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Sustainable Advancements in Hot In-Place Recycling

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ABSTRACT: Hot In-Place Recycling (HIR) continues to gain momentum as a sustainable pavement rehabilitation method, supported by innovations in equipment, mix design, and environmental control technologies. Modern HIR systems incorporate weight-based proportioning mechanisms that allow precise control of reclaimed asphalt pavement (RAP), rejuvenators, and corrective additives, enabling the use of up to 100% RAP in surface courses while maintaining consistent mix quality. Recent developments in rejuvenating agents and performance-graded binder systems have enabled the effective restoration of aged asphalt binder properties, thereby improving mixture durability. Using 100% RAP in HIR drastically lowers greenhouse gas emissions, conserves natural resources, and minimizes construction waste. Additionally, improved project scoping practices now allow for more accurate identification of suitable HIR candidates. This paper summarizes key technological developments, process fundamentals, and field performance demonstrating that HIR is a sustainable and cost-effective alternative to conventional resurfacing methods.

1 INTRODUCTION

Hot In-Place Recycling is a pavement rehabilitation technique in which the existing asphalt surface is heated, softened, reprocessed, and relaid in situ, eliminating the need for material removal and off-site processing. While the method has been used for decades, early applications were limited by inconsistent heating, poor emissions control, and lack of performance-based specifications.

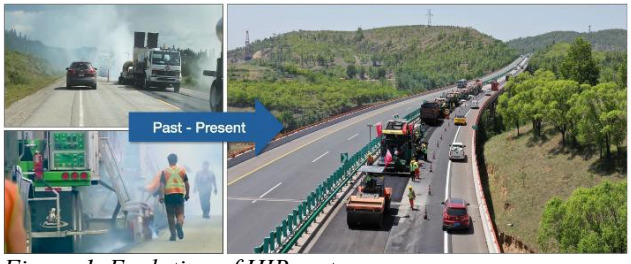


Figure 1. Evolution of HIR systems.

Technological advancements originating in Canada—particularly the introduction of staged heating and improved mixing systems—have significantly enhanced process reliability. More recently, mass-controlled proportioning systems have aligned HIR operations with asphalt plant production principles, ensuring consistent material quality. As a result, HIR is now widely recognized as a viable alternative to conventional mill-and-overlay for pavements with early to moderate distress.

2 GLOBAL NEED FOR SUSTAINABLE ROAD MAINTENANCE

Road networks are continuously subjected to traffic loading, binder oxidation, and environmental degradation, necessitating ongoing maintenance. Conventional resurfacing methods are resource-intensive, requiring large volumes of virgin materials and extensive transportation, leading to significant energy use and emissions.

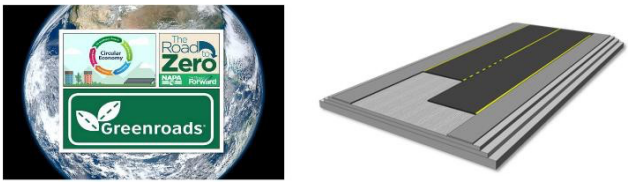


Figure 2. More Recycling is Key in Reducing GHG.

Life-cycle assessments show that over half of emissions associated with asphalt resurfacing originate from upstream activities such as extraction, processing, and hauling. In the context of net-zero

targets, there is increasing emphasis on minimizing material consumption and environmental impact.
HIR directly addresses these challenges by recycling pavement in place, significantly reducing material demand, energy consumption, and transportation requirements.

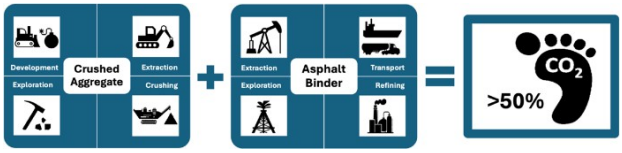


Figure 3. Reduction in Carbon Footprint.

3 LIMITATIONS OF CONVENTIONAL MILL AND OVERLAY

The conventional mill-and-overlay process involves cold milling of the existing surface followed by placement of new hot mix asphalt. While effective, it presents several limitations including cold milling damages aggregate and alters gradation, reducing reuse quality. RAP stockpiles often contain inconsistent materials from multiple sources. Specifications restrict RAP content (15–40%), limiting reuse. Significant hauling increases fuel consumption, cost, and emissions. Consequently, a large portion of reclaimed material is downcycled, diminishing environmental and economic efficiency.

4 FUNDAMENTALS OF HOT IN-PLACE RECYCLING

HIR involves heating and softening the existing pavement, followed by hot milling, mixing with rejuvenators or additives, and immediate placement and compaction—all conducted in a continuous on-site process. The three primary HIR methods are: Heater scarification, Repaving, and Remixing. Among these, remixing is the most advanced and widely adopted approach due to its ability to achieve deeper recycling, improved gradation control, and effective binder restoration.

Table 1. Historic HIR Challenges.

Issues	Challenges
Pavement heating	- Blue smoke emissions - Hazardous hot fumes
Binder rejuvenation	- Inaccurate additive metering - Lack of homogenous mixing
Engineering practise	- Project selection criteria - HIR Specifications



Figure 4. Early Canadian multi-stage HIR processing with progressive heating, hot milling, and pugmill mixing.

5 EVOLUTION OF HIR TECHNOLOGY

Early HIR systems faced challenges including overheating, blue smoke emissions, inadequate binder activation, and poor mixture consistency. The lack of precise additive control further limited performance reliability.

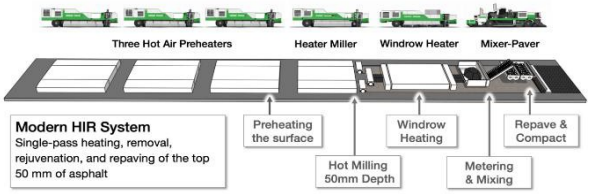


Figure 5. New mass controlled multistage HIR process

Significant progress was achieved with the introduction of multi-stage processing systems, which incorporated recirculating hot-air heating, staged thermal control, integrated pugmill mixing. These innovations improved temperature uniformity, emissions control, and mixture consistency. Concurrent adoption of performance-based specifications further enhanced reliability.

More recently, mass-controlled proportioning systems have transformed HIR by enabling weight-based dosing of RAP, rejuvenators, and additives. This advancement provides plant-like precision, reducing variability and improving overall pavement performance.

6 THERMAL PROCESSING AND EMISSIONS CONTROL

Modern HIR systems employ a staged heating process to achieve uniform thermal penetration while minimizing environmental impact. The process includes:
- Preheating: Recirculating hot-air systems gradually heat the pavement to approximately 50 mm depth.
- Hot milling and windrowing: Material is removed and prepared for further heating.

- Windrow reheating: Controlled heating to ~140°C ensures full binder activation.
- Mixing and placement: Rejuvenators and additives are blended, followed by compaction.

Closed-loop heating systems capture and combust volatilized hydrocarbons, eliminating visible emissions and improving work-zone safety. This controlled process ensures consistent material properties and effective binder restoration.

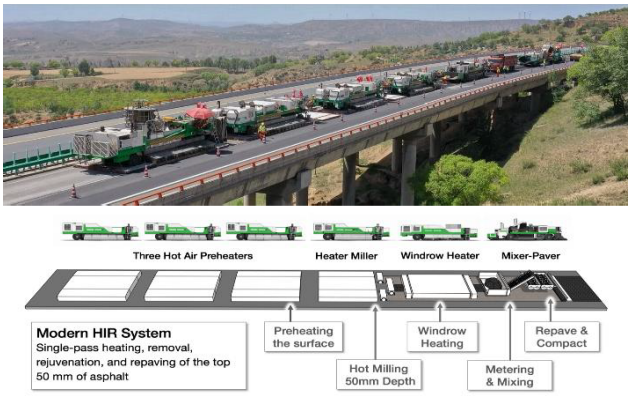


Figure 6. Weight-based mix proportioning and integrated mixer–paver HIR systems.

7 CASE STUDIES

Field applications demonstrate the effectiveness and reliability of modern HIR. Key examples are:
- Ontario (MTO, 1999): Comparable performance to mill-and-overlay with service lives of 7–10 years and improved joint performance.
- Ottawa–Carleton: Approximately 30% cost reduction with improved mixture consistency using performance-based specifications.
- Costa Rica (2005-2006 - Pan-American Highway): Successful large-scale rehabilitation (~180 km) with recycling depths up to 65 mm.
- China (2023–2024): Demonstrated scalability, consistent quality, and elimination of visible emissions with modern systems.

These case studies confirm that HIR can achieve performance equal to conventional methods under a range of conditions.

8 ENVIRONMENTAL AND PERFORMANCE BENEFITS

The environmental benefits of HIR are substantial and primarily result from the in-place reuse of existing materials. By eliminating the need for hauling and reducing reliance on new material production, HIR significantly lowers greenhouse gas emissions, energy consumption, and traffic disruption. The preservation of aggregate integrity through hot milling further enhances material efficiency by maintaining original gradation and minimizing fines generation.

From a performance perspective, modern HIR systems provide improved mixture consistency through precise control of material proportions and enhanced thermal processing. This results in effective binder restoration, uniform volumetric properties, and performance characteristics comparable to, or in some cases exceeding, those of new asphalt mixtures. Field observations have consistently demonstrated satisfactory compaction, rutting resistance, and moisture durability.

9 CONCLUSIONS

Hot In-Place Recycling has evolved into a technically robust and environmentally sustainable pavement rehabilitation method. Advancements in staged thermal processing, emissions control, and mass-controlled proportioning have addressed historical limitations and significantly improved performance reliability. Modern HIR systems are capable of producing high-quality recycled mixtures suitable for highway applications, while offering substantial environmental and economic benefits.

The successful implementation of HIR depends on appropriate project selection, performance-based specifications, and rigorous quality control. When these conditions are met, HIR provides a cost-effective and sustainable alternative to conventional rehabilitation methods, supporting long-term pavement performance and reduced environmental impact.

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