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A Review of Asphalt Recycling Technologies and the Role of Engineered Bitumen for Sustainable Road Maintenance in Nigeria

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ABSTRACT
Asphalt recycling has emerged globally as a cost-effective and sustainable method for road maintenance. Reclaimed Asphalt Pavement (RAP) is the most recycled material in the world, yet its adoption in Africa and Nigeria remains limited. This review synthesizes international practices in asphalt recycling (Copeland, 2016; FHWA, 1995), highlights African experiences (SANRAL, 2014; NCW, 2018), and examines rejuvenator technologies with particular focus on Waste Cooking Oil (WCO) (Al-Sabaeei et al., 2018; Ismail & Al-Hdabi, 2019). A conceptual framework is introduced—the "Double Waste to Wealth Asphalt Initiative"—which combines RAP with WCO to produce engineered bitumen with 100% local content. The review emphasizes the importance of incorporating Asphaltene-Maltene (A/M) ratio and Maltene Distribution Ratio (MDR) into Nigeria's bitumen testing protocols for both virgin and aged binders (Airey, 2000), thereby improving quality control and performance assessment. The paper concludes with policy recommendations for Nigeria to scale up asphalt recycling as a mainstream road maintenance method, ensuring value-for-money, sustainability, and alignment with national infrastructure goals.
Keywords: Asphalt Recycling · Reclaimed Asphalt Pavement · Waste Cooking Oil · Engineered Bitumen · A/M Ratio · MDR · Nigeria

I. INTRODUCTION

Road infrastructure is vital for economic development, trade, and social integration. However, the rising cost of maintenance, shortage of quality aggregates, and dependence on imported bitumen challenge the sustainability of Nigeria's road sector. Conventional methods—milling, overlays, and patching—generate large volumes of RAP, which are mostly discarded as waste. Globally, asphalt recycling has been proven to reduce costs by 40–80% (UNEP, 2019), conserve materials, and reduce environmental impacts. This review aims to contextualize global best practices, identify research gaps in Africa, and propose a conceptual pathway for Nigeria through engineered bitumen technology.

1. Global Practices in Asphalt Recycling

The United States, Germany, the Netherlands, and Japan have integrated asphalt recycling into mainstream pavement management. In the U.S., more than 73 million tonnes of RAP are recycled annually, making asphalt the most recycled material (Copeland, 2016). The Netherlands reintegrates more than 90% of RAP into new pavements as part of its circular economy model (UNEP, 2019). Japan and Germany similarly achieve high recycling rates through central plant and hot in-place techniques (FHWA, 1995). These experiences show that RAP, when combined with proper rejuvenation, can meet performance standards for durability and safety.

Table1.0 Global Evolution of Asphalt Recycling Practices at a Glance

Country	Start Period	RAP Usage (%)	Techniques Used	Notable Practice
USA	1970s	~80–95%	Hot recycling, cold in-place, full-depth	Most RAP reused of any material
Germany	1970s–1980s	~85–90%	Hot recycling at central plant	Integrated into standard specs
Japan	1980s	~70–80%	Central plant, hot in-place	High-quality RAP control
Netherlands	1980s–1990s	>90%	Hot recycling	Circular economy model

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Country	Start Period	RAP Usage (%)	Techniques Used	Notable Practice
South Africa	2000s	Emerging	Cold in-place, foamed bitumen recycling	SANRAL & CSIR pilot projects
Egypt	2010s	Pilot level	Lab trials only	Awaiting scale-up
Kenya	2010s	Pilot level	Lab-based evaluations	Tech transfer ongoing
Nigeria	2010s–2020s	<10% (nascent)	Lab and policy stage; limited field use	2018 NCW recommendation yet to scale

2. Asphalt Recycling in Africa

African adoption of asphalt recycling remains limited. South Africa has pioneered cold in-place and foamed bitumen recycling, supported by SANRAL and CSIR (SANRAL, 2014). Kenya and Egypt have undertaken pilot studies and lab trials, while Nigeria remains at a nascent stage. Despite a 2018 National Council on Works communique urging adoption, RAP utilization in Nigeria is still below 10% (NCW, 2018). Challenges include lack of specifications, testing protocols, and institutional awareness.

3. Types of Asphalt Recycling Methods

Asphalt recycling methods are classified by processing location and temperature (FHWA, 1995):

- **Hot In-Place Recycling (HIP):** Heating, scarifying, remixing, and laying in-place.

Figure 1 Hot In-Place Recycling

- **Cold In-Place Recycling (CIP):** On-site milling and mixing without heat.

Figure.2. Cold In- Place Recycling (CIP)

- **Central Plant Recycling (CPR):** RAP mixed with binder at a plant

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Figure.3. Central Plant Recycling.

- **Full Depth Reclamation (FDR):** Recycling all pavement layers in-place with stabilizers.

Figure 4. Full Depth Reclamation (FDR)

Each technique has unique cost, material, and performance implications, and can be applied depending on pavement failure mode.

4. Rejuvenators in Asphalt Recycling

Aged bitumen within RAP loses elasticity due to oxidation and volatilization, resulting in brittleness. Rejuvenators restore binder properties by replenishing maltenes and softening asphaltenes. Waste Cooking Oil (WCO), abundant in Nigeria, is rich in fatty acids that mimic the maltene fraction, making it a sustainable and cost-effective rejuvenator (Al-Sabaeei et al., 2018; Ismail & Al-Hdabi, 2019). Research has shown that WCO can restore ductility and viscosity of aged binders, enabling higher RAP contents in asphalt mixtures.

5. Conceptual Contribution: The Double Waste to Wealth Asphalt Initiative

This initiative proposes the simultaneous utilization of RAP and WCO to produce a 100% local-content engineered bitumen. By combining two waste streams, this approach advances Nigeria’s circular economy agenda while reducing dependency on imported bitumen. Incorporating engineered bitumen blends into road maintenance will not only reduce costs but also improve sustainability and promote local innovation.

6. Bitumen Aging Indices: A/M Ratio and MDR

Bitumen consists of two main fractions: asphaltenes (solid) and maltenes (fluid). As bitumen ages, the asphaltene-to-maltene (A/M) ratio increases, while the Maltene Distribution Ratio (MDR) declines, leading to brittleness and reduced performance (Airey, 2000). This review recommends that Nigeria adopt A/M ratio (0.2–0.4) and MDR (0.3–0.6) testing protocols for virgin, aged, and engineered binders. These indices, alongside traditional penetration, softening point, and viscosity tests, provide a more holistic evaluation of binder rheology and long-term performance.

7. Research Gaps and Framework

Despite global advances, limited African research exists on the integration of RAP with sustainable rejuvenators. There is a lack of field trials, long-term performance monitoring, and standardized protocols. This review identifies the need for pilot studies, university collaboration, and inclusion of engineered bitumen research into Nigeria’s road policy framework.

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8. Policy Implications for Nigeria

Nigeria's highway agencies and MDAs should:

- Select candidate pilot roads for recycling under existing budgets.
- Secure Certificate of No Objection under Part VII, Section 39(2)(b) of the Public Procurement Act (2007).
- Develop national specifications for RAP and rejuvenators.
- Adopt A/M and MDR indices in bitumen testing protocols.
- Partner with universities for research and monitoring.
- Scale asphalt recycling into mainstream road maintenance strategies.

II. CONCLUSION

Asphalt recycling presents Nigeria with an opportunity to achieve sustainable, cost-effective, and high-performing road infrastructure. By adopting RAP, local rejuvenators such as WCO, and enhanced binder testing protocols (A/M ratio and MDR), Nigeria can align with global best practices while promoting local innovation. The Double Waste to Wealth Asphalt Initiative provides a conceptual pathway to transform waste into value, ensuring long-term durability and value-for-money in road maintenance.

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