Athena Sustainable Materials Institute

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Concrete Pavement LCA & LCCA
A Manitoba Case Study

Assessing potential life cycle strategies

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Authors and Overview

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- Evaluated base case PCC roadway design and 10 scenarios
  - LCA via Athena's Pavement LCA software
    - Materials, Construction, M&R and Use phase LC effects
  - LCCA via spreadsheet model
    - Agency and User cost (PVI - pavement vehicle interaction)

Athena Pavement LCA

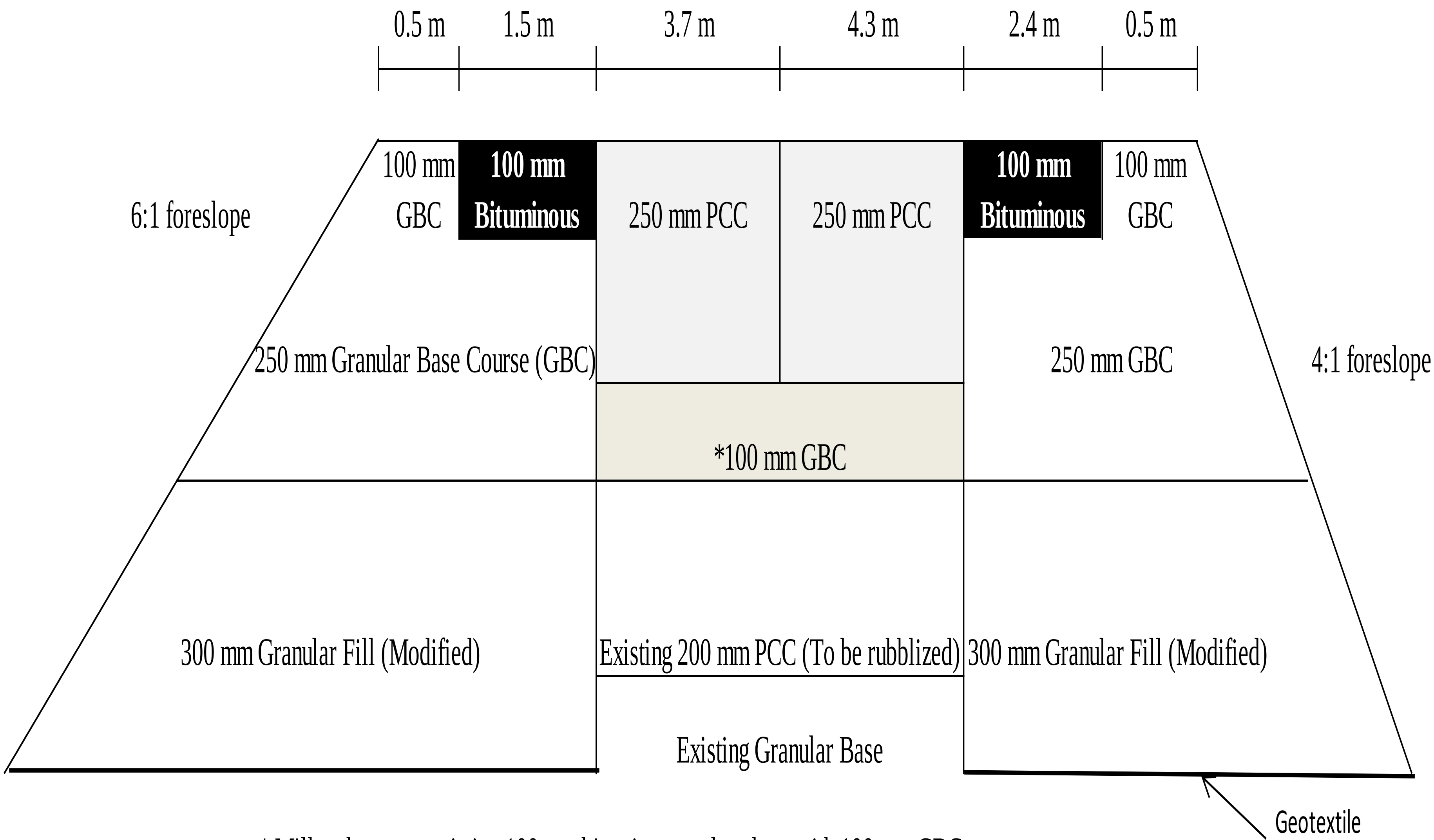
Objectives

- Complete retrospective analysis of past practice
  - MI recently changed PCC design specs, what's been achieved
- What are the cost implications of greening MI's PCC roadway designs?
- Investigate what else can be done to improve the LC environmental, cost and performance of MI's PCC roadways

Case Study: Project Description

- Manitoba PTH 75 pavement re-constructed in 2015
  - Northbound side of four lane divided highway
  - Total length = 11.02 km
  - Traffic data: AADT = 3,900 (1-way), heavy vehicles (trucks) 650/day, annual traffic growth = 2%
- Prior pavement = 100 mm AC, 200 mm PCC and 125 mm granular base
  - Pre-construction: Mill existing AC and rubblize existing PCC
- Construction: 100 mm granular base and 255 mm PCC
  - Diamond grind the new PCC (5 mm loss)
  - AC (100 mm) and gravel surfaced shoulders

Roadway Cross Section (not to scale)



* Mill and remove existing 100 mm bituminous and replace with 100 mm GBC

Manitoba PCC Pavement Life Cycle Strategy

Item	Activity	Quantity	Year
1	New or Re-Construction	100%	0
2	Concrete Partial Depth Repairs	2% Surface Area	15
3	Concrete Partial Depth Repairs	5% Surface Area	25
4	Concrete Full Depth Repairs	10% Surface Area	25
5	Diamond Grinding	100% Surface Area	25
6	Concrete Partial Depth Repairs	5% Surface Area	40
7	Concrete Full Depth Repairs	15% Surface Area	40
8	Diamond Grinding	100% Surface Area	40
9	Salvage Value	5 Years of Service Life (1/3 of Items 7 plus 8)	50

Base Case & Alternative Scenarios

Case #	Case Description	Analysis Rationale
Base	355 kg cementitious, 15% fly ash, 0% slag, 276 tonnes steel and regular M & R	Impacts of past practice
1	355 kg cementitious, 20% fly ash, 0% slag, 276 tonnes steel and regular M & R	Effect of additional fly ash
2	355 kg cementitious, 15% fly ash, 25% slag, 276 tonnes steel and regular M & R	Effect of slag/ternary mix
3	307 kg cementitious, 15% fly ash, 0% slag, 276 tonnes steel and regular M & R	Effect of tarantula optimization
4	355 kg cementitious, 15% fly ash, 0% slag, 126 tonnes steel and regular M & R	Effect of reduced steel
5	307 kg cementitious, 20% fly ash, 0% slag, 276 tonnes steel and regular M & R	Combined effect of reduced cementitious and increased fly ash

Alternative Scenarios (cont'd)

Case #	Case Description	Analysis Rationale
6	307 kg cementitious, 20% fly ash, 0% slag, 126 tonnes steel and regular M & R	Combined effect of reduced cementitious and steel, and increased fly ash (new MI spec.)
7	307 kg cementitious, 20% fly ash, 25% slag, 126 tonnes steel and regular M & R	Combined effect of new MI spec. and slag/ternary mix
8	307 kg cementitious, 20% fly ash, 25% slag, 126 tonnes steel and Extended M & R	Effect of extended M and R
9	355 kg cementitious, 15 % fly ash, 0% slag, 0 steel, TCP, regular M&R	Effect of thin concrete panel (TCP) 200mm thickness
10	307 kg cementitious, 15 % fly ash, 25% slag, 0 steel, TCP, extended M&R	Effect of reduced cementitious, TCP, ternary mix and extended M&R

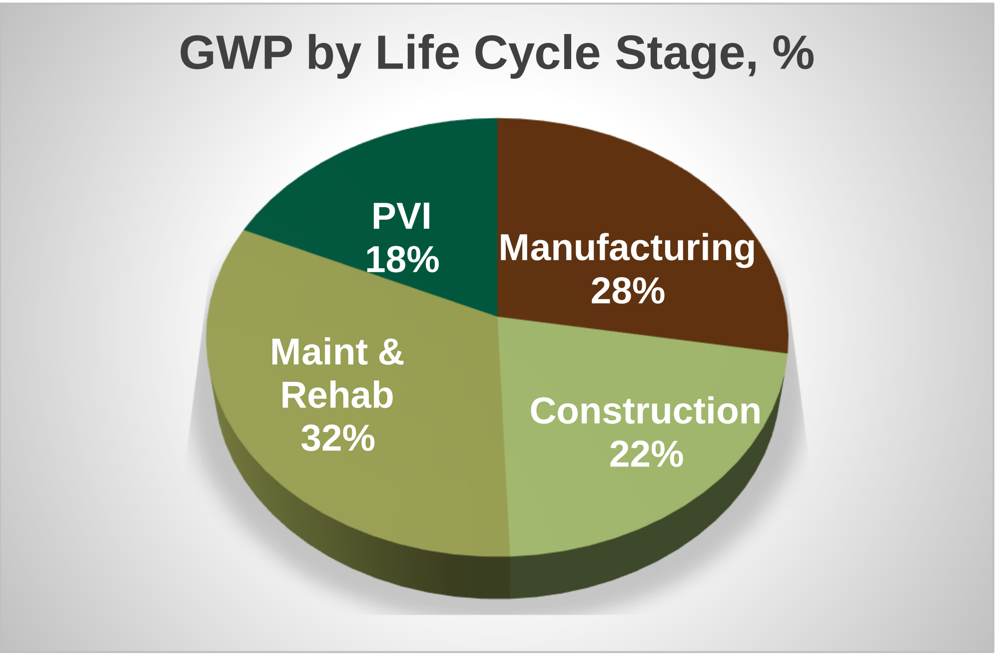
Pavement Vehicle Interaction (PVI)

- Calculating effects of increased fuel consumption due to roughness and deflection between major rehabilitations

- PVI Parameters:
  - Vehicle operating speed = 100 km/h
  - Initial international roughness index (IRI) = 0.665 m/km (after re-construction)
  - Pre diamond ground (terminal) IRI = 2.5 m/km
  - Post diamond ground IRI = 1.0 m/km
  - Thickness loss per diamond grind = 5 mm

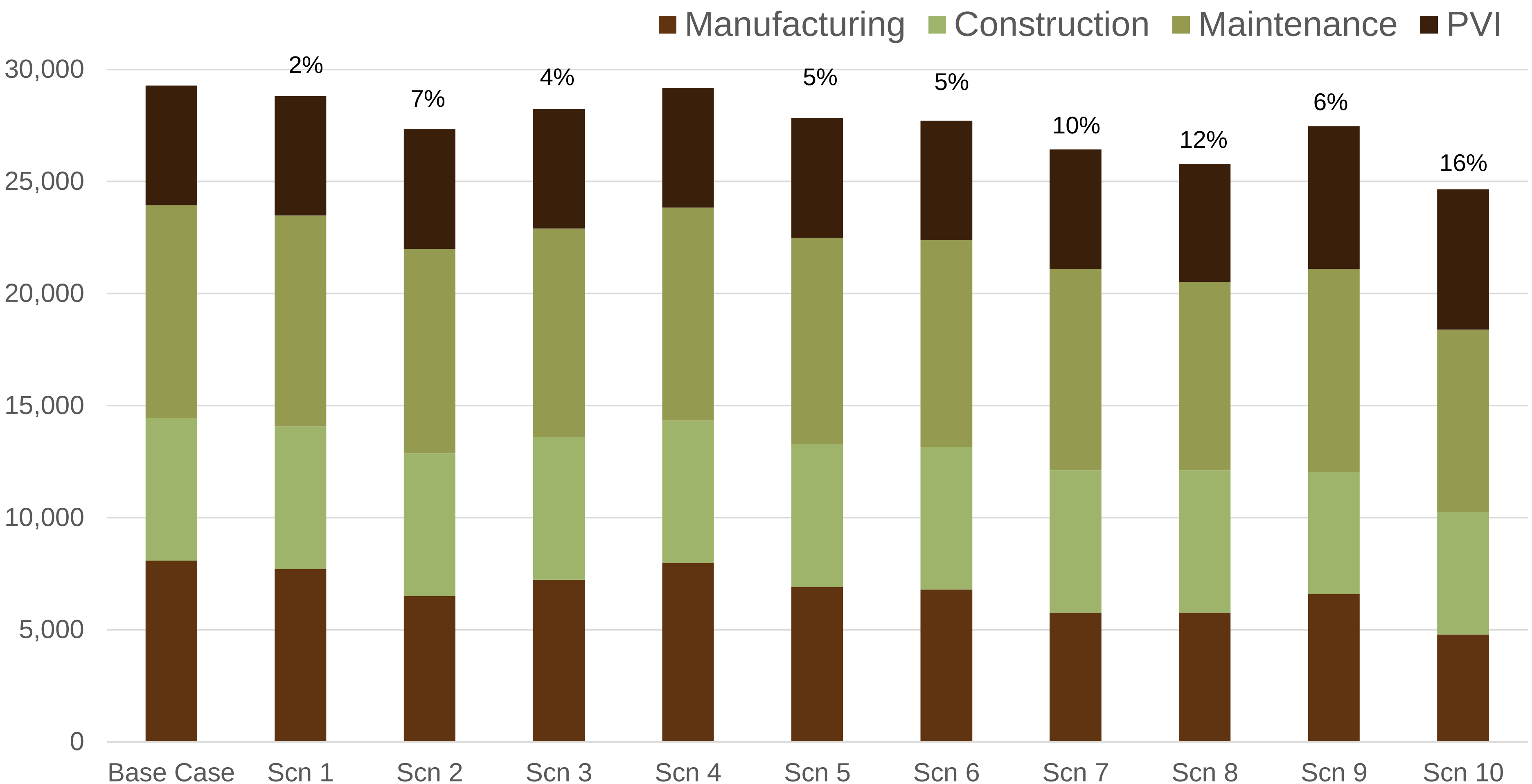
Base Case LCA Results – 50 yr. analysis period

		Life Cycle Stages							
Base Case	Units	Manufacturing	Construction	Maint & Rehab	Embodied Total	Use Phase - Excess Fuel Use due to PVI IRI	Deflection	Total PVI Effects	Grand Total
Global Warming Potential	mtons CO_2 eq	8,108	6,359	9,505	23,972	3,702	1,633	5,334	29,306
Acidification Potential	mtons SO_2 eq	36	57	78	171	33	10	43	214
HH Particulate	mtons PM2.5 eq	14	3	6	23	2	1	2	26
Eutrophication Potential	mtons N eq	2	4	5	11	2	1	3	13
Smog Potential	mtons O_3 eq	540	1,923	2,490	4,952	1,112	358	1,470	6,422
Total Primary Energy	GJ	111,008	92,399	129,007	332,415	53,793	23,777	77,570	409,985
Non-Renewable Energy	GJ	110,750	92,360	128,935	332,045	53,770	23,772	77,543	409,588
Fossil Fuel Consumption	GJ	90,985	92,216	124,871	308,071	53,687	23,754	77,441	385,512



- Over 80% of GWP due to materials, their placement & roadway maintenance
  - Equivalent to driving 6,190 passenger cars for a year
- Hence obvious focus for alternative design scenarios
- PVI significant user cost

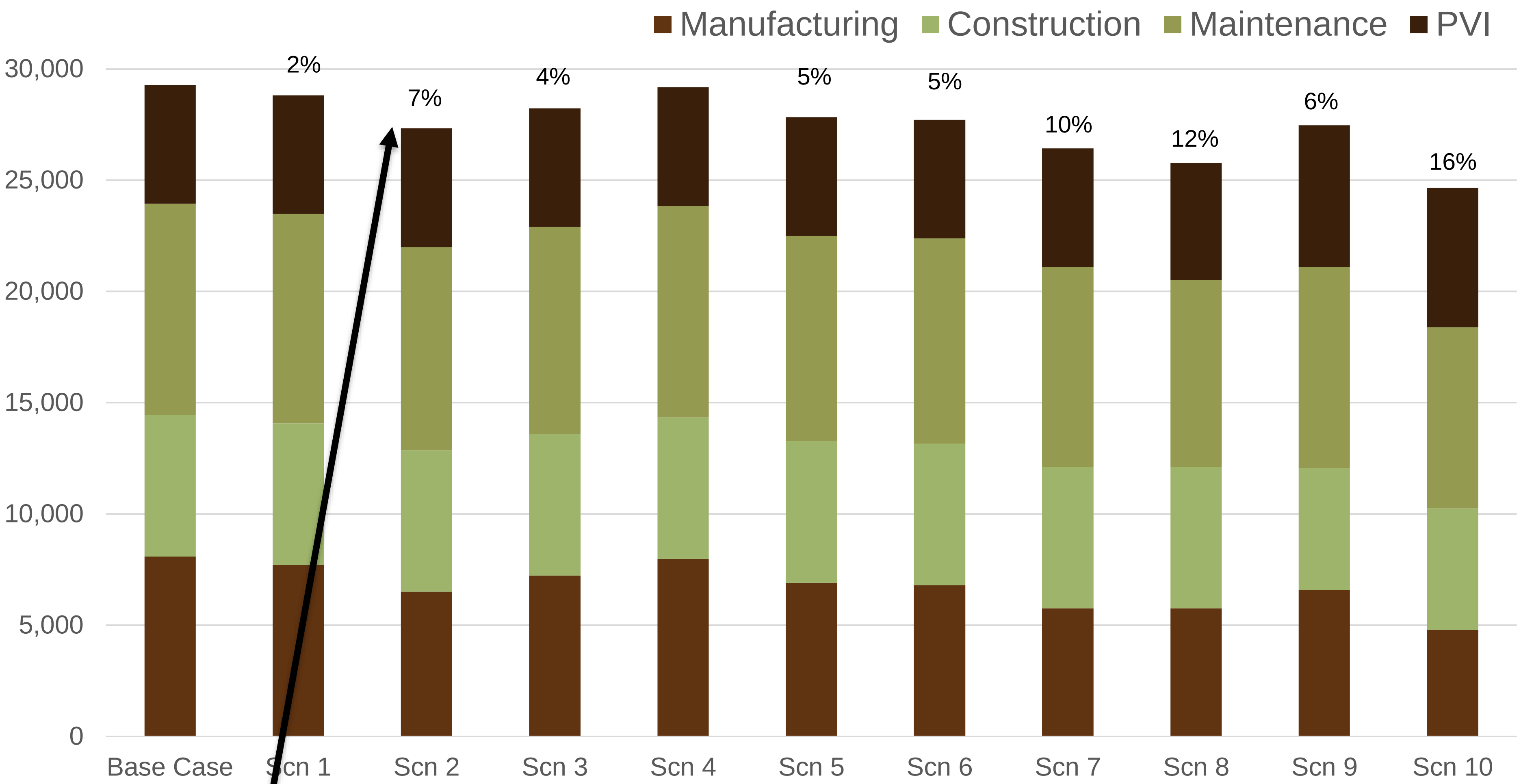
LCA Scenario Analysis Results (GWP- tonnes CO_2 equivalent)



Embodied effects = material manufacturing + construction + M&R

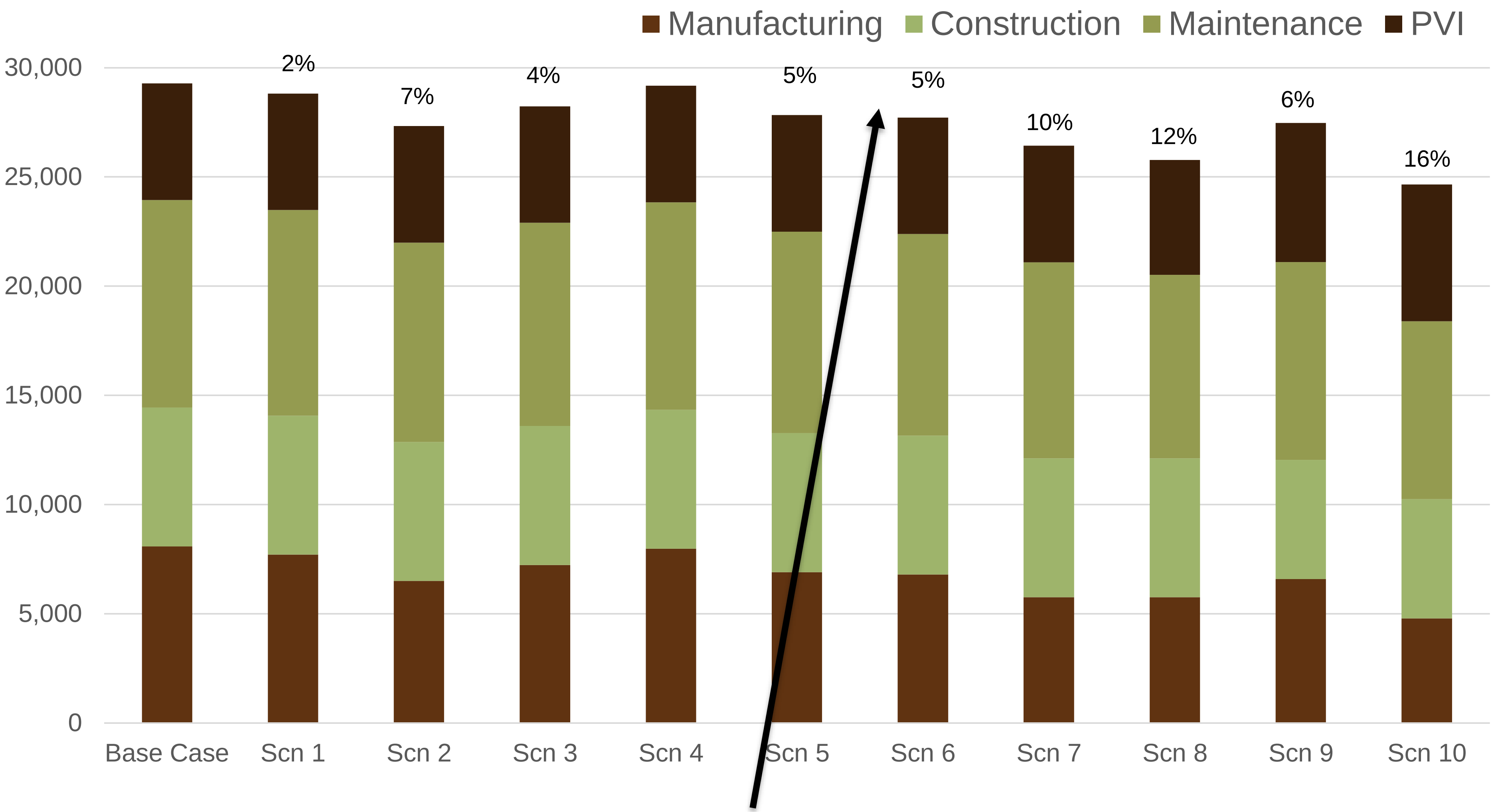
PVI effects = increased fuel consumption due to roughness and deflection

LCA Scenario Analysis Results (GWP- tonnes CO_2 equivalent)



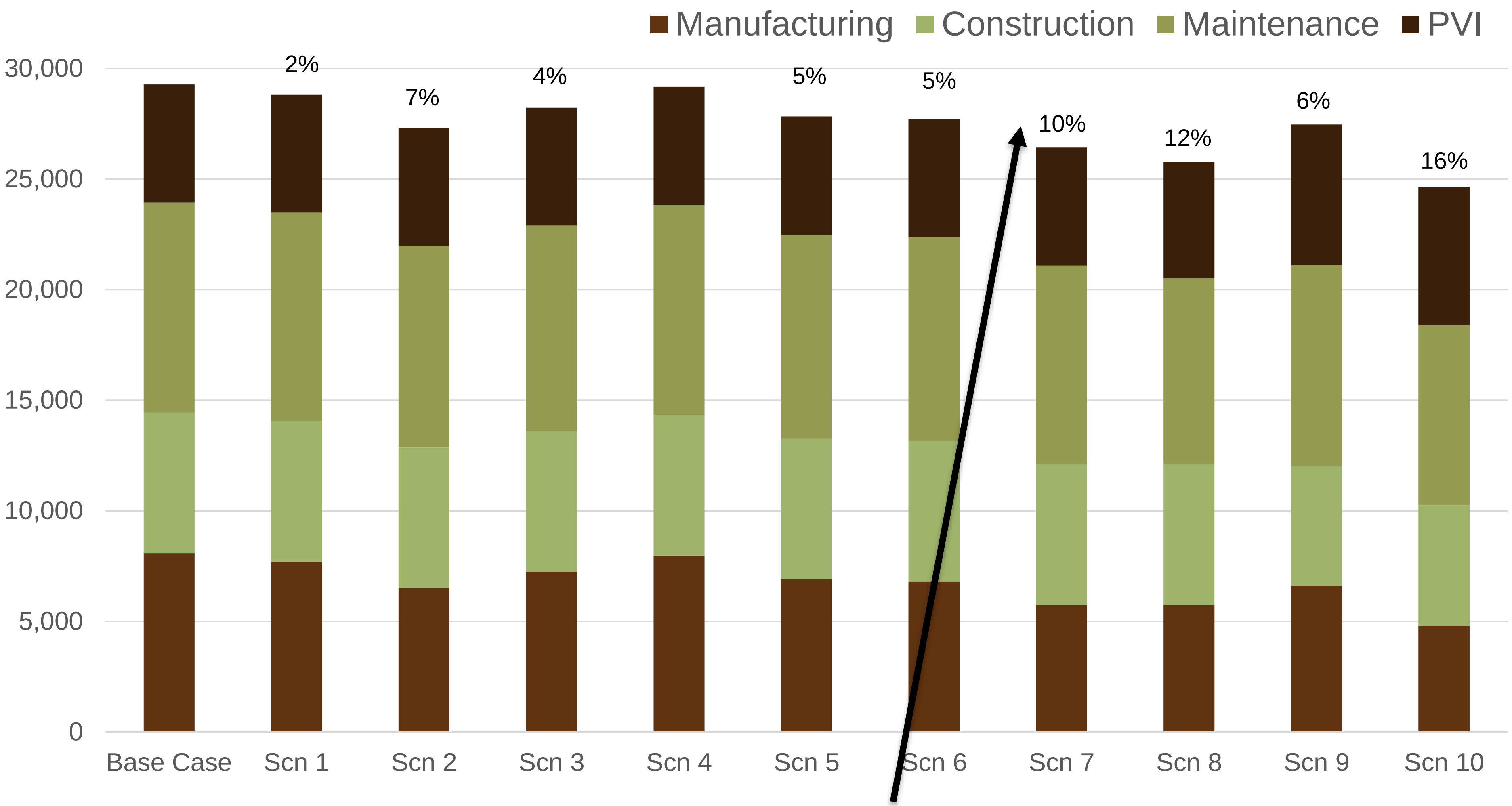
Effect of ternary mix – 15% FA + 25%SC

LCA Scenario Analysis Results (GWP- tonnes CO_2 equivalent)



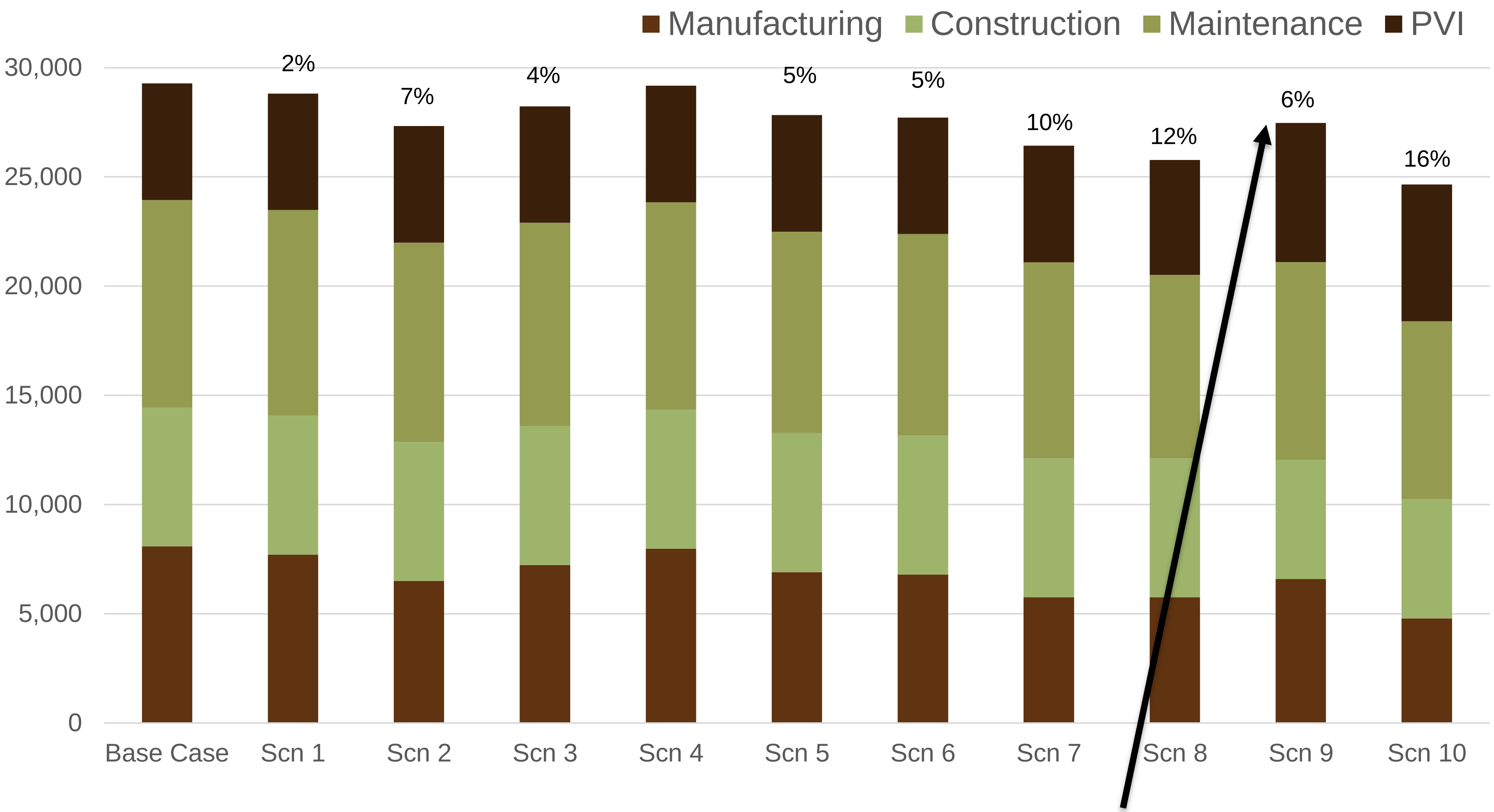
Current Practice - 307 kg cementitious, 20% fly ash, 0% slag, 126 tonnes steel and regular M & R

LCA Scenario Analysis Results (GWP- tonnes CO_2 equivalent)



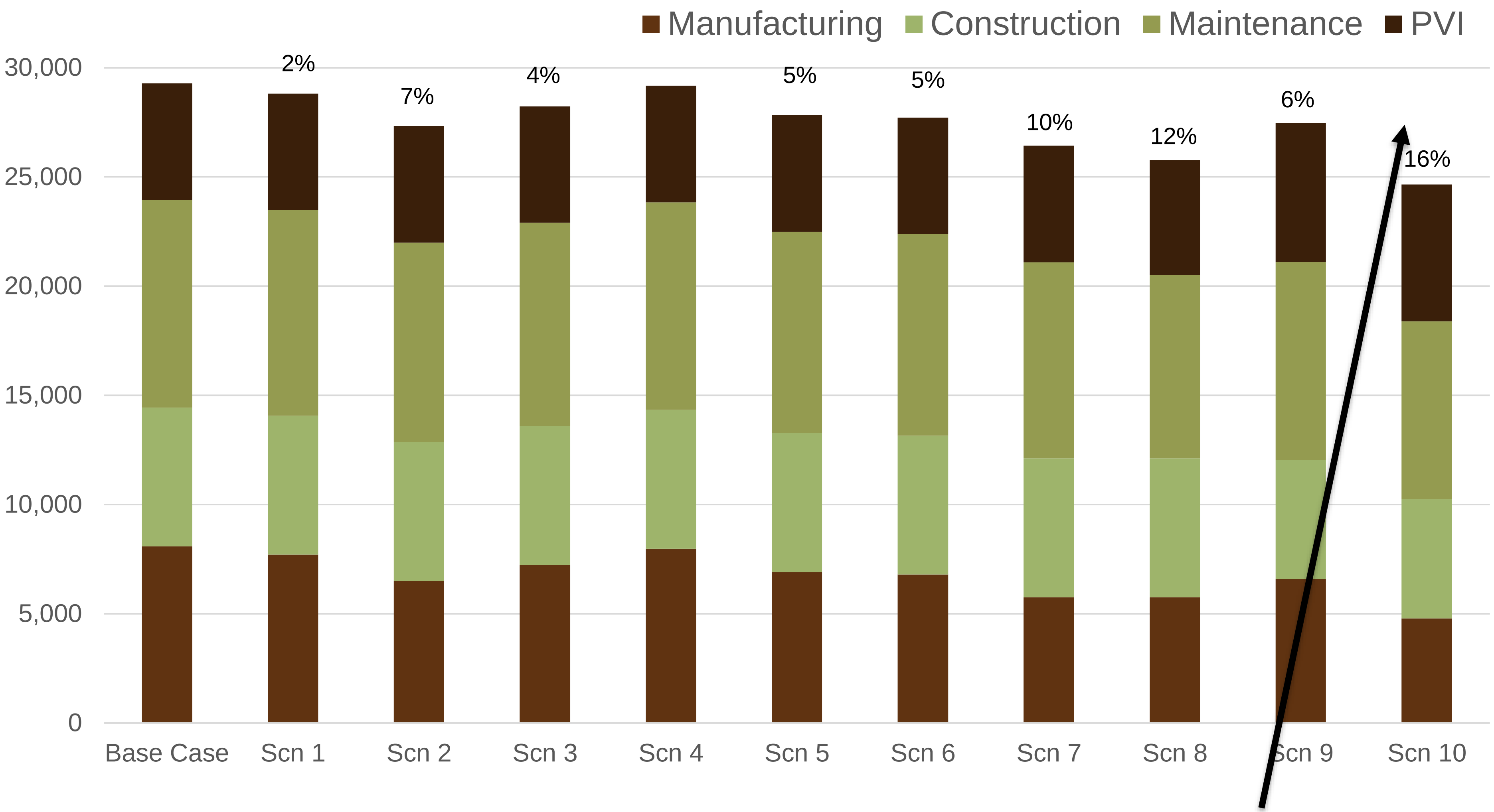
Current Practice – with slag/ternary mix

LCA Scenario Analysis Results (GWP- tonnes CO_2 equivalent)



355 kg cementitious, 15 % fly ash, 0% slag, 0 steel, TCP, regular M&R

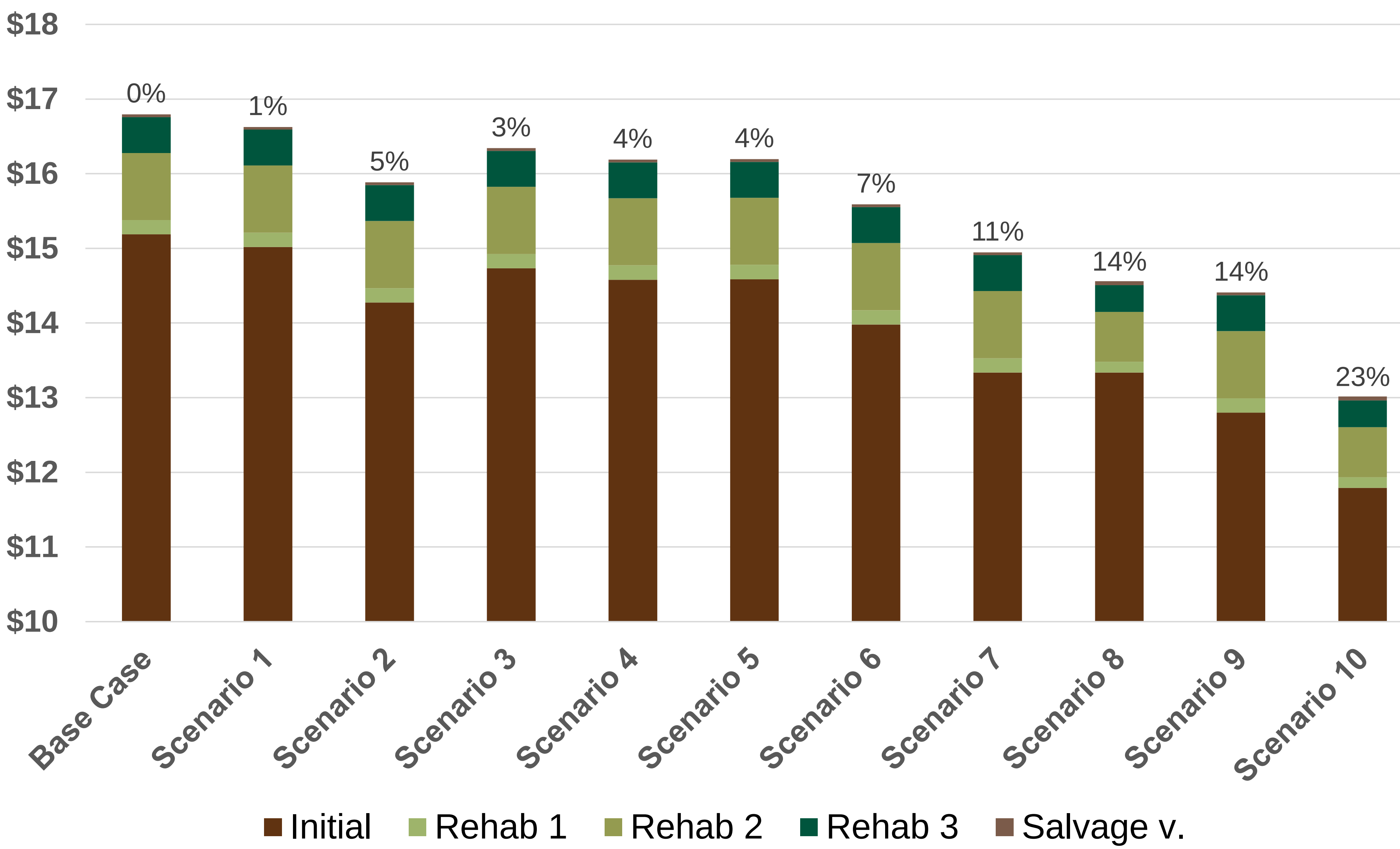
LCA Scenario Analysis Results (GWP- tonnes CO_2 equivalent)



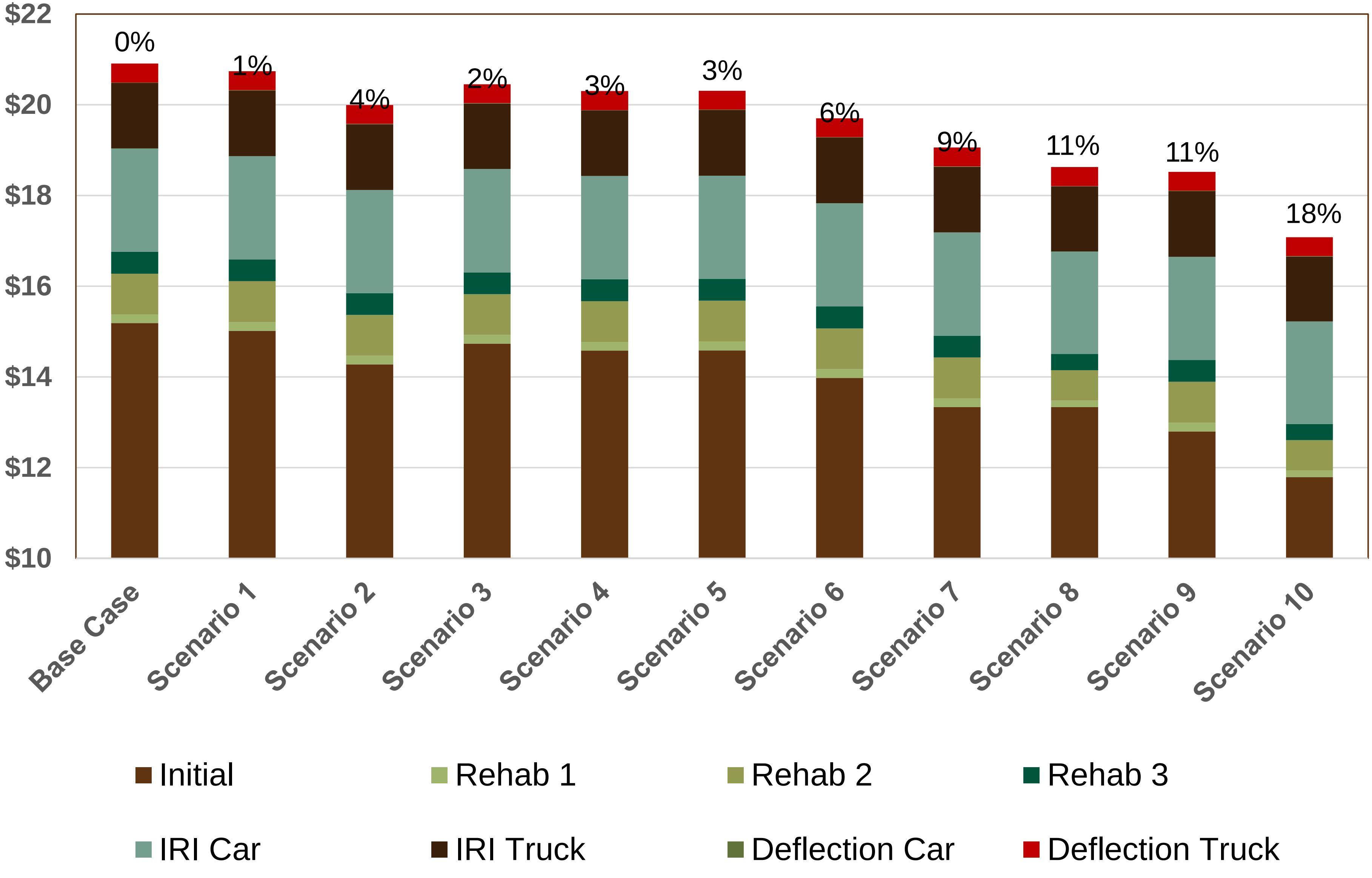
307 kg cementitious, 15 % fly ash, 25% slag, 0 steel, TCP, extended M&R

LCCA Scenario Results - Agency Cost

Net Present Value, million $ (50-yr analysis, 3% disc. rate)



LCCA Results – Agency and User (PVI) Costs
Net Present Value, million $



Summary

- Directionally LCA and LCCA scenario results mirror one another
  - Greening PCC roadway design results in lower LC cost – win/win
  - Embodied effects similar to agency cost – both account for 80% of their respective GWP outcome
- PVI also significant contributor - 20% of GWP effect and LCCA outcome
  - PVI higher LC cost than M&R strategy
  - Possible opportunity to spend more on M&R to reduce PVI induced user cost – trade-off analysis
- Enhanced mix designs (ternary mixes) in combination with new slab technology (TCP) may offer considerable improvements over MI's current LC strategy

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Get in touch with us for more information.

QUESTIONS?