Study of the most sustainable and cost-effective options for rehabilitating flexible pavements

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Australian Pavement Recycling and Stabilisation Conference

Sustainable Pavements for Future Generations

Pullman Albert Park, Melbourne • 22nd August 2023

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Pavement Recycling and Stabilisation Association

Contents

- Research objectives
- Introduction to base stabilisation
- Modelling stabilised base courses according to Austroads approach
- Laboratory evaluation of FTB and ETB
- Thickness design with different stabilised applications
- Life Cycle Assessment using SEVE Software
- Cost analysis using the roadresource.org tool

Research objectives

Finding the optimum pavement solution for medium and high-traffic roads

- Investigation of 3 different pavement structures and two different traffic scenarios
  - Granular base + HMA
  - Foam Treated Base + HMA
  - Emulsion Treated Base + HMA
- Investigation of Lab study to find the optimum characteristics for FTB and ETB
- Pavement designs for all pavement and traffic scenarios using the CIRCLY software
- Life Cycle Assessment for all pavement and traffic scenarios using the SEVE software
- Cost comparison for different alternatives with the roadresource.org tool

Introduction

Treated base / Stabilised base

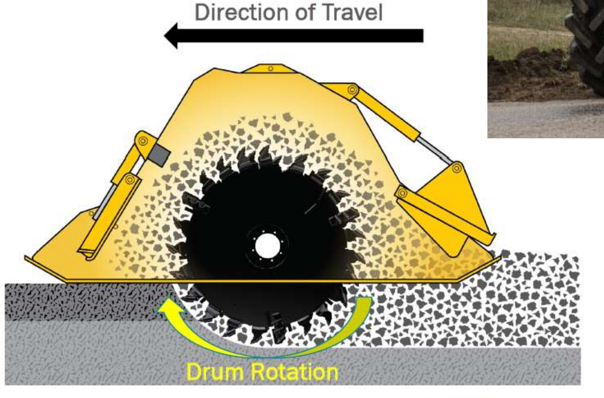
- Definition: An intimate mixture of natural and/or crushed aggregates with lab-designed amount of different binders (cement, lime, bitumen, emulsion, chemicals, etc) and water that hardens after compaction and cures, to form a strong durable paving material

Two different main categories

- In-place
- In-plant

In-place stabilisation

- Cement/Lime spreading
- Pulverization/Crushing/Mixing
  - Secondary binder added to mixer (if needed)
- Initial compaction
- Levelling
- Final compaction
- Curing (if needed)



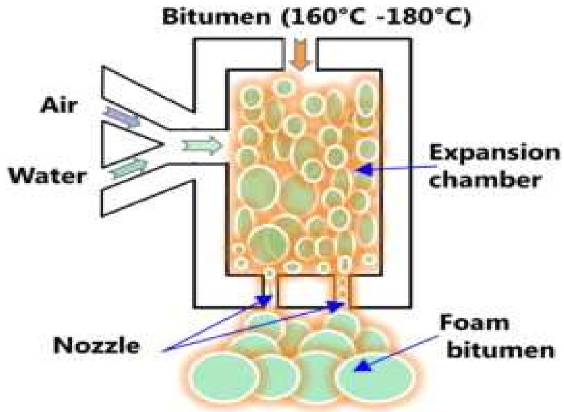
Binder (additive) types

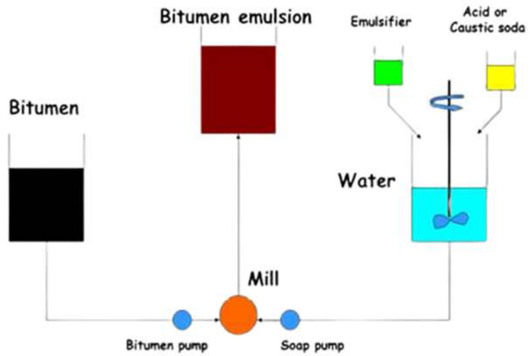
Dry

- Cement
- Lime
- Bentonite
- CKD (Cement Kiln Dust)
- LKD (Lime Kiln Dust)
- Fly ash
- Mineral consolidators

Liquid

- Hot bitumen
  - *Foamed*
- Bitumen emulsions
  - *CSS-1*
  - *CSS-1h*
  - *HFMS-2S*
  - *Proprietary emulsions*
- Calcium chloride
- Magnesium chloride
- Enzymes
- Others





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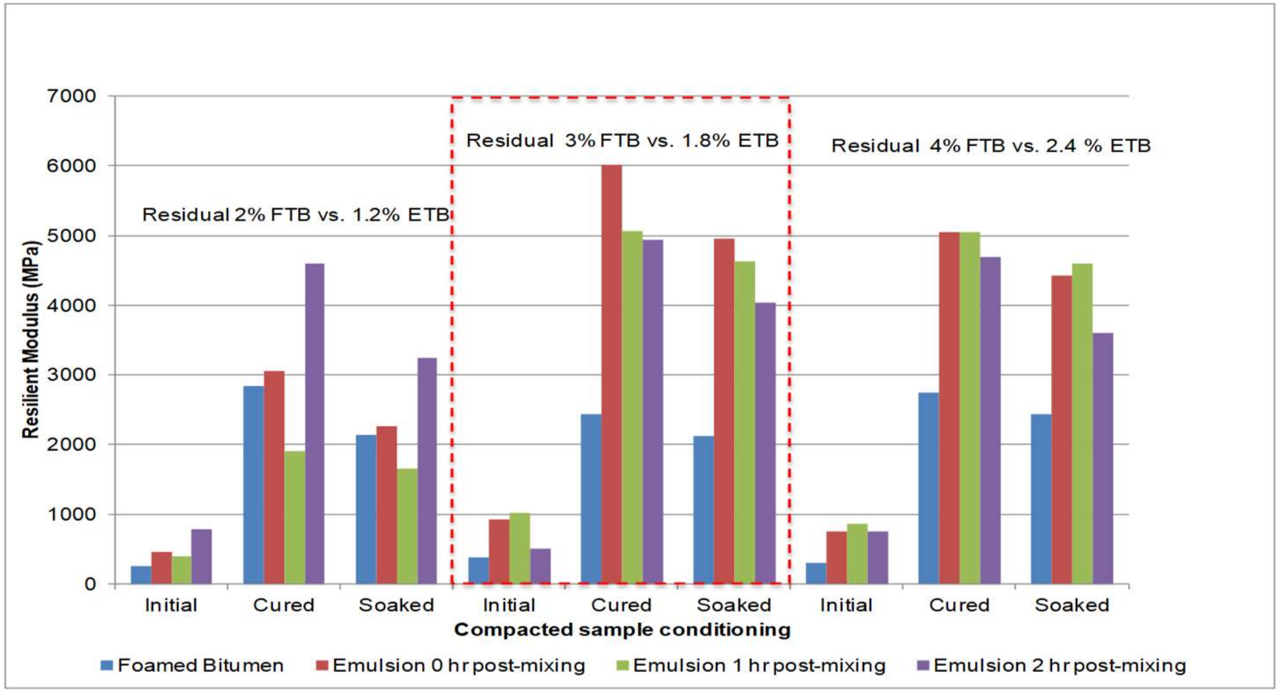
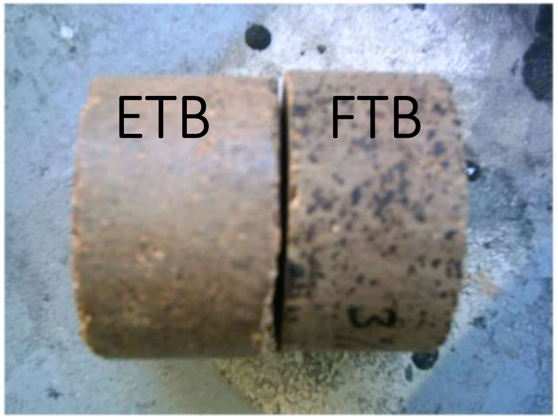
Laboratory studies

Lab study – presented in previous Auststab conference

- Modulus of ETB vs FTB in different bitumen contents
- Emulsion type and content, filler type and content have a big impact on ETB performance





Homogeneity of bitumen dispersion

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Laboratory studies

New lab studies on ETB mixes

Number	Emulsion type	Emulsion content (%)	Cement content (%)	Modulus (MPa)
1	A	7.5	0	291
2	A	7.5	1	1350
3	A	5	0	790
4	A	5	1	1944
5	B	7.5	0	2676
6	B	7.5	1	1219
7	B	5	0	2479.67
8	B	5	1	571.5
9	C	7.5	0	1976.5
10	C	7.5	1	1119
11	C	5	0	3587.3
12	C	5	1	1174.3

- Impact of formulation of emulsion on the performance of the ETB mixes
- Use of cement doesn't lead systematically to an increase in the modulus
- Formulation should be done for each aggregate case by case

Thickness design

Different design approaches

- Austroads assumes FTB as an asphaltic layer with low bitumen content.

  Fatigue – Stiffness relation is similar to that of Asphalt and is related to bitumen volume.

$$N = \left(\frac{K}{\mu\epsilon}\right)^5$$

- NZ assumes FTB as an enhanced waterproof (stop potholes) granular material with a modulus fixed at 800 MPa and no fatigue equation.

Thickness design

Using CIRCLY software (Linear Elastic Layer method)

Two different traffic scenarios / Three different pavement sections

Pavement sections	Traffic 1 (ESA=1E7)	Traffic 2 (ESA=1E8)
Granular base + HMA	Case study 1	Case study 4
FTB + HMA	Case study 2	Case study 5
ETB + HMA	Case study 3	Case study 6

Thickness design

Austroads AGPT02
Guide to Pavement Technology Part 2: Pavement Structural Design

☑ Design thickness of layer highlighted below ☑ Calculate Cost Total Cost: $82.44/m2

No.	ID	Title	Minimum Thickness	Maximum Thickness	Current Thickness	CDF
1	AC20-ver2	AustStab conference			60.00	7.97E-02
2	FTB-ver2	FTB AustStab conference			300.00	7.90E-01
3	Sub-ver2	AustStab conference			0.00	4.23E-04

☑ Design thickness of layer highlighted below ☑ Calculate Cost Total Cost: $143.92/m2

No.	ID	Title	Minimum Thickness	Maximum Thickness	Current Thickness	CDF
1	AC14-ver2	AustStab conference			50.00	2.04E-07
2	AC20-ver2	AustStab conference			100.00	1.00E+00
3	Gran-ver2	AustStab conference			442.79	
4	Sub-ver2	AustStab conference			0.00	1.48E-03

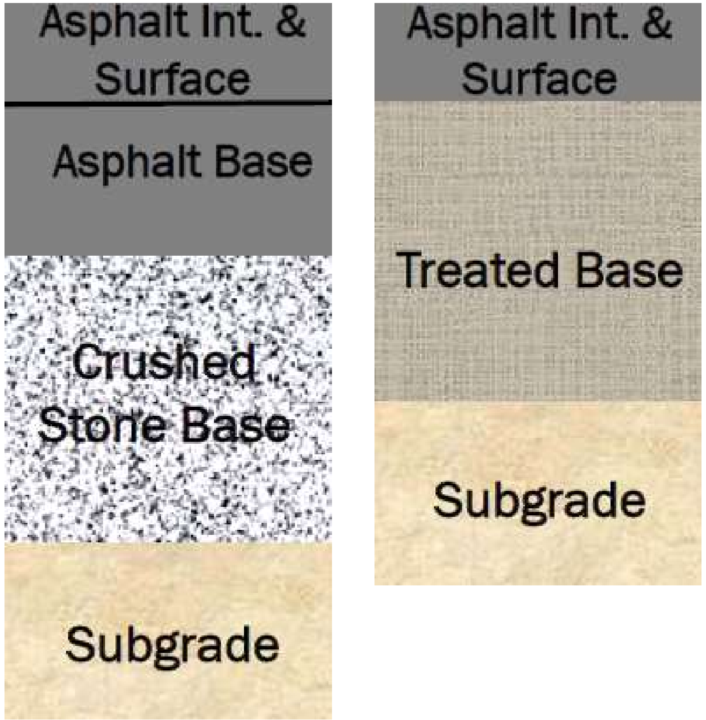
Thickness design – Material assumptions

- Performance exponent (k) for subgrade = 0.00915
- Modulus of ETB has been measured in the lab
- Emulsion content of the ETB is considered 5% in order to have asphaltic behaviour

	Vertical modulus (MPa)	$\frac{E_v}{E_h}$	Poisson's ratio	Bitumen content (%)	Bitumen volume (%)	Performance exponent (b)	Shift factor
AC14	4000	1	0.4	5.3	12.7	5	6
AC20	4500	1	0.4	4.7	11.3	5	6
FTB	1500	1	0.4	3	6.9	5	6
ETB	3000	1	0.4	3 (residual)	6.9	5	6
Granular base	800	2	0.35	-	-	-	
Subgrade	50	2	0.45	-	-	7	

Thickness design

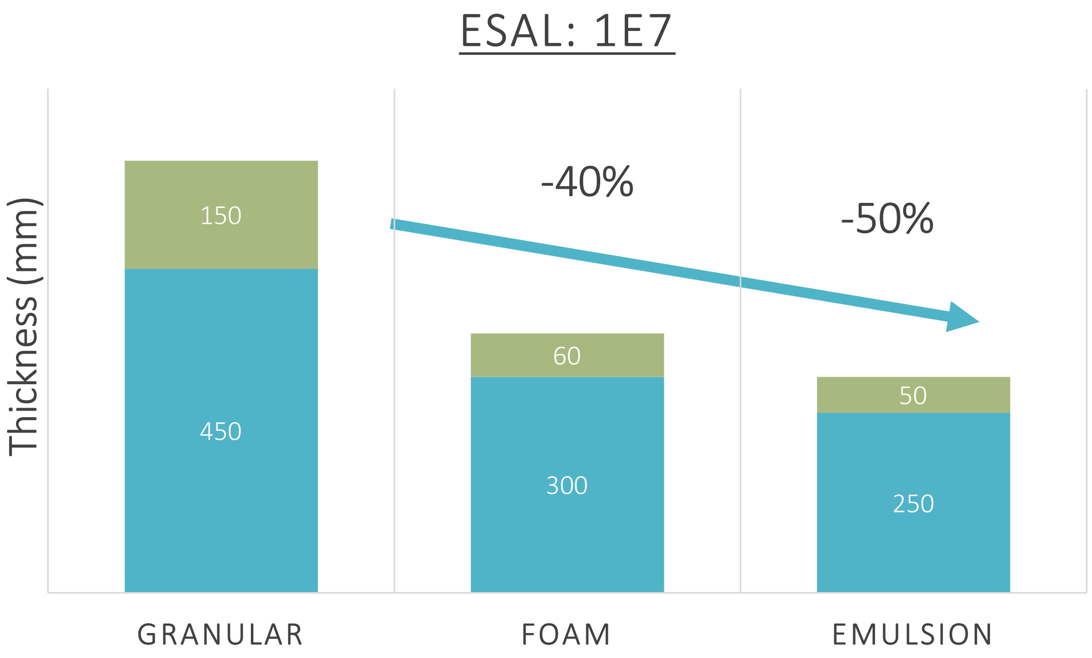
- Project reliability factor: 97.5
  - Asphalt fatigue RF: 9
- TLD: 110 – M7 Motorway
  - ESA/HVAG: 0.907
- N_{DT}: 1.1e7 and 1.1e8
- Thicknesses were calculated for all 6 case studies.

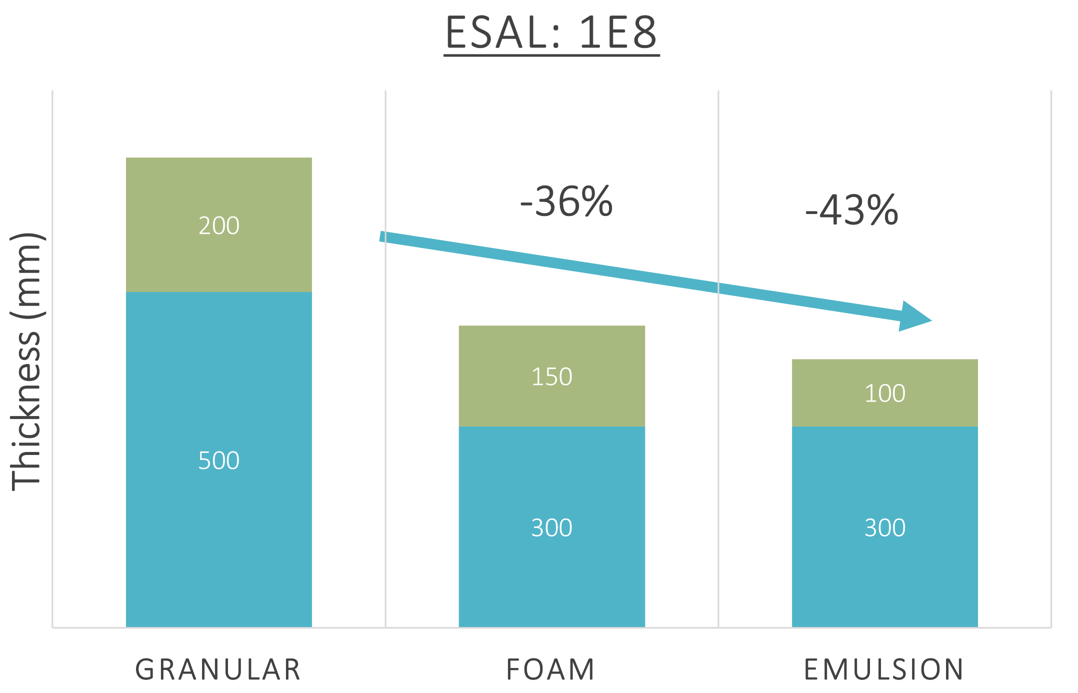


Thickness design – Results

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
	ESAL: 1E7			ESAL: 1E8		
AC14	50 mm	60 mm	50 mm	50 mm	50 mm	40 mm
AC20	100 mm	-	-	150 mm	100 mm	60 mm
GB	450 mm	-	-	500 mm	-	-
FTB	-	300 mm	-	-	300 mm	-
ETB	-	-	250 mm	-	-	300 mm
Sum	600 mm	360 mm	300 mm	700 mm	450 mm	400 mm

Thickness design – Results





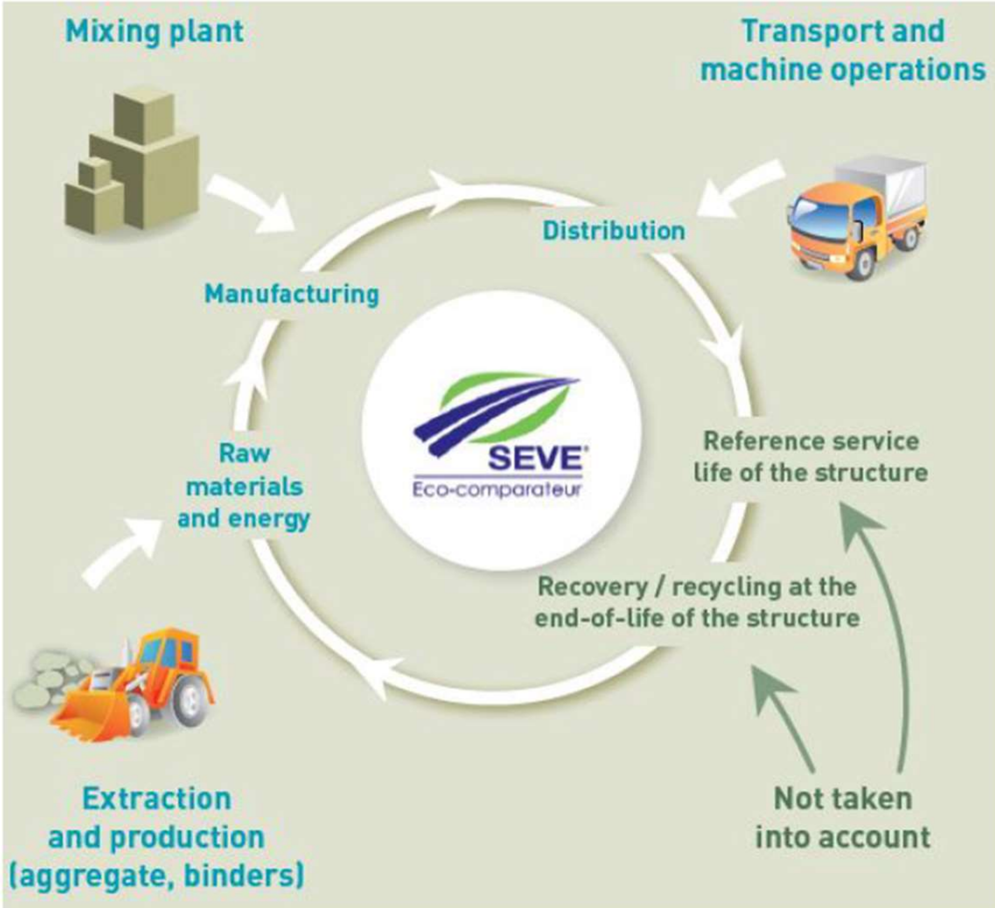
Life Cycle Assessment

- An eco-comparator developed by the road transport industry (equivalent to AfPA) in France in 2010
- New web base version in 2022
- English version available
- Environmental assessment of each phase of building and maintenance of roads, earthworks and utility networks
- Compare two or more technical solutions based on the partial life cycle analysis (LCA)

Life Cycle Assessment

- Follow general principles of ISO 14040: 2006 - EN ISO 14044: 2006
- Database of materials, machines, products shared by all the users
- Database of formulas (concrete, asphalt) specific to each manufacturing plant (production tools for asphalt or concrete)
- Emission factor customized to local conditions (country based)

SEVE
Eco-comparateur



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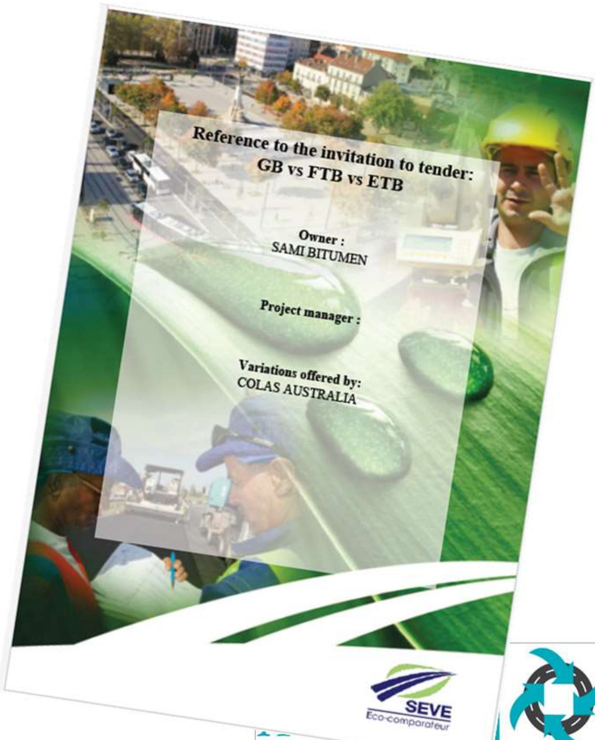
Life Cycle Assessment

SEVE
Eco-comparateur

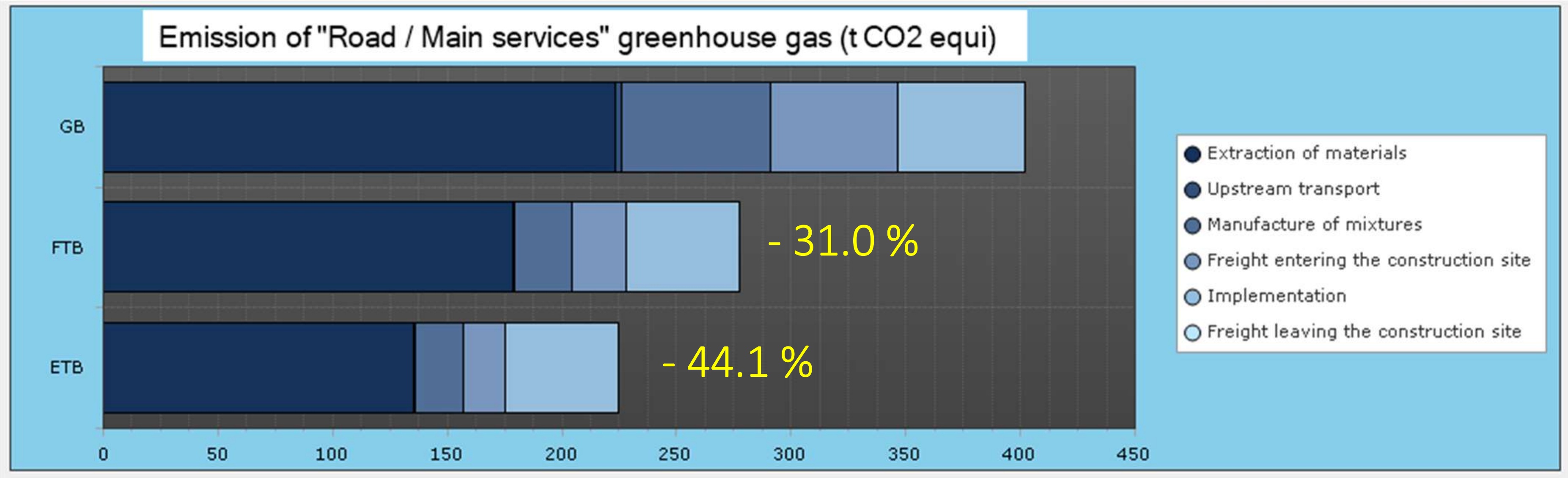
Life cycle assessments carried out for each scenario on 4 indicators

- GHG emission
- Energy consumption carried
- Resource conservation
- Ton-kilometer saved



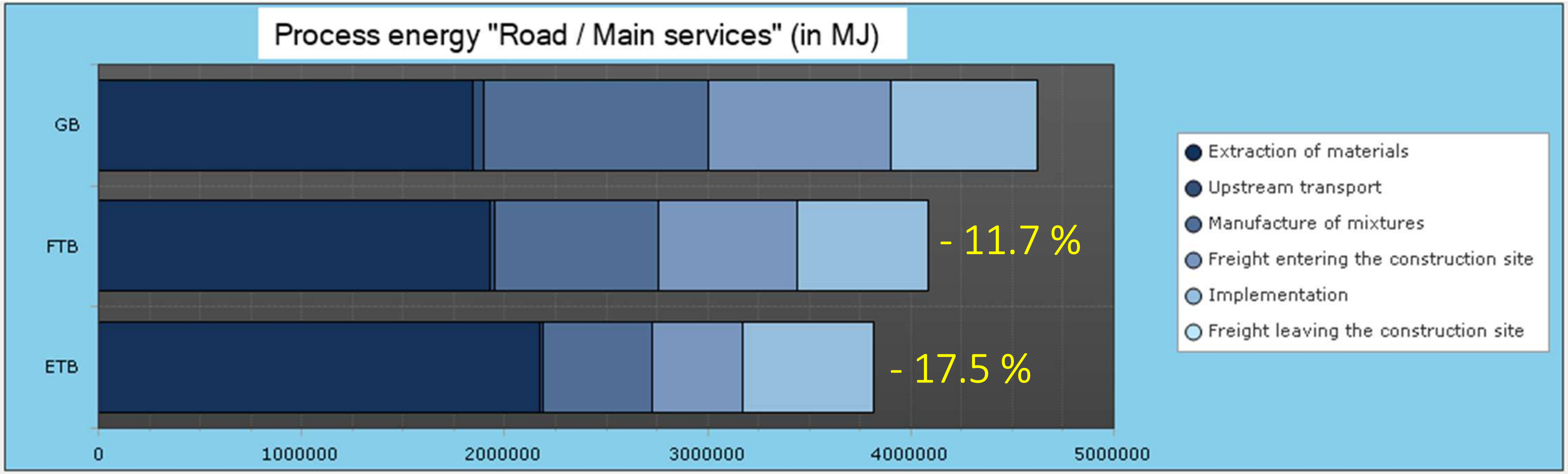
Life Cycle Assessment

- GHG Emission comparison between Cases #1 #2 #3



Life Cycle Assessment

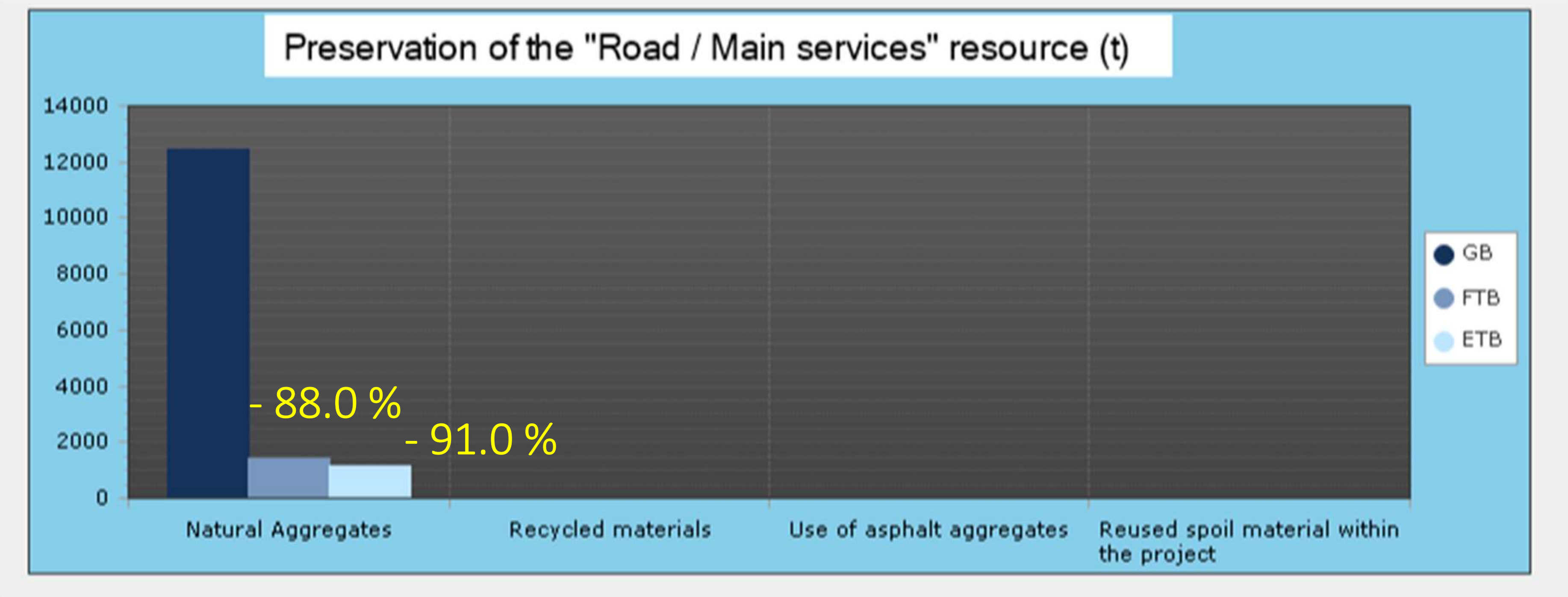
- Energy consumption comparison between Cases #4 #5 #6



Life Cycle Assessment

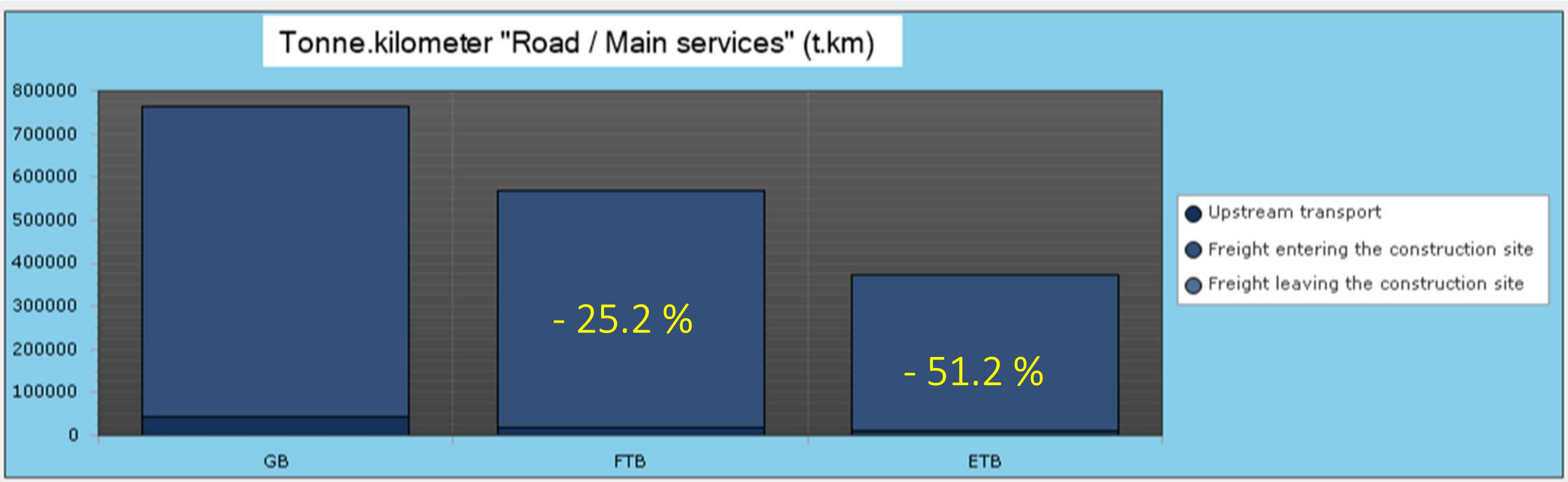
SEVE
Eco-comparateur

- Resource conservation indicator Cases #1 #2 #3



Life Cycle Assessment

- Ton.kilometer indicator Cases #4 #5 #6



Life Cycle Cost calculator

RoadResource.org™
Provided By: PPRA

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Unit Costs for each application

Number	Layer	Rough unit prices ($) – including supply, transport, application
1	AC14	$220 per ton. (assumed density: 2.5 ton/m^3)
2	AC20	$200 per ton. (assumed density: 2.5 ton/m^3)
3	GB	$75 per ton. (assumed density: 2 ton/m^3) – including base material, transport, lay and compaction
4	FTB	$76 per ton. (assumed density: 2.3 ton/m^3) – in-place recycling, 0% admix aggregate, 3% foam bitumen, 2% lime
5	ETB	$92 per ton. (assumed density: 2.3 ton/m^3) – in-place recycling, 0% admix aggregate, 5% bitumen emulsion

* Prices represent the average quotes provided by three different contractors for a typical project in either NSW or VIC.

Initial Cost calculation

RoadResource.org
Provided By: PPRA

Initial price calculation for each design and ESA scenarios (Australian Dollar per square meter)

Case	ESAL: 1E7	ESAL: 1E8
Granular base	$144	$178
Foam treated base	$82	$130
Emulsion treated base	$78	$114

45% and 43% lower price when using ETB and FTB instead of Granular base for 1E7 ESAL.
36% and 27% lower price when using ETB and FTB instead of Granular base for 1E8 ESAL.

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Life Cycle Cost calculator

RoadResource.org™
Provided By: PPRA

Inflation/CPI
5 %

Interest Rate
2.5 %

CONVENTIONAL PLAN

Year	Treatment Type	Cost in Constant Dollars	Future Cost	Present Value
1	Granular Base + HMA	144.00	151.20	147.51
5	Bonded Wearing Course	8.35	10.66	9.42
15	Minor Mill & Fill	11.72	24.37	16.82
20	Major Mill & Fill	19.90	52.80	32.22
	Select...		0.00	0.00
ADD ROW		$183.97	$239.03	$205.97

Net Present Value: **$205.97 / SM**

OPTIMIZED PLAN

Year	Treatment Type	Cost in Constant Dollars	Future Cost	Present Value
1	Emulsion Treated Base + HM	78.00	81.90	79.90
3	Fog Seal	0.68	0.79	0.73
7	Micro Surfacing- Single Lift	3.31	4.66	3.92
10	Scrub Seal	2.70	4.40	3.44
15	Micro Surfacing- Double Lift	4.69	9.75	6.73
20	Minor Mill & Fill	11.72	31.10	18.98
ADD ROW		$101.10	$132.60	$113.70

Net Present Value: **$113.70 / SM**

%45 cost reduction in the life cycle

Conclusion

Costs Benefits

- On average, ETB and FTB have 40% and 35% reduction in the initial cost of the project
- In 20 years of life cycle cost analysis, using ETB will have around 45% less cost comparing a granular base

Engineering Benefits

- Enhance Road Performance with better Strength, impermeability and flexibility
- CDFs are lower in asphalt layers in ETB and FTB applications
- On average, 46% and 38% reduction in thickness for ETB and FTB comparing granular base

Conclusion

Environmental Benefits

- Reduce fuel consumption and greenhouse gas emissions with reduced trucking and thickness
- On average, 31.0% and 44.1% reduction in GHG emission for FTB and ETB comparing granular base
- 11.7% and 17.5% reduction in energy consumption for FTB and ETB comparing granular base
- 88% and 91% less virgin material for ETB and FTB applications
- 51.2% and 25.2% less transportation for ETB and FTB applications

Time Savings Benefits

- In-place work eliminates time for trucking and hauling
- Reducing total pavement thickness can increase productivity significantly

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