	16.1	16.1
2.60	0.0	0.0	0.1	1.2	3.6	6.6	9.6	12.2	14.1	15.5	16.5	17.0	17.2	17.3	17.2
2.70	0.0	0.0	0.4	2.3	5.5	9.0	12.1	14.6	16.4	17.6	18.3	18.6	18.6	18.5	18.2
2.80	0.0	0.0	1.0	4.0	8.0	11.9	15.1	17.4	18.9	19.7	20.1	20.2	20.0	19.6	19.2
2.90	0.0	0.1	2.3	6.7	11.4	15.5	18.5	20.4	21.5	21.9	22.0	21.7	21.3	20.8	20.2
3.00	0.0	0.6	4.8	10.6	15.7	19.6	22.1	23.6	24.1	24.2	23.8	23.3	22.6	21.9	21.1
3.10	0.0	2.3	9.1	15.8	20.9	24.3	26.1	26.8	26.8	26.4	25.7	24.8	23.8	22.9	22.0
3.20	0.1	6.7	15.9	22.6	27.0	29.3	30.2	30.2	29.5	28.5	27.4	26.2	25.0	23.9	22.8
3.30	2.3	15.9	25.2	30.7	33.6	34.7	34.4	33.4	32.1	30.6	29.0	27.5	26.1	24.8	23.5
3.40	15.9	30.9	36.9	39.8	40.7	40.0	38.5	36.6	34.5	32.5	30.5	28.7	27.1	25.6	24.2
3.50	50.0	50.0	50.0	49.4	47.7	45.2	42.3	39.4	36.7	34.1	31.8	29.8	27.9	26.2	24.8
3.60	84.1	69.1	62.9	58.6	54.3	49.9	45.8	41.9	38.6	35.6	33.0	30.7	28.6	26.8	25.2
3.70	97.7	84.1	74.4	66.9	60.1	53.9	48.6	44.0	40.1	36.7	33.9	31.4	29.2	27.3	25.6
3.80	99.9	93.3	83.2	73.3	64.5	57.0	50.7	45.5	41.2	37.6	34.5	31.9	29.6	27.6	25.9
3.90	100.0	97.6	88.6	77.5	67.3	58.9	52.0	46.5	41.9	38.1	34.9	32.2	29.9	27.8	26.1
4.00	100.0	98.8	90.4	78.9	68.3	59.5	52.5	46.8	42.1	38.3	35.1	32.3	29.9	27.9	26.1
4.10	100.0	97.6	88.6	77.5	67.3	58.9	52.0	46.5	41.9	38.1	34.9	32.2	29.9	27.8	26.1
4.20	99.9	93.3	83.2	73.3	64.5	57.0	50.7	45.5	41.2	37.6	34.5	31.9	29.6	27.6	25.9
4.30	97.7	84.1	74.4	66.9	60.1	53.9	48.6	44.0	40.1	36.7	33.9	31.4	29.2	27.3	25.6
4.40	84.1	69.1	62.9	58.6	54.3	49.9	45.8	41.9	38.6	35.6	33.0	30.7	28.6	26.8	25.2
4.50	50.0	50.0	50.0	49.4	47.7	45.2	42.3	39.4	36.7	34.1	31.8	29.8	27.9	26.2	24.8
4.60	15.9	30.9	36.9	39.8	40.7	40.0	38.5	36.6	34.5	32.5	30.5	28.7	27.1	25.6	24.2
4.70	2.3	15.9	25.2	30.7	33.6	34.7	34.4	33.4	32.1	30.6	29.0	27.5	26.1	24.8	23.5
4.80	0.1	6.7	15.9	22.6	27.0	29.3	30.2	30.2	29.5	28.5	27.4	26.2	25.0	23.9	22.8
4.90	0.0	2.3	9.1	15.8	20.9	24.3	26.1	26.8	26.8	26.4	25.7	24.8	23.8	22.9	22.0
5.00	0.0	0.6	4.8	10.6	15.7	19.6	22.1	23.6	24.1	24.2	23.8	23.3	22.6	21.9	21.1
5.10	0.0	0.1	2.3	6.7	11.4	15.5	18.5	20.4	21.5	21.9	22.0	21.7	21.3	20.8	20.2
5.20	0.0	0.0	1.0	4.0	8.0	11.9	15.1	17.4	18.9	19.7	20.1	20.2	20.0	19.6	19.2
5.30	0.0	0.0	0.4	2.3	5.5	9.0	12.1	14.6	16.4	17.6	18.3	18.6	18.6	18.5	18.2
5.40	0.0	0.0	0.1	1.2	3.6	6.6	9.6	12.2	14.1	15.5	16.5	17.0	17.2	17.3	17.2
5.50	0.0	0.0	0.0	0.6	2.3	4.7	7.4	9.9	12.0	13.6	14.7	15.5	15.9	16.1	16.1
5.60	0.0	0.0	0.0	0.3	1.4	3.3	5.7	8.0	10.1	11.8	13.1	14.0	14.6	14.9	15.1
5.70	0.0	0.0	0.0	0.1	0.8	2.3	4.2	6.4	8.4	10.1	11.5	12.5	13.3	13.8	14.1
5.80	0.0	0.0	0.0	0.1	0.5	1.5	3.1	5.0	6.9	8.6	10.0	11.2	12.0	12.6	13.0

PRODUCTION

Multi Fuel Burners

Piloted

Partially Implemented

- Burners capable of using various fuel sources based on market availability and economics.

Hydrogen Burners

Blue Sky | Testing | Piloted

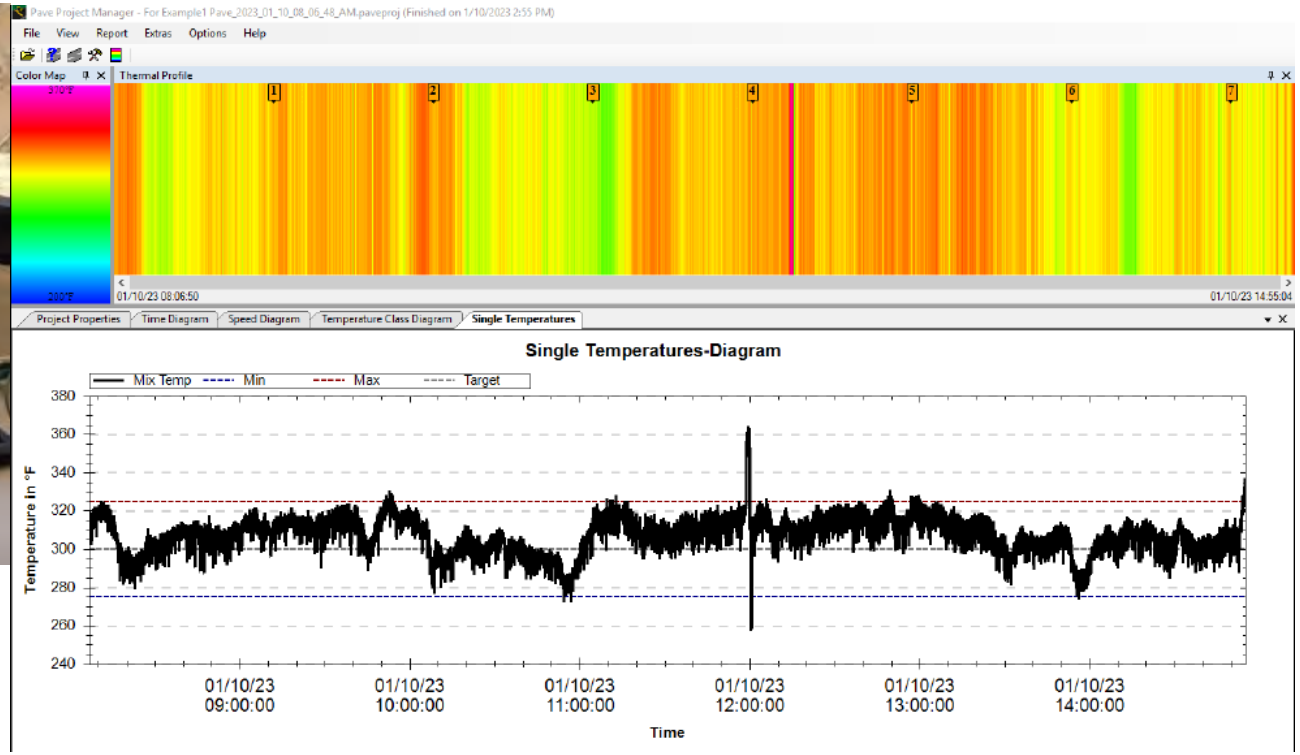
- Eliminates CO_2 emissions associated with the plant burner.
- Can also run hydrogen + natural gas

https://www.worldhighways.com/wh6/news/revolutionary-asphalt-plant-heating-ammann

Real Time Plant Production Temperature Monitoring

- Continuous mix temperature at plant.
- Simple, prototype systems being developed.

Piloted → Partially Implemented



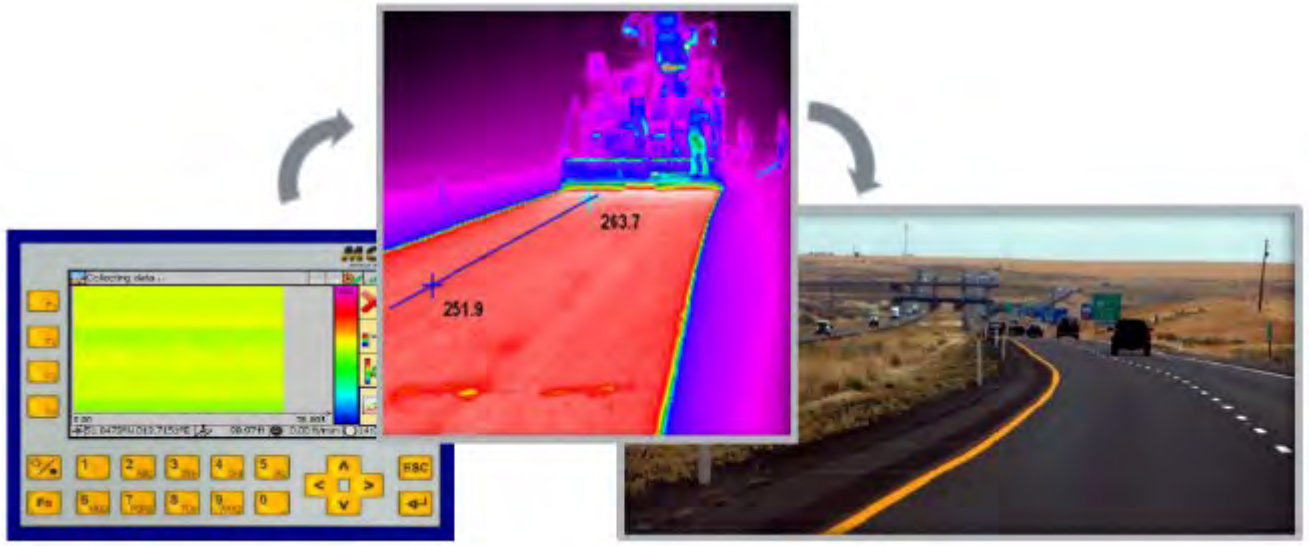
Valuable documentation and training tool!

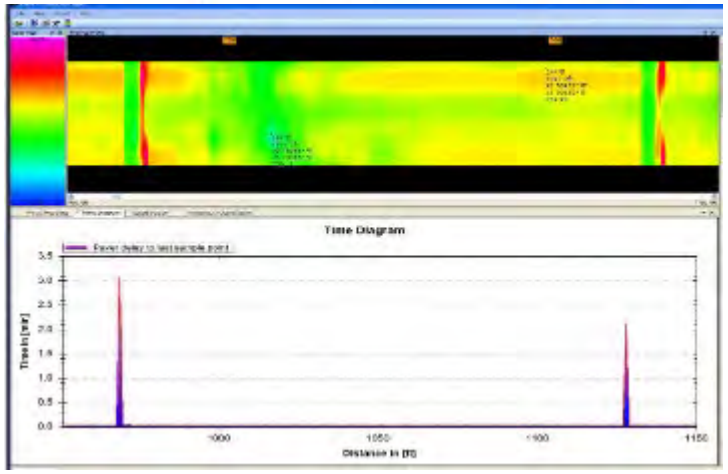
CONSTRUCTION

Thermal Profiling

Partially Implemented

- Technology has been around, but continues to be improved and value obtained.
- Ultimate value is operator training to improve quality.

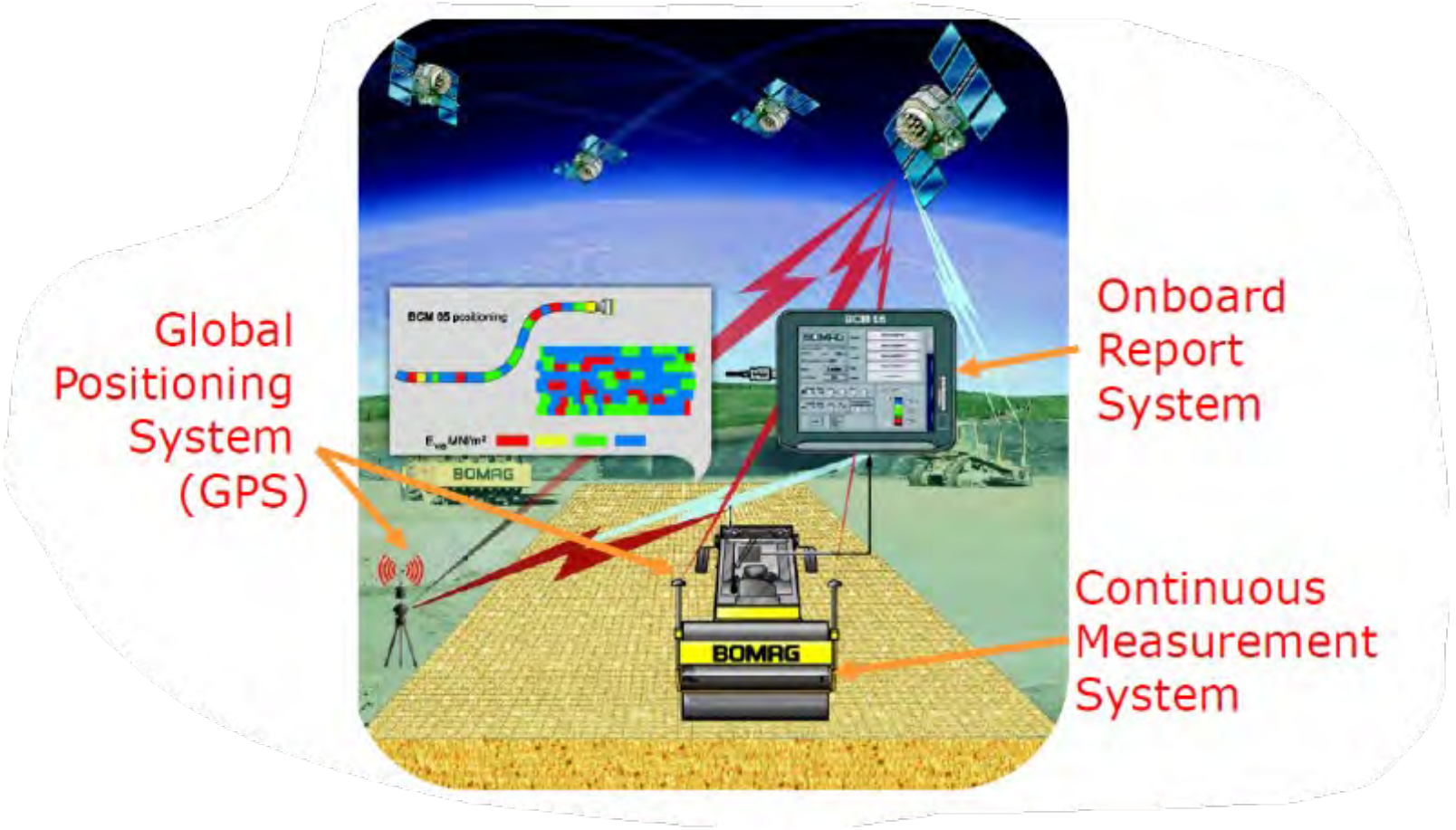




Intelligent Compaction

Partially Implemented

- Same as thermal profiling. Technology been around but continues to evolve.
- Coverage mapping is valuable.



Automated Rollers

Blue Sky

- Technology is relatively new.
- Operator removal is safety enhancement.
- Remote or autonomous operation.

https://www.volvoce.com/global/en/news-and-events/news-and-stories/2021/volvo-ce-unveils-cx01-single-drum-asphalt-compactor-concept-at-the-utility-expo/

3D Paving

Partially Implemented

- Automated paver set up based on specified 3D design
- Enhanced smoothness

GENERAL

EV Charging Roadways

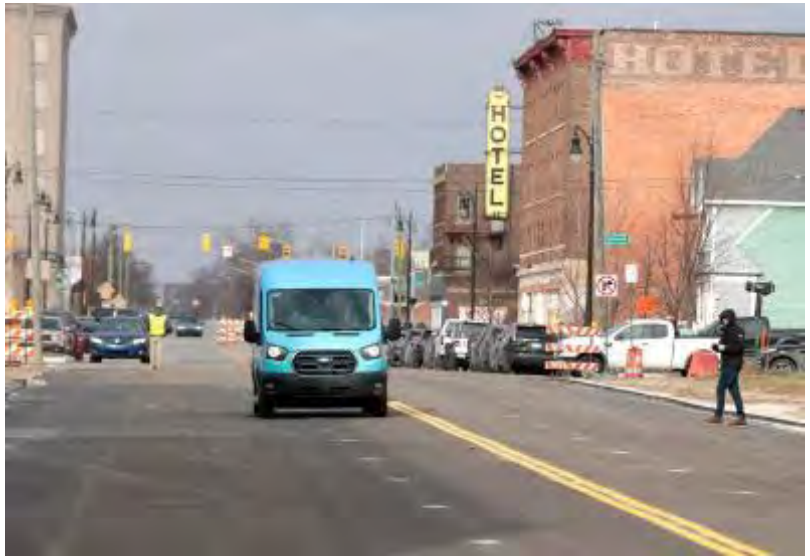
Blue Sky | Testing | Piloted

- Magnetic resonance induction charging
  - Coil of copper wire embedded in the street to transfer electricity from the grid to electric vehicles passing overhead. An on-board receiver pulls in that electricity, typically in low amounts, to provide the battery a continuous charge.


11-30-23

Detroit's road of the future will charge your car as you drive on it

The first public EV charging roadway in the U.S. is now open.



https://www.fastcompany.com/90990095/detroits-road-of-the-future-will-charge-your-car-as-you-drive-on-it

https://www.fox2detroit.com/news/first-wireless-charging-road-in-u-s-set-to-be-unveiled-in-detroit

Pennsylvania Zero-Emission Vehicle (ZEV) Roadmap

- PennDOT and DEP are working to develop electric vehicle charging corridors on main highways in Pennsylvania. The goal is to have chargers available every 50 miles, located no more than 5 miles from the highway.

Advancing Sustainability through Powered Infrastructure for Roadway Electrification (ASPIRE)

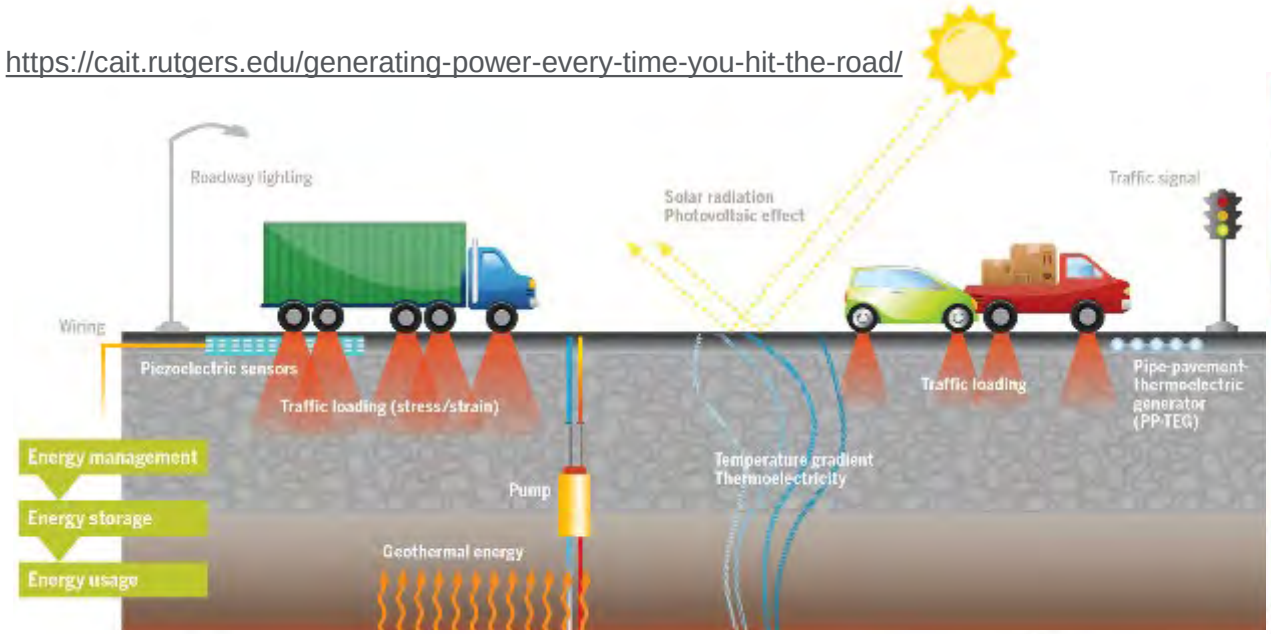
- Scope is to eliminate range and charging as barriers to electric vehicle use. Solutions include plug-in and wireless charging systems that are integrated into roadways, parking structures and networked with the electric grid and traffic management systems.

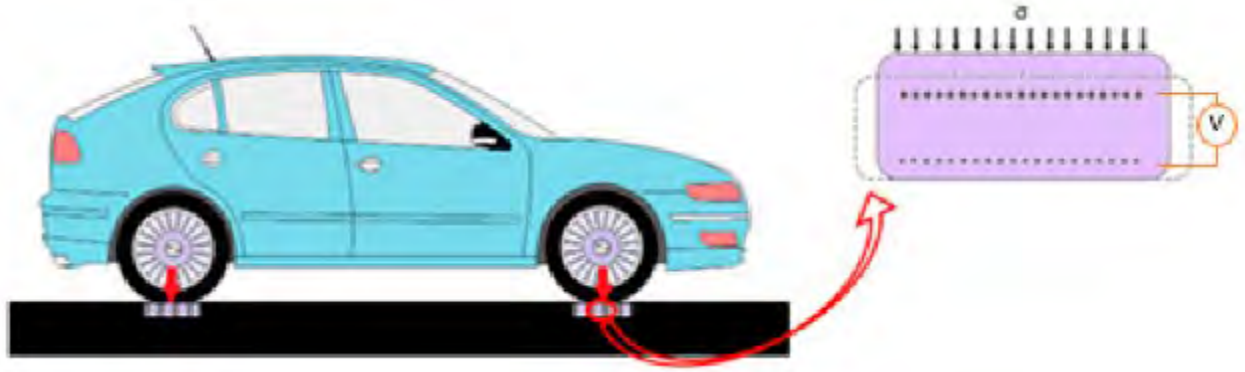
Energy Harvesting

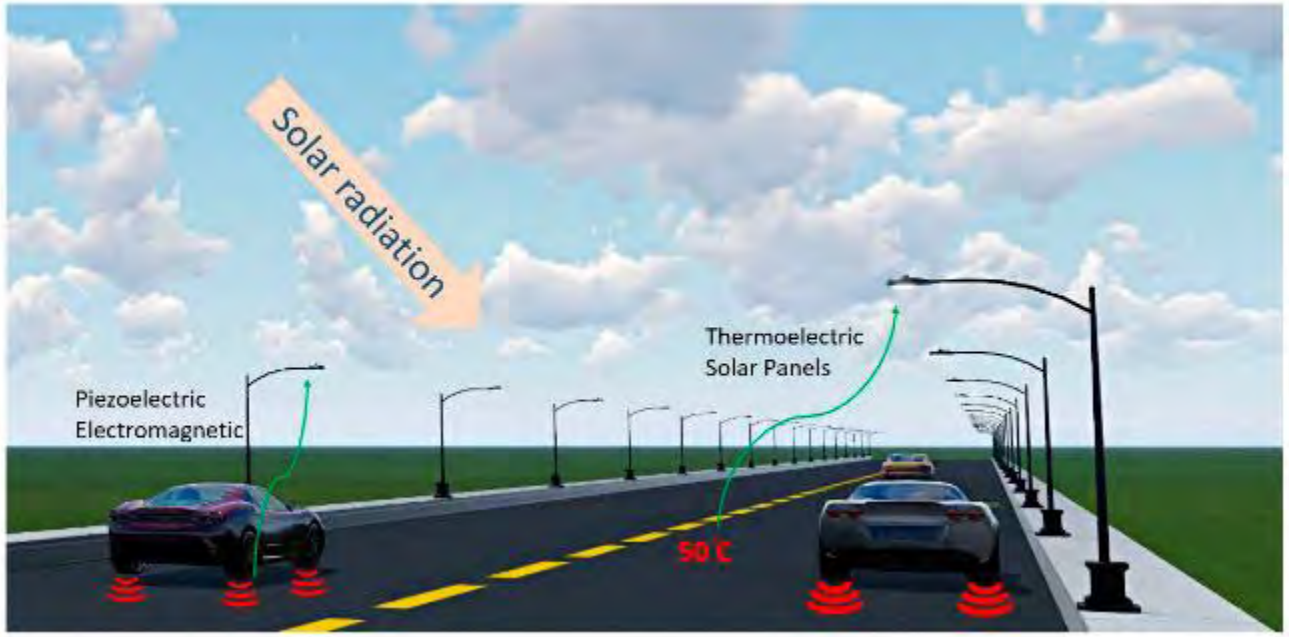
Blue Sky

- Can energy (from thermal and mechanical vibration) be harvested or captured via trafficking.

https://cait.rutgers.edu/generating-power-every-time-you-hit-the-road/







https://www.mdpi.com/2071-1050/12/17/6738

Pavement Resiliency

Resilience is defined by the Federal Highway Administration (FHWA) as “The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions”

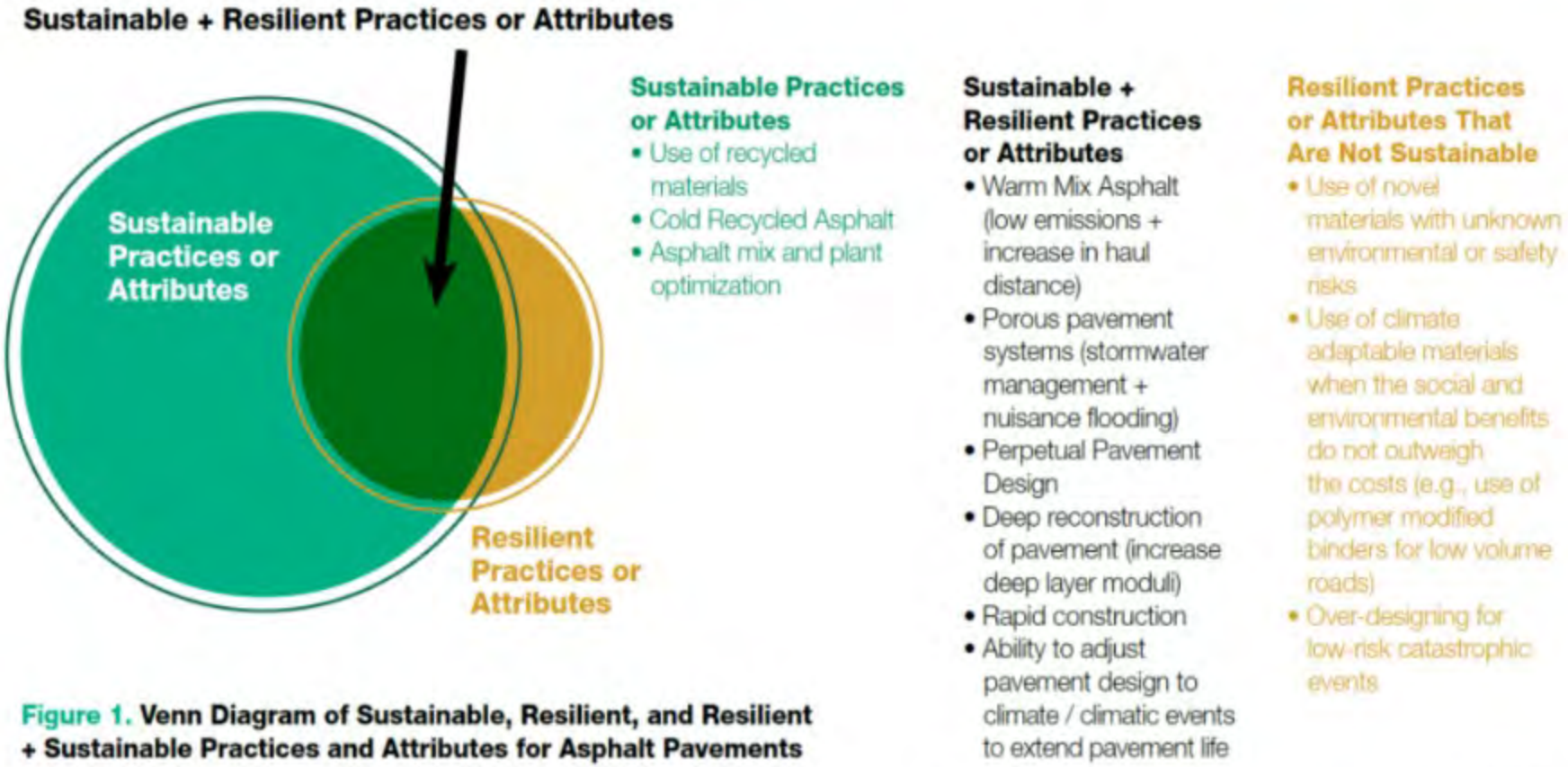


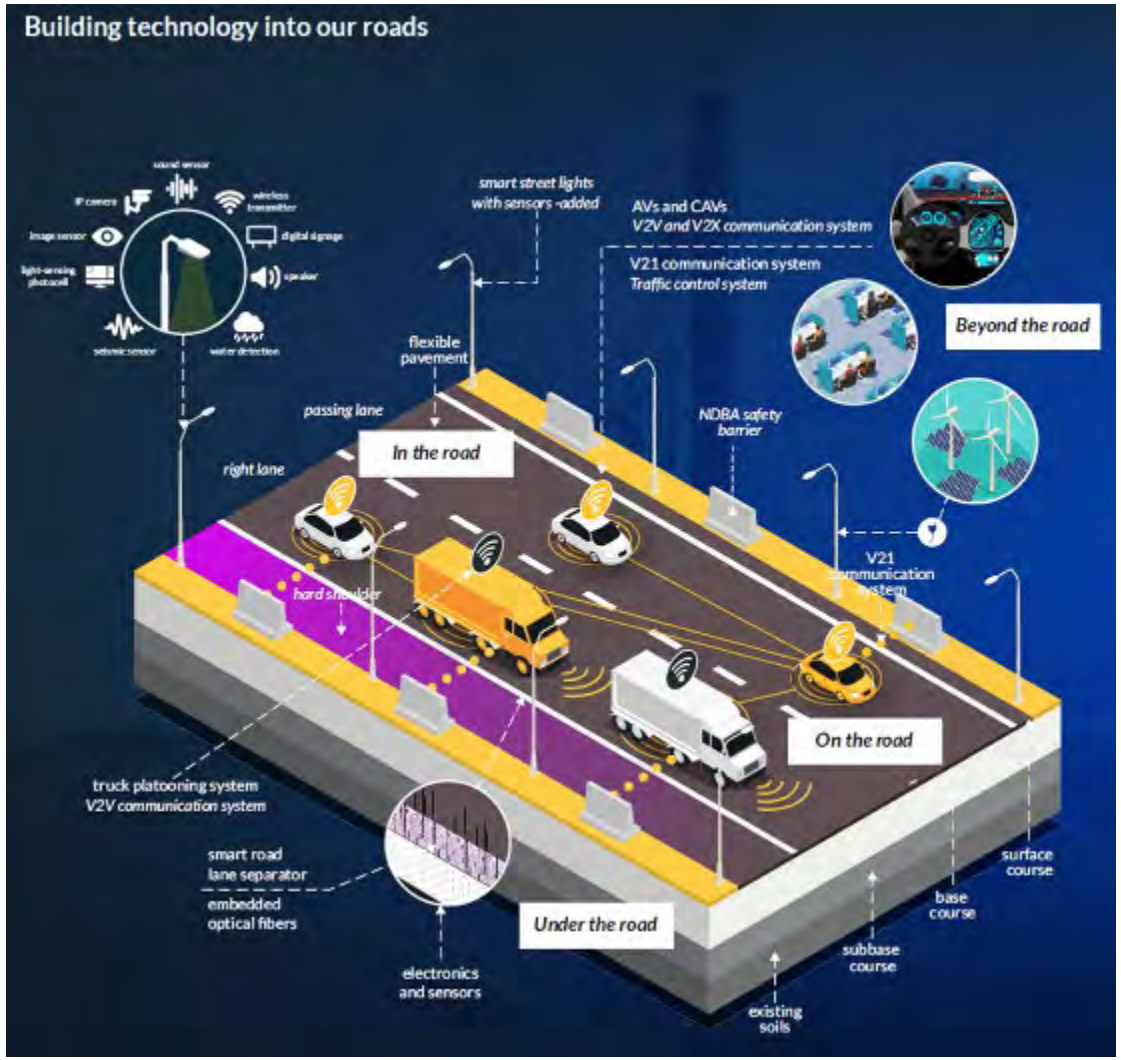
Figure 1. Venn Diagram of Sustainable, Resilient, and Resilient + Sustainable Practices and Attributes for Asphalt Pavements

Figure 1. Venn Diagram of Sustainable and Resilient Practices and Attributes for Asphalt Pavements (Bowers and Gu 2021)

Pavement Communications

Partially Implemented

- Vehicle to Vehicle (V2V)
  - Smart technology that enables vehicle data to exchange from one vehicle to another.
- Vehicle to Infrastructure (V2I)
  - Captures data such as traffic congestion, weather advisories, bridge clearance levels, traffic light status, and then wirelessly transmits it to inform drivers of conditions they need to be aware of which aids in safety.
- Vehicle to Everything (V2X)
  - Notify drivers of dangerous weather conditions, accidents and traffic congestion nearby, and other dangerous behaviors happening in close range.



https://hgventures.com/futureofroads/

PEOPLE

Workforce of Tomorrow

- **FACTS:**
  1. People will remain the absolute key to success!
  2. Workers are increasingly hard to find and retain.

What Will the “Future” Look Like

- Effective and responsible use of local and recycled materials designed via an innovative balanced mix design system using appropriate performance tests.
- Enhanced use of automation to help control, manage, produce and construct mixes for optimal quality and economics.
- Pavements will serve multiple functions.
- Procurement practices will demand sustainability.
- **PEOPLE** will continue to be the key to success.

Our Imagination is the Starting Point for Innovation

- Be curious
- Be open minded
- Be creative
- Be open to failure

- ***Be ready!!!***

Thank You