ASPHALT TECHNOLOGIES FOR THE ROAD TO NET ZERO

February 2, 2022

EVERETT CREWS, INGEVITY

Outline

I. What is net zero

II. What are "carbon emissions": greenhouse gases

III. Greenhouse gases: origins (nations and sectors) and impacts (Global Warming Potential)

IV. What is the atmospheric carbon situation now

V. What do decarbonization abatement activities look like worldwide

    National and international goals

    Key industry examples: energy, petroleum, lime/cement

VI. The asphalt paving industry's decarbonization plans

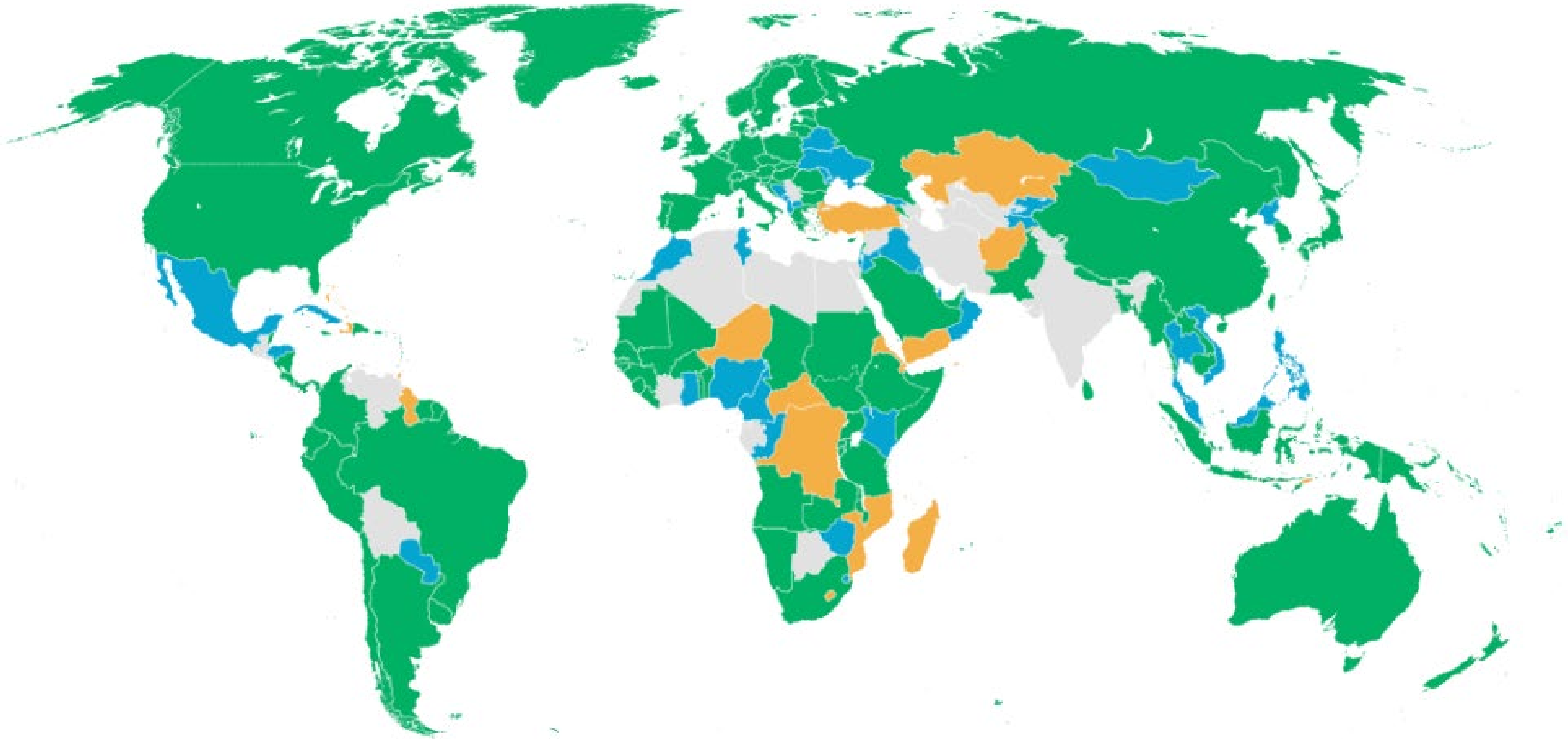
VII. Tools already available & innovations to decarbonize each phase of a pavement LCA

VIII. Have we arrived at a tipping point

IX. What is needed to bring all the solutions together

I. What Is Net Zero?

Net Zero is a goal of at least 138 nations, wherein by the year 2050 (or sooner) the quantity of “**carbon emissions**” emitted to the atmosphere by those nations is equal to quantity of “**carbon emissions**” removed from the atmosphere by either natural means and by man-made technologies.



Source of graphic is Reference 4.

Oct. 2021

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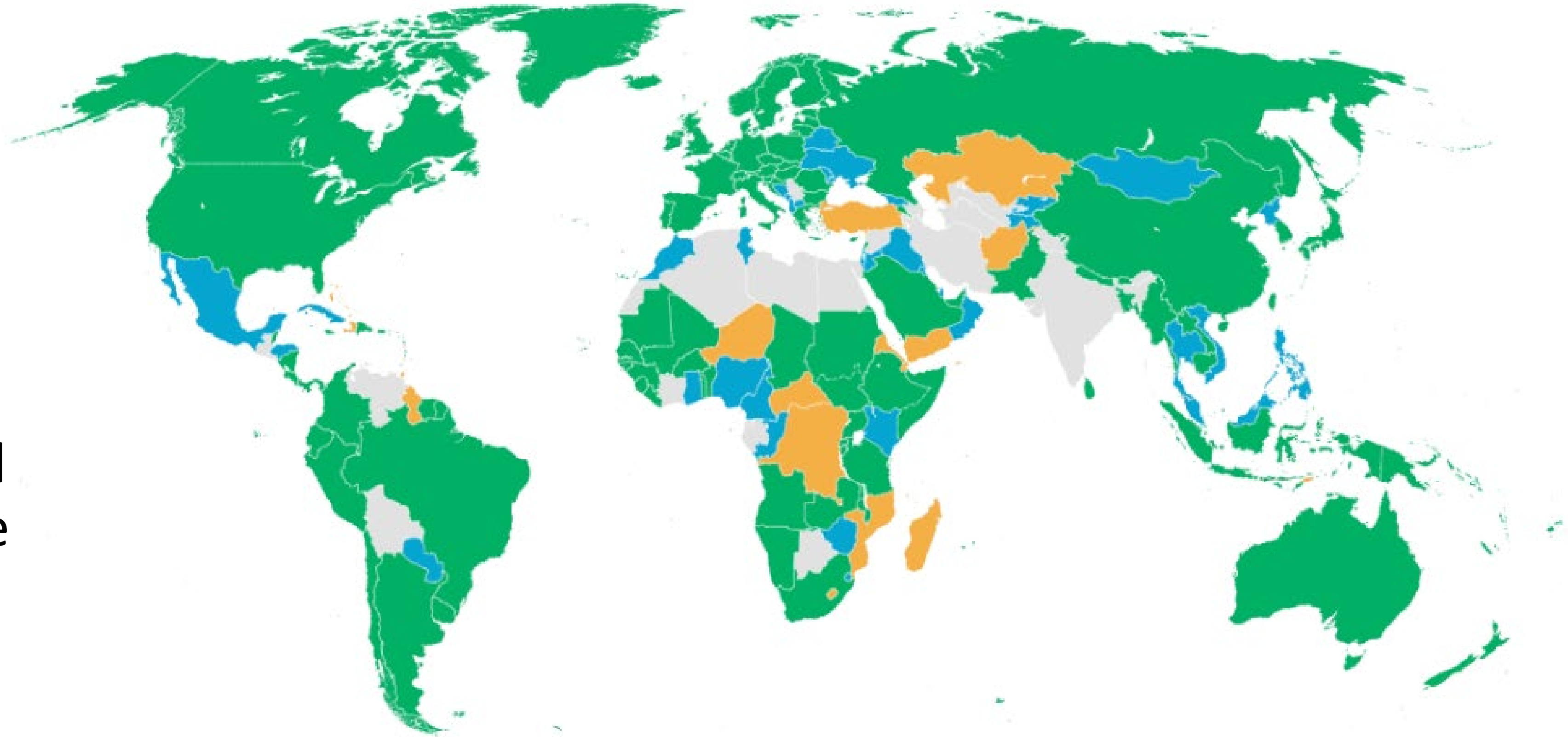

Goals were once linked to a reference year, like 1990.

Source of graphic is Reference 4.

Oct. 2021

I. What Is Net Zero?

Net Zero: the UN goal is more directly ambitious.

Source of graphic is Reference 4.

II. What Are "Carbon Emissions?"

"Carbon emissions" linked to atmospheric temperature rise are also called **Greenhouse Gases** (**GHG's**), with **significant examples** being

H_20

CO_2

CH_4

N_2O

Chlorofluorcarbons (**CFC's**), **HCFC's**, **CC's**, **BC's**, etc. (over 7 dozen in Reference 2)

SF_6 and other fully fluorinated compounds

II. Carbon Emissions & GHG Environmental Impacts

GHG's **absorb thermal energy (heat) to differing degrees**. So, GHG's act like the glass roof of a greenhouse, tapping heat in the Earth's atmosphere.

GWP

To enable calculations of total environmental impacts of a mixture of different GHG's, scientists use an index called the **Global Warming Potential or GWP**.

Also, GHG's **persist in the atmosphere** for different periods of time. So, the GWP also reflects the heat absorption capacity of the GHG for a given number of years. **100 years** is the most common period considered in the USA.

GWP indexes a gases capacity to absorb (trap) heat in the atmosphere for a given period of time

GWP Values of Select GHG's

Chemical Name	Chemical Formula	Heat Capacity, kJ/kg/°K	Lifetime in Atmosphere, years	GWP 100-year
Carbon dioxide	CO_2	0.6 (0°C)	1000's	**1**
Methane	CH_4	5.79 (-100°C)	12.4	**25 - 28**
Nitrous Oxide	N_2O		121	**265 – 300**
Chlorofluorocarbon				
CFC-11	CCl_3F	~ 1-1.5	45	**4660**
Hydrochlorofluorocarbons				
HCFC-21	$CHCl_2F$	1.25-1.5 (-25 to 25°C)	1.7	**148**
Chlorocarbons				
Methylene chloride	CH_2Cl_2	-	0.4	**9**
Fully Fluorinated Species				
Sulfur hexafluoride	SF_6	1.99 (at STP)	3200	**22,800 – 23,500**

GWP = kg CO_2-equiv = kg CO_2 + 26*kg CH_4 + 298*kg N_2O +400-12,000*kg HCFC + 22,800*kg SF_6

Source of data is Reference 2. & (a) Ohta, T., et.al. Heat Capacity of SF6, **J. Chem. Thermo.**, 1994, 26, 3, 319.

III. GHG Origins

Type of gas	Share gas in GHG	Main source drivers/ Other source drivers	Share in gas total	Year of statistics
CO_2	72%	Coal combustion	39%	2019
		Oil combustion	31%	2019
		Natural gas combustion	18%	2019
		Cement clinker production	4%	2018
		Subtotal drivers of CO_2	**92%**	
CH_4	19%	Cattle (rumination and droppings)	21%	2018
		Rice cultivation (area harvested)	10%	2018/19
		Natural gas production (including distribution)	14%	2019
		Oil production (including associated gas venting)	9%	2019
		Coal mining	10%	2019
		Landfill: municipal solid waste generation ~ food consumption	10%	2018**
		Waste water	11%	2018**
		Subtotal drivers of CH_4	**85%**	
N_2O	6%	Cattle (droppings on pasture, range and paddock) *	23%	2018
		Synthetic fertilisers (N content) *	13%	2017
		Animal manure applied to soils *	5%	2018
		Crops (share of N-fixing crops, crop residues and histosols)	11%	2017/18
		Fossil-fuel combustion	11%	2019
		Manure management (confined)	4%	2018
		Indirect: atmospheric deposition & leaching and run-off (NH_3)*	9%	2017/18
		Indirect: atmospheric deposition (NO_x from fuel combustion)	7%	2017/18
		Subtotal drivers of N_2O, incl. other, related drivers (*)	**83%**	
F-gases	3%	HFC use (emissions in CO_2 eq)	61%	NA/2018 **
		HFC-23 from HCFC-22 production (emissions in CO_2 eq)	22%	NA/2018 **
		SF_6 use (emissions in CO_2 eq)	14%	NA/2018 **
		PFC use and by-product (emissions in CO_2 eq)	3%	NA/2018 **
		Subtotal drivers of F-gases	**100%**	

Source of Table is Reference 3.

III. GHG Origins

For decades, SF_6 has been the preferred dielectric in medium (1-36 kV) to high-voltage switch-gear, transformers, and circuit-breakers, (to prevent arcing).

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Source of Table is Reference 3.

III. Who Makes All the GHG's?

3%

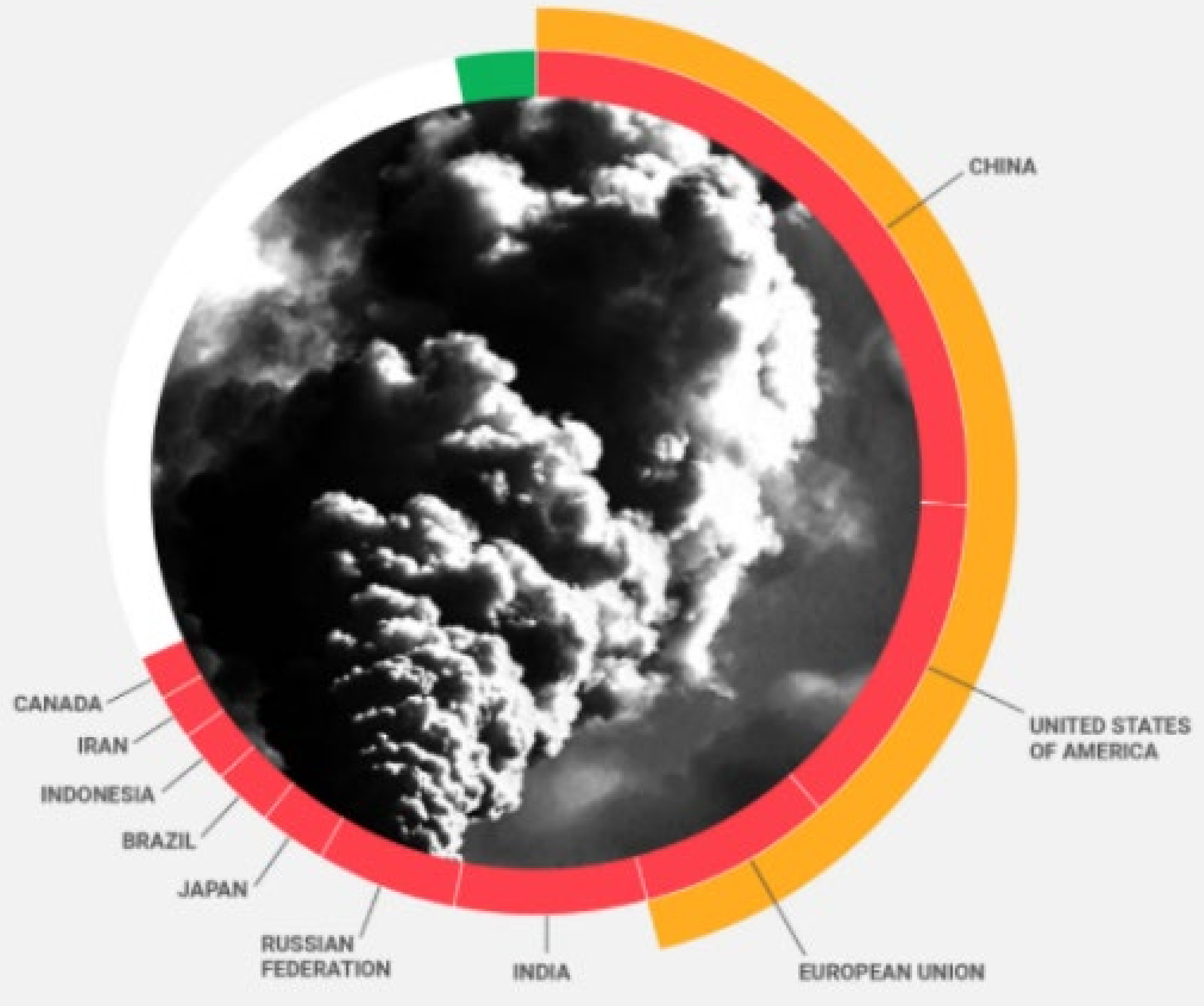
Contribution of the 100 least-emitting countries

68%

The 10 largest greenhouse gas emitters contribute over two-thirds of global emissions

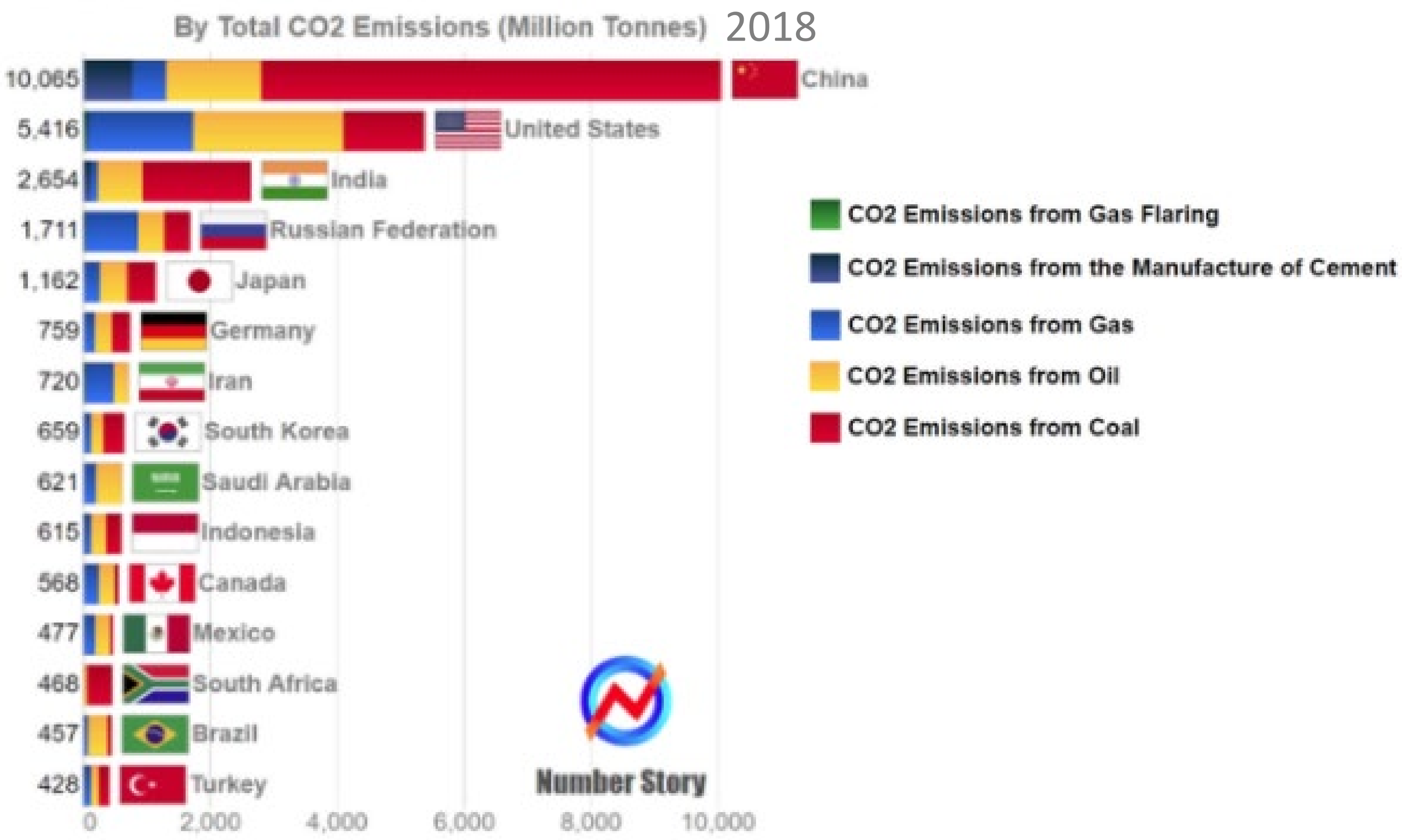
46%

The top 3 greenhouse gas emitters contribute 16 times the emissions of the bottom 100 countries



Source of data is Reference 4.

III. What Are These Nations Doing to Emit So Much CO_2?



Source of data is Reference 4.

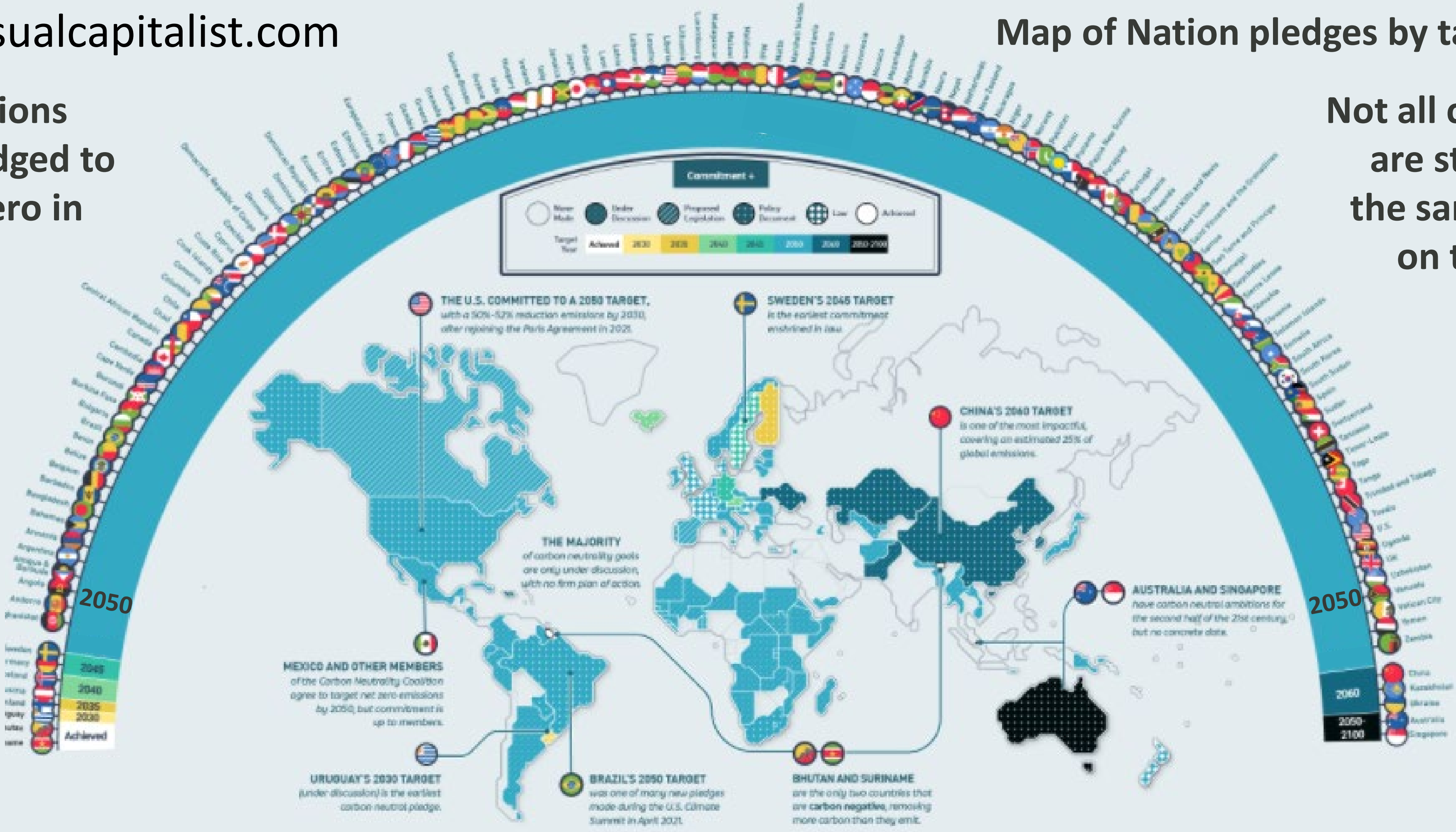
National Initiatives and Goals for Net Zero

www.visualcapitalist.com

Map of Nation pledges by target year

Most nations have pledged to be Net Zero in 2050.

Not all countries are starting in the same place on the road.



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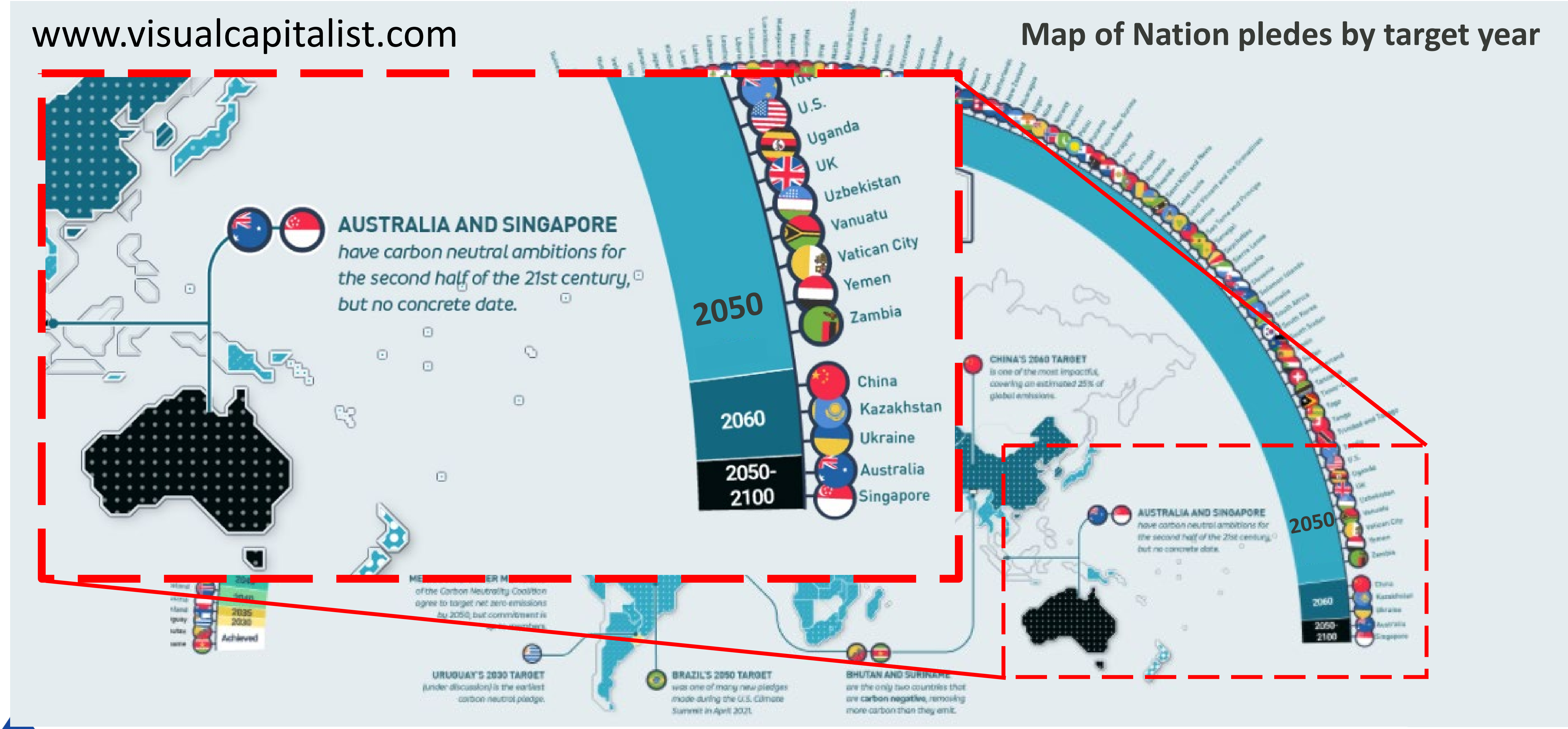
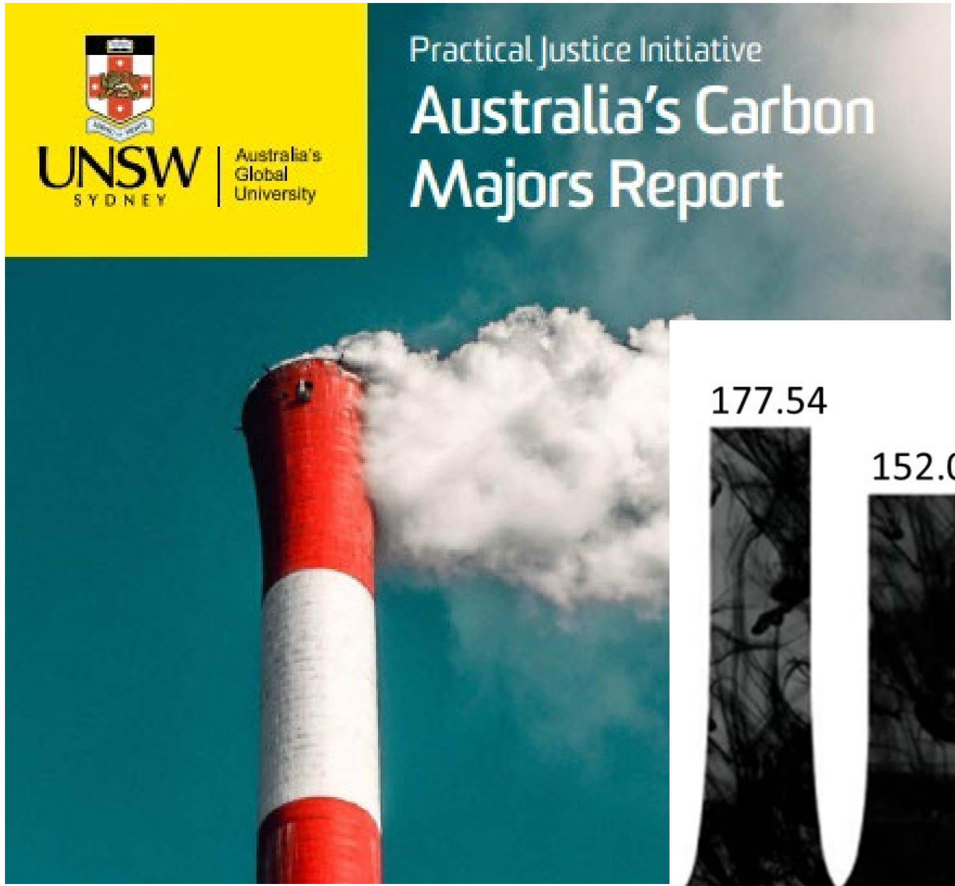
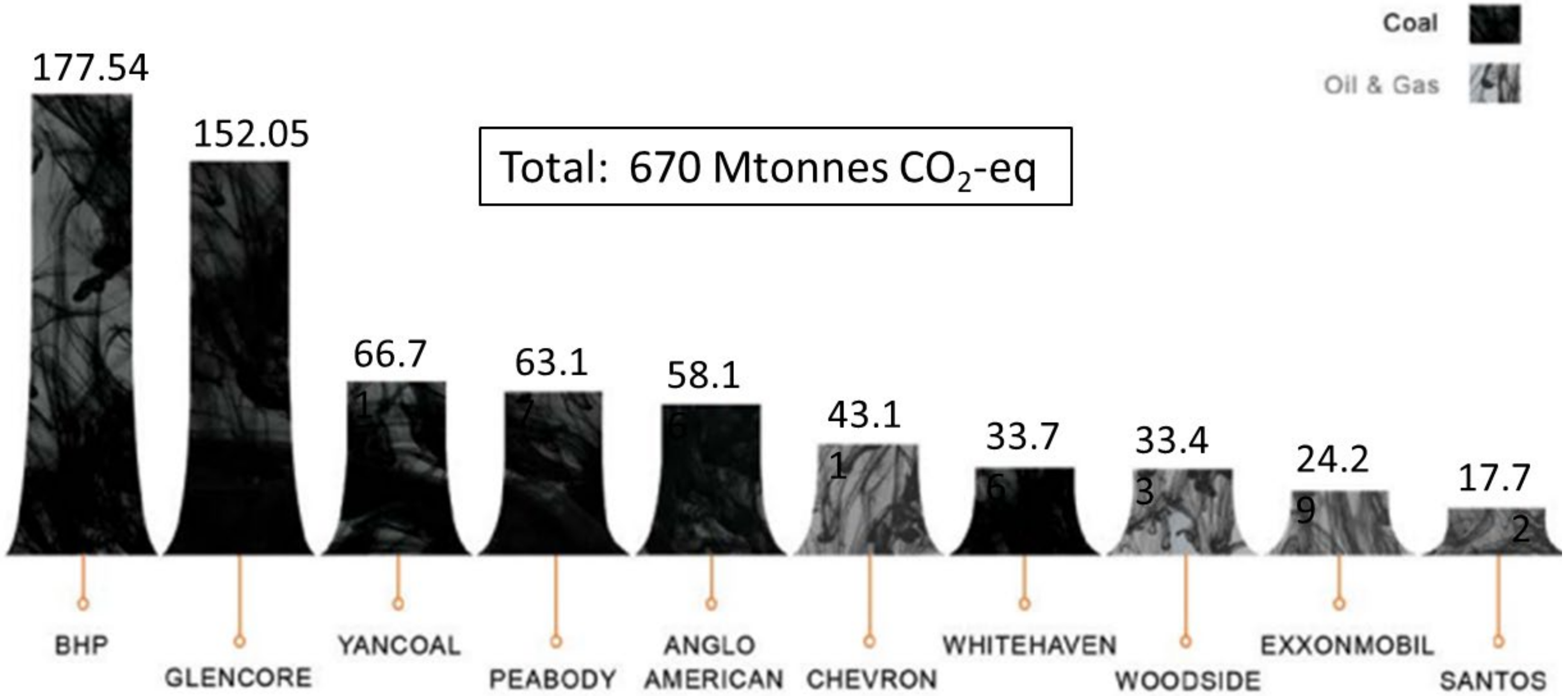


National Initiatives and Goals for Net Zero





Moss, J. et. al., "Practical Justice Initiative," 2018, climatejustice.co/carbon-majors/

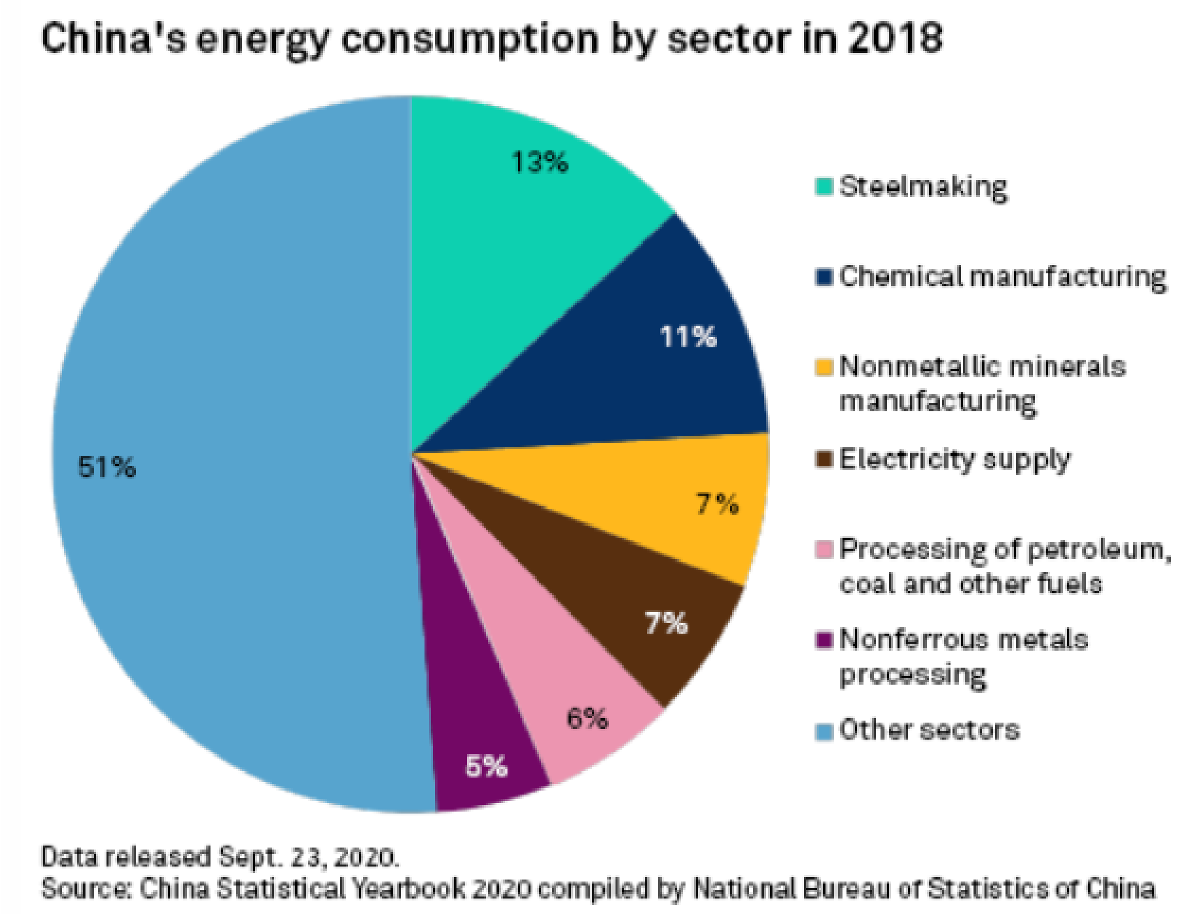
National Initiatives and Goals for Net Zero

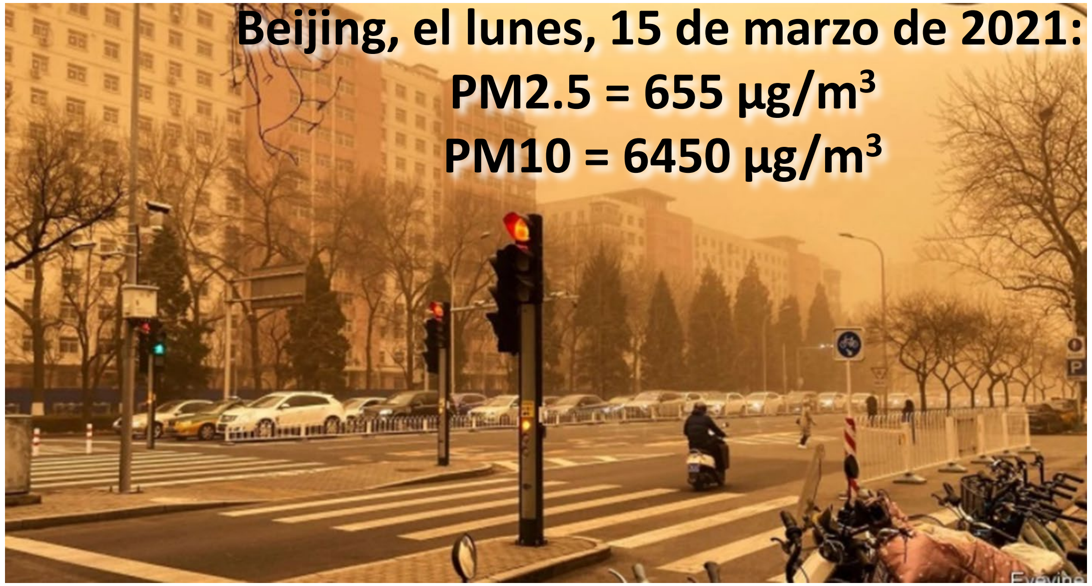
Key recommendations for carbon majors

1. **No sales of mine assets as going concerns**
   - Fossil fuel mines to be retired not on sold to other companies
2. **Carbon major sites to be restored**
   - Funds to be set aside for site rehabilitation
   - Rehabilitation costs to take precedence over shareholder returns
   - Profit sharing ought to occur from 'clean' parts of the business
3. **Compensation for contribution to past harms**
   - Compensatory mechanisms must address past emissions at least since 1990
   - Affected workers and communities to be assisted
4. **Compensation should not only be domestic**
   - Compensation should address the needs of those harmed globally

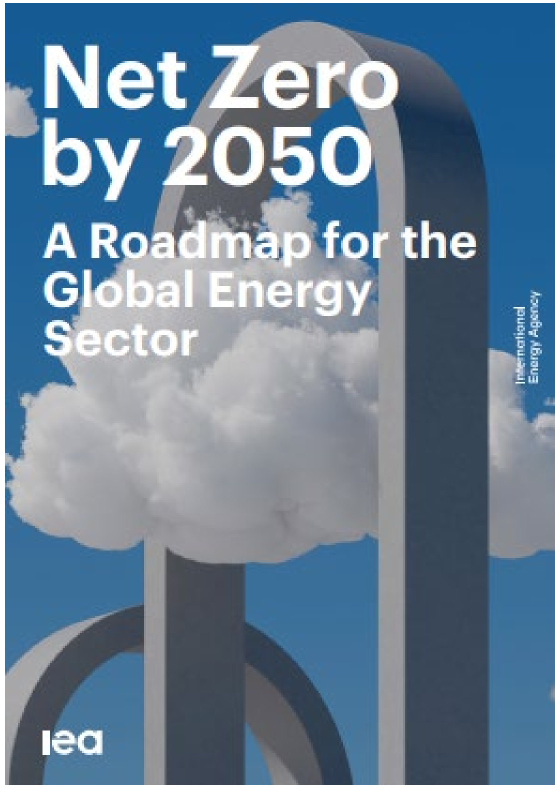
Moss, J. et. al., "Practical Justice Initiative," 2018, climatejustice.co/carbon-majors/

National Initiatives and Goals for Net Zero

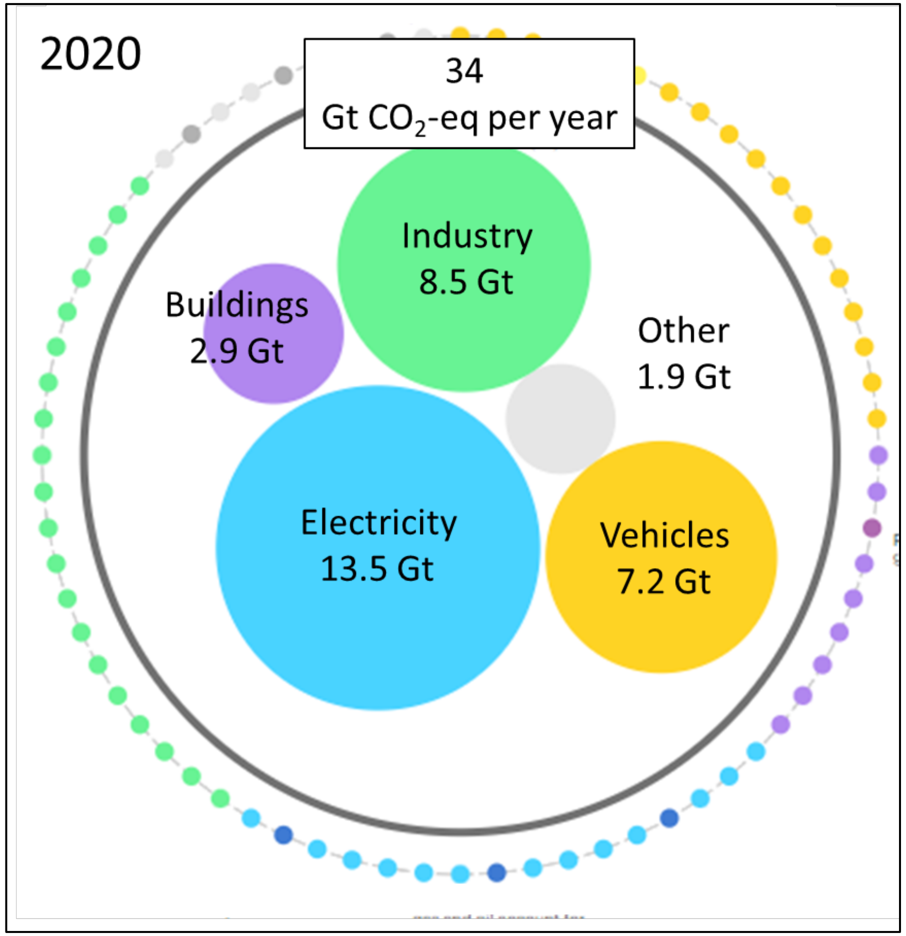




What Are Other Organizations Planning? The IEA



October 2021



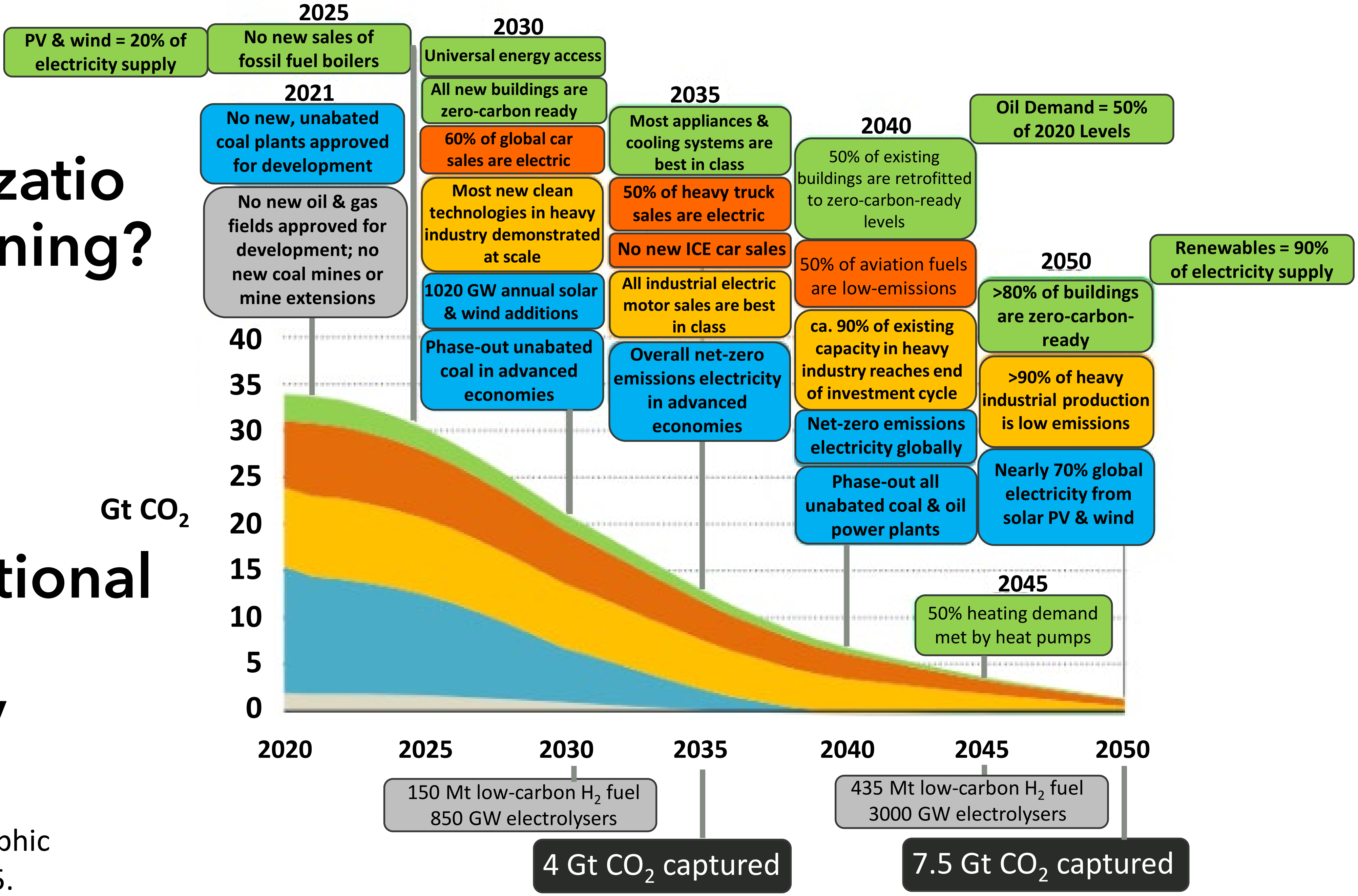
Critical (prioritized) areas for sustainable technology development should be

- electrification (solar PV & wind & nuclear (France, e.g.)
- hydrogen alternative to CH_4 in homes/diesel in transport (from electrolyzers),
- bioenergy, biofuels, and
- carbon capture, utilization, and storage (CCUS) and direct-air CCUS.

Incidentally, < 0.2% of the 5 G-tons of CO_2 /year in the USA results from asphalt mix production (in Stage A3 of LCA).

What A Other Organizations Planning?

The International Energy Agency



Source of graphic is Reference 5.

New Technologies for Carbon Capture Use & Sequestration

ExxonMobil "plant to achieve net zero greenhouse gas emissions (Scope 1 and 2) from our unconventional oil and natural gas operated production in the **Permian Basin** in the United States." (Ref. 6) Implementation elements of their plan include wind, solar PV, CH_4 with CCUS; minimize flaring; equipment upgrades.

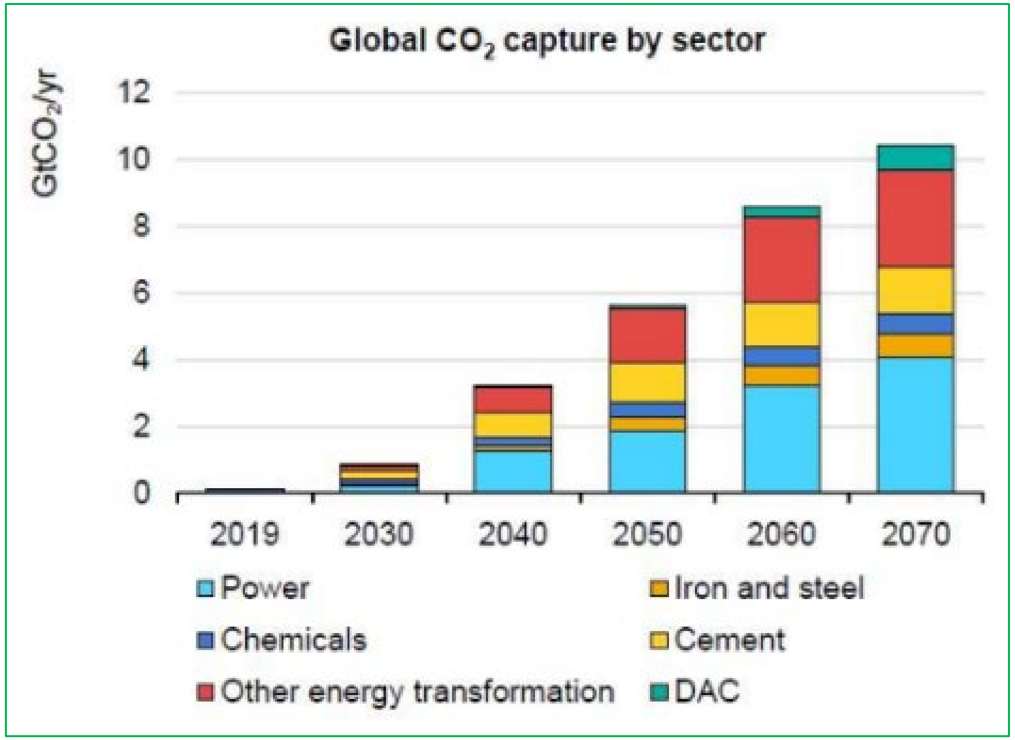


Chart "Global CO2 Capture by Sector 2019-2070" from Ref. 3.

New Technologies for Carbon Capture Use & Sequestration

energyfactor BY EXXONMOBIL

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11 companies announced in September 2021 their support for advancing CCS in Houston. That effort is estimated to require more than $100 billion in private and public investments and generate thousands of new jobs.

Exxon Mobil Corp. announced yesterday it **will relocate its corporate headquarters to the Houston area** from suburban Dallas and combine its chemical and refining divisions in a major shake-up aimed at reducing costs.

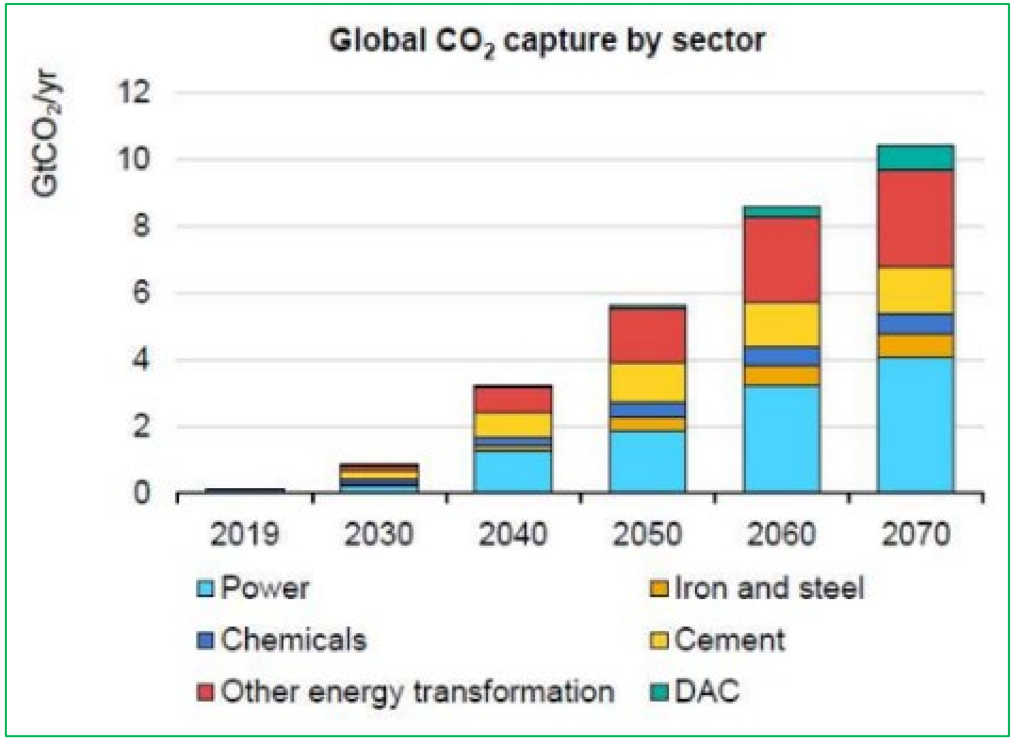
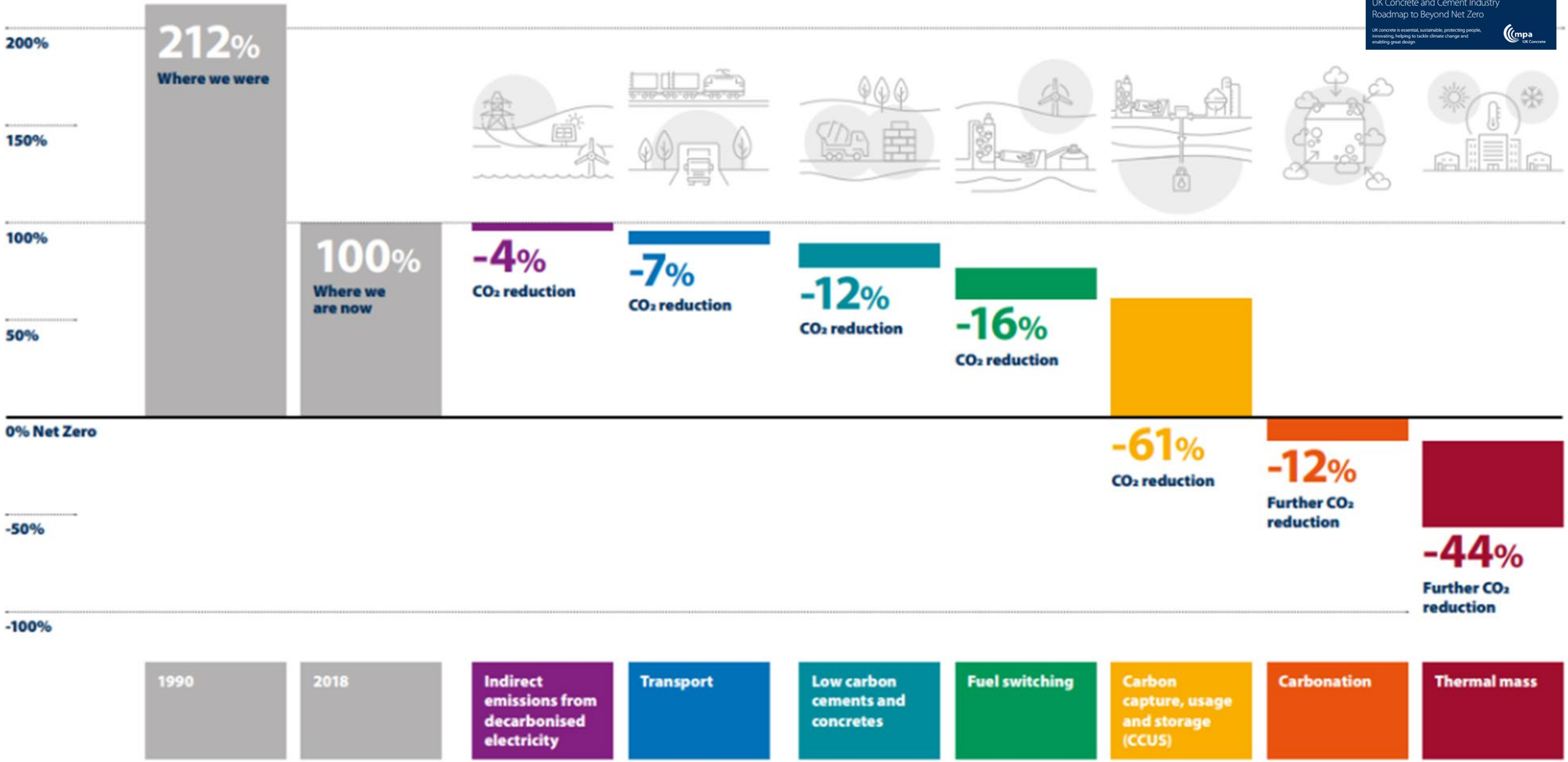


Chart "Global CO2 Capture by Sector 2019-2070" from Ref. 3.

What Are Other Organizations Planning? The UK Concrete and Cement Industry



The Asphalt Industry Is Already Positioned Well

Richard Willis, NAPA Conference, Phoenix, AZ, January 2022.

The Asphalt Industry Is Already Positioned Well

In 2016, NAPA published its first Life Cycle Assessment and accompanying Environmental Product Declaration tool (Emerald EcoLabel) for asphalt mixtures in the USA covering raw material harvesting (A1) to the mix plant gate (A3).

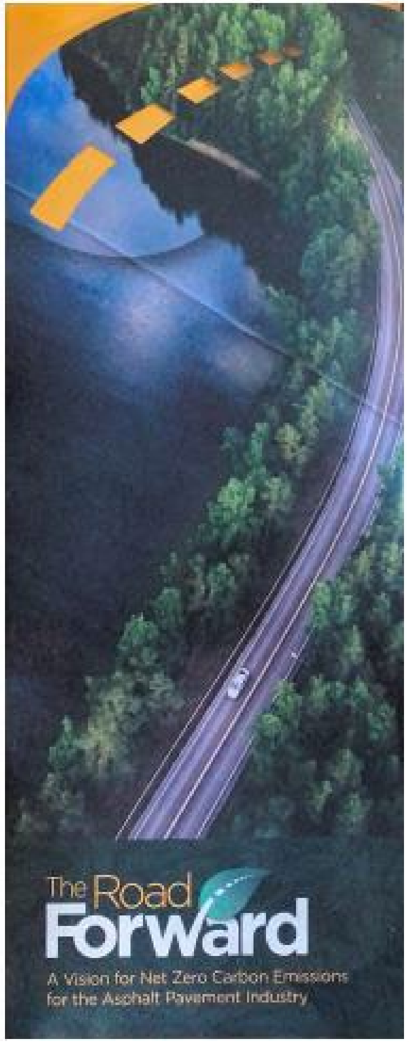
NAPA NATIONAL ASPHALT PAVEMENT ASSOCIATION

Emerald ECO LABEL

Environmental product declarations provide information on the environmental impacts of products through their entire life cycle or some portion thereof.

PARAMETER	UNIT	A1	A2	A3
Global Warming Air, incl. Biogenic Carbon	[kg CO2-Equiv.]	17.4	74.8	15.8
Ozone Depletion Air	[kg CFC 11-Equiv.]	3.62e-09	3.18e-09	7.07e-12
Acidification	[kg SO2-Equiv.]	0.103	0.58	0.013
Eutrophication	[kg N-Equiv.]	0.00626	0.0372	0.000663
Smog Air	[kg 03-Equiv.]	1.9	19.1	0.375
Abiotic Depletion for Fossil Resources	[MJ surplus energy]	MND*	MND*	MND*

The Asphalt Industry Is Already Positioned Well



ACKNOWLEDGEMENTS

We gratefully acknowledge the eagerness and dedication of the Climate Stewardship Task Force, charged with developing objectives for the industry related to sustainability and resilience, along with a communications strategy and a research and implementation roadmap to advance the industry toward those objectives. Thank you.

TASK FORCE LEADERSHIP

Chair: **Ron Sines**, CRH Americas Materials Inc.
Vice-Chair: **Dan Gallagher**, Gallagher Asphalt Corp.
NAPA Staff: **Richard Willis & Joseph Shacat**

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NAPA

Presentation by Richard Willis, Ph.D., VP Engineering Research & Technology, NAPA, NAPA Annual Conference, Phoenix, AZ, January 2022.

The Asphalt Industry Is Already Positioned Well

A Strategic Plan Has Been Developed

Climate Stewardship Task Force

Goal 1: Achieve net zero carbon emissions during asphalt production and construction by 2050.

Goal 2: Partner with customers to reduce emissions through pavement quality, durability, longevity, and efficiency standards by 2050.

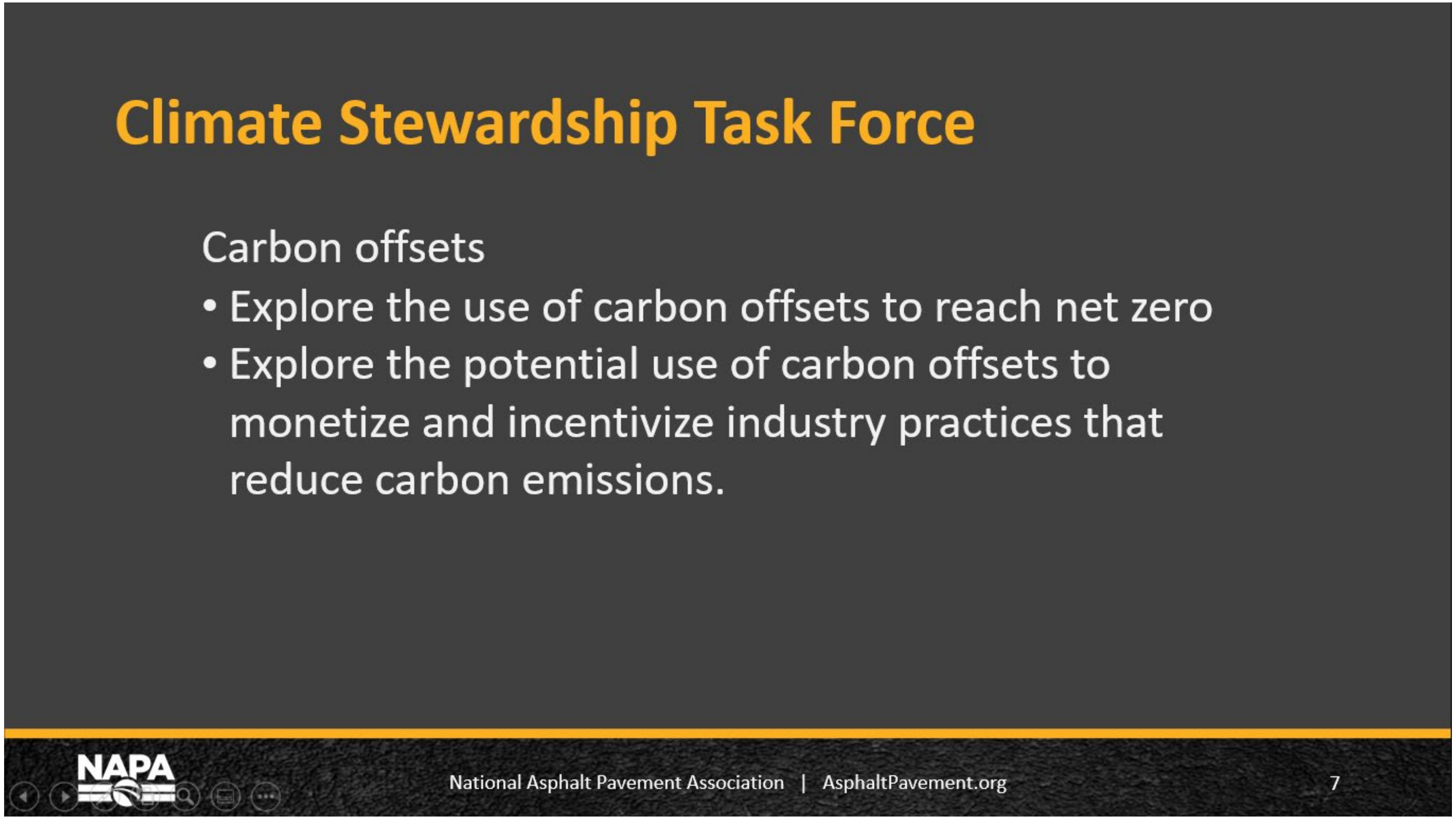
Goal 3: Develop a net zero material supply chain by 2050.

Goal 4: Transition to electricity from renewable energy providers in support of net zero carbon electricity generation by 2050 and reduce electrical intensities.

Richard Willis, NAPA Conference, Phoenix, AZ, January 2022.

The Asphalt Industry Is Already Positioned Well

A Strategic Plan Has Been Developed



Richard Willis, NAPA Conference, Phoenix, AZ, January 2022.

An Example of Carbon Offsets: Trees

Carbon capture by trees depends on many factors including the species of tree (broader crown and wider leaves, e.g.) and its size (larger trees have more leaves for CO_2 capture).

An average **mature** tree captures (converts CO_2 to sugars in photosynthesis) about 48 lb of CO_2 per year.

Angel Oak, a live oak in Charleston, is 400-500 years old.

European Environment Agency. (2012). Trees help tackle climate change. [online] Available at: https://www.eea.europa.eu/articles/forests-health-and-climate-change/key-facts/trees-help-tackle-climate-change.

CCPR: A Tool for Low-Carbon Capacity Expansion?

NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

Emerald
ECO LABEL

Product Category Rules (PCR)

For Asphalt Mixtures

Version 2.0 Public Review Draft

Effective Date: [Month Year]

Validity Period: Through [Month Year]

6406 Ivy Lane, Suite 350 | Greenbelt, MD 20770 | 888-468-6499
www.AsphaltPavement.org/EPD

Table 1. MasterFormat Numbers and Titles that Asphalt Mixtures Are Typically Used For.

Number	Title
32 11 26	Asphaltic Base Courses
32 11 26.13	Plant Mix Asphaltic Base Courses
32 12 16	Asphalt Paving
32 12 16.13	Plant-Mix Asphalt Paving
32 12 16.19	Cold-Mix Asphalt Paving
32 12 16.23	Reinforced Asphalt Paving
32 12 16.26	Fiber-Modified Asphalt Paving
32 12 16.27	Fiber-Reinforced Asphalt Paving
32 12 16.29	Polymer-Modified Asphalt Paving
32 12 16.33	Granulated Rubber-Modified Asphalt Paving
32 12 16.36	Athletic Asphalt Paving
32 12 19	Asphalt Paving Wearing Courses
32 12 19.19	Porous Friction Asphalt Paving Wearing Courses
32 12 43	Porous Flexible Paving
32 16 13.33	Asphalt Curbs

Source Reference 11.

CCPR: A Tool for Low-Carbon Capacity Expansion?

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Cold Central Plant Recycling (CCPR). CCPR is a process that produces asphalt mixtures with high quantities of RAP (typically at least 85% by weight of total mix) at ambient temperatures, significantly reducing the environmental impacts associated with asphalt mix production by eliminating the need to dry and heat aggregates and leveraging the use of recycled materials to reduce the upstream impacts associated with raw materials. CCPR mixtures can be produced in a purpose-built plant that only produces CCPR mixtures, or in a conventional asphalt plant that also produces HMA and WMA. When a conventional asphalt plant (one that produces HMA and/or WMA) uses CCPR technology to produce asphalt mixtures at ambient temperature, **CCPR mixtures can be subdivided from HMA and WMA mixtures by segregating burner fuel consumption from CCPR mixtures**. This approach is feasible since CCPR technology allows asphalt mixtures to be produced without application of heat (FHWA, 1997). For example, if a conventional asphalt plant produces and sells 100,000 tons of HMA and/or WMA mixtures and 50,000 tons of CCPR mixtures during the 12-month data collection period and consumes 200,000 gallons of diesel fuel for burner operations, burner fuel consumption for the HMA and WMA asphalt mixtures would be 2 gallons of diesel per ton of HMA and WMA mixtures and 0 gallons of diesel fuel per ton of CCPR mixtures. This approach requires burner fuel consumption to be separately measured

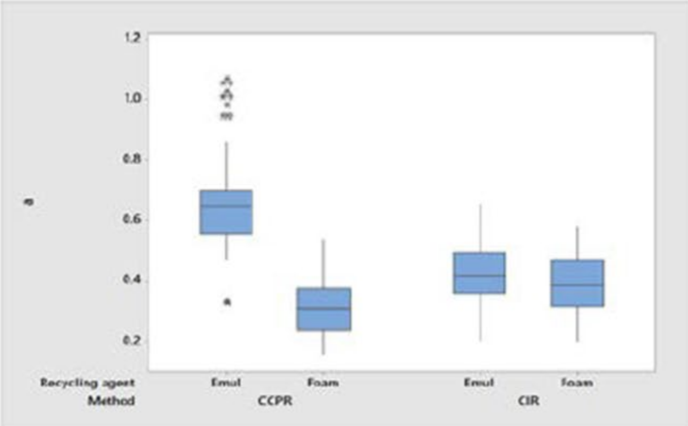
Page **40**

Source Reference 11.

CCPR: A Tool for Low-Carbon Capacity Expansion?

Structural Coefficients – US 280

Section	Method	Recycling agent	N	Average	Std. Dev.
U40	CCPR	Foam	84	0.31	0.092
U41	CCPR	Emulsion	125	0.66	0.154
U43	CIR	Emulsion	126	0.43	0.092
U44	CIR	Foam	126	0.38	0.103



SEVENTH RESEARCH CYCLE

NCAT TEST TRACK CONFERENCE

Adriana Vargas, PhD, "Structural Contribution Of Recycled Sections On Lee Road 159 And US 280," NCAT Test Track Conference, Seventh Research Cycle, 22-24 June 2021.

CCPR: A Tool for Low-Carbon Capacity Expansion?

IRI less than 95 in/mi are considered to be "good" road segments.

Field Performance – US 280

After 6 years of service

Section	Description	Rutting (mm)	IRI (in/mi)	Cracking (%)
U40	Foamed CCPR	4.3	86.1	8.2
U41	Emulsion CCPR	3.6	92.9	2.2
U43	Emulsion CIR	4.5	98.7	2.0
U44	Foamed CIR	4.4	66.3	1.0

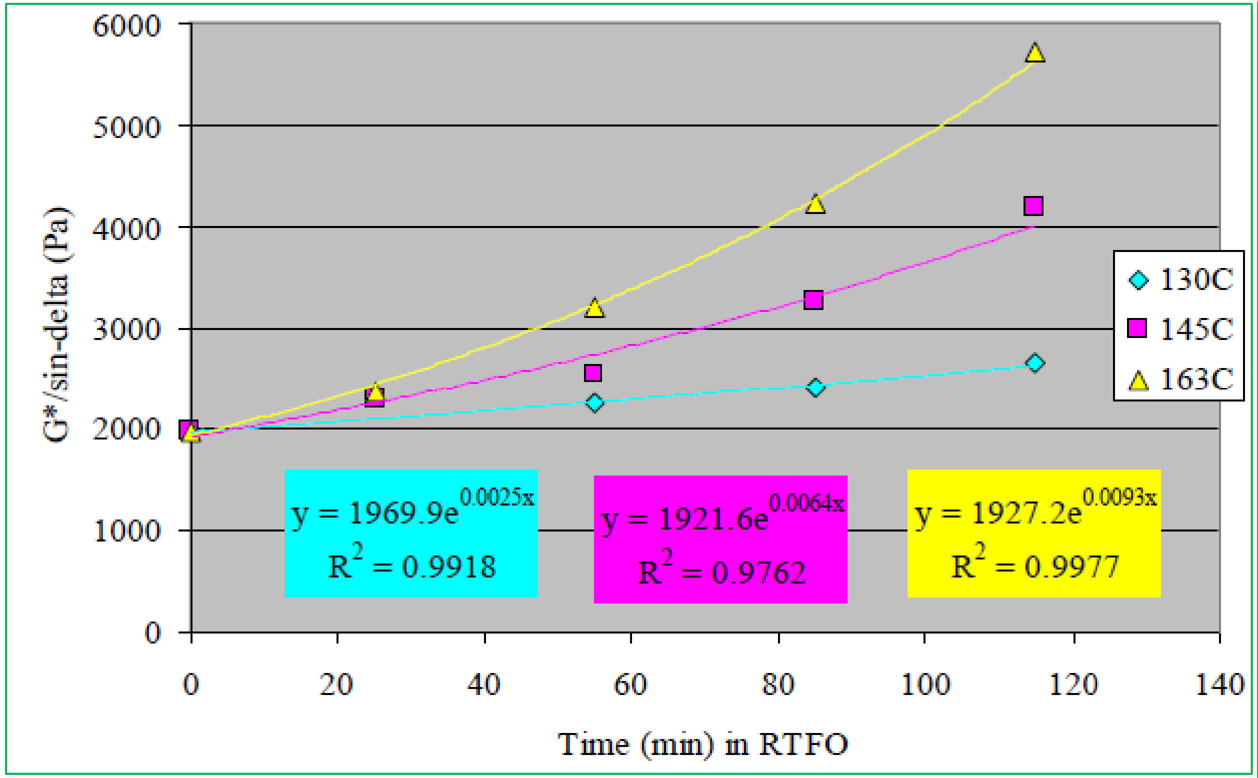
Lowest a

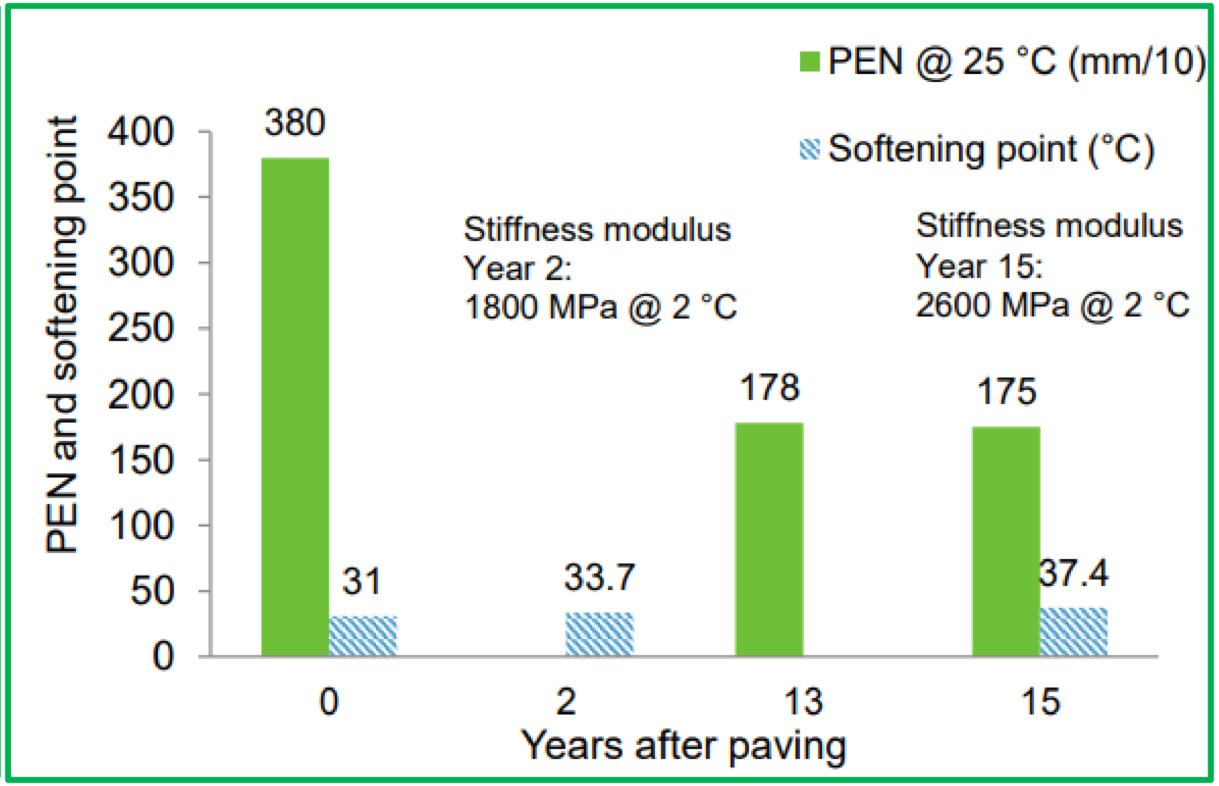
Highest a

SEVENTH RESEARCH CYCLE NCAT TEST TRACK CONFERENCE

Adriana Vargas, PhD, "Structural Contribution Of Recycled Sections On Lee Road 159 And US 280," NCAT Test Track Conference, Seventh Research Cycle, 22-24 June 2021.

CCPR: Binder is Not Age-Hardened During Mix Production





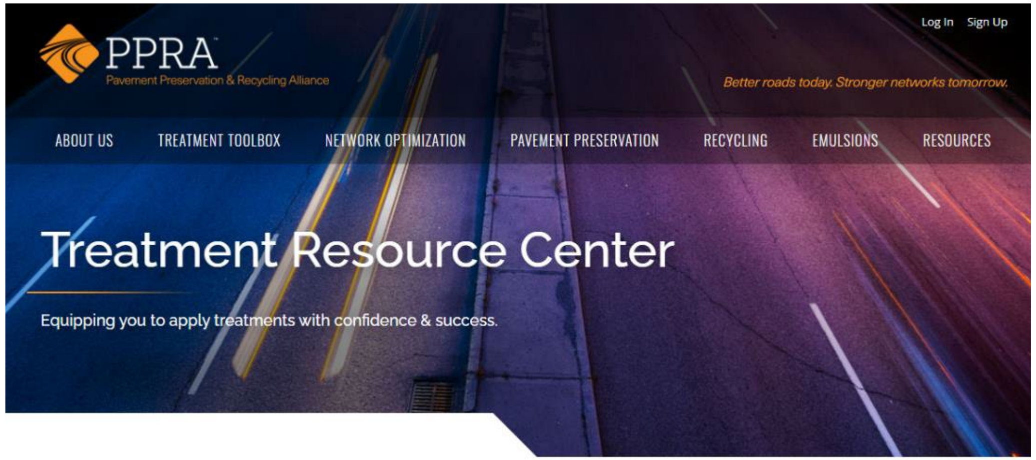
Plot slopes versus temperature (0.0093, 163), (0.0064, 145), (0.0025, 130) and you find at 117°C, this binder doesn't harden in the RTFO (i.e., the slope = 0).

Nynas scientists cored wearing courses constructed with emulsion-based virgin cold mixtures after 15 years. The binder stiffness had changed only slightly. "Cold mix" means ZERO oxidative aging during mix production.

Source Reference 10.

CCPR: A Tool for Low-Carbon Capacity Expansion?

To learn more about CCPR, you can visit roadresource.org



Cold Central Plant Recycling

MORE TREATMENTS...

OVERVIEW
- ABOUT
- PROCESS & VARIATIONS
- EXPECTATIONS
- COST
- HISTORY
- BEST PRACTICES

PRE-CONSTRUCTION
- SITE SELECTION
- MATERIAL SELECTION
- MIX DESIGN
- SPECIFICATION REVIEW

CONSTRUCTION
- PREPARATION
- WEATHER REQUIREMENTS
- EQUIPMENT
- CALIBRATION
- TRAFFIC CONTROL
- APPLICATION

QUALITY ASSURANCE
- INSPECTION
- TESTING PROTOCOL
- TROUBLESHOOTING
- ACCEPTANCE

RESEARCH & PERFORMANCE

SUCCESS STORIES

PHOTO GALLERY

FOR PAVEMENT CONDITION C D F (PCI of 0)

In many locations, stockpiles of high quality RAP are available and Cold Central Plant Recycling (CCPR) can produce a high quality economical paving material preventing a valuable resource from being landfilled. CCPR is the process in which the asphalt recycling takes place at a central location using a stationary cold mix plant and an existing stockpile of RAP. The stationary plant could be a specifically designed plant or a CIR train minus the cold planing machine set up in a stationary configuration. CCPR methods are also appropriate when an existing pavement cannot be in-place recycled due to logistical reasons or must be removed to allow treatment of underlying materials. CCPR mixtures can be designed for immediate use as a recycled pavement or designed for stockpiling and later use.

- 20-50% less expensive than conventional maintenance, reconstruction and new construction methods
- Reduces greenhouse emissions by up to 50%
- Resues 100% of existing materials
- Same day return to traffic, 20-40% faster construction times
- adds 15-20 years (combined with appropriate wearing course)
- Most agencies use Structural Layer (a) Coefficients between 0.30 - 0.38 (Recent research indicates values from 0.36-0.44 may be more appropriate)

Issues Addressed
- When used in place of an asphalt overlay, CCPR addresses the same distresses as the overlay
- When used in conjunction with CIR, CCPR treats the same distresses to a deeper depth in the pavement structure
- When used on a road that cannot be in-place recycled, CCPR treats the same distresses as CIR

Attributes
- CCPR can be used in new construction as a base or binder mix.
- CCPR can be used to widen or pave shoulders
- CCPR uses existing stockpiles of RAP
- CCPR can be used when it is not possible to CIR a road

Common Combinations

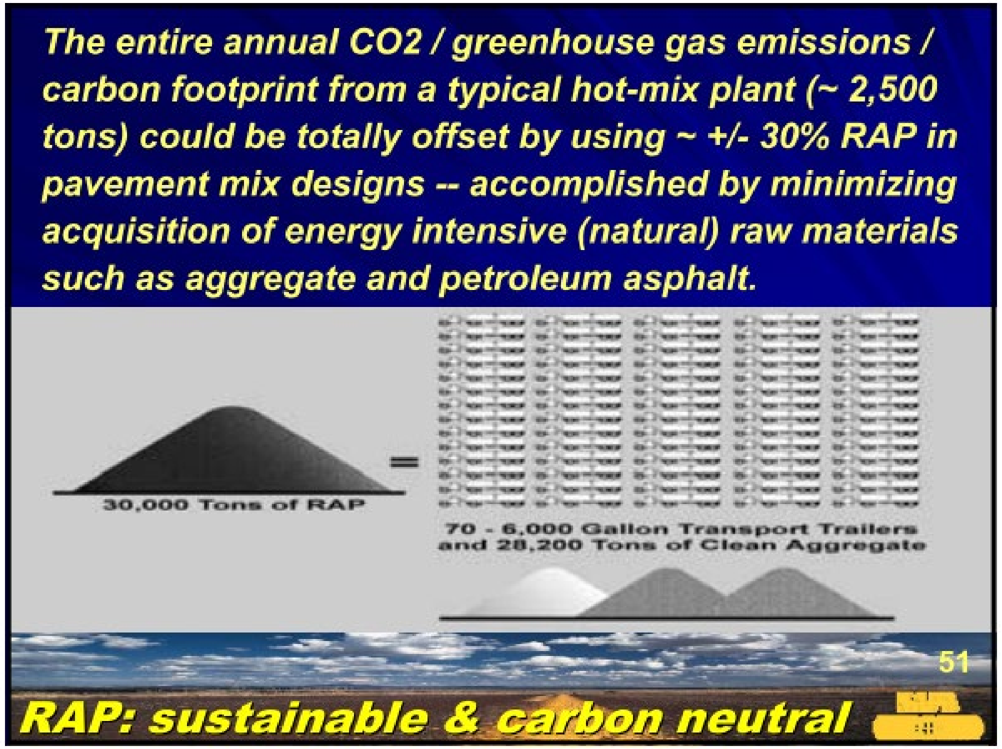
Tools At-Hand and Innovations in the Offing

Five Phases of Pavement LCA

PRODUCT	A1	Extraction, Production
	A2	Transport
	A3	Manufacturing
CONSTRUC–TION	A4	Transport
	A5	Construction, Installation
USE	B1	Use
	B2	Maintenance
	B3	Repair
	B4	Replacement
	B5	Refurbishment
	B6	Energy Use
	B7	Water Use
END OF LIFE	C1	Demolition
	C2	Transport
	C3	Processing
	C4	Disposal
BEYOND	D	Reuse, Recycling, Recovery

GREEN TOOLS ALREADY IN USE OR UNDER DEVELOPMENT

RAP, RAS, Slag, Fly Ash, Jet Grout Waste; Bio-binders, asphalt rubber, plastic extenders



30K tons RAP = 70, 6K AC transports + 28.2K tons Virgin Agg

Marks, H. NAPA, SEAPUG Hilton Head, 2009

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Bituminous Liquid	Bitumen Emulsion[a]	Unmodified Bitumen	Polymer-Modified Bitumen
Functional Unit (F.U.), tonnes	1	1	1
Converted F.U., tonnes practical liquid[b]	1.667	1	1
Converted F.U., lb	3675	2205	2205
Reported Emissions to Air, CO_2 / F.U., grams	255669	226167	346016
Reported Emissions to Air, CO_2 / F.U., lb	563.1	498.2	762.1
CO_2 emissions, lb / lb bituminous liquid	0.15	0.23	0.35
% Difference Compared to Unmodified Bitumen	-32	0.0	53

(a) Eurobitume reported emulsion functional unit as 1 tonne of bitumen residue.

(b) 1 tonne of bitumen residue in a 60% residue emulsion, would convert to 1.667 tonnes emulsion.

Euobitume Life Cycle Inventory of Bitumen, 2012.

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Holly-Frontier
125 MMgy Artesia - PTU
90 MMgy Cheyenne – RDU on line 2022

The U.S. National Biodiesel Board is forecasting 22.6 billion litres (**6 B gallons**) of new annual renewable diesel production capacity by 2024, in addition to today's 3.7 billion litres (**0.8 B gallons**).

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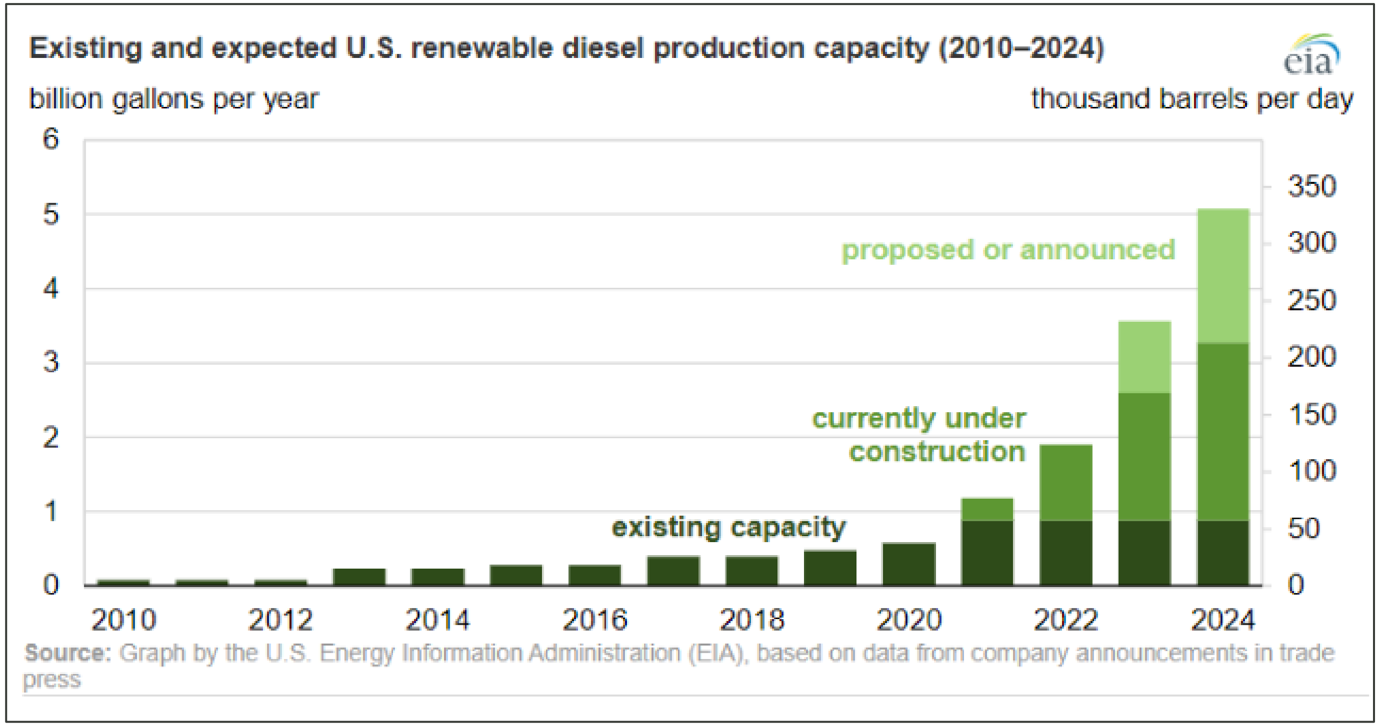

Up to 6 B gallons of new annual renewable diesel

Source of Data is Ref. 12

Tools At-Hand and Innovations in the Offing

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Press release

Highways England accelerates switch to lower carbon asphalts

Highways England is accelerating the use of warm mix asphalts as standard across its supply chain as part of a drive toward net zero carbon emissions.

From: Highways England

Published 18 August 2021

www.gov.uk/government/news/highways-england-accelerates-switch-to-lower-carbon-asphalts

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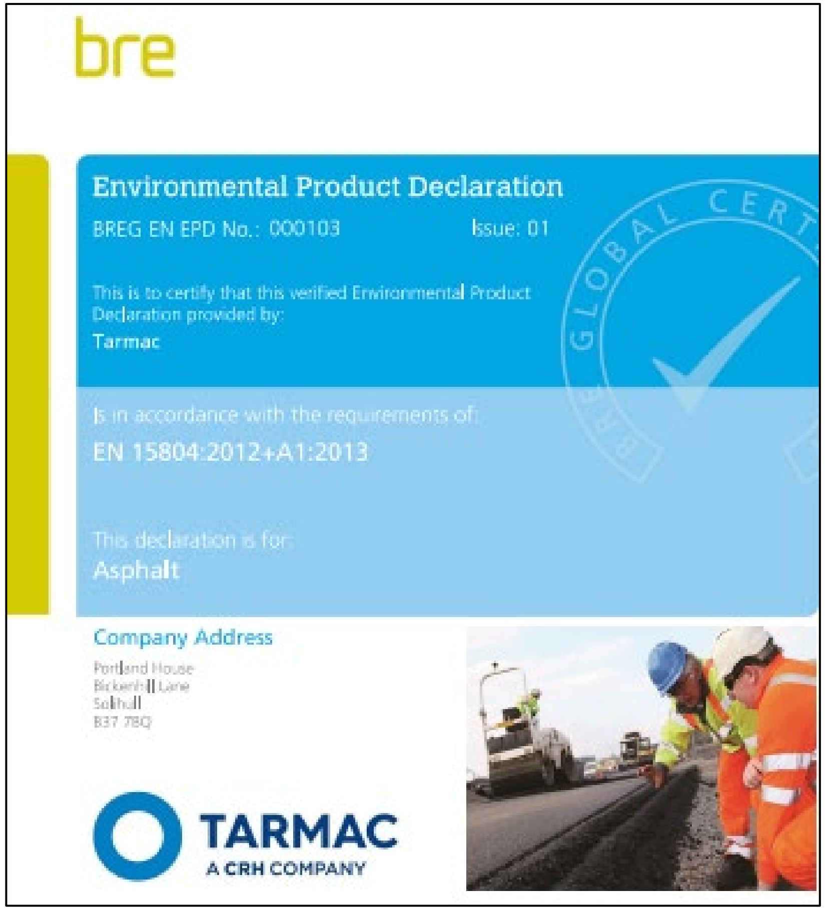
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Environmental Product Declaration

BREG EN EPD No.: 000103 Issue: 01

This is to certify that this verified Environmental Product Declaration provided by:

Tarmac

Is in accordance with the requirements of:

EN 15804:2012+A1:2013

This declaration is for:

Asphalt

Company Address

Portland House
Bickenhill Lane
Solihull
B37 7BQ

TARMAC
A CRH COMPANY

In the UK, EPD's for asphalt mixtures reflect the fact that "energy allocation" is different for HMA and WMA.

Tools At-Hand and Innovations in the Offing

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HMA

Indicator	Unit	A1-A3 Merged A1/A2/A3
Environmental impacts p		
GWP	kg CO_2 eq.	70.00
ODP	kg CFC 11 eq.	3.23E-05
AP	kg SO_2 eq.	0.409
EP	kg $(PO_4)^{3-}$ eq.	0.102
POCP	kg C_2H_4 eq.	0.0735
ADPE	kg Sb eq.	0.000236
ADPF	MJ eq.	2740

WMA

Indicator	Unit	A1-A3 Merged A1/A2/A3
Environmental impacts p		
GWP	kg CO_2 eq.	64.4
ODP	kg CFC 11 eq.	3.14E-05
AP	kg SO_2 eq.	0.386
EP	kg $(PO_4)^{3-}$ eq.	0.0971
POCP	kg C_2H_4 eq.	0.0713
ADPE	kg Sb eq.	7.36E-05
ADPF	MJ eq.	2690

Excerpted from Tarmac Public EPD's

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ADPE	kg Sb eq.	0.000236
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WMA

-9% GWP

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Excerpted from Tarmac Public EPD's

Tools At-Hand and Innovations in the Offing

PRODU

CONST
TION

USE

END O

BEYON

Effect of Compaction on Asphalt Concrete Performance

1989

ROBERT N. LINDEN, JOE P. MAHONEY, AND NEWTON C. JACKSON

This paper presents information on how compaction (specifically, air voids) influences the performance of dense asphalt concrete pavement surfaces. The information is based on three separate sources: the existing literature on the subject, a questionnaire survey of 48 state highway agencies on compaction practice, and performance data from the Washington State Pavement Management System. All three information sources show some correlation between the degree of compaction and the performance of asphalt concrete pavement. Overall, a 1 percent increase in air voids (over the base air-void level of 7 percent) tends to produce *about* a 10 percent loss in pavement life.

This paper is the result of research on how compaction—specifically, air voids—affects the performance of dense asphalt concrete pavement. Three information sources support the findings: a literature review; a survey of state highway agencies (SHAs); and data from the Washington State Pavement Management System (WSPMS).

PREVIOUS RESEARCH

Other researchers have found that asphalt concrete performance is in part a function of compaction, and hence air voids, in dense mixtures. Two frequently used terms indicative of performance are fatigue cracking and aging.

Fatigue Cracking

Fatigue cracking (or "alligator cracking") usually describes cracked pavement that has been repeatedly bent by heavy

Another way to approach air voids is to ask how they affect the thickness of asphalt concrete. As demonstrated by Finn and Epps (*1*), the effective thickness of asphalt concrete layers decreases as air voids increase. Finn and Epps evaluated two thicknesses of asphalt concrete, 4 and 6 in., at a starting point of 7 percent air voids (7 percent is generally considered achievable in normal paving construction). The following tabulation summarizes their findings.

Percent Air Voids in Asphalt Concrete	*Effective Thickness of Asphalt Concrete (in.)* Example 1	Example 2
7	4.0	6.0
8	3.5	5.0
9	3.0	4.5
10	2.5	4.0
12	2.0	4.0

Thus, if the air voids are increased from a desirable level of 7 percent to a very poor compaction level of 12 percent, a 4-in.-thick asphalt concrete layer effectively lasts only as long as a 2-in. layer; a 6-in. layer is reduced to the effectiveness of a 4-in.-thick layer.

Aging

Aging of asphalt concrete can be evaluated in many ways. One way pertinent to this research is to judge aging by considering asphalt penetration and determining how air voids affect that property.

Goode and Owings (*4*) showed that, for asphalt concrete

ALREADY IN USE OR UNDER DEVELOPMENT

out Waste; Bio-binders, asphalt rubber, plastic extenders

ewable biodiesel; Electric vehicles

RAP; New equipment; new fuels; CCPR

sel; Electric vehicles

mpaction aid); New equipment

"... each 1% increase in air voids (over a base air void level of 7 percent) results in about a 10% loss in pavement life (or about 1 year less)."

Reference 13.

Tools At-Hand and Innovations in the Offing

Five Ph

ͦLUTIONS ALREADY IN USE OR UNDER DEVELOPMENT

PRODUCT

Ash, Jet Grout Waste; Bio-binders, asphalt rubber, plastic extenders

esel & renewable biodiesel; Electric vehicles

CONSTRUC–TION

ors; higher RAP; New equipment; new fuels; CCPR

9

able biodiesel; Electric vehicles

s (WMA compaction aid); New equipment

USE

END OF LIFE

BEYOND

FHWA Demonstration Project for Enhanced Durability of Asphalt Pavements through Increased In-place Pavement Density, Phase 2

FHWA-HIF-19-052

Image: FHWA

May 2019

U.S. Department of Transportation
Federal Highway Administration

"A 1% increase in in-place density was estimated to extend the service life by 10 percent, conservatively."

Reference 14.

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WMA & rejuvenators; higher RAP; New equipment; new fuels; CCPR

Biodiesel & renewable biodiesel; Electric vehicles

Improved densities (WMA compaction aid); Tamping screeds; New equipment

During USE PHASE, **pavement maintenance and preservation tools** provide our industry with numerous proven technologies for extending the service life of pavements both cost-effectively and with very low carbon intensity.

Tools At-Hand and Innovations in the Offing

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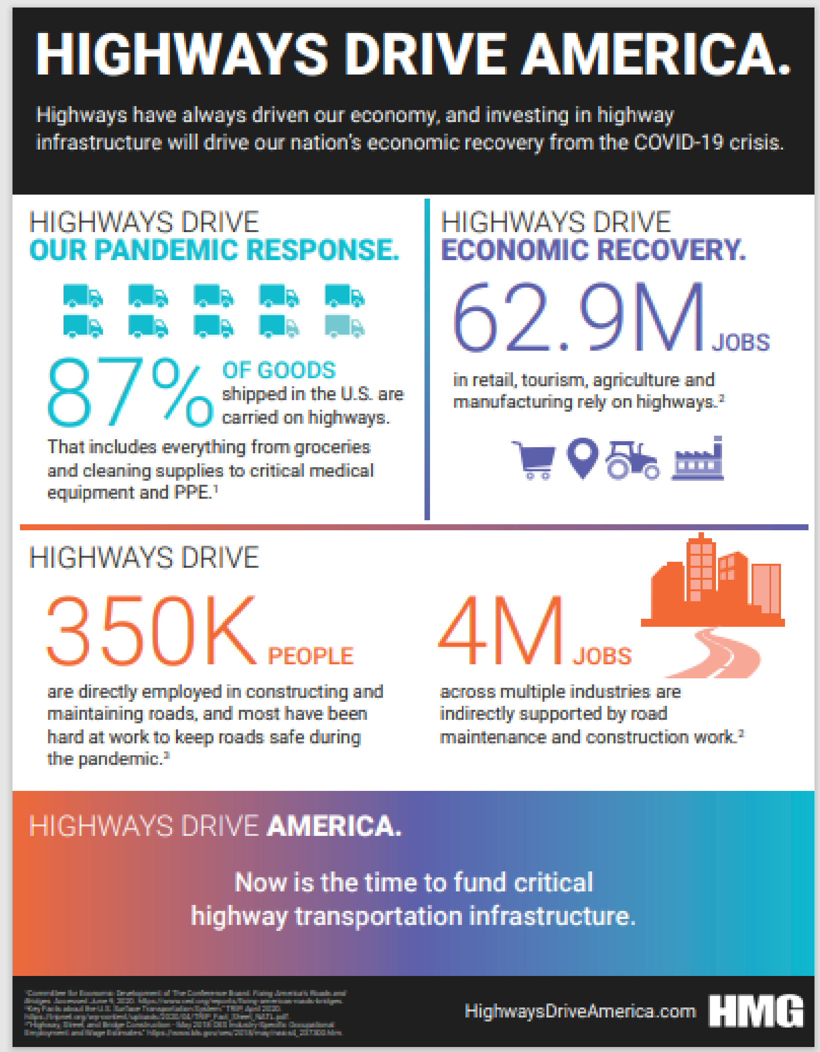
Biodiesel & renewable biodiesel; Electric vehicles

Improved densities (WMA compaction aid); Tamping screeds; New equipment

And, we have had Perpetual Pavements (50-yr service lives) technology since the 1970's.

Shown I-90 in Washington State (from WA DOT)

CCPR and Increased Capacity without Increased GWP



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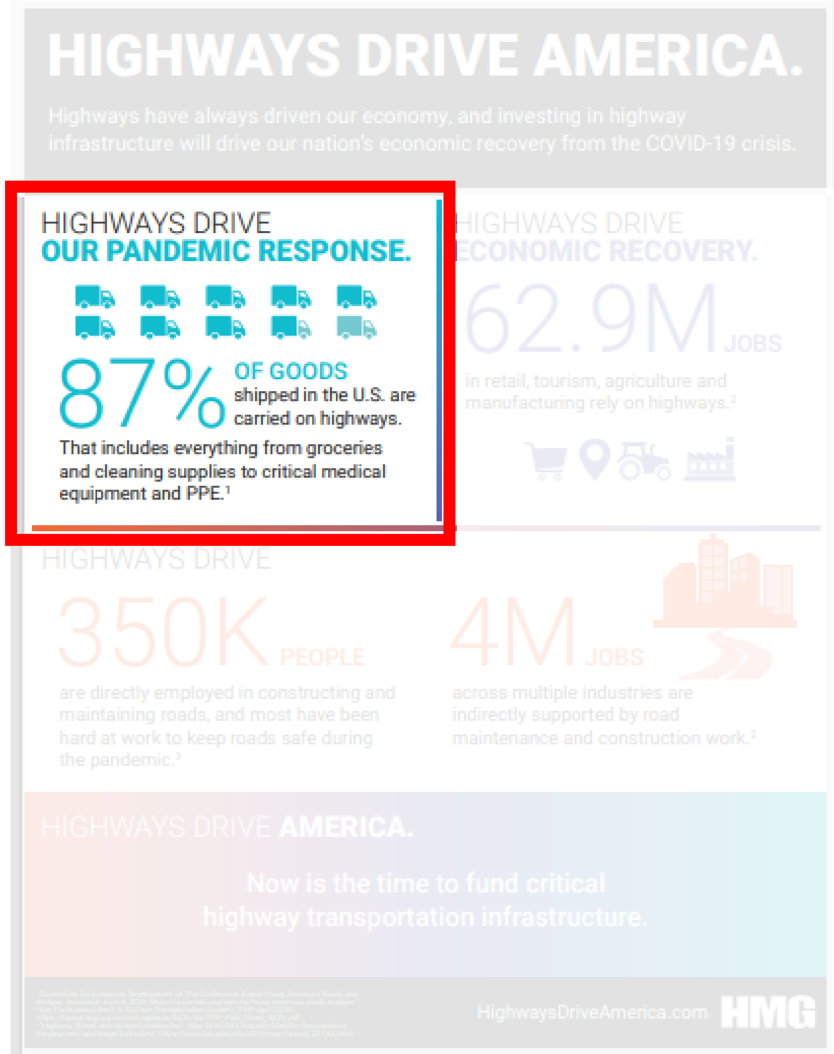
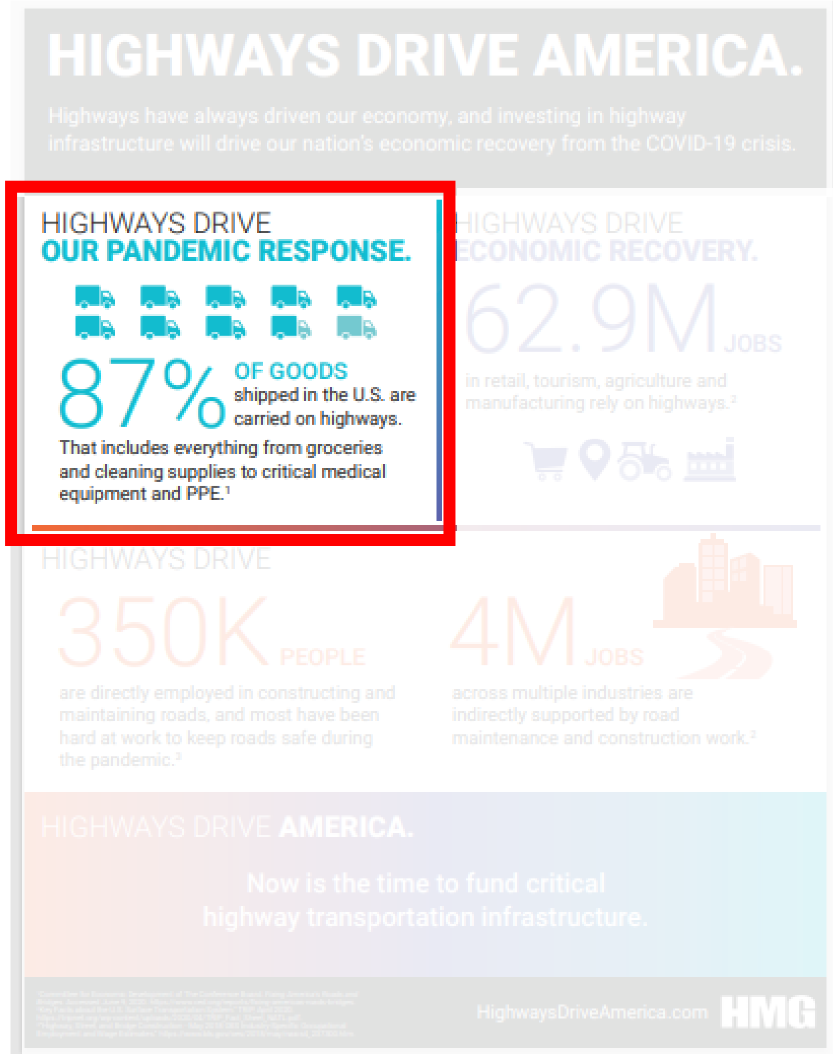
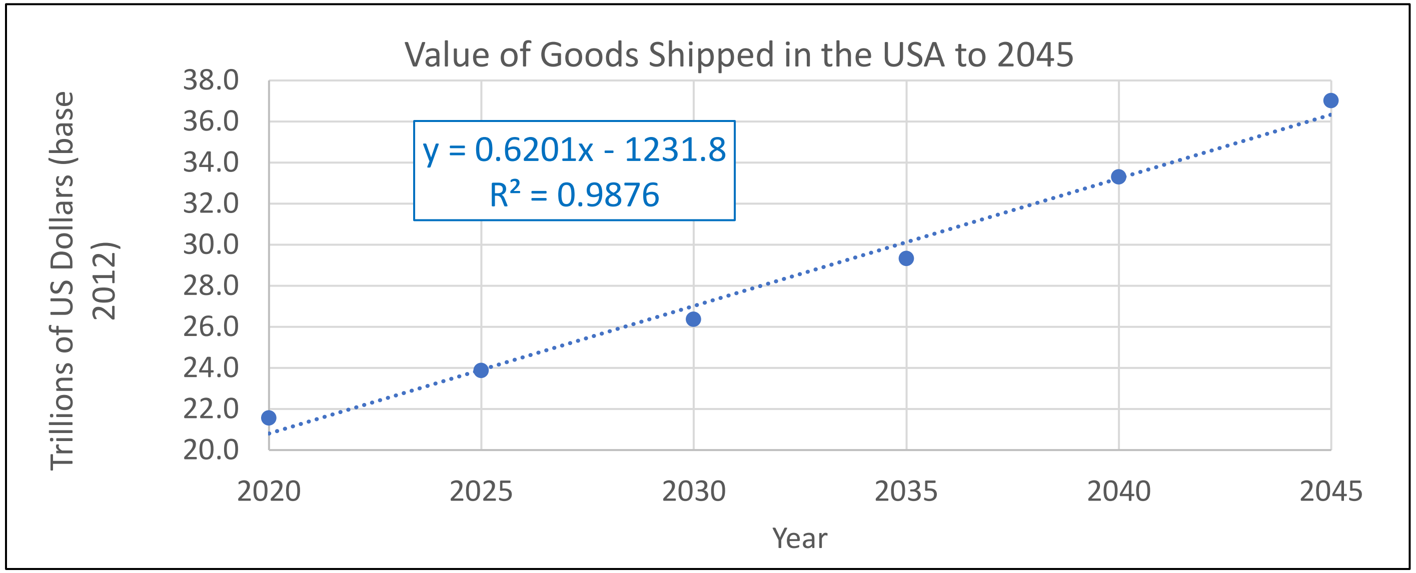


NAPA Source Ref. 9.

www.bts.gov/newsroom/dot-releases-30-year-freight-projections

CCPR and Increased Capacity without Increased GWP



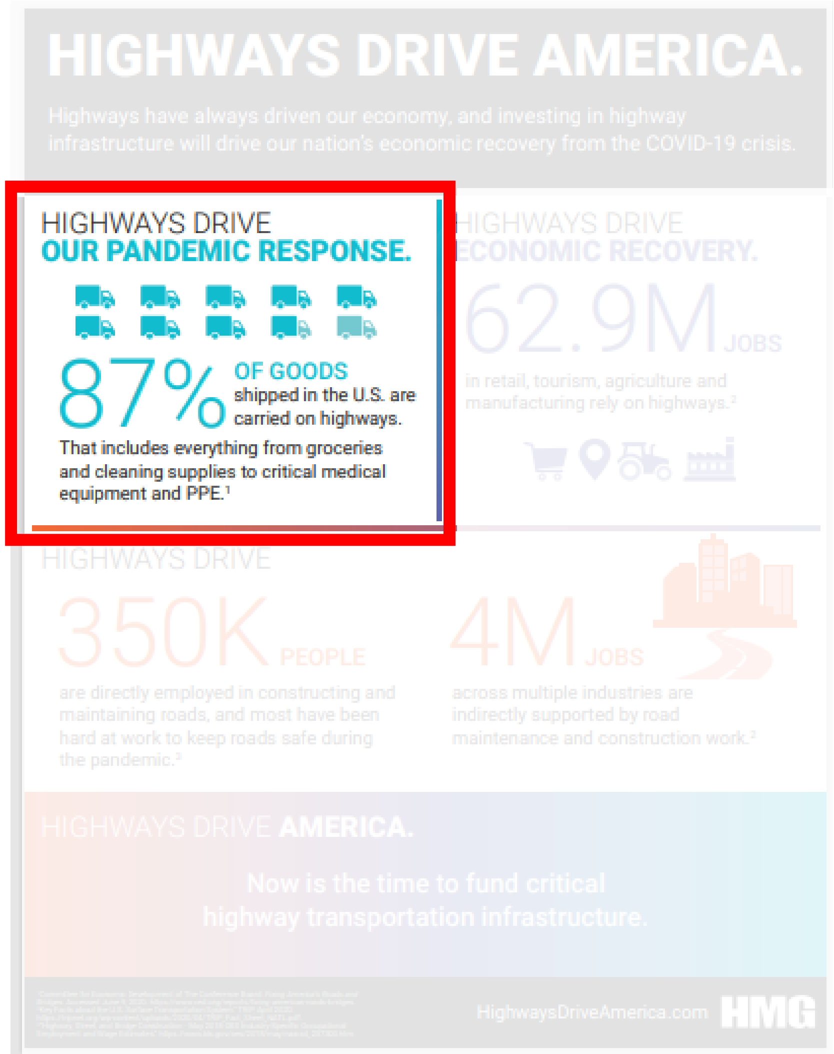


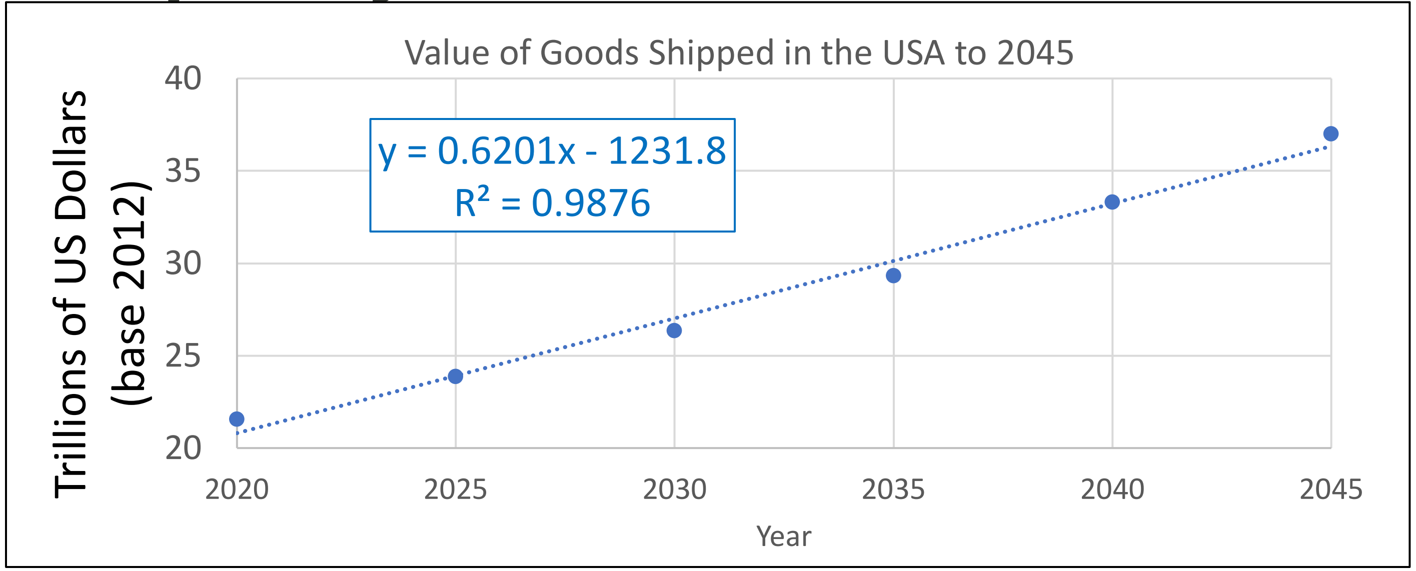
Value of Goods Shipped in the USA is projected to increase by $620 billion per year until 2045. 87% of that value is carried by trucks on our highways.

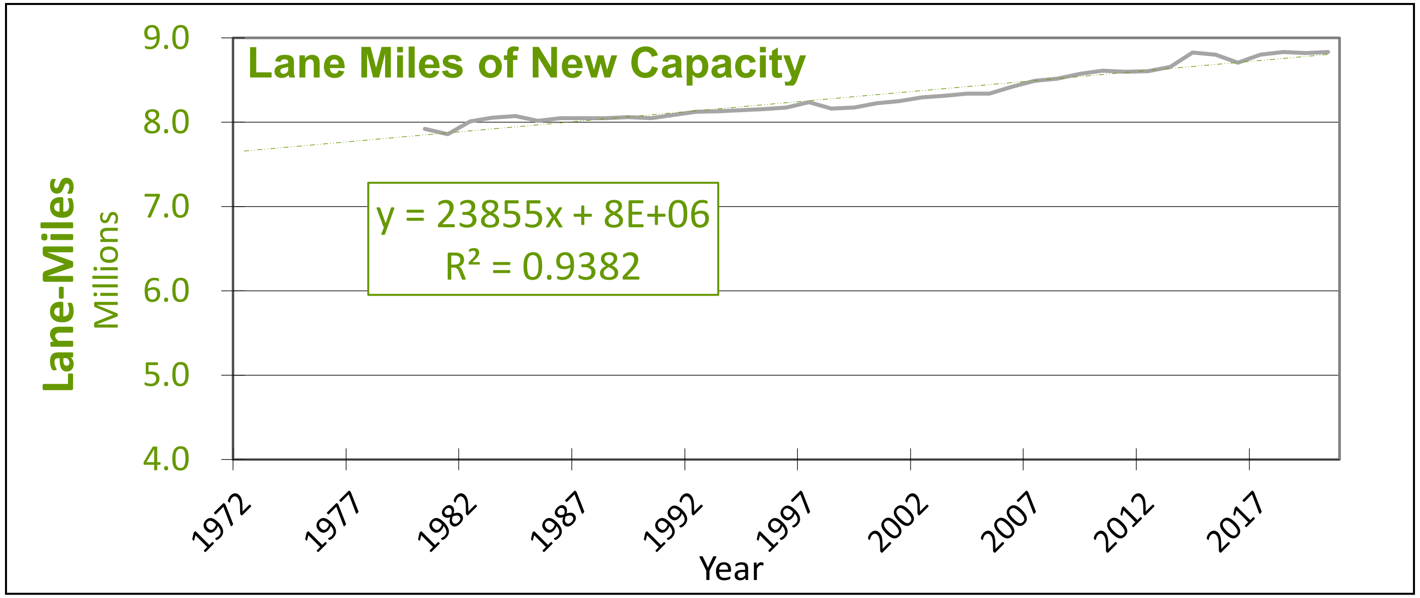
NAPA Source Ref. 9.

www.bts.gov/newsroom/dot-releases-30-year-freight-projections

CCPR and Increased Capacity without Minor GWP







NAPA Source Ref. 9.

We Can Increase Capacity with Reduced GWP

Value of Goods Shipped in the USA to 2045

40

60-87% of our GDP depends on truck-shipped goods.

Value of Goods Shipped is projected to increase by 620 Billion US$ / year to 2045.

Vehicle-Miles Traveled increases by 45.25 billion vehicle-miles traveled/year.

But highway capacity has increased at only 23,855 lane-miles per year.

Can highway capacity growth (23,855 lane-miles/year = 8 lane-miles / county) support GDP growth projections?

Funding issues, notwithstanding, can we increase capacity while also reducing our industries carbon emissions using at-hand tools:
more recycle-ables, more reduced temperature mixtures, more CCPR, more perpetual pavements, to name a few

Year

NAPA Source Ref. 9.

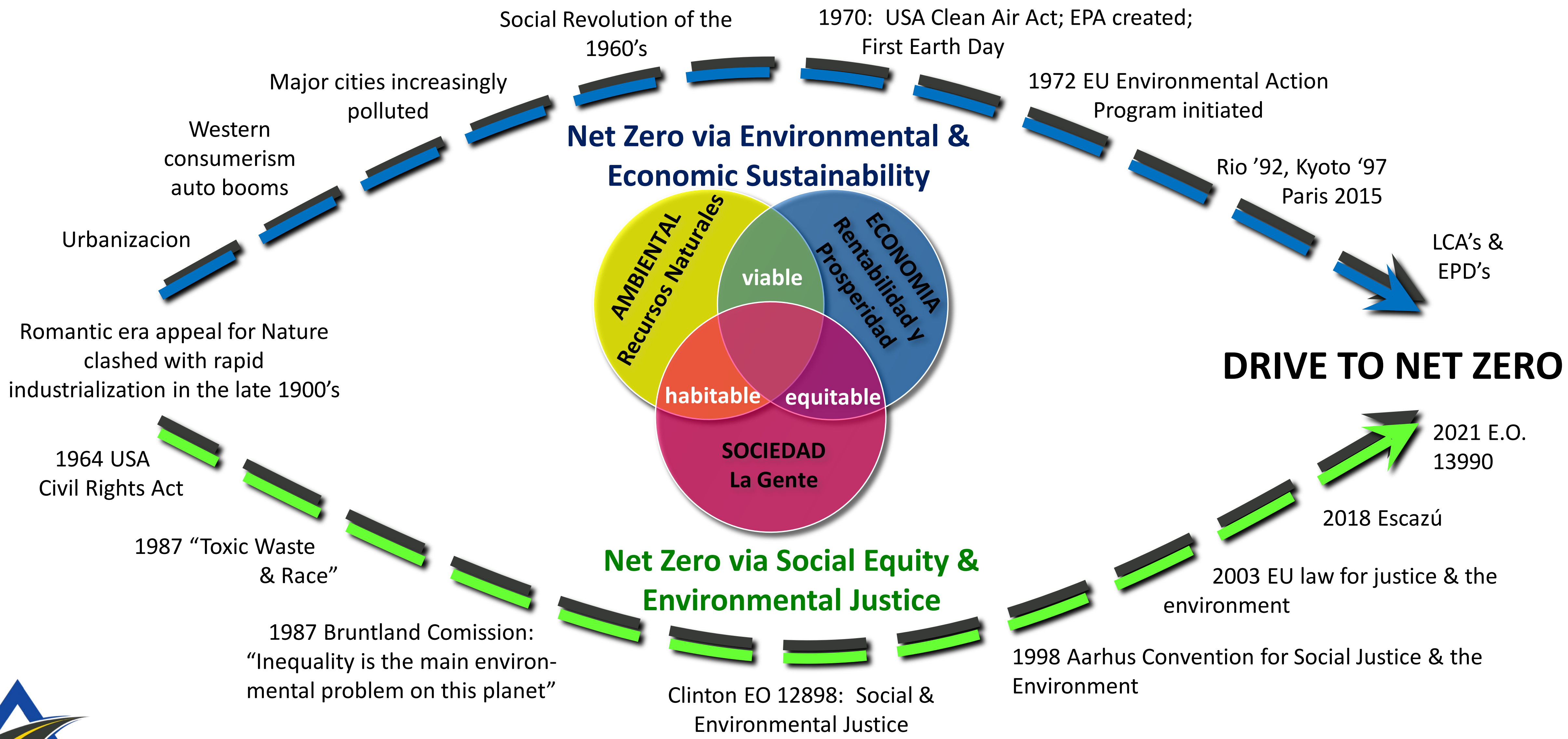
We Have the Tools to Increase Capacity with Reduced GWP

Renewable fuels, equipment improvements, electrification (Scope 3 wind & solar), WMA, CCPR, rejuvenators, are elements of a viable strategy to meet our 2050 socio-economic (equity) and environmental (net-zero) goals.

Industry growth and highway capacity increases can be met, all while...

- Lowering fossil fuel consumption,
- Reducing the industry’s carbon footprint,
- Reducing emissions of air pollutants, odors, and GHG’s,
- Allowing higher recyclables consumption and reducing waste, and
- Imparting superior performance and longer service life.

The Long Arcs of Economic, Social, and Environmental Progress



A Tipping Point

"Earthrise" taken by Bill Anders, Christmas Eve, 1968, as he and two other Apollo 8 astronauts began mankind's first orbit around the far side of the moon.

Have We Reached Our Tipping Point?

What's our modern "Earthrise?"

Changes in Human Behavior – the Lurking Variable

Entity in 2018	land use	farm	animal feed	processing	transport	retail	packaging	SUM
Beef (beef herd)	16.3	39.4	1.9	1.3	0.3	0.2	0.2	59.6
Lamb & Mutton	0.5	19.5	2.4	1.1	0.5	0.2	0.3	24.5
Cheese	4.5	13.1	2.3	0.7	0.1	0.3	0.2	21.2
Beef (dairy herd)	0.9	15.7	2.5	1.1	0.4	0.2	0.3	21.1
Dark Chocolate	14.3	3.7	0	0.2	0.1	0	0.4	18.7
Coffee	3.7	10.4	0	0.6	0.1	0.1	1.6	16.5
Pig Meat	1.5	1.7	2.9	0.3	0.3	0.2	0.3	7.2
Poultry Meat	2.5	0.7	1.8	0.4	0.3	0.2	0.2	6.1
Fish (farmed)	0.5	3.6	0.8	0	0.1	0	0.1	5.1
Eggs	0.7	1.3	2.2	0	0.1	0	0.2	4.5
Rice	0	3.6	0	0.1	0.1	0.1	0.1	4
Tofu	1	0.5	0	0.8	0.2	0.3	0.2	3
Milk	0.5	1.5	0.2	0.1	0.1	0.3	0.1	2.8
Wine	-0.1	0.6	0	0.1	0.1	0	0.7	1.4
Soymilk	0.2	0.1	0	0.2	0.1	0.3	0.1	1
Peas	0	0.7	0	0	0.1	0	0	0.8
Other Fruit	0.1	0.4	0	0	0.2	0	0	0.7
Potatoes	0	0.2	0	0	0.1	0	0	0.3
Root Vegetables	0	0.2	0	0	0.1	0	0	0.3
Citrus Fruit	-0.1	0.3	0	0	0.1	0	0	0.3
Nuts	-2.1	2.1	0	0	0.1	0	0.1	0.2

What can we sacrifice for progress?

8.8 lb GWP

13.2 lb GWP

The pup will emit 2 X's my SUV when fully grown

Thank You.

Everett Crews, Dir. R&D Pavement Technologies

Ingevity Corporation

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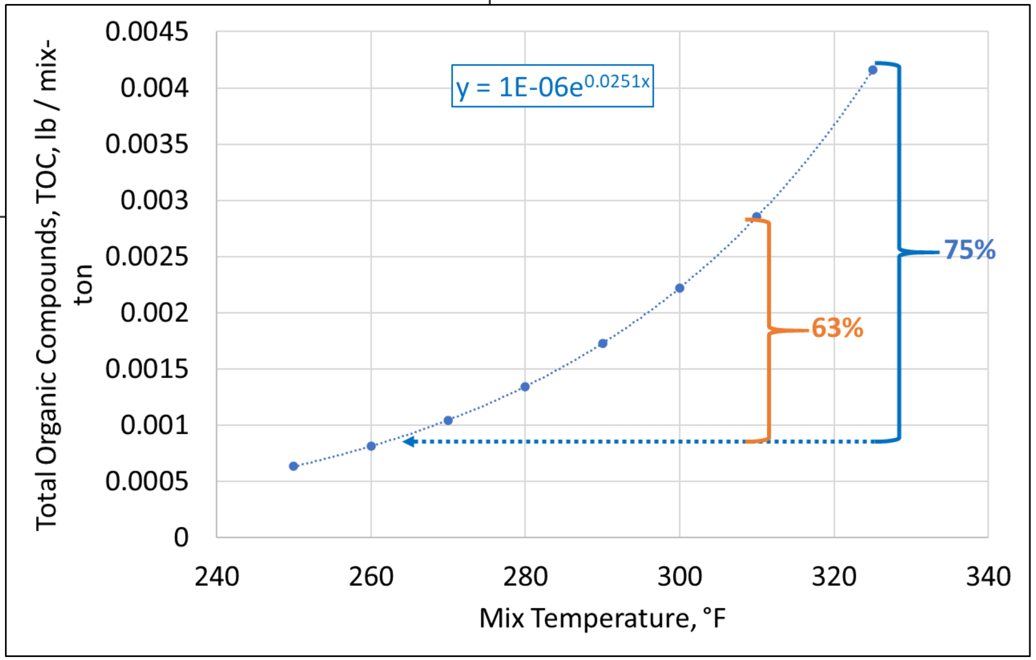
For example, to estimate TOC emissions from drum mix plant load-out operations using an asphalt loss-on-heating of 0.41 percent and temperature of 290°F, the following calculation is made:

$$
\begin{aligned}
EF &= 0.0172(-V)e^{((0.0251)(290 + 460) - 20.43)} \\
&= 0.0172(-(-0.41))e^{((0.0251)(290 + 460) - 20.43)} \\
&= 0.0172(0.41)e^{(-1.605)} \\
&= 0.0172(0.41)(0.2009) \\
&= 0.0014 \text{ lb TOC/ton of asphalt loaded}
\end{aligned}
$$



By lowering the mix temperature from 325°F to 270°F, the TOC emissions were reduced by 75%.

By lowering the mix temperature from 310°F to 270°F, the TOC emissions were reduced by 63%.

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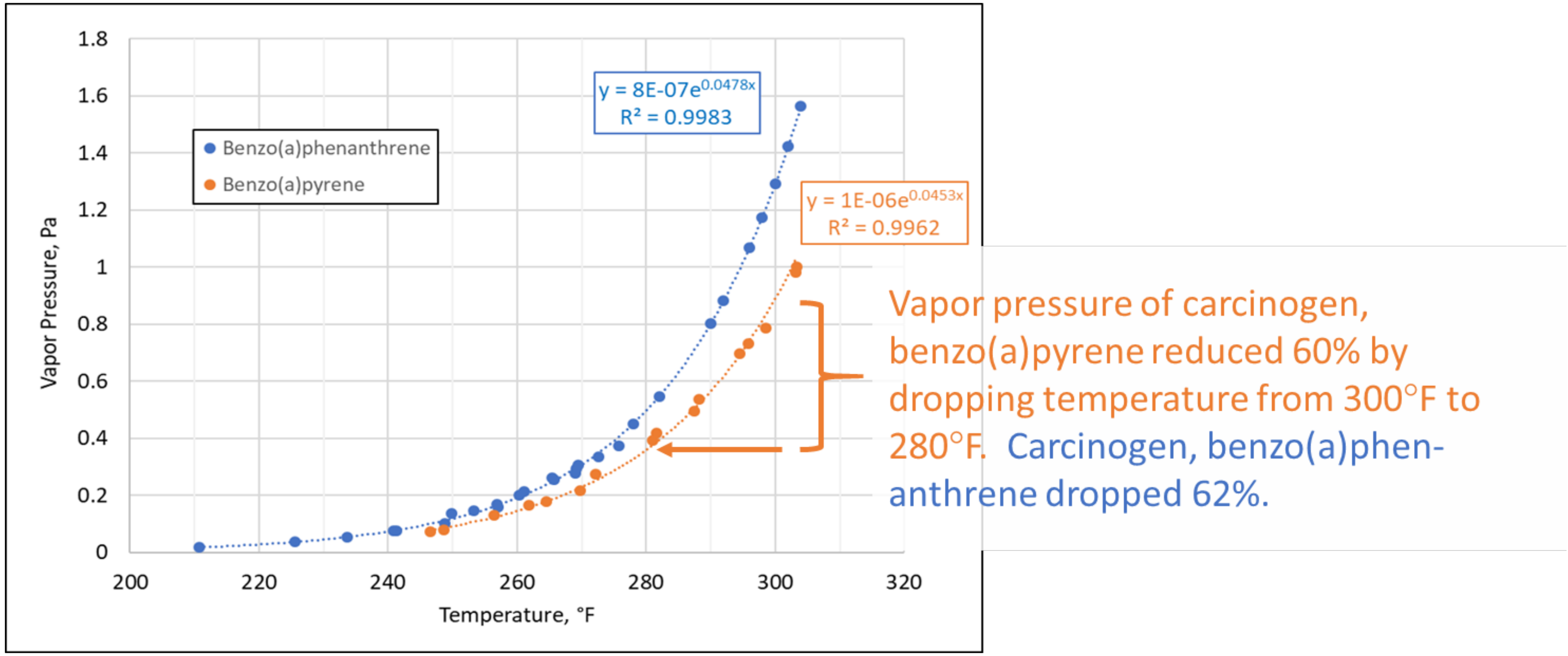

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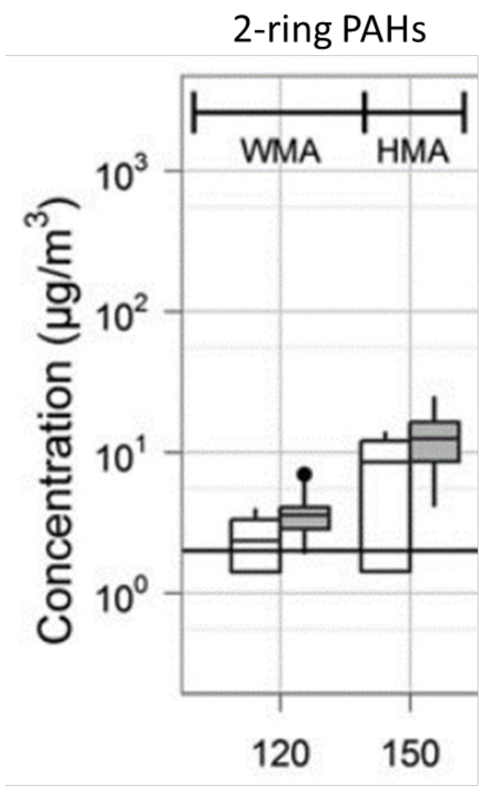
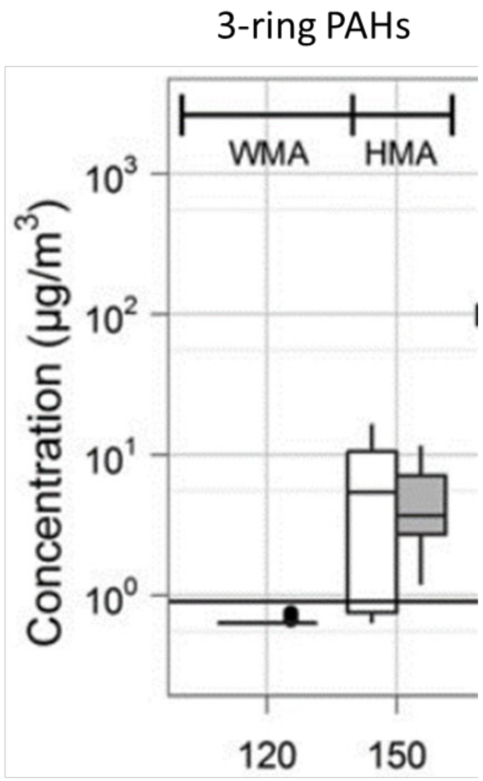
This research, like that of many others, showed that reducing temperatures to **WMA** ranges (120°C) significantly reduces **2-ring and 3-ring PAH's** to near or below detection limits.





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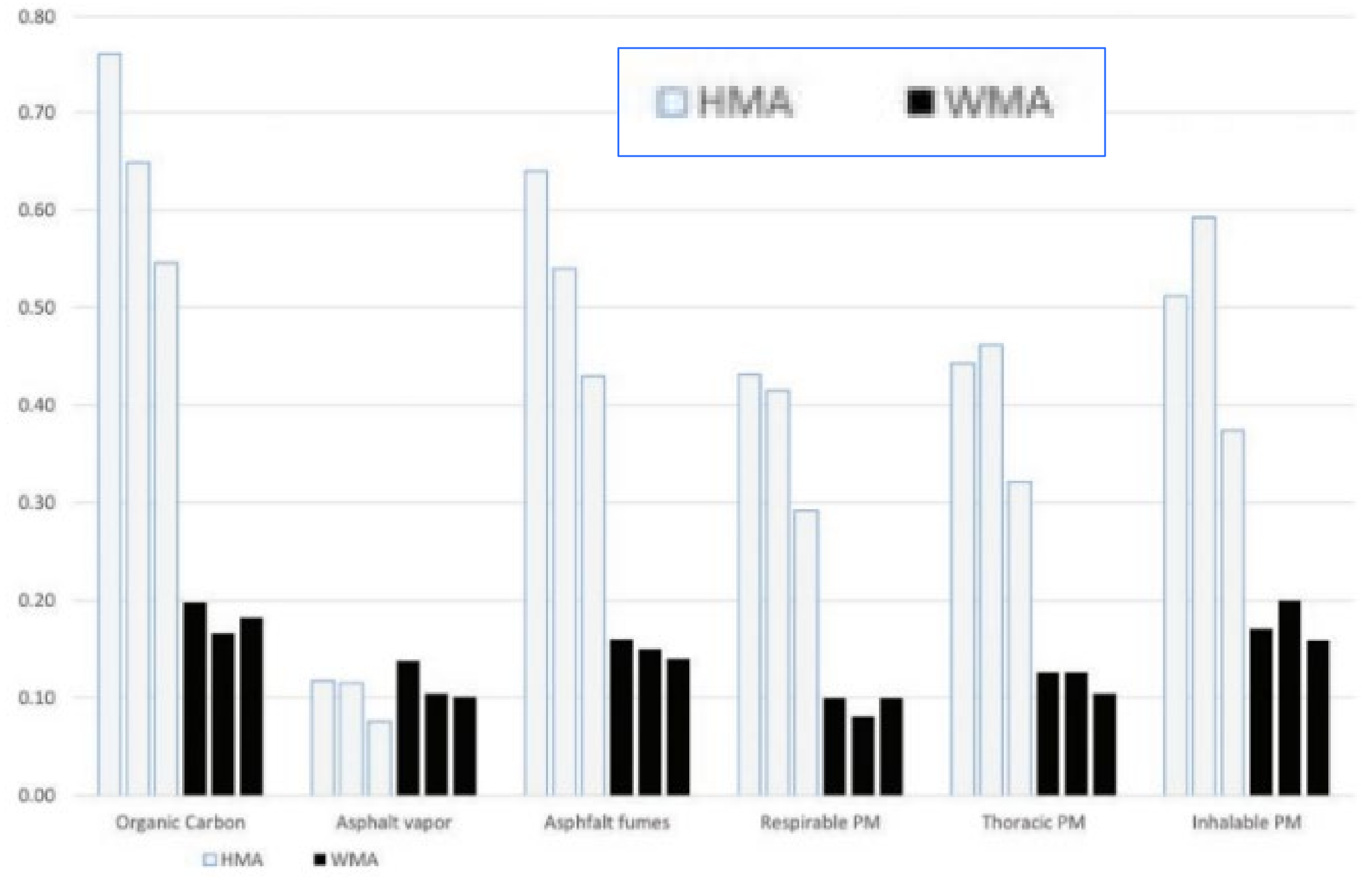

Figure 2. Individual measurements of organic carbon (mg m^{-3}), asphalt vapor (p.p.m.), asphalt fumes (mg m^{-3}), respirable particulate matter (PM) (mg m^{-3}), and thoracic PM (mg m^{-3}) and inhalable PM (mg m^{-3}) during paving with PmB HMA and PmB WMA.