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Concrete Pavement Preservation and Climate Change

Thomas Van Dam, Ph.D., P.E.
Principal

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Background

- Changes in global climate from human activities are occurring
  - Supported by historical observation and climate modeling
- Optimistic models predict substantial climate change over the next century
  - Rate of change dependent on human activities
  - Long life of emitted heat-trapping, greenhouse gases and slow feedback functions of atmospheric systems drive climate change

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Resources

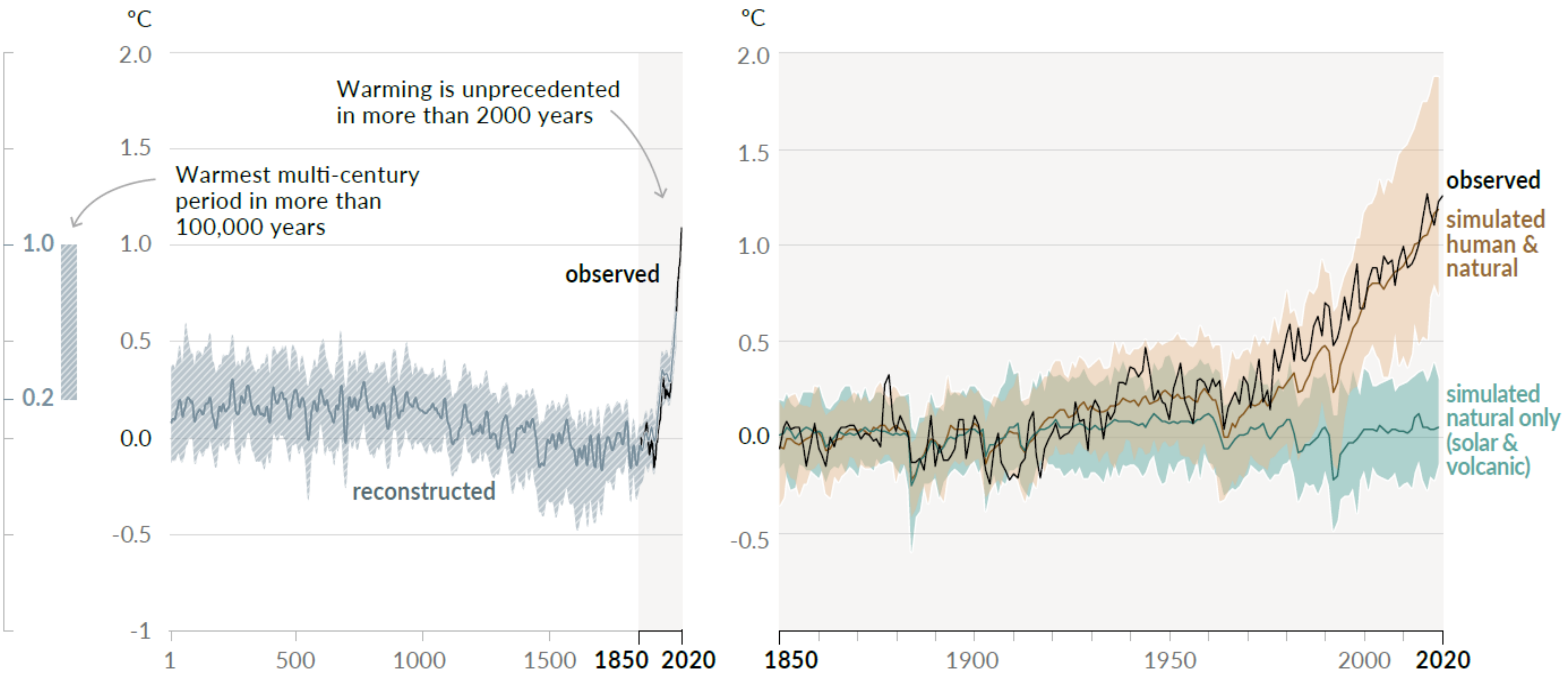
- Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) Climate Change 2021 The Physical Science Basis
- U.S. Global Change Research Program's Fourth National Climate Assessment. Nov. 2018.
- NCHRP Report 750: Strategic Issues Facing Transportation, Volume 2: Climate Change, Extreme Weather Events, and the Highway System. Dec. 2014.

Certainty

"It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred"

IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis*

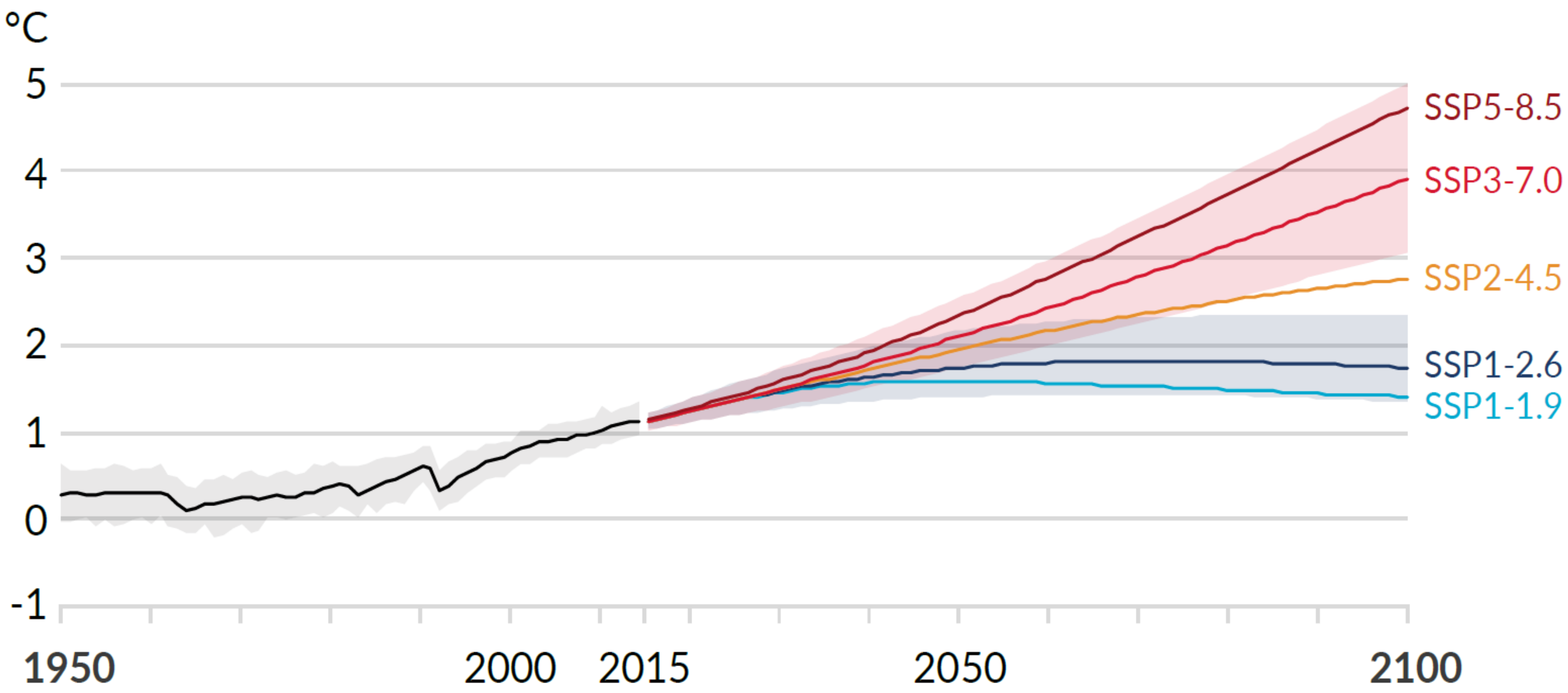
Changes in Global Surface Temperatures Relative to 1850-1900 (IPCC 2021)



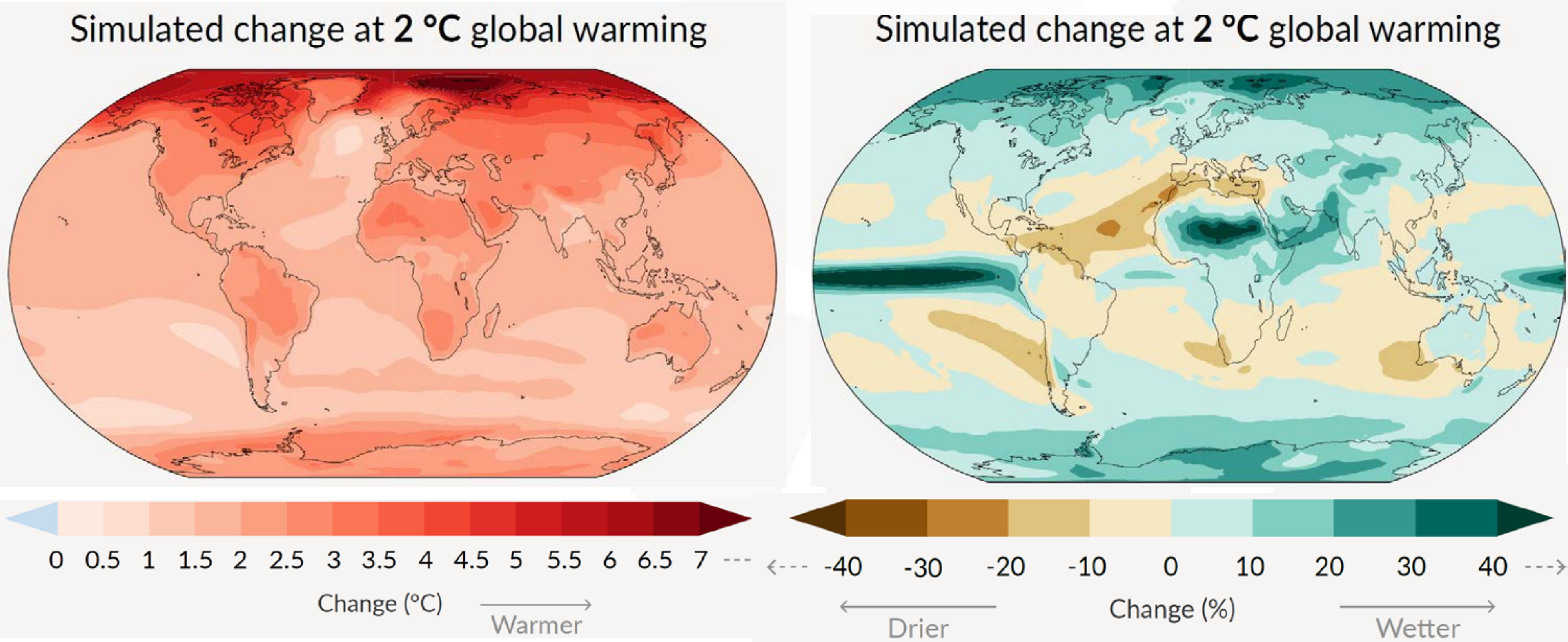
Uncertainty

- Climate change projections limited by uncertainty in future GHG emissions
- Results of climate modeling based on projected GHG emission scenarios
- Modeling in IPCC AR6 uses various scenarios
  - SSP refers to Shared Socio-economic Pathways (SSP) describing the socio-economic trends underlying the scenario, rated 1 through 5
  - The second number is the approximate level of radiative forcing (in $W\ m^{-2}$) resulting in the scenario in the year 2100
  - Higher radiative forcing results in increased warming
  - SPP2-4.5 represents intermediate emissions that are similar to current levels whereas SPP1-1.9 represents net-zero by 2050 and then negative

Global Surface Temperature Increases Compared to 1850-1900

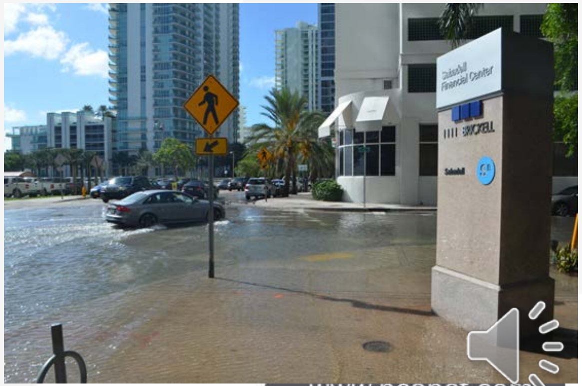


Regional Differences (IPCC 2021)



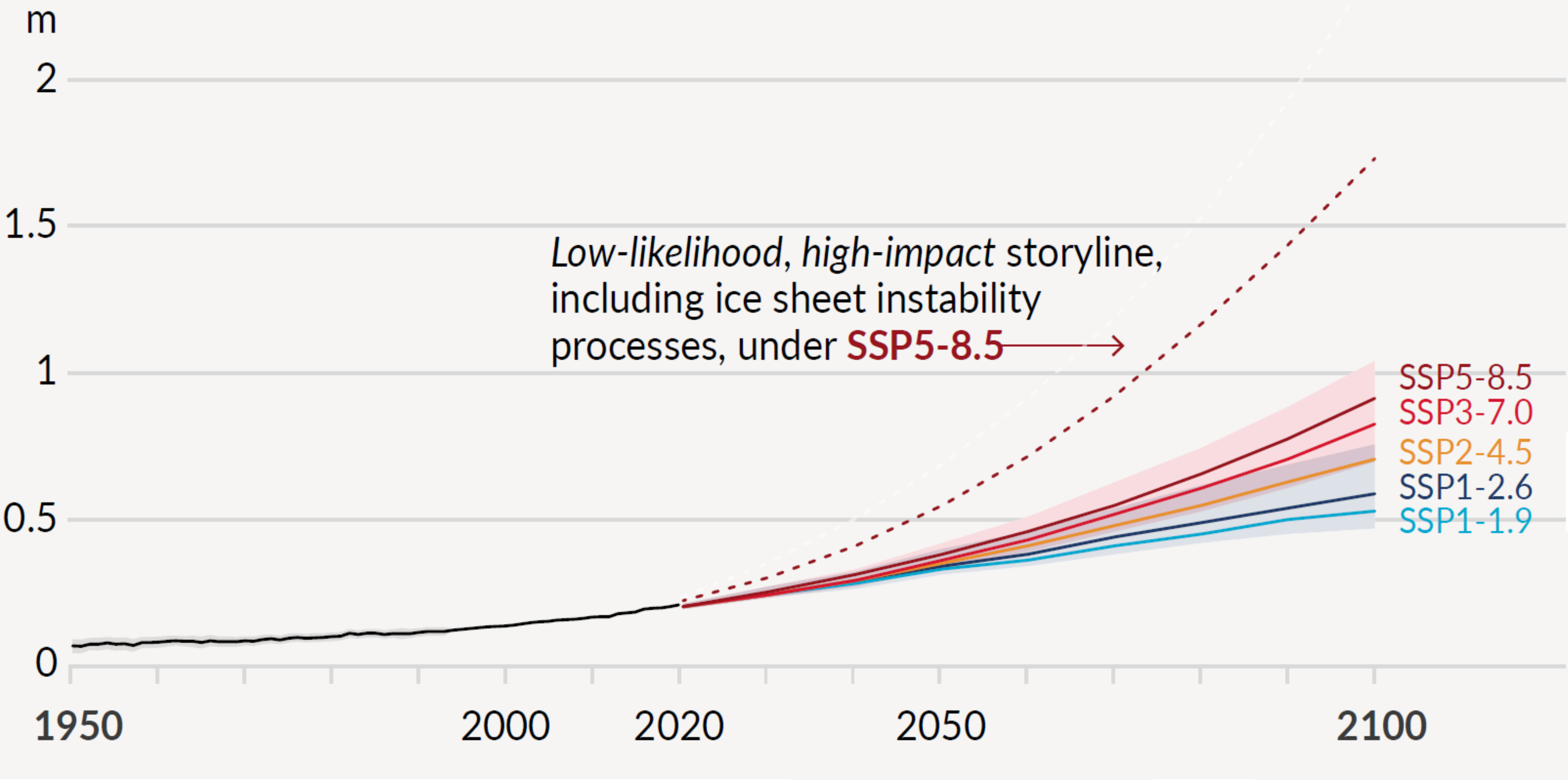
Droughts, Wildfires, Extreme Storms, and Sea Level Rise





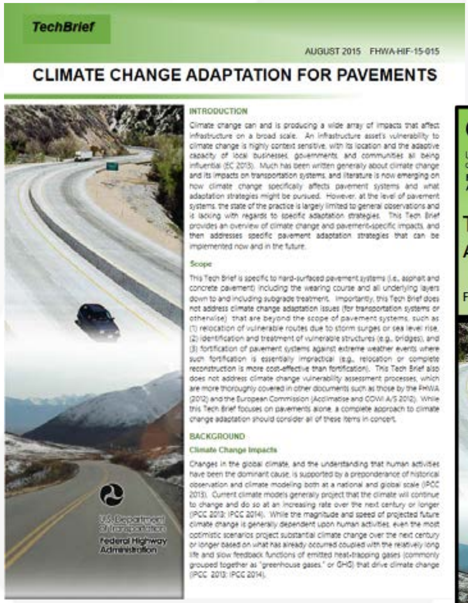
- Droughts and Wildfires
  - Possible increase in chronic, long-duration drought
  - Increased large forest fire incidence in Western U.S.
- Extreme storms
  - Increase in tropical cyclone intensity and frequency
  - Tornado activity becomes more variable and unpredictable
  - Winter storm activity becomes more variable and unpredictable
- Sea level rise
  - Increase in depth, frequency, and extent of tidal flooding
  - Increase in frequency and extent of flooding during costal storms

Projected Sea Level Rise



FHWA Sustainable Pavements: Work Products

- Sustainable Pavements Program Roadmap
- Toward Sustainable Pavement Systems: A Reference Document
- LCA framework document
- Tech briefs
- Case studies


TechBrief

AUGUST 2015 FHWA-HIF-15-015

CLIMATE CHANGE ADAPTATION FOR PAVEMENTS

INTRODUCTION

Climate change can and is producing a wide array of impacts that affect infrastructure on a broad scale. An infrastructure asset's vulnerability to climate change is highly context sensitive, with its location and the adaptive capacity of local businesses, governments, and communities all being influential (EC 2013). Much has been written generally about climate change and its impacts on transportation systems, and literature is now emerging on how climate change specifically affects pavement systems and what adaptation strategies might be pursued. However, at the level of pavement systems, the state of the practice is largely limited to general observations and is lacking with regards to specific adaptation strategies. This Tech Brief provides an overview of climate change and pavement-specific impacts, and then addresses specific pavement adaptation strategies that can be implemented now and in the future.

Scope

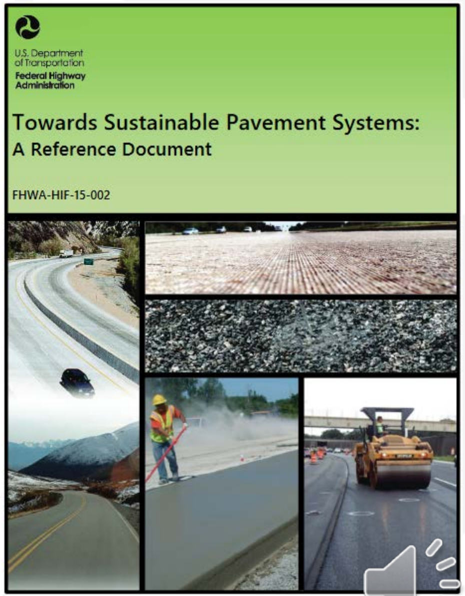
This Tech Brief is specific to hard-surfaced pavement systems (i.e., asphalt and concrete pavement) including the wearing course and all underlying layers down to and including subgrade treatment. Importantly, this Tech Brief does not address climate change adaptation issues (for transportation systems or otherwise) that are beyond the scope of pavement systems, such as (1) relocation of vulnerable routes due to storm surges or sea level rise, (2) identification and treatment of vulnerable structures (e.g., bridges), and (3) fortification of pavement systems against extreme weather events where such fortification is essentially impractical (e.g., relocation or complete reconstruction is more cost-effective than fortification). This Tech Brief also does not address climate change vulnerability assessment processes, which are more thoroughly covered in other documents such as those by the FHWA (2012) and the European Commission (Acclimatise and COWI A/S 2012). While this Tech Brief focuses on pavements alone, a complete approach to climate change adaptation should consider all of these items in concert.

BACKGROUND

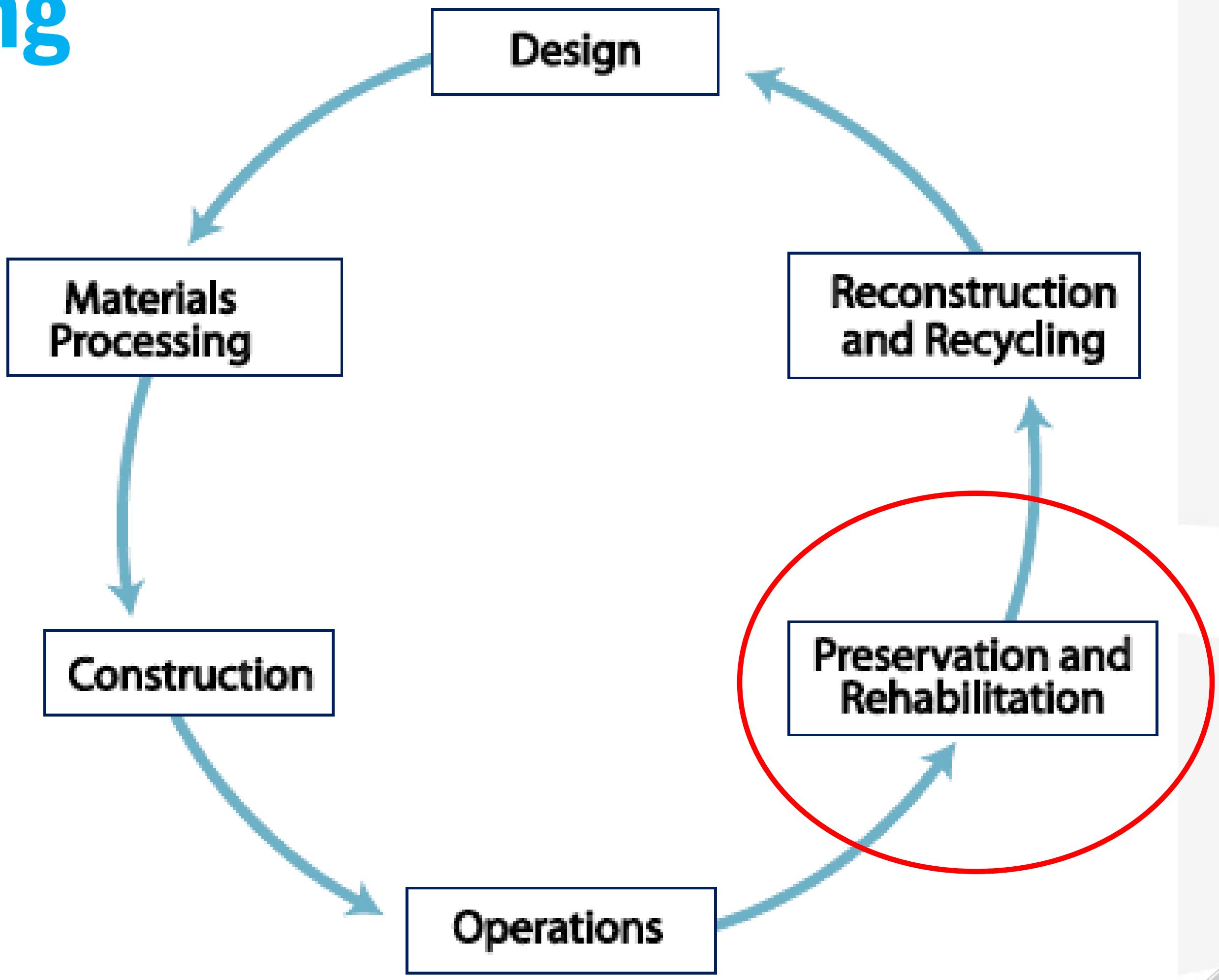
Climate Change Impacts

Changes in the global climate, and the understanding that human activities have been the dominant cause, is supported by a preponderance of historical observation and climate modeling both at a national and global scale (IPCC 2013). Current climate models generally project that the climate will continue to change and do so at an increasing rate over the next century or longer (IPCC 2013; IPCC 2014). While the magnitude and speed of projected future climate change is generally dependent upon human activities, even the most optimistic scenarios project substantial climate change over the next century or longer based on what has already occurred coupled with the relatively long life and slow feedback functions of emitted heat-trapping gases (commonly grouped together as "greenhouse gases," or GHG) that drive climate change (IPCC 2013; IPCC 2014).

U.S. Department of Transportation
Federal Highway Administration



Sustainable Solutions Require Life-Cycle Thinking



How Does Concrete Preservation Impact Climate Change?

- Extending the life of a concrete pavement reduces GHG emissions associated with construction over the life cycle
- Keeping smooth pavements smooth reduces vehicle GHG emissions
- Grinding a carbonated concrete surface will sequester additional CO_2

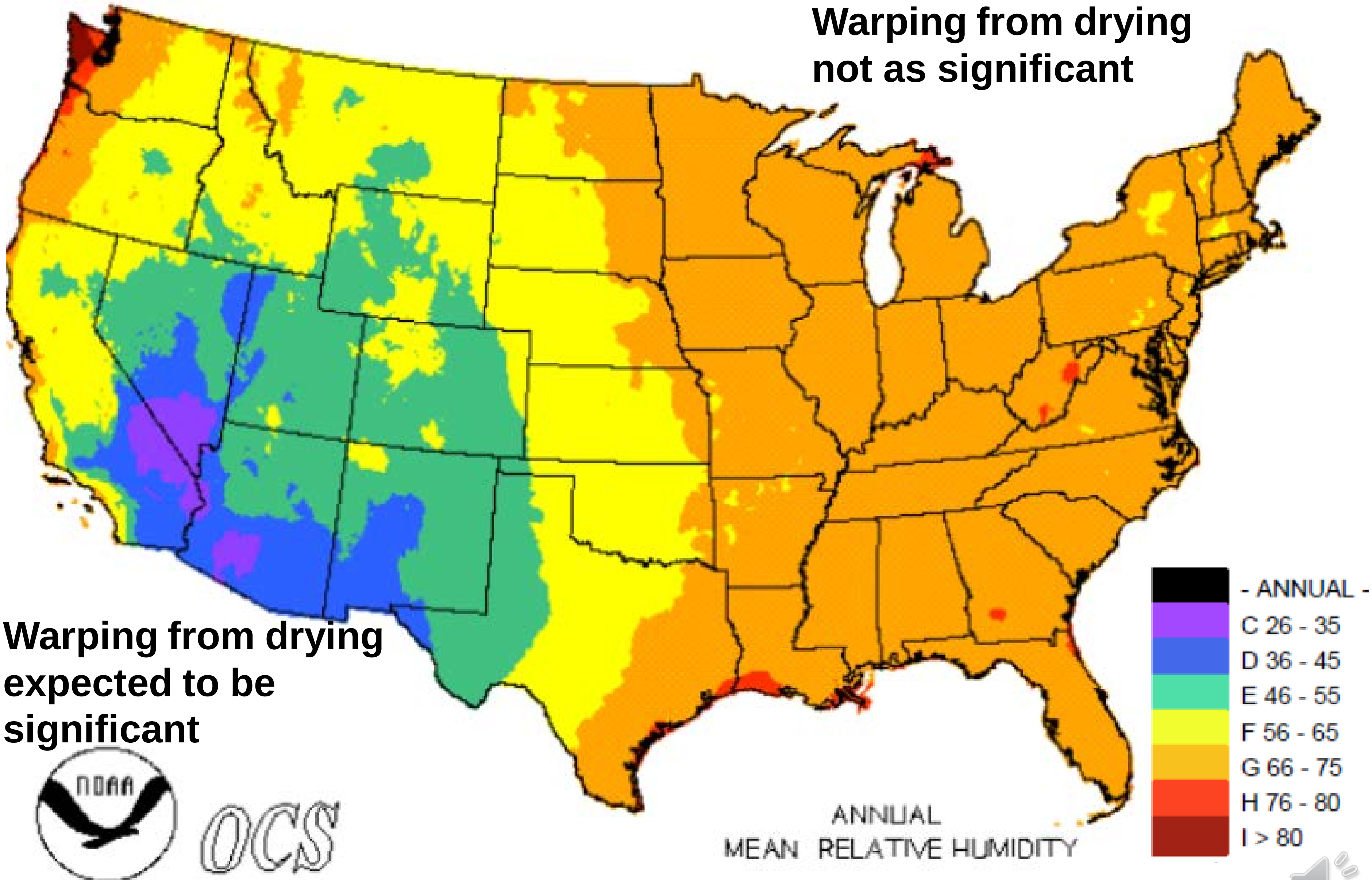
Benefits of Extended Pavement Life

- Reduction in material acquisition, processing, and construction
- Reduction in congestion due to major reconstruction
  - Results in reduced GHG emissions
- These benefits are significant and quantifiable over the life cycle

Ride Quality and Concrete Pavements

- Concrete pavements are being constructed with improved ride quality
- Over time, ride quality decreases for many reasons
  - Distress development (cracking, faulting, spalling)
  - Slab curvature due to temperature and moisture gradients

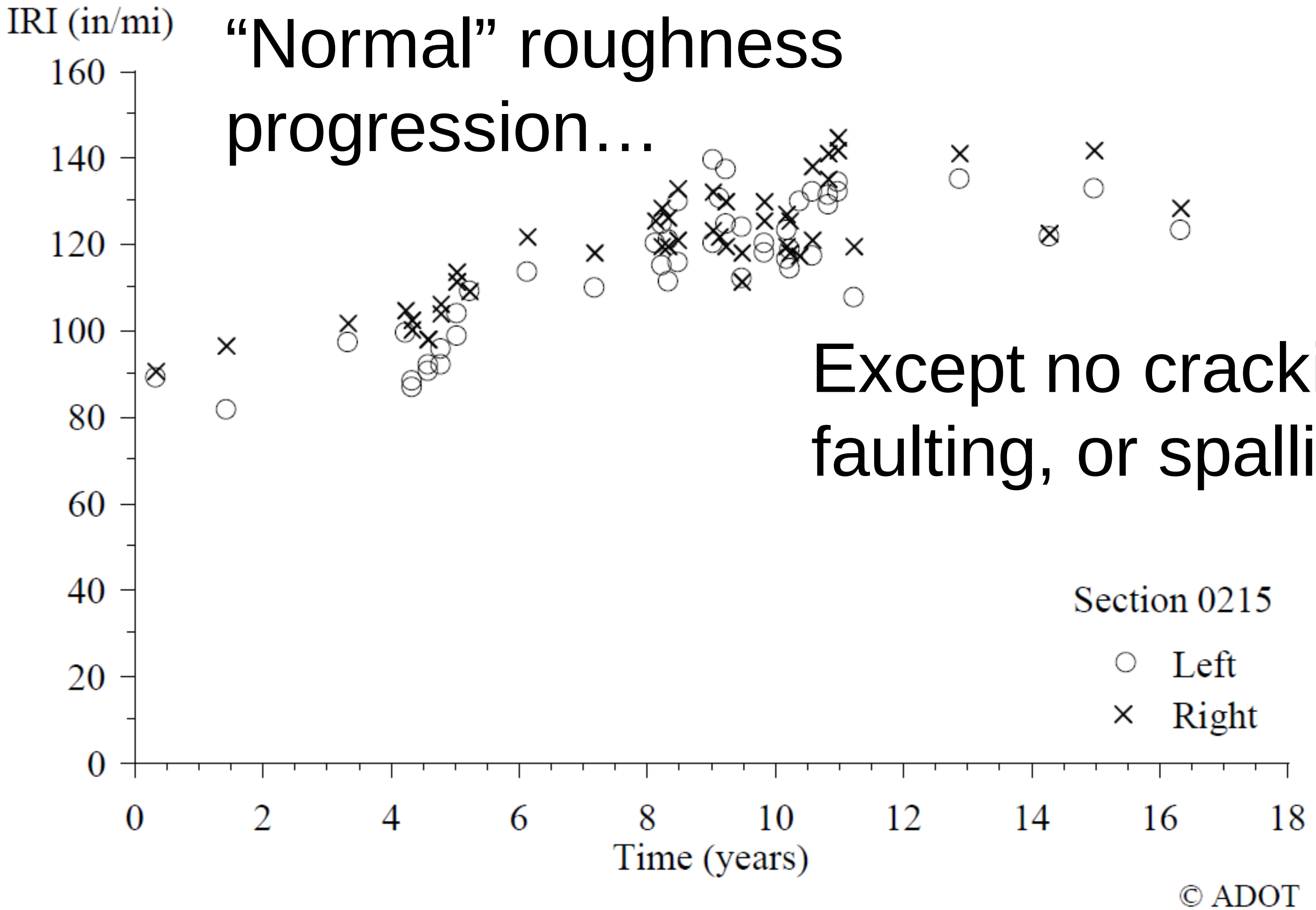
Warping from drying not as significant



Warping from drying expected to be significant

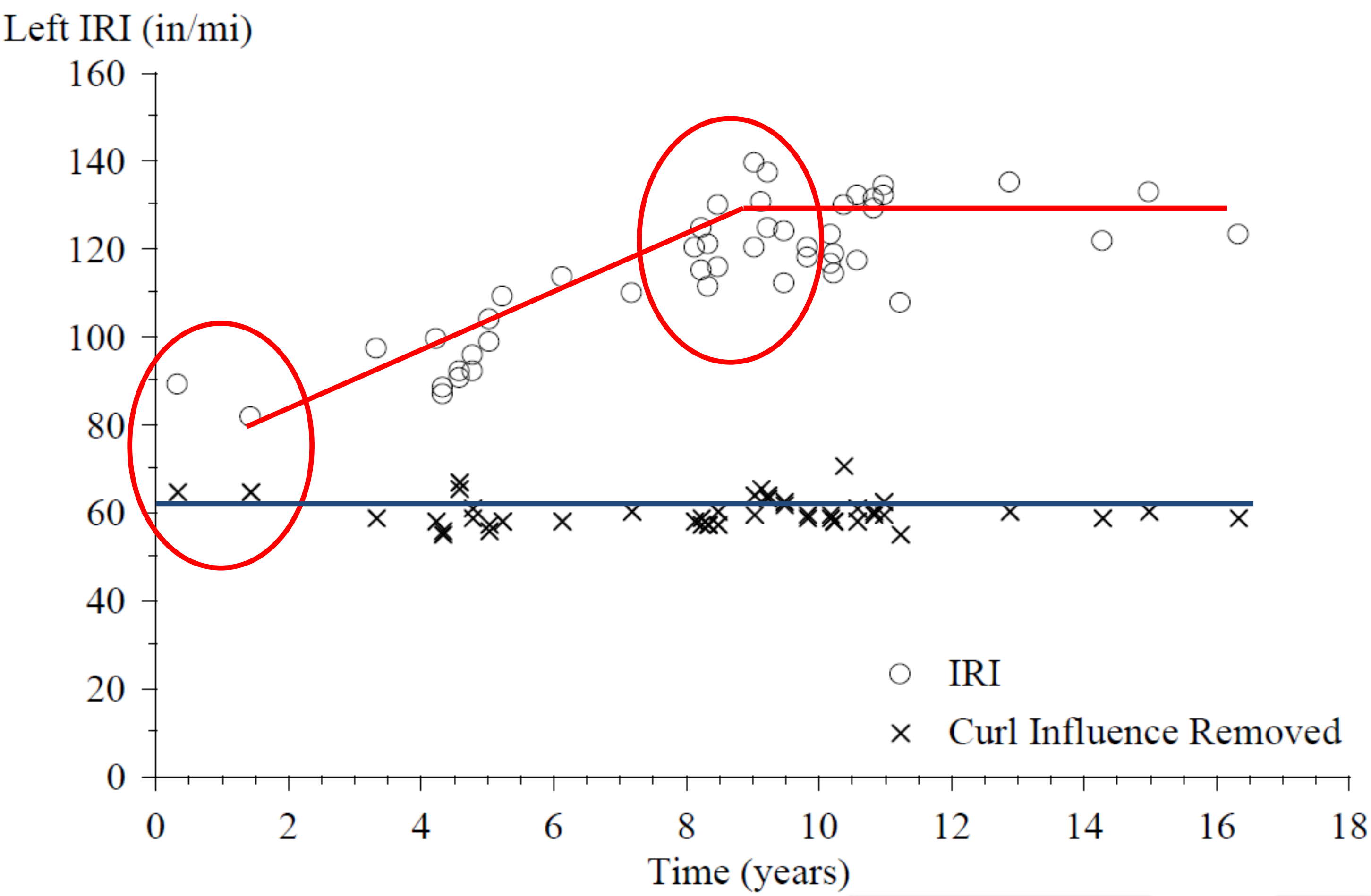
IRI Over Time for LTPP Section 040215 as Part of Arizona SPS-2

"Normal" roughness progression…



Except no cracking, faulting, or spalling

IRI Progression (Section 040215) Left Wheel Path



Pavement Smoothness and Fuel Consumption

- It is well-documented that vehicle fuel efficiency is related to the smoothness of the pavement
  - Smoother pavements result in less fuel consumption and less GHG emissions
  - This is foundational to the World Bank HDM 4 model and has been validated by recent research by NCHRP, Caltrans, and in Europe

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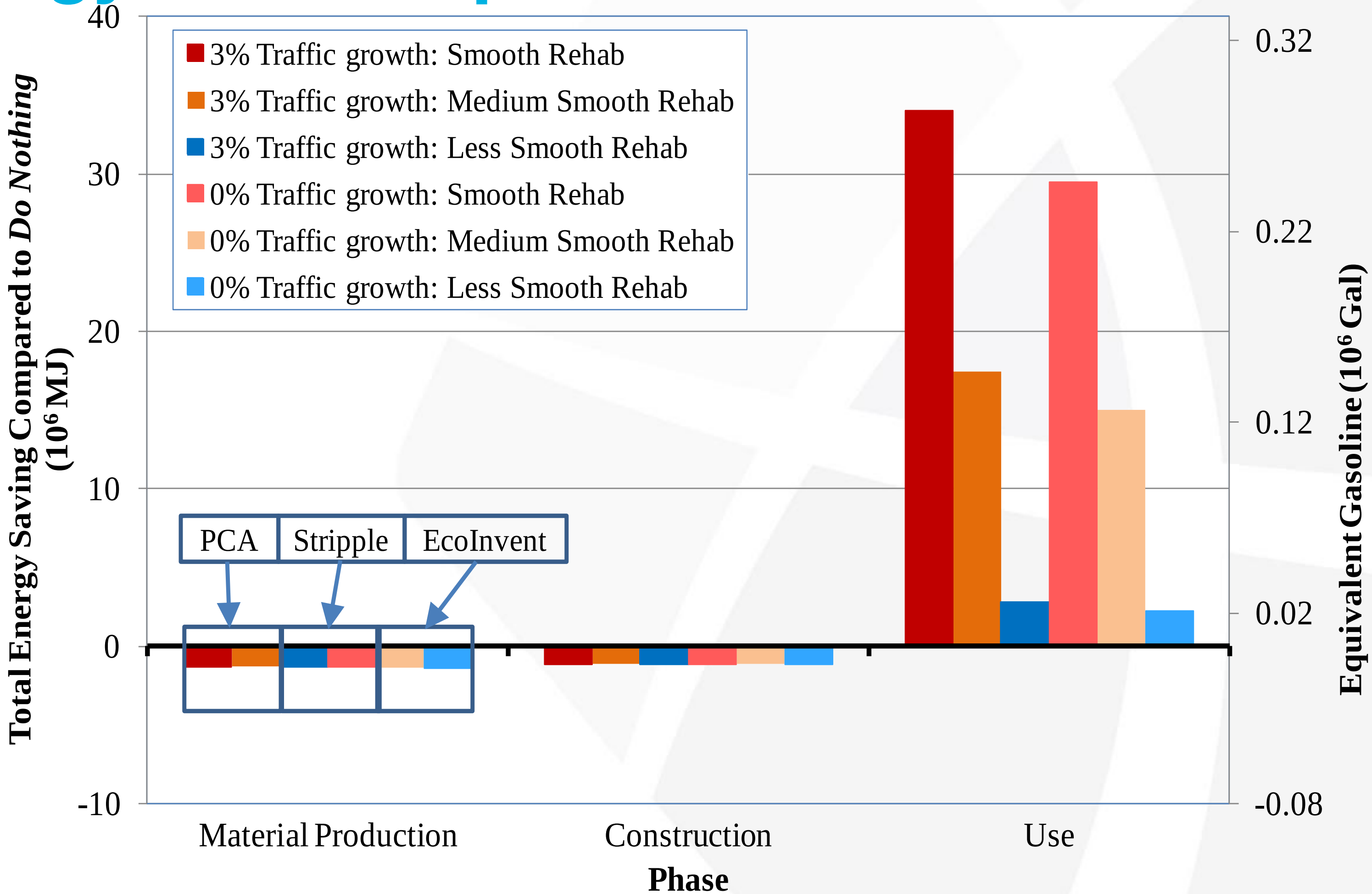
LCA Results: Smooth Pavements Reduce Energy Consumption and Emissions



From Work at UC-Davis: Wang et al. 2012

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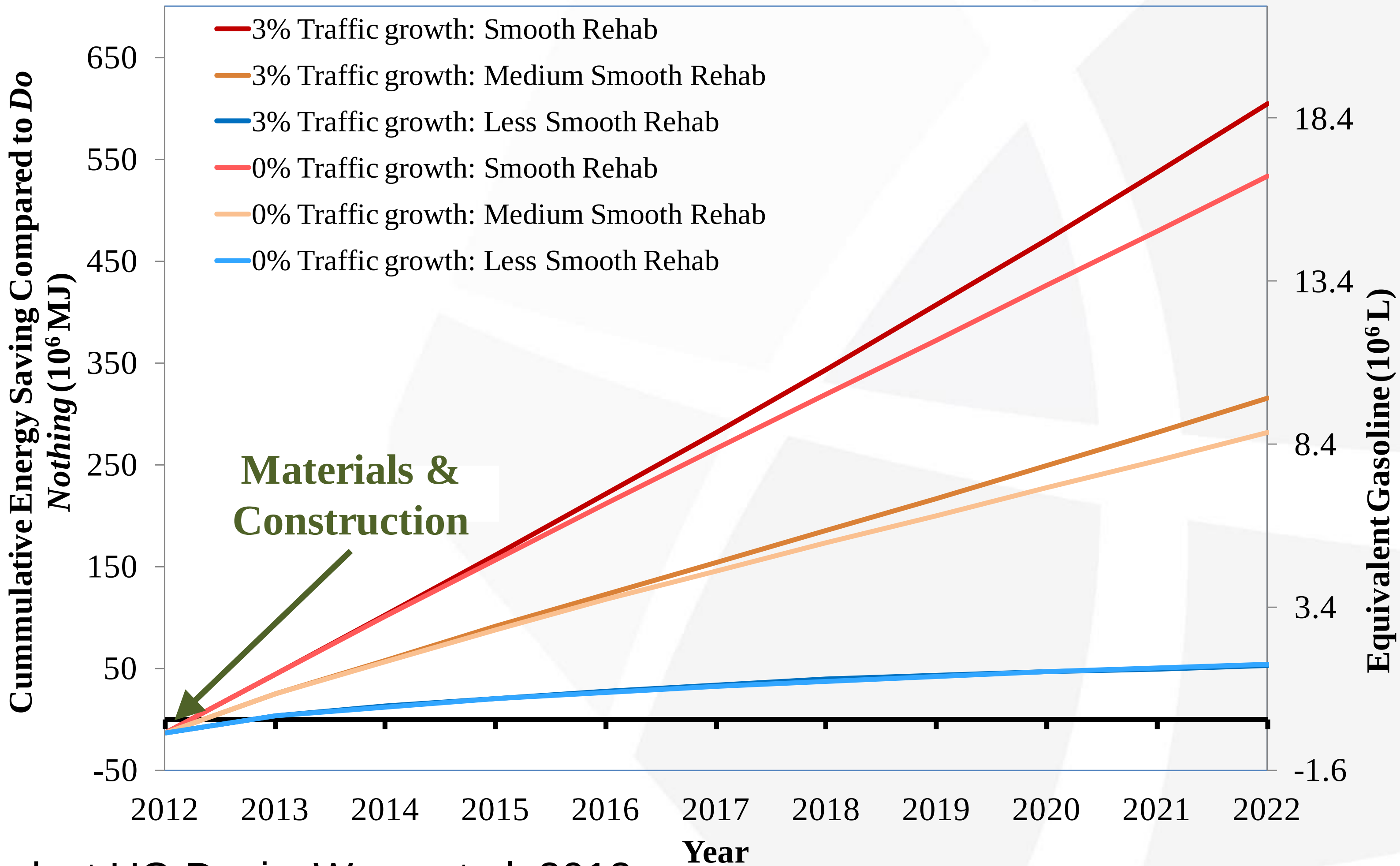
Cumulative Life Cycle Energy Savings



From Work at UC-Davis: Wang et al. 2012

IRI Trigger Values

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

From Work at UC-Davis: Wang et al. 2012

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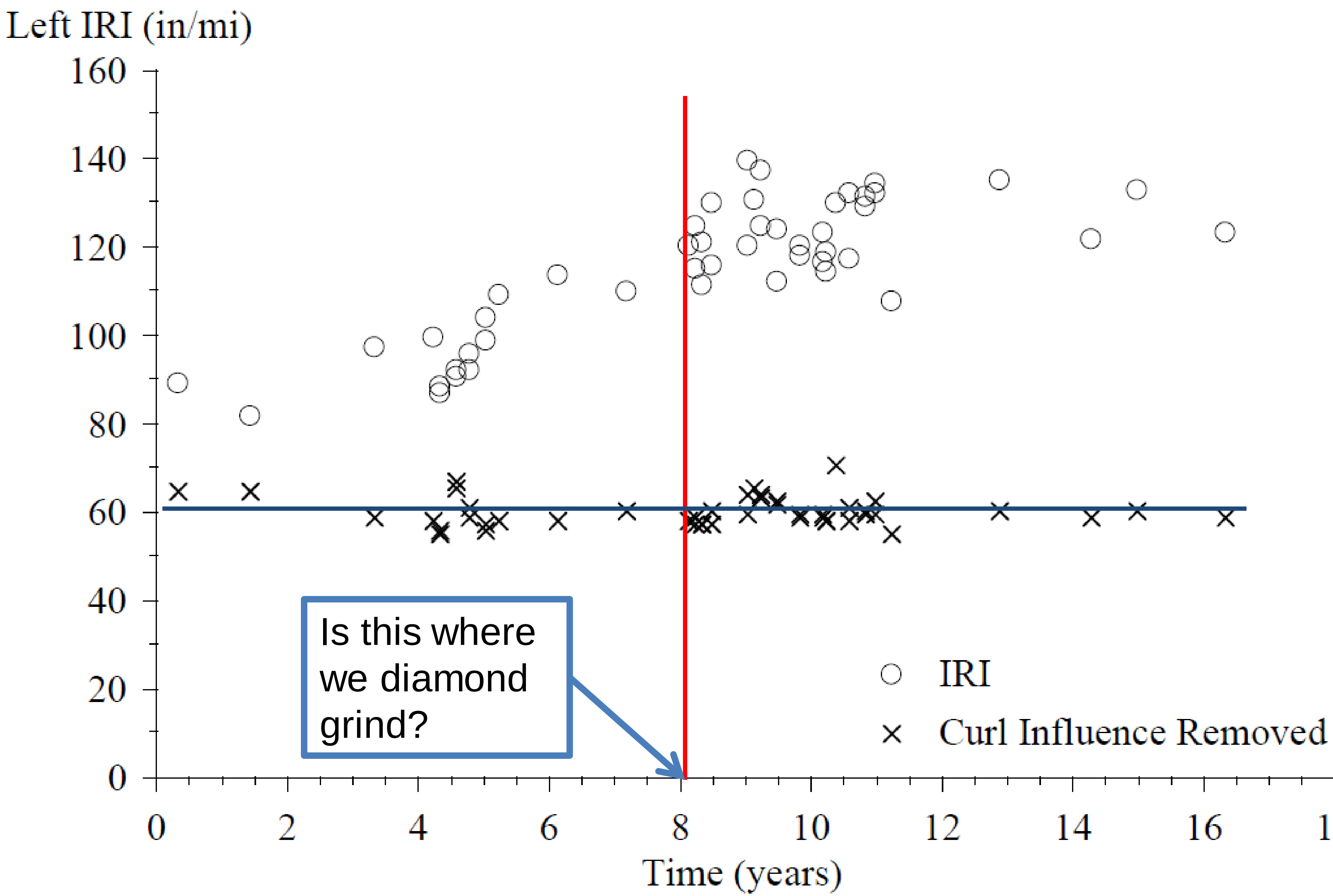
Timing of First Preservation?



What About CO_2 Sequestration Through Carbonation?

- Anderson, et. al. 2019. “Carbonation as a method to improve climate performance for cement based materials. *Cement and Concrete Research* .124 (2019) 105819
- Paper quantifies uptake of CO_2 by concrete through carbonation
  - $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

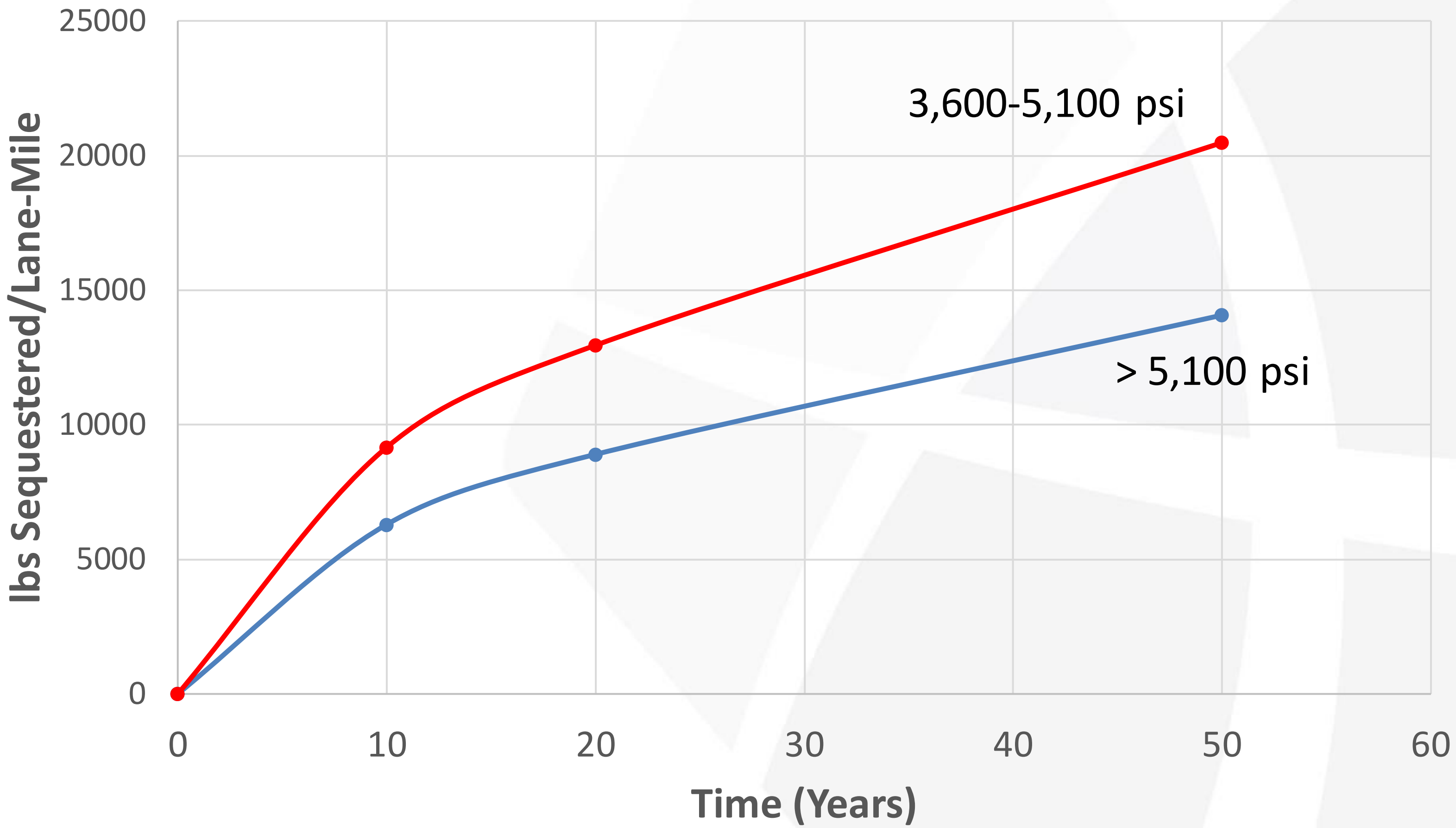
How Much Carbonation Occur in a Typical U.S. Concrete Pavement?

- Depends on exposure and quality of concrete
- Exposure depends on climate (wet or dry) and degree subjected to rain
- Quality of concrete
  - In the paper is related to strength
  - It is permeability that matters
- In general, dry concrete that is permeable (low strength) will have a higher degree of carbonation than wet concrete that has low permeability (high strength)
  - Pavements are typically of higher strength and wet

Applying This to a Typical U.S. Pavement

- Assume 564 lbs/CY pure portland cement mix with a compressive strength of 4000 psi that is exposed to rain
- The amount of CO_2 sequestered through carbonation is calculated to be between 0.2-0.3 lbs/ft^2 of surface area in 50 years
  - Roughly 14,000-20,000 lbs per lane-mile

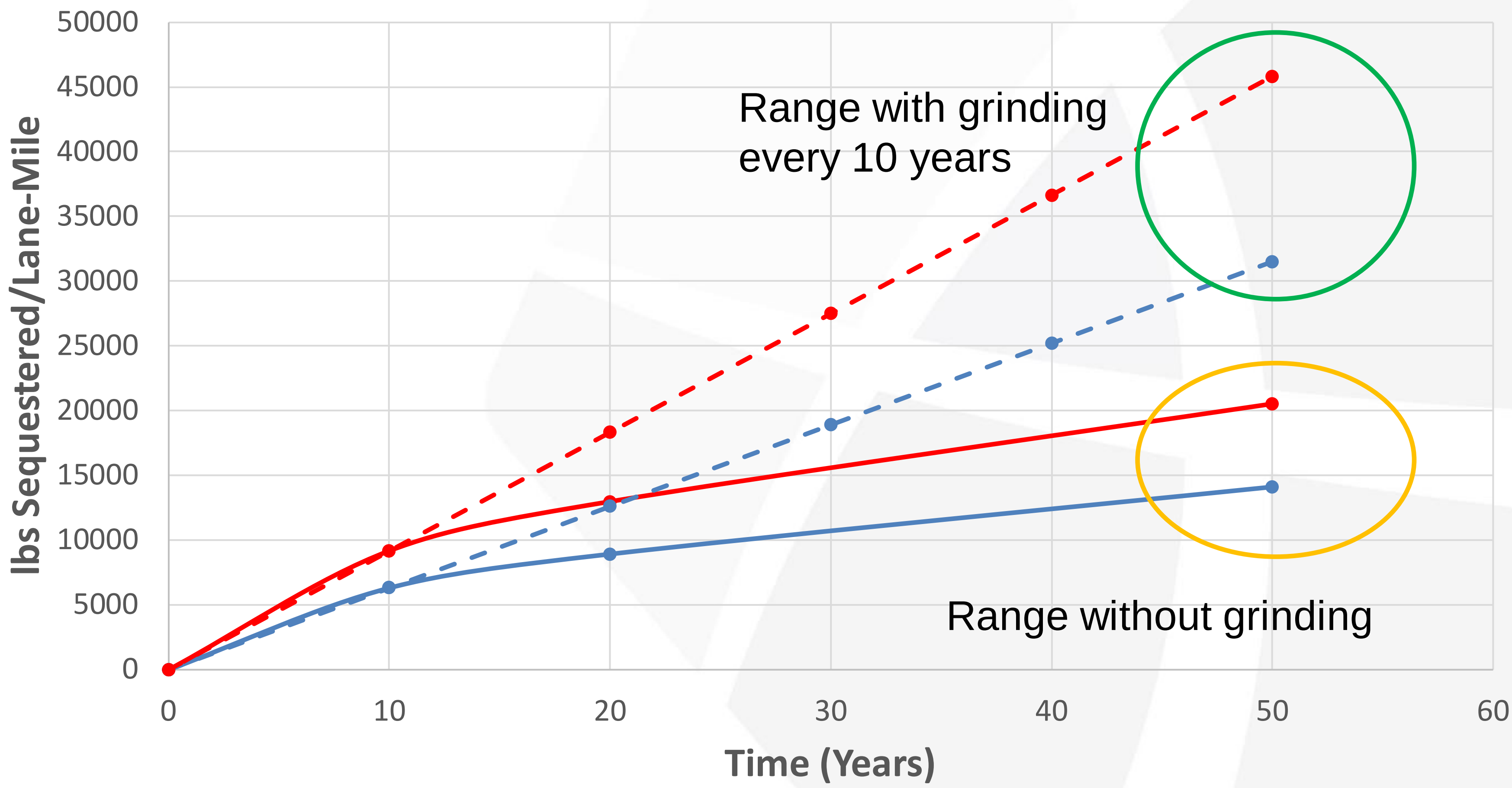
Pounds CO_2 Sequestered Over Time per Lane-Mile



Rate of Sequestration Decreases With Time

- Rate of carbonation related to the square root of time
- Roughly 45% of carbonation over 50 years occurs by Year 10
- Diamond grinding every 10 years will create a fresh surface for carbonation
  - Will more than double the amount of sequestered CO_2
  - Accounting for GHG emissions associated with grinding, likely close to net zero
- Overlaying concrete with asphalt will shut out atmospheric CO_2 and terminate sequestration

Pounds CO_2 Sequestered Over Time per Lane-Mile



Summary

- Climate change is real and anthropogenic GHG are a contributing factor
- Preserving concrete pavements to a high level of serviceability is inherently a sustainable solution
- Vehicles operating on smooth pavements have better fuel efficiency and less GHG emissions
  - Keep smooth pavements smooth
- Grinding concrete surfaces not only makes them smoother but can more than double the amount of CO_2 sequestered

Questions?

Thomas Van Dam, Ph.D., P.E., FACI
Principal
NCE
tvandam@ncenet.com
775-527-0690