Evaluating the Environmental Impacts of Aramid Fiber in Asphalt Mixtures

A Cradle-to-Grave Life Cycle Assessment

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The Road Forward INTERNATIONAL SUMMIT
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Topics for Today

1. Problem & Motivation
2. Introduction to Aramid Fiber
3. Project Summary
4. Results: Global Warming Potential (GWP) & Sensitivity Analysis
5. Field Performance: PCI & Life Extension
6. Conclusions & Takeaways

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Problem & Motivation

- Asphalt mixtures can be a **carbon-intensive** construction material.
- **Extended service life** reduces frequency of energy and material intensive interventions (rehabilitation and/or reconstruction).
- Can **aramid fibers** deliver measurable system-level (cradle-to-grave) environmental benefits?

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Introduction to Aramid Fiber

Introduction

- Fibers (in general) in asphalt mixes have been practiced **since the 1980s.**
  - Polyethylene terephthalate (PET) and polyacrylonitrile (PAN)
- Aramid fiber is a **structural, heat-resistant fiber** that is stronger than steel (i.e.: Kevlar)
- **Engineered (aramid) fibers** are used to improve the mechanical properties of the mixture such as **rutting, cracking, and structural modulus**.
- Adding **aramid fibers** to dense graded mixes can **improve their mechanical performance.**

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Introduction

- **In 2021, Underwood and Zeiada** developed methodology to determine the layer coefficient for an aramid fiber reinforced asphalt mixture.
  - Conservative estimate for the layer coefficient is 0.52 (~20%) with typical asphalt concrete layer coefficient of 0.44.
  - Aramid fibers demonstrated these benefits using FlexPave as compared to a non-fiber control:
    - 14.9% lower damage with a 45.7% reduction in cracking.

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Introduction (continued)

- **In 2021, NCAT** added the following test sections, per agency vote, in the **3-year additive group study** that was extended to 6 years:
  - **Aramid fiber**
  - Plastics
  - Reactive polymers
  - Ground tire rubber
  - SBS (control)

Why Use Aramid Fiber?

- **Primary goal** of adding aramid fibers is to **enhance the mechanical performance in terms of cracking and rutting resistance.** Think of aramid fiber being like **“rebar for asphalt”** keeping it strong, flexible, and dispersed throughout the mixture.
- There are new findings by researchers and manufactures to fill the **gaps** on how to:
  - **Design** asphalt mixtures with aramid fibers
  - **Disperse the aramid fibers** in the mixture to produce a homogeneous material
- **ASTM D8395-23** Standard Specification for Aramid Fiber for Asphalt Mixtures is now available.

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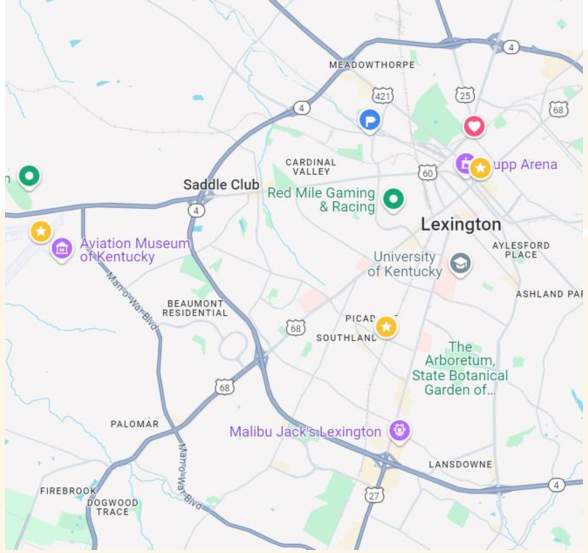
Case Study:
Man O War, Lexington KY

Full Depth & Overlay

Project: Man O' War at LEX Airport 25 cm (10") Intersection



- **Owner:** Lexington-Fayette Urban County Government
- **Contractor:** ATS Construction
- **Description:** Lexington needed an asphalt mixture solution to replace 25 cm (10") concrete intersection. Called on BATT to verify mix and potential solution with aramid fiber.
- **Test Sections** @ 2.1 oz/ton (65.6 g/tonne) aramid fiber + 76-22
  - No intersection control. Did leave 2 lanes near airport turning lane without fiber in the surface (control).
- **Construction:** 2020

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Project Goals and Challenges

- **Replace 10" concrete** intersections at Man O War near Lexington Bluegrass airport (LEX) with asphalt pavement.
- How to design and options:
  - Grid
  - ~~Dig out with extra base,~~
  - Modify asphalt mixture to meet structural need
- Night paving with many lane closure restrictions

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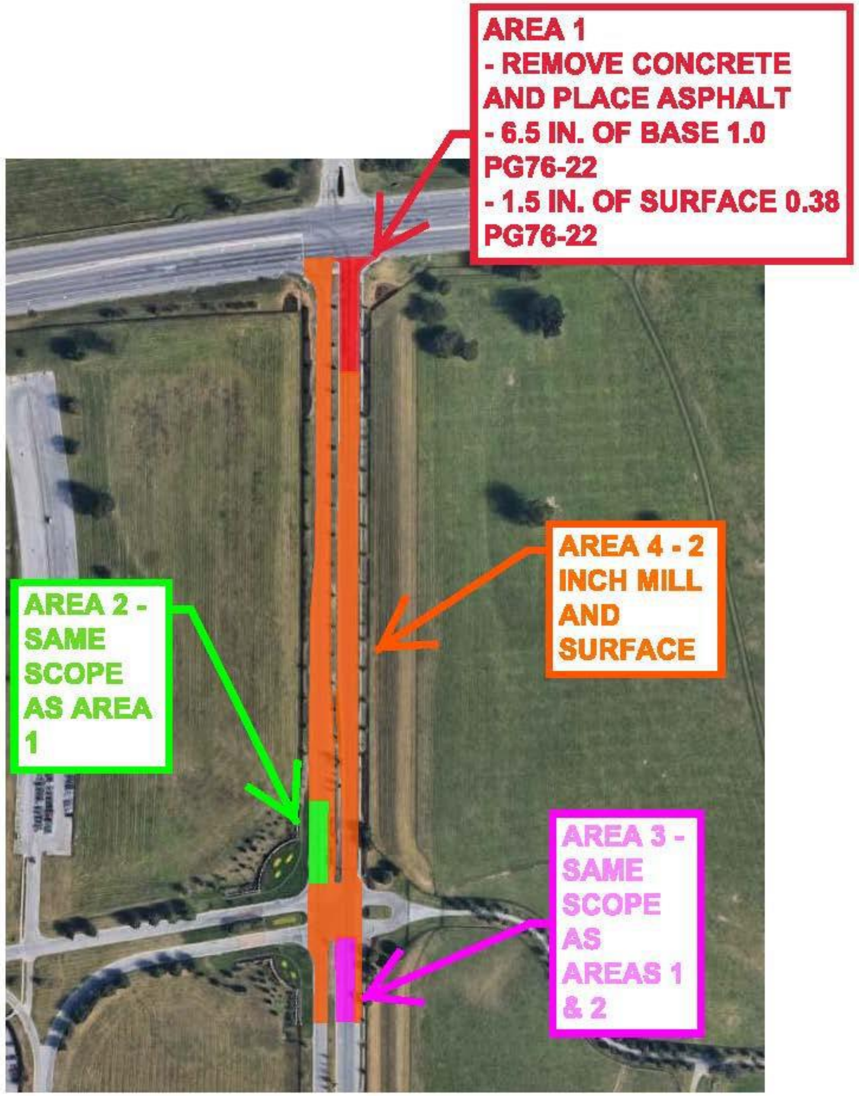
Man O' War Boulevard

- **Tear out of concrete and rebuild** of 10" (25 cm) intersections at LEX airport – HIGH PROFILE
- Mainline is also 10" (25 cm) thick and around 40+ years old. Just **mill and overlay** with 2" (50 mm) HMA
    - Lanes near airport drive did not have fiber for comparison



Pavement Design

Control Section			Aramid Fiber Section		
Pavement Layer	Mix Design Description	Layer Thickness (in)	Pavement Layer	Mix Design Description	Layer Thickness (in)
Surface Course	0.38D (20% RAP)	2	Surface Course	0.38D (20% RAP)	2
Base Course 1	1.0D (20% RAP)	4.0	Base Course 1	1.0D (20% RAP)	4.0
Base Course 2	1.0D (30% RAP)	4.0	Base Course 2	1.0D (30% RAP)	4.0
Aggregate Base		6	Aggregate Base		6
Subgrade		Semi-infinite	Subgrade		Semi-infinite

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Mix Design for Life Cycle Assessment

	0.38D Typical	0.38D with Aramid Fiber	1.0D Typical	1.0D with Aramid Fiber
Upper PG Grade	64	64	64	64
Lower PG Grade	-22	-22	-22	-22
Nominal maximum aggregate size (inches)	0.38	0.38	1	1
Heating	Hot Mix 300F	Hot Mix 300F	Hot Mix 300F	Hot Mix 300F
Percent RAP by Mass (%)	18.88	18.88	28.74	18.88
RAP truck distance (miles)	7.22	7.22	7.22	7.22
Natural Stone - Limestone #8 from Kentucky (% mix by Mass)	18.88	18.88	9.58	18.88
Natural Stone - Limestone #7 from Kentucky (% mix by Mass)	0	0	14.37	0
Natural Stone - Limestone #57 from Kentucky (% mix by Mass)	0	0	23.95	0
Natural Stone - LSS (Washed) from Kentucky (% mix by Mass)	47.2	47.2	19.16	47.2
Natural Stone - Natural Sand from Kentucky (% mix by Mass)	9.44	9.44	0	9.44
Truck Distance for Aggregate (miles)	21.5	21.5	0	21.5
Virgin Binder Content, %	5.6	5.6	4.2	5.6
Truck Distance Virgin Binder (miles)	3.9	3.9	0	3.9
Aramid Fiber from Kentucky (% mix by mass)	0	0.00656	0	0.00656
Sum (% mix by mass)	100	100.01	100	100.01

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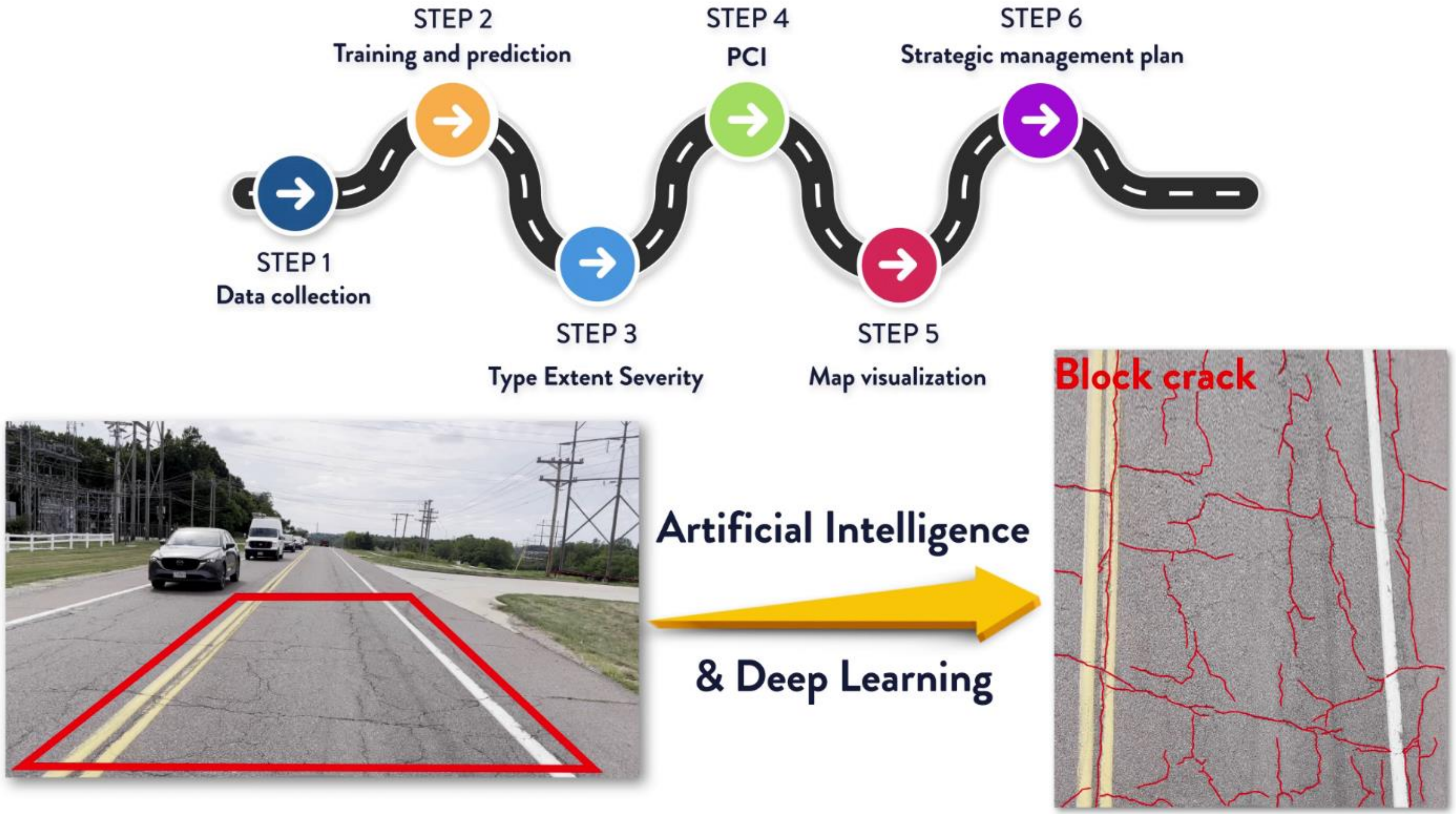
Aramid Fiber Life Extension

BATT Vision PCI Powered by Tiger’s Eye Tech

Pavement Monitoring with AI/Machine Learning



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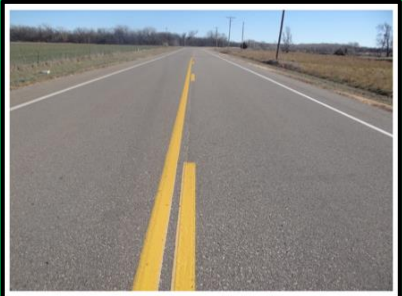
PCI with Suggested Repair Levels

	PCI	PCI	Representative Pavement Surface	Repair Activities
ROUTINE MAINTENANCE	86 - 100	**90**		Pavements with PCI Indexes above 85 or 'Good' may require periodic joint/crack sealing and local patching.
PAVEMENT PRESERVATION	65 - 85	**70**		Pavements with PCI Indexes ranging from 'Satisfactory' to 'Good' may require surface treatments (seal coat, slurry seal, micro surfacing), thin overlays, and/or joint/crack sealing.
MAJOR REHABILITATION	40 - 64	**40**		Pavements that have deteriorated below a PCI of 64, or within the range of 'Poor' to 'Fair' conditions may require major rehabilitation such as pavement mill and overlay, overlay, hot-in-place recycling and overlay, cold-in-place recycling and overlay, or cold central plant recycling and overlay or PCC restoration activity.
MAJOR ONSTRUCTION	0 - 39	**15**		Pavements that have deteriorated below a PCI of 40, or within the range of 'Failed' to 'Very Poor' conditions may require major reconstruction.

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Aramid Fiber Pavement Life Extension

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PCI Summary of 8 Projects

Project Location	Year Constructed	Project Age, Years	2024 Pavement Condition Index (PCI)		Change in PCI Per Year (Linear Fit)		Life Extension Estimate Based on PCI, Years
			Control	Fiber	Control	Fiber	
Beckley Station (Louisville KY, 2015)	2015	10	26	68	-6.3	-3.0	2-3
Stafford Lane (Plainfield IN, 2018)	2018	7	72	85	-4.1	-2.4	2-3
Highway 7 (York Region, Canada, 2018)**	2018	8	53* *PCI measured in 2025*	84* *PCI measured in 2025*	-5.9	-2.0	3-4
Mercer Rd (Lexington KY, 20% vs 45% RAP + fiber/bio oil, 2020)	2020	5	70	83	-6.6	-3.6	2-3
Man O War (Lexington KY, 2020)	2020	5	65	73	-6.6	-5.8	2-3
UPS Facility (Walton KY, 2023)	2023	2	na	93			NA
Loves Truckstop (Sadieville, KY, 2015)	2015	10	70	85	-4.4	-2.0	2-3

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Reference Service Life

- The functional unit is 1 yd^2 of pavement installed in a road for a 50-year analysis period.
- The baseline, unmodified unit of pavement under this study is assumed to have a reference service life (RSL) of 18 years.
- Previous research studies have shown that the addition of aramid fiber will extend the time to pavement intervention. To capture this effect, it is assumed that for each maintenance and rehabilitation cycle, the time to intervention will be 20% longer than conventional asphalt concrete which is conservative based on the estimates previously shown.

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System Boundary for LCA

System Boundary Summary

Product Stage (A1-A3)

Included	Excluded
Extraction and processing of asphalt mixtures, aggregate, and aramid fiber	Creation of supplier facilities
Transportation of materials to the manufacturing location	Manufacturing of supplier operational equipment or transport vehicles
Manufacturing of product, including energy, water, and material usage and water disposal	Packaging of products

Construction

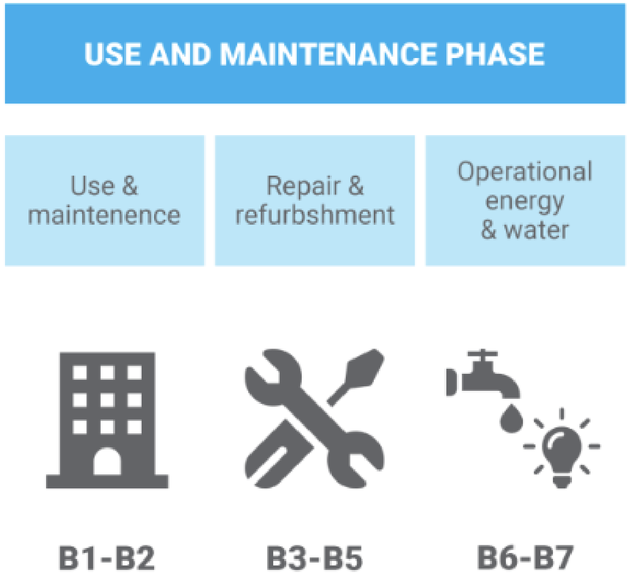
Included	Excluded
Transportation from the manufacturing gate to the customer, including fuel usage	Production of multi-use installation tools
Installation of pavement system in the roadway	Packaging of asphalt mixtures and aggregate

CONSTRUCTION PHASE

Transport to site & installation

A4-A5

Use Phase (B1-B7) - Expected Timeline of Intervention Activity During the 50-year Lifetime



Intervention Cycle and Type		Expected Intervention Year for Baseline Pavement (years)	Expected Intervention Year for Aramid Fiber (years)
Cycle 1	M2 – Minor Reconstruction (Overband crack sealing and microsurfacing)	6.5	8
Cycle 2	M1 – Major Reconstruction (Cold Milling and Overlay)	11.5	13.5
Cycle 3	R1 – Major Reconstruction (HMA Reconstruct)	15	18
Cycle 1	M2 – Minor Reconstruction (Overband crack sealing and microsurfacing)	22	26.5
Cycle 2	M1 – Major Reconstruction (Cold Milling and Overlay)	26.5	32
Cycle 3	R1 – Major Reconstruction (HMA Reconstruct)	30.5	36
Cycle 1	M2 – Minor Reconstruction (Overband crack sealing and microsurfacing)	37	44.5
Cycle 2	M1 – Major Reconstruction (Cold Milling and Overlay)	41.5	
Cycle 3	R1 – Major Reconstruction (HMA Reconstruct)	45.5	

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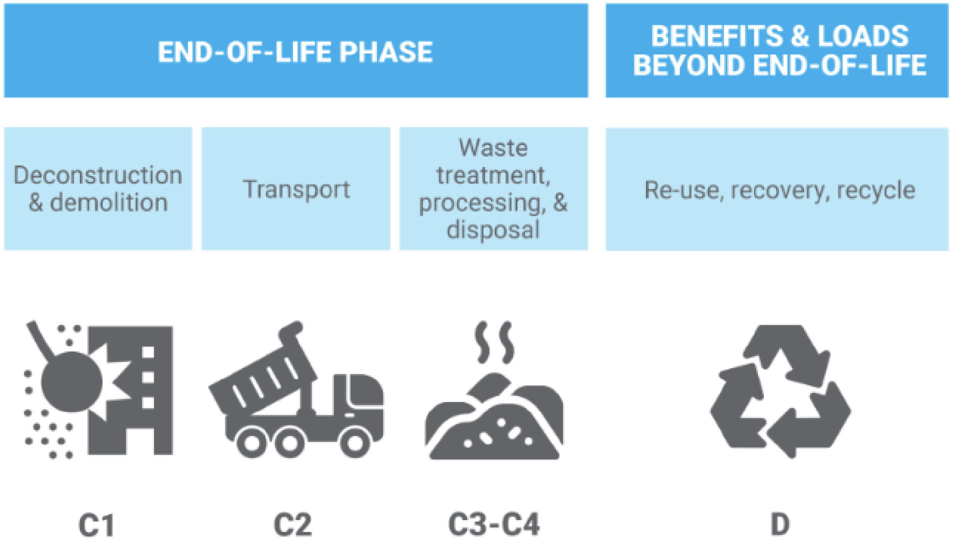
End of Life Phase (C1-C4)



Included	Excluded
Energy and materials required for deconstructing the product	Production of end-of-life capital equipment and facilities
Transportation of the product to the end-of-life facility	
Waste and processing for reuse, recycling, energy recovery, and/or reclamation	

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Life Cycle Assessment

Life Cycle Impact Assessment

- Environmental impacts for each mix design were calculated using the NAPA Emerald Ecolabel software platform.
- Impact results for Global Warming Potential (GWP) 100 years, includes biogenic CO_2 have been calculated using TRACI 2.1.

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Scope & Functional Unit

- Cradle-to-Grave LCA of pavement system with and without aramid fiber.
- Functional Unit: 1 yd^2 installed pavement over a 50-year analysis period.
- Intervention Schedule: +20% time to intervention with aramid fiber.

Cradle-to-Gate

Indicator	A1 – A3 without aramid fiber	A1 – A3 with aramid fiber
GWP, kg CO_2 eq	31.72	31.92

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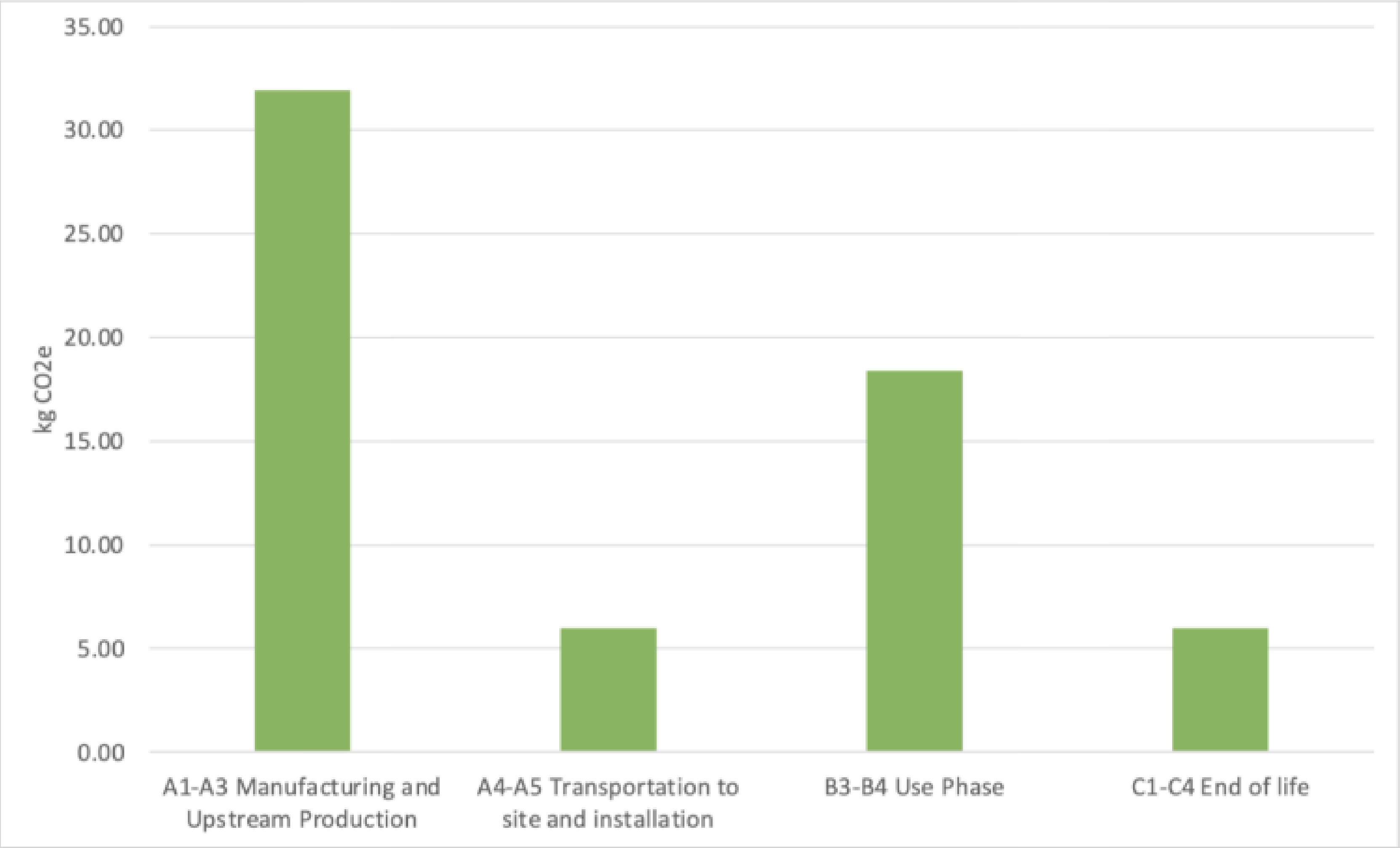
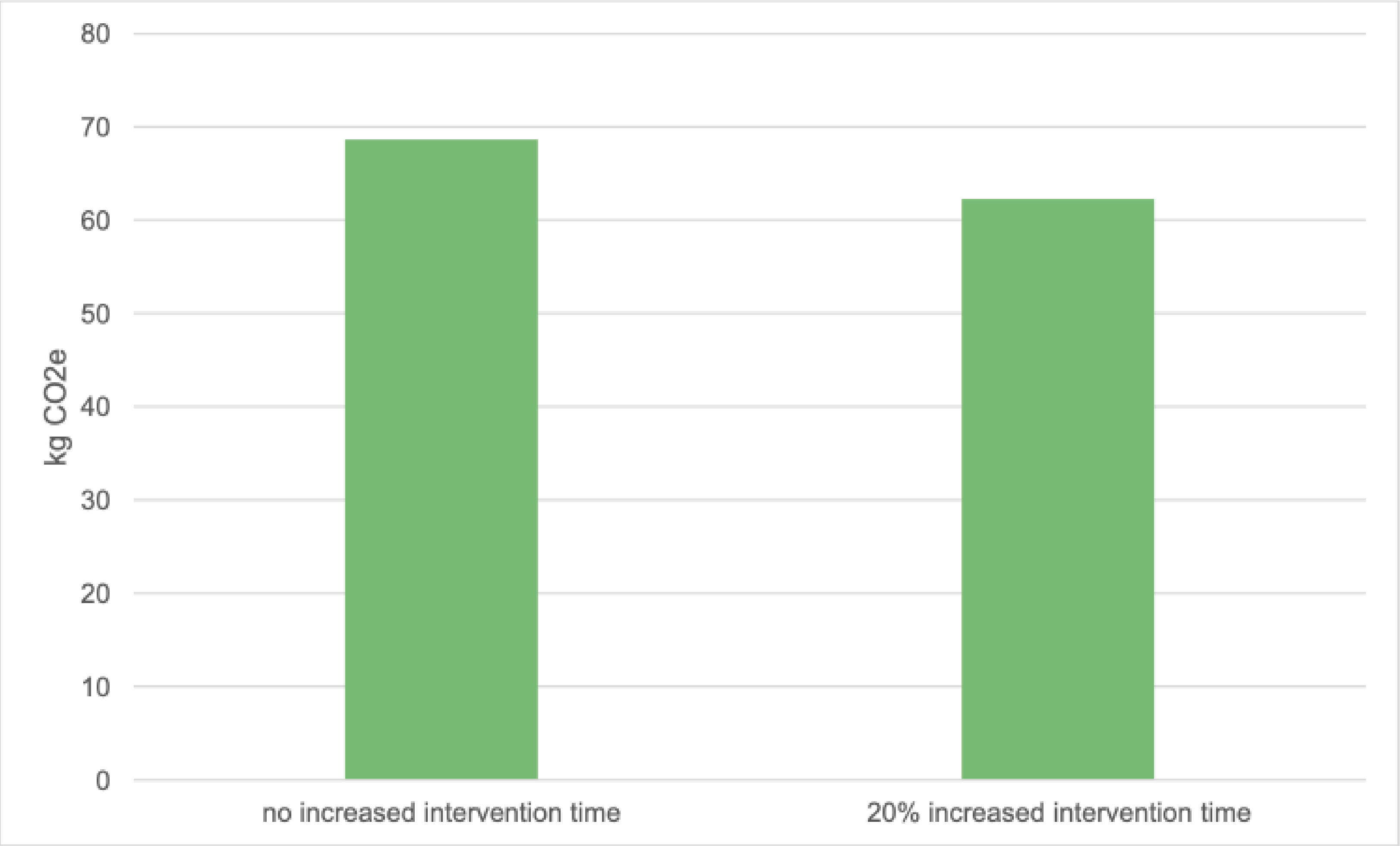
GWP Separated by System Boundary – Aramid Fiber



GWP Comparison

Indicator	20% Longer Intervention Time
GWP, kg CO_2 eq	-10%



Field Performance

BATT Vision PCI Powered by Tiger's Eye Tech

Man O War Field Performance

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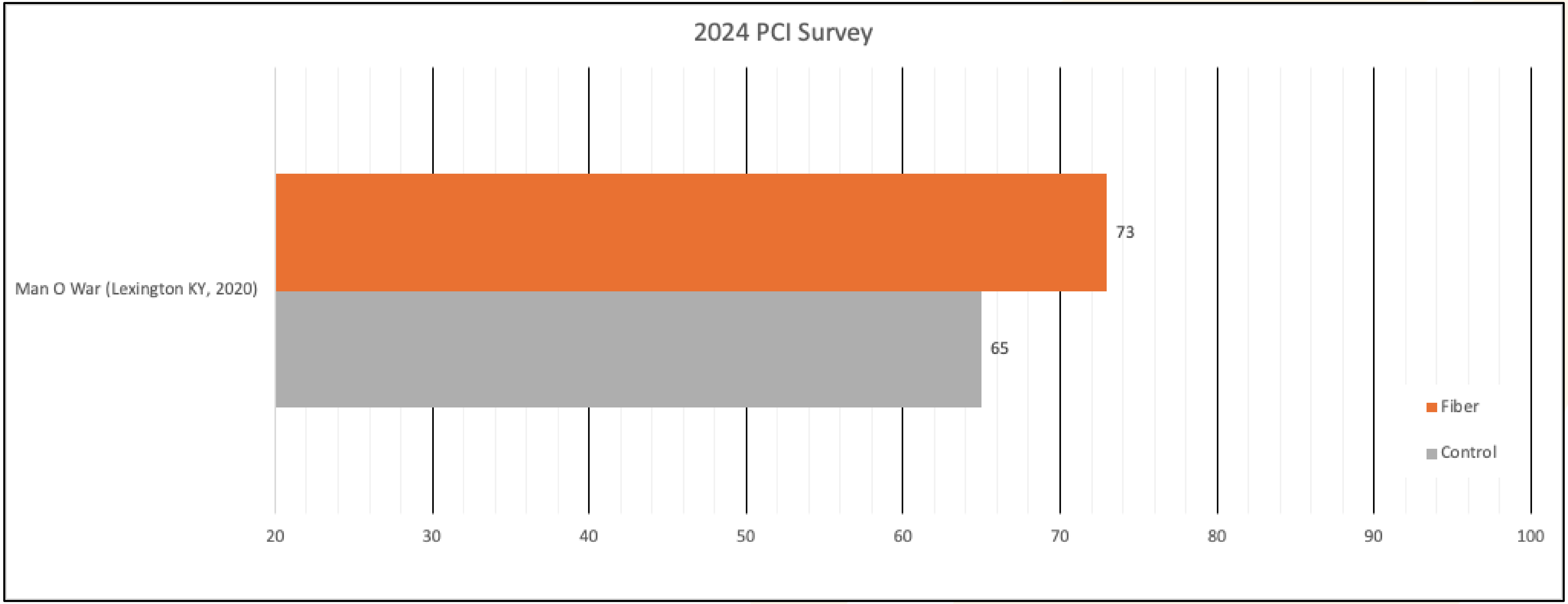
PCI Summary


2024 PCI Survey
Man O War (Lexington KY, 2020)
73
65
Fiber
Control
20
30
40
50
60
70
80
90
100

Summary

- Key findings include:
  - Aramid fiber inclusion has negligible impacts on A1-A3 phases on a mass and GHG basis, and
  - Extended pavement service life reduces cradle-to-grave impacts (10% reduction) by minimizing maintenance and rehabilitation operations when using aramid fiber.

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