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# Incorporating Sustainable Practices in Asphalt Industry

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## Abstract

Shrink of nonrenewable natural resources and the pollution generated by many manufacturing industries have initiated a global determination for pushing the industry toward more sustainable products. Asphalt as the principal element of almost any street and highway pavement is integral in transportation development, which, in turn, is pivotal for sustainable development. On the other hand, the material consumption and pollution generated in the asphalt industry pose significant threats to the environment and, therefore, to sustainability. This chapter reflects some of the sustainability concerns of the asphalt industry and discusses some of the possible solutions to mitigate them. The sustainability considerations are categorized into four phases of asphalt life cycle namely: (1) extraction of materials, (2) processing of raw materials, (3) transportation of asphalt raw materials and products, and (4) reusing and recycling at the end of a pavement's life. In each phase, best practices to improve and maintain the sustainability of asphalt pavements are discussed. This chapter also discusses sustainable approaches and technologies in the asphalt industry such as warm mixes, permeable asphalt pavements as well as the potentials for improving the mechanical properties of asphalt pavements particularly in terms of resisting heavy load traffic, clogging, and freeze-thaw.

**Keywords:** asphalt pavement sustainability, warm mix, permeability, emission

## 1. Introduction

The massive demand for asphalt pavement is a response to the growing length of highways and the number of vehicles worldwide. In the USA, for example, highway networks are approximately 8 million miles and facilitate over 3 million vehicle miles yearly [1]. According to Green Car Reports, there are nearly 1.2 billion vehicles in operation today, and this number is constantly growing to reach the estimated number of 2.5 billion by 2050. The massive number of vehicles has expanded the need for more streets and highways most of which require asphalt paving. Additionally, the pavements that are in use require periodic repairs and replacements of asphalt. This explains an enormous increasing demand for asphalt.

This chapter discusses a comprehensive approach to maximize the sustainability of the asphalt industry. This approach is presented in the two following major parts. (1) Assessment of asphalt's environmental impacts in its life cycle. In this section, the sustainable practices in the four phases of asphalt's life cycle (material procurement, processing of raw materials, transportation of products, and end of a

product's life) are discussed. (2) Sustainable approaches in the asphalt industry. This section is divided into two parts that discuss two main directions in pushing the asphalt industry to improve its contribution to sustainability. The first direction is enhancing the technology of warm mix asphalts, which explains the benefits and the existing shortcomings of these mixes that require further research. The second part discusses the opportunities for reducing the transfer of pollutants through runoffs by using permeable asphalt pavements. The barriers to more widespread use of permeable asphalt pavements that need to be considered by the asphalt industry are also presented.

The chapter is expected to provide an understanding of the adverse impacts of the asphalt industry on the environment, how these impacts can be mitigated, and what additional steps must be taken to enhance the existing sustainable methods in different stages of asphalt's life cycle.

## **2. Is asphalt an unsustainable product by itself?**

Despite the impression from the detrimental impacts of asphalt on the environment, in compassion with other pavements, asphalt can be addressed as a sustainable material. According to Gambetes, producing asphalt pavements requires almost 20% less energy than other pavements. Additionally, the construction and rehabilitation of these pavements are relatively quick as no curing is needed before the repaired road segment is ready to use. This is beneficial in reducing the exposure to construction process pollutions, in saving taxpayers' money, and in reducing the time of road closure, which contributes to the societal bottom line of suitability.

Recycling in the asphalt industry is not a goal for the future. It is already happening in massive amounts. For example, the USA, as the leading recycler of asphalt, reclaims approximately 65 million tons of its products annually and reused almost 99% of it [2]. The asphalt industry also contributes to the reuse of other materials such as tires, glass, blast furnace slag, and asphalt roofing shingles.

In terms of maintenance and rehabilitation, asphalt pavements are also less expensive than concrete pavements. Although their service life is relatively shorter compared with concrete pavements, with proper design, construction, and maintenance, they can continue to serve for decades without wearing out. Their maintenance is faster and less expensive than concrete pavements. This is why rubbishing or covering worn out concrete pavements with an asphalt surface is a common practice for repairing concrete pavements.

Research findings support that asphalt pavements provide superior contact between the vehicle tires and the road surface, which enhances vehicle safety. When designed with open-graded, asphalt pavements can effectively reduce the rainwater splash, which can potentially improve visibility and reduce accidents.

Asphalt pavements are relatively low noise pavements and are beneficial to be used in urban areas where reducing noise pollution is essential. According to the research [2], asphalt pavements can lower the noise between 3 and 10 dB, which affects similar to doubling the distance from the road to the people who can hear the road noise (**Figure 1**).

To answer the question if asphalt pavements contribute to sustainability or are detrimental to it, certain facts must be considered as follows:

1. The sustainability must be compared with other alternatives of pavements. If a pavement is more sustainable than other alternatives, even if, it has a burden on the sustainability triple bottom lines, it is considered as the sustainable



**Figure 1.**  
*The sustainability benefits of asphalt pavements compared with other pavements.*

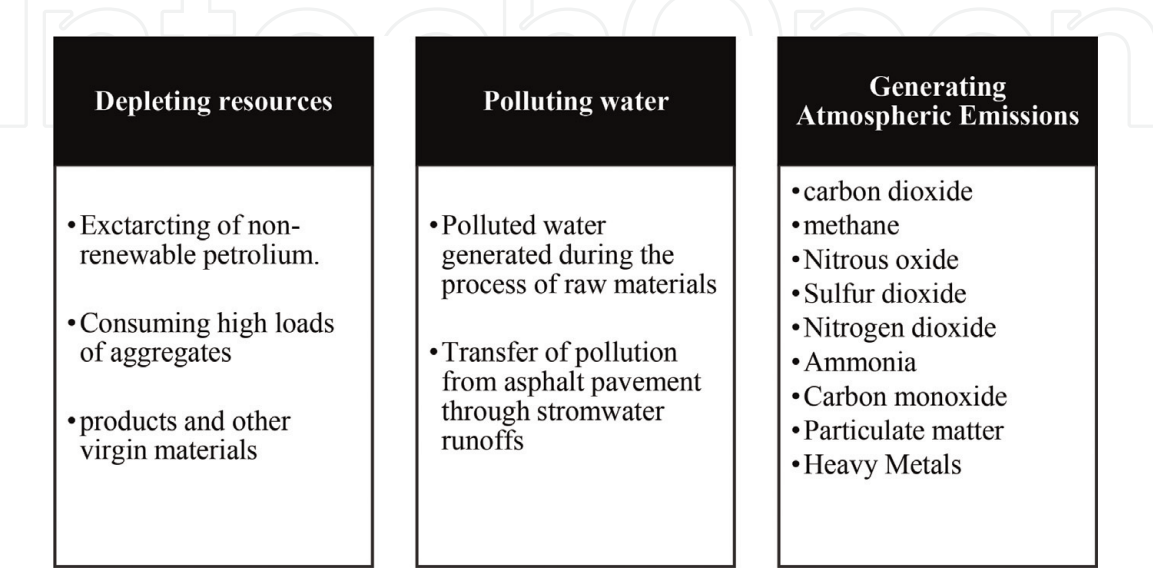
option. Based on this comparison, asphalt pavements are one of the most sustainable options for pavements.

2. The sustainability must be compared with the optimum potential sustainability that can be achieved in the procurement, design, production, shipping, construction, rehabilitation, replacement, and reuse of the product. Based on this approach, there is high potential in modifying the technology of asphalt pavements to enhance their sustainability.

**3. How does the asphalt industry affect the environment?**

The asphalt industry negatively impacts the environment in three ways. This is shown in **Figure 2**. As a petroleum-based product, asphalt mixes carry a significant amount of chemicals that can impact the environment during extraction, transportation of raw materials, processing, and using.

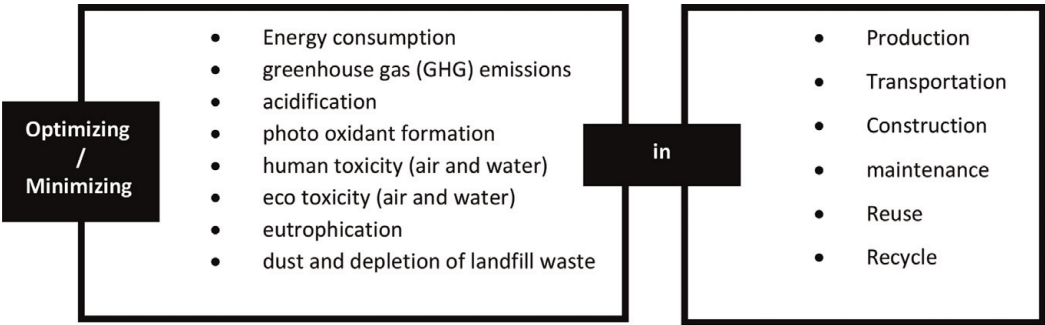
Another primary adverse environmental impact of asphalt is on water. Hazardous chemicals, dust, and other particles can penetrate to asphalt paving surfaces and then be transferred through stormwater runoffs. The polluted runoffs can eventually affect water bodies and endanger aquatic life, reduce water quality, and degrade the views to name a few. This explains the asphalt industry must focus vigorously on the ways to mitigate the accumulation and transfer of pollutants. The third major adverse impact of the asphalt industry is generating atmospheric emissions. A wide range of hazardous emissions are released particularly in the process of heating the mix. These emissions contribute to global warming and lead to various impacts on the environment as well as on the human health.



**Figure 2.**  
*The primary adverse impacts of the asphalt industry on the planet.*

4. What are the main approaches in improving the asphalt industry’s sustainability?

Once the detrimental impacts of asphalt on the environment are identified, practices to minimize these impacts must be established and followed. **Figure 3** shows some of the indicators of asphalt sustainability as it relates to material, construction, maintenance, and use [3]. The figure indicates why the sustainability of asphalt industry has significant potentials for improvement in multiple aspects. The challenge is the tradeoff of compromising some of the mechanical properties of asphalt to make it more sustainable. For instance, a wide range of emissions can be reduced by lowering the temperature of heating the asphalt mixes, but there are some uncertainties if the reduced temperature can maintain an asphalt pavements resistance against fatigue or heavy loads. This will be discussed in more details in Section 5.2.2. Therefore, the sustainable approaches must keep a balance between lowering the adverse environmental impacts and the functionality, mechanical property, and durability of asphalt pavements.



**Figure 3.**  
*Potential approaches to improve environmental sustainability in the asphalt industry.*

5. Mitigating asphalt’s negative environmental impacts in its life cycle

The life cycle assessment or cradle-to-grave is an integral element of sustainability evaluation. This approach must be applied for asphalt analysis to assess its impacts on global warming and climate change, depletion of fossil fuels, and human well-being to name a few [4]. Life cycle assessment encompasses a wide range of decisions and activities in different phases of asphalt production, transportation, use, and reuse. In addition to extraction, significant amounts of materials such as bitumen, fuel oil, and gasoline are transferred and stored in asphalt plants. Opportunities to modify the traditional practices that are commonly used in asphalt plants must be studied for each plant. There exist common best practices that can be followed by the managers of asphalt plants. **Table 1** shows the four primary steps in life assessment of asphalt products (data from [5]). These four stages and some best practices to apply in each of them are discussed in the following.

5.1 Material procurement (phase 1)

The practices used in the procurement of virgin materials can significantly identify the level of sustainable production of asphalt mixes. While main asphalt ingredients are primarily byproducts of the petroleum industry; considering the magnitude of their production, there are independent practices for enhancing the sustainable procurement of virgin materials in the asphalt industry. Based on the



discussed sustainability concerns about the asphalt industry, the following target can be defined to push this industry toward more sustainable practices:

5.1.1 *Extraction of materials*

The enormous demand for nonrenewable raw materials to produce asphalt pavements is a threat to sustainability. For instance, 83% of all street pavements in the USA are made of asphalt [6]. The primary step in contributing to sustainability in the procurement of asphalt materials is reducing the demand for the extraction of nonrenewable petroleum resources and other virgin materials. One of the greatest advantages of asphalt is its recyclability for almost unlimited times. The fact that asphalt pavements are 100% recyclable can be interpreted that there is no certain end life for them [7]. **Figure 4** shows the sustainable procurement process of

Cradle to grave process	Phases	How the assessment must be performed
Cradle to gate	Phase 1. Material procurement	<ul style="list-style-type: none"><li>• Extraction of materials</li><li>• Reuse and recycle</li></ul>
	Phase 2. Processing of raw materials	<ul style="list-style-type: none"><li>• Energy consumption reduction</li><li>• Pollution and emission reduction</li></ul>
	Phase 3. Transportation of product	<ul style="list-style-type: none"><li>• Vehicles' air pollution reduction</li><li>• Preventing the spill of polluting materials during transportation</li></ul>
Gate to grave	Phase 4. End of a product's life	<ul style="list-style-type: none"><li>• Connecting end use point to reuse and recycle</li></ul>

**Table 1.**  
*The primary steps of a life-cycle assessment of asphalt products.*



**Figure 4.**  
*Sustainable procurement process of materials in an asphalt plant.*

materials in an asphalt plant. As it is seen in each of the six following steps, there are potentials to maintain the sustainability of operations. The asphalt plant's determination and leadership in establishing these practices is pivotal in the successful application of these practices and policies.

## 5.2 Processing of raw materials (phase 2)

The most energy-intensive phase of asphalt production is the processing phase as it requires a high temperature for burning and processing of raw materials. This phase is also the most polluting phase due to the emissions that are normally generated in different heating processes. Therefore, energy and pollution reduction are the primary sustainability goals of this phase. This is explained in the following.

### 5.2.1 Energy consumption reduction

To have a holistic energy consumption reduction approach, the consumers of energy in the typical production phase should first be identified. In the following, some of the main energy consumers in the production process are identified.

(1) Fuel or electricity needed for construction equipment that is applied in the production process, (2) energy to operate burners that dry aggregates, and (3) fuel for heating liquid asphalt binder and other mixing processes (natural gas, propane, diesel fuel, recycled fuel, biofuels, etc.)

The comprehensive study of the system to identify the potentials for energy consumption reduction is required. Some of the best practices in this regard are the following:

1. Supplying energy from more sustainable sources (solar and wind power)
2. Constant maintenance of the tools and equipment to maintain their efficiency
3. Minimizing wastes of energy in heating processes
4. Replacing low-efficiency tools with new efficient ones
5. Optimizing the layout, production queuing, and supply of raw materials to minimize energy consumption

### 5.2.2 Pollution and emission reduction

The second main goal in sustainable processing of asphalt is pollution and emission reduction. To enhance the environmental sustainability of the asphalt industry, controlling certain chemicals must be the target. **Table 2** shows the primary hazardous chemicals, how they are generated in the asphalt industry, and why they must be controlled.

It should be noted that lowering the mixing temperature can substantially contribute to both energy consumption and emission reduction. Therefore, it is crucial to invest in modifying asphalt technology in this direction. Warm mix asphalt is the product of this approach, which is one of the most impactful modifications in asphalt technology to make it more sustainable. Warm mixes will be discussed in Section 6.1.

Research shows that the reduced energy consumption required in the manufacture of warm mix asphalts can lower the carbon dioxide emission between 30 to 40% [8] and 30 to 50% reduction on the fumes at bituminous plants, which is

Hazardous chemicals	Why they must be controlled (selected hazards and the chemical causes)	Primary generation area
Carbon dioxide (CO <sub>2</sub> )	Global warming, climate change, human toxicity	Construction
Methane (CH <sub>4</sub> )	Global warming (21 times more than carbon dioxide), photo-oxidant formation	Construction
Nitrous oxide (N <sub>2</sub> O)	Global warming	Construction
Sulfur dioxide (SO <sub>2</sub> )	Acidification, photo-oxidant formation, human toxicity	Construction
Nitrogen dioxide (NO <sub>2</sub> )	Acidification, eutrophication, human toxicity, photo-oxidant formation	Construction + End of life
Ammonia (NH <sub>3</sub> )	Acidification, eutrophication, human toxicity	Construction + end of life
Carbon monoxide (CO)	Human toxicity, photo-oxidant formation	Construction
Nonmethane volatile organic compound (NMVOC)	Ecotoxicity, human toxicity, photo-oxidant formation	Construction + maintenance
Hydrocarbon (HC)	Ecotoxicity, human toxicity	Construction + maintenance + use
Particulate matter (PM)	Human toxicity	Construction
Heavy metals	Human toxicity	Construction
Arsenic (As)	Ecotoxicity, human toxicity	Maintenance + use
Cadmium (Cd)	Ecotoxicity, human toxicity	Maintenance + use
Lead (Pb)	Ecotoxicity, human toxicity	Maintenance + use
Mercury (Hg)	Ecotoxicity, human toxicity	Maintenance + use
Chemical oxygen demand (COD)	Eutrophication	End of life
Phosphate (PO <sub>4</sub> )	Eutrophication	End of life
Nitrate	Eutrophication	End of life
Phosphorus (P)	Eutrophication	End of life
Nitrogen (N)	Eutrophication	End of life

**Table 2.**  
*Hazardous chemicals that must be controlled to enhance the environmental sustainability of the asphalt industry.*

significantly beneficial for workers on a paving team [9]. Additionally, reduced emissions enable to establish asphalt plants closer to urban areas [10]. This, in turn, can reduce transportation pollution, cost, and increase the accessibility of asphalt materials for urban construction. **Table 3** compares the emission generated by hot and warm mix asphalts ([11] as cited by [8]).

As it is seen in **Table 3**, the amount of emission reductions for replacing hot mix with warm mix asphalts is significant. These reductions contribute to reducing the global warming effects at a large scale, pollution for neighboring urban areas at a middle scale, and a healthier environment for the people working at the asphalt plant in a small scale.



5.3 Transportation of asphalt raw materials and products (phase 3)

Asphalt industry is involved with a massive demand for transportation to (1) supply the raw materials for the production and (2) deliver the products to consumers in an almost nonstop basis. Additionally, being a petroleum product, asphalt materials and products carry high loads of chemicals that can potentially be hazardous to the environment (as it was listed in the **Table 3**). **Table 4** shows some of the indicators of sustainable transportation of asphalt raw materials and products.

5.4 End of a product’s life (phase 4)

Considering the huge amount of asphalt-paved streets and highways, an enormous amount of asphalt pavements can reach their end-of-life point in any selected interval. The sustainable approach of cradle to cradle attempts to connect the end of

Type of emission	Hot mix asphalt	Warm mix asphalt	Reduction
Temperatures (°C)	155–165	110–120	45
Gases temperature (°C)	65.6	50.3	15
CO <sub>2</sub> (%)	2.12	1.59	25
CO (ppm)	217	151.6	30
NO <sub>x</sub> (mg/m <sup>3</sup> , e.g., NO <sub>2</sub> )	26.8	21.5	25
Environmental dust (mg/m <sup>3</sup> )	168	21	88

**Table 3.**  
*Comparing the emission generated by hot and warm mix asphalt.*

Sustainable transportation approach	How to implement
Reducing the number of trips	<ul style="list-style-type: none"><li>• Increase the capacity of delivery in each trip</li><li>• Optimize trips to deliver more in fewer trips</li></ul>
Enhancing the safety of trips	<ul style="list-style-type: none"><li>• Building private roads for main access to the asphalt plant</li><li>• Putting signs around the heavy vehicle</li></ul>
Reducing the distance of trips	<ul style="list-style-type: none"><li>• Locating the asphalt plants with optimal distance to multiple consumers</li><li>• Creating temporary asphalt plants near road projects</li></ul>
Protecting health and well-being	<ul style="list-style-type: none"><li>• Reduce the vehicles’ pollution or use hybrid vehicles</li><li>• Reduce transportation noise</li></ul>
Protecting the hosting roads environment	<ul style="list-style-type: none"><li>• Minimize spill of chemicals form the vehicle</li><li>• Be responsible for fixing possible damages to the environment</li><li>• Ongoing maintenance and smog check of vehicles</li><li>• Replacing polluting and old vehicles with efficient and green vehicles</li></ul>
Promote local consumption	<ul style="list-style-type: none"><li>• Give priority to local projects to avoid long trips</li></ul>

**Table 4.**  
*Principles of sustainable transportation of asphalt raw materials and products.*

life to reuse of asphalt pavements. The primary solution to reduce the demand for more raw materials for asphalt production is the reuse of asphalt and mixing it with virgin materials. Asphalt mixes contain a considerable amount of recyclable materials such as coarse and fine aggregates. To maximize the asphalt reuse, production of certain types of asphalts must be encouraged.

#### *5.4.1 Reclaimed asphalt pavements (RAP)*

Using reclaimed asphalt pavement (RAP) in producing new bituminous mixes has multiple sustainability advantages including significant cost and energy savings and environmental benefits due to a reduction in the waste generated in road maintenance and rehabilitation processes [12, 13].

According to the National Asphalt Pavement Association of the USA, reclaimed asphalt pavements are removed or reprocessed pavement materials containing asphalt and aggregates. These materials are the debris of construction activities such as reconstruction, resurfacing, and diggings to gain access to buried utilities [14]. Based on the estimates, 41 million metric tons of RAP is produced yearly in the United States [14]. According to EAPA [15], in Europe, approximately 50 million tons of RAP is produced annually. This enormous volume of RAP can be reused to produce new bituminous mixtures [8].

The environmental and economic advantages of applying RAP in hot mix asphalts can be maximized by producing totally recycled hot mixed produced with 100% RAP. The challenge to do this is improving the mechanical properties of these mixes such as workability, durability, binder aging, and fatigue cracking resistance [16].

#### *5.4.2 Recycled asphalt shingles (RAS)*

##### *5.4.2.1 Waste plastic*

Waste plastic is another massive source of material reuse to procure the asphalt ingredients. Only in the USA, 42.6 1-l bottles are purchased every year. It is estimated that on a global scale, 200 billion plastic water bottles are consumed by people [17]. The abundant amount of plastic waste and its suitability to be used in the asphalt industry creates a massive opportunity to reduce the need for virgin materials. The research has identified and encouraged this opportunity [18, 19].

## **6. Sustainable approaches in the asphalt industry**

This section discusses the next steps in improving the sustainability of asphalt industry. The two main approaches discussed are (1) warm mix asphalts and (2) permeable asphalt pavements. In each section, the sustainability advantages are explained. Additionally, the shortcomings of the existing technologies and potentials for improvement are discussed. **Table 5** provides a summary of this section.

### **6.1 Warm mix asphalts**

Reducing the temperature of mixes is a fundamental sustainability approach in asphalt industry as it contributes to both energy reduction and emission mitigation [9, 10, 20, 21]. Warm mix asphalt is the result of the temperature reduction approach. Research findings support that using them contributes to reducing energy consumption and air emissions [22]. Regular hot mixes need a temperature

of 150°C or more for production and compaction [23]. Warm mixes can lower the demand for energy by reducing the heat needed between 16 and 55°C (Figure 5) [24].

The decline of required temperature for processing asphalt mixes is proportional with requiring less fuel/ton to heat the mix. For instance, hot mix asphalt may require a temperature of 180°C and more than 7 l of fuel per ton and half warm asphalt may require to be heated between 60 and 80°C and less than 4 l of fuel per ton [9]. Reduction of fuel, in turn, leads to a reduction in fuel costs between

Technology type	How it contributes to sustainability	Shortcomings that need to be resolved
Warm mix asphalts	<ul style="list-style-type: none"><li>• Reduces energy demand for heating the mix</li><li>• Reduces emissions</li></ul>	<ul style="list-style-type: none"><li>• Low resistance to fatigue</li><li>• Moisture damage due to incomplete drying of aggregates</li></ul>
Permeable asphalt pavements	<ul style="list-style-type: none"><li>• Controls urban runoffs</li><li>• Prevents transfer of pollution to water bodies</li></ul>	<ul style="list-style-type: none"><li>• Low resistance to high compressive loads</li><li>• Clogging</li><li>• Freeze-thaw issues</li></ul>

Table 5.  
Sustainable technologies in asphalt industry.



Figure 5.  
Low temperature of production for warm mix asphalt (courtesy of Federal Highway administration).

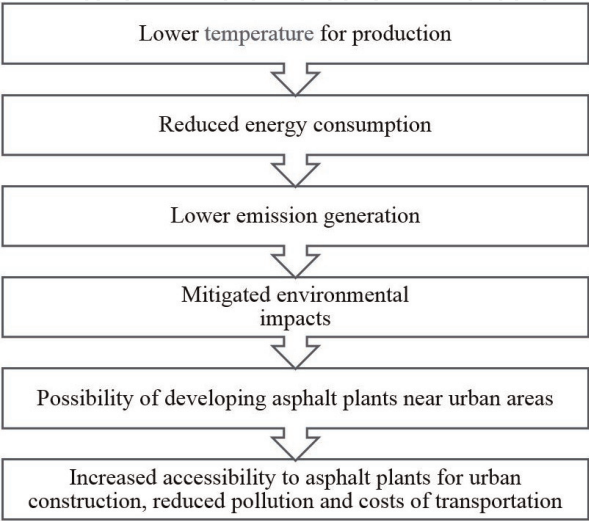


Figure 6.  
How warm mixes contribute to sustainability.

25 and 35% [11]. **Figure 6** shows some of the sustainability advantages of these mixes (data from [25]).

Another advantage of warm mixes is the possibility of using reclaimed asphalt pavements in them [8]. In addition, sustainability advantages (see **Figure 7**) and research findings indicate that the mechanical properties of these mixes are not compromised to make them more environmentally friendly. These mixes have stiffness very close to hot mixes, and their water sensitivity and fatigue resistance are comparable with hot mixes.

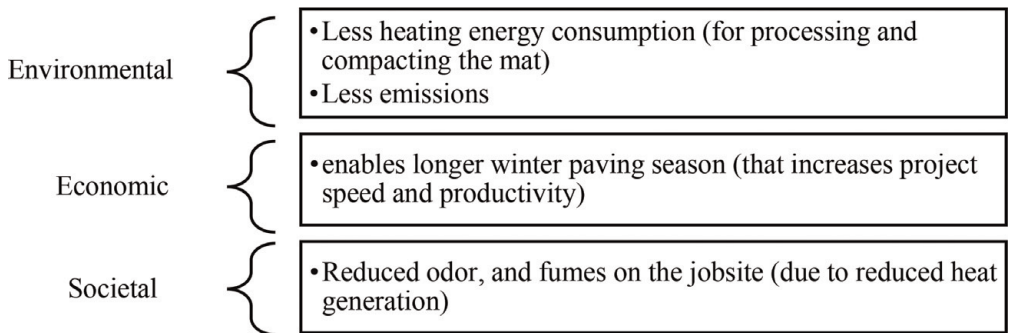
6.1.1 Research status of warm mix asphalt mixtures

An impactful approach in increasing the sustainability of warm mix asphalts is the use of rubberized asphalt concrete (RAC). This novel technology, which is addressed as WarmRAC, is both economically and environmentally sound [26]. Although these mixes have been used since the 1960s in the US [27], their technology is still evolving. Research has shown a satisfactory functionality of these pavements for improving aging, oxidation, fatigue, skid, reflection cracking, and rutting resistance as well as mitigating noise generation [26], improved durability and lower maintenance costs [28, 29]. To enhance various aspects of warm mix pavements, the research findings can be categorized into design, construction, performance, and recycling [26] as shown in **Table 6** (data from [26]).

6.1.2 Potentials for improvement in warm mix asphalt technology

Warm mix asphalt technology has been evolving since they were introduced [30–33]. The prerequisite of reducing the energy needed for processing and compacting the mat is reducing the shear resistance of the mixture. Research shows that the primary approach in extending asphalt pavement’s durability is the prevention of fatigue in them resulting from repeated loading and unloading by the traffic [33, 34]. The findings [11] indicate that warm mix asphalts have quite satisfactory performance in resisting cracking caused by fatigue [8].

1. Further reduction of required temperature for processing. As it was explained above, the reduction of the temperature in proceeding warm mix asphalts is proportional to energy consumption reduction, fewer fuel costs, lowered emission, and mitigated pollutions. Therefore, research must invest in further reduction of the processing temperature of these mixes. This reduction must maintain the expected mechanical properties of mixes. Optimizing the trade-off between lower temperature and the mechanical performance required further research.



**Figure 7.**  
*Sustainability advantages of warm mix asphalt.*



Main category	Subcategories	Potentials for improvement
Design	Material selection	Responsiveness to climate Responsiveness to high loads of traffic
	Mix gradation	Gap and open gradation Using in dense graded mixtures
	Optimum bitumen content selection	The relationship between bitumen content and durability, permeability, water susceptibility, and compaction
	Laboratory performance evaluation	Enhancing lab methods for conditioning/curing of test samples, workability, etc.
Construction	Temperature issues	Solving temperature issues during construction (through reducing the viscosity of binder)
	Production rate	Increasing the production rate to increase the construction speed
	Compaction	Achieving the target compaction density of WMA
Performance	Comparing different types of WarmRAC	Warm rubberized asphalt binder, Warm mix rubberized asphalt concrete, etc.
Recycling	Recycling methods for WarmRAC	The differences between recycling WarmRAC and conventional mixes Increasing the reusability
Environmental analysis	Potential environmental effects of RAC pavements	Air quality and occupational exposure Water quality

**Table 6.**  
*Research approaches in enhancing the warm mix asphalt technology.*

2. Incorporating RAP in warm mix asphalt. Both warm mix asphalts and RAP are the results of sustainable approaches in asphalt production. The combination of both approaches is expected to maximize the sustainability of asphalt production. These innovative warm mixes are recycled asphalt with bitumen emulsion. Applying them is expected to contribute to both the economy and the environment. The lowered temperature allows using a larger amount of materials for recycling. This can reduce material use and increase energy savings and reduce costs [35]. A variety of lab tests have been conducted to evaluate the mechanical properties of these mixes including fatigue, bending, rutting, Marshall immersion, aging, and freeze-thaw-cycle splitting. The findings show that application of RAP can negatively impact the moisture and low-temperature cracking resistance, rutting resistance, aging, tensile strength ratio (TSR), and fatigue resistance [36]. On the other hand, there are findings that indicated an improved performance of mixes that use RAP [37]. Further research is required to resolve the possible poor performance of these mixes considering their significant contributions to sustainability.

**6.2 Reducing the transfer of pollutants through runoffs by using permeable asphalt pavements**

One of the primary negative impacts of the expansion of asphalt pavements is modifying the natural conditions of runoff paths by extending impervious surfaces that cannot effectively capture runoffs [38]. Stormwater runoffs contribute to various environmental issues including pollution of water bodies, reduction of groundwater recharge, and increasing the rivers' water temperature [39]. According to USEPA, urban runoffs are the leading source of water quality



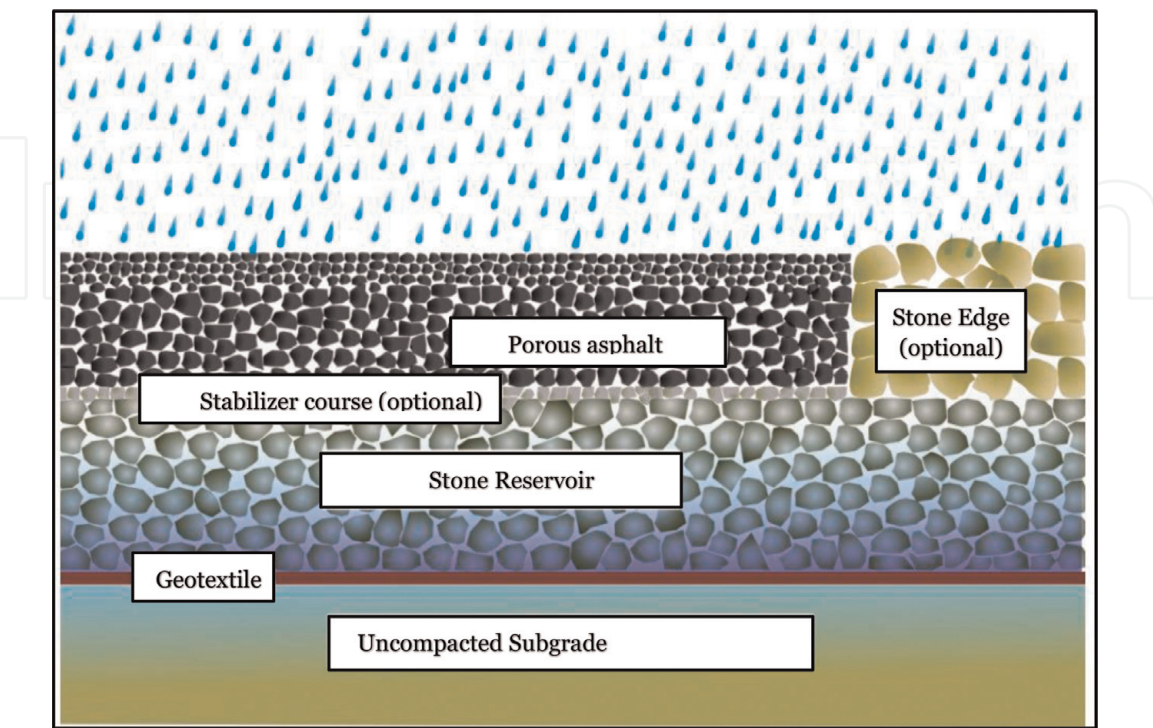
impairment to surveyed estuaries and the third-largest source of impairments to surveyed lakes [40]. Considering these significant detrimental impacts on the environment, the asphalt industry has an indispensable role in developing asphalt design and production modifications that contribute to stormwater runoff control. A primary approach in doing so is increasing the runoff capturing capacity of pavements (**Figure 8**).

*6.2.1 The sustainability advantages of using permeable asphalt pavements*

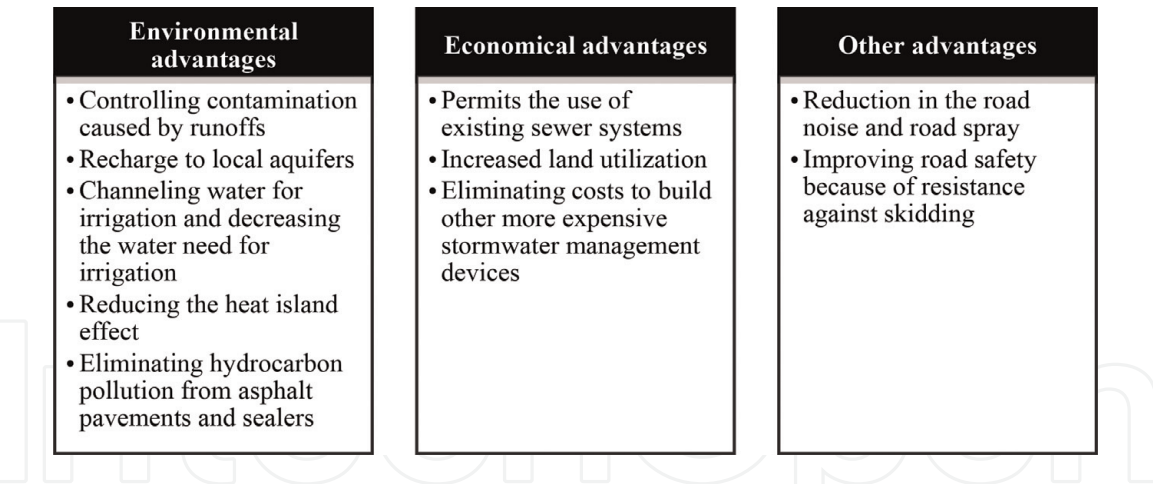
Permeable, pervious, or porous asphalt pavements have been identified as one of the dominant solutions and best management practices (BMPs) in controlling urban runoffs. They assist the transfer of runoffs to drain through the layers of the pavement into the ground below. The technology of permeable asphalt is still evolving, and significant ongoing research is currently followed to enhance the functionality of these pavements in different aspects such as durability, runoff capturing capacity, and ease of maintenance. Some of the sustainability advantages of using permeable pavements are shown in **Figure 9** [41].

As it can be seen (from **Figure 9**), the advantages of pervious pavements are significant, and a vigorous attempt must be made to encourage the asphalt industry to replace impervious pavements with permeable pavements wherever they can be applied. While this transition may be costly, the savings that can be made from eliminating the need to make more expensive stormwater runoff control devices such as retention ponds and swales, specifically in urban areas where land is very expensive, compensate the additional costs [42].

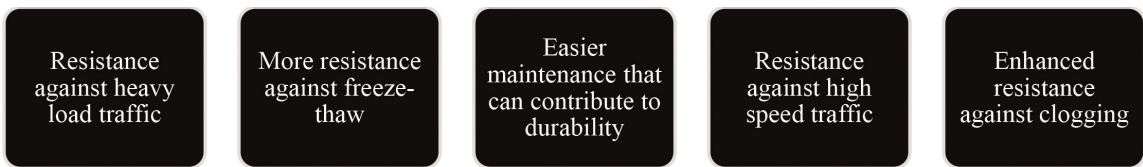
Additionally, the application of permeable asphalt pavements is more critical in urban areas for two reasons. One is the rapid growth of cities that is accompanied by replacing the soil and natural runoff paths with concrete and asphalt pavements [43]. According to the United Nations' report, in 2010, more than half of the earth's population lived in cities [44]. According to the research, between 60 and 100% of



**Figure 8.**  
*Typical porous asphalt pavement with stone reservoir cross section (courtesy of Federal Highway Administration).*



**Figure 9.**  
*The advantages of using permeable pavements for the triple sustainability bottom lines.*



**Figure 10.**  
*Potentials for pervious asphalt pavements' mechanical property advancement.*

the total urban areas have impermeable surfaces [45]. This is exacerbated by the multiple negative impacts of construction projects with long and often extended project durations [46, 47]. The second reason is the high presence of chemical pollutants and particles in urban runoffs [48]. This can be attributed to housing, vehicles, and industry activities in cities [49–51].

6.2.2 Research status of permeable asphalt pavements and filling the knowledge gap

Although there are adequate reasons for increasing the application of permeable pavements, there are certain barriers that limit their application. The research in the asphalt industry should focus on minimizing these barriers. The predominant barrier with this regard is the reduced resistance of permeable pavements against high loads of traffic. Considering that parking lots are one of the sensitive urban areas to collect polluted runoffs, the low compressive strength of permeable pavements limit their application for the parking lots where heavy equipment tools are parked. Also, the resistance of these pavements must be improved to withstand high-speed traffic. Another potential for mechanical property improvement is the permeable pavement's resistance against freeze-thaw as these pavements can capture and store water particularly when they are poorly constructed, and the infiltration process in them takes longer than it should normally take. Also, the clogging of these pavements over time and as a result of exposure to fine particles reduced their functionality [41]. **Figure 10** shows four potentials for improvement in the permeable pavements that require further research.

7. Summary and discussion

This chapter discusses the instrumental role of expanding asphalt pavements in nations' growth and development and the enormous and ever-rising demand to


asphalt. It was stated that although asphalt production, in comparison, with other types of pavements is not considered an unsustainable industry, due to massive volumes of its production, it can have significant impacts on the sustainability triple bottom line and, more particularly, on the environment. The main sustainability in this regard was consumption of virgin materials, energy, and water as well as emission of pollutants. A key solution for pushing asphalt industry was suggested to be a comprehensive life-cycle analysis to identify all the possible potentials to implement sustainable practices in the four phases of material procurement, processing, transportation, and end of life point. Some policy recommendations were provided in each category. This chapter also discusses the opportunities for further advancement of the current sustainable approaches in the asphalt industry. The two main approaches were warm mix asphalts and pervious asphalt pavements. It was explained that although these technologies have significant sustainability advantages, there are some drawbacks in their application that need to be resolved through a collaborative effort of the industry and research. Some of the potentials of mechanical improvements of the two technologies were mentioned. It is essential that the individuals involved in the asphalt industry understand the essentiality of applying sustainable practices, gain enough knowledge and expertise of how to implement them, and then pursue the application of sustainable practices throughout the production process. Researchers, on the other hand, are responsible to target mitigating the existing environmental risks of asphalt pavements.

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