CAMBRIDGE SYSTEMATICS

Cool Pavement Report

EPA Cool Pavements Study - Task 5

draft

report

prepared for

Heat Island Reduction Initiative, U.S. Environmental Protection Agency

prepared by

Cambridge Systematics, Inc.

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Executive Summary

Cities can be several degrees warmer than surrounding regions due to the built environment and the concentration of human activity, a phenomenon referred to as an urban heat island. Pavements have become an important contributor to this effect by altering landcover over significant portions of an urban area. Analyses in cities such as Chicago, Houston, Sacramento, and Salt Lake City have shown that pavements for both travel and parking can account for 29 to 39 percent of urban land surface.

Researchers have studied ways to reduce the urban heat island effect, and have identified vegetation, "cool roofing" materials, and "cool pavements" as mitigation strategies. While good ways to use vegetation are understood and cool roofing products have been identified, the idea of cool pavements has yet to gain wide dissemination and acceptance among local transportation and public works agencies and private-sector developers and owners. Several reasons account for this situation. First, there are technical hurdles in identifying the best cool pavement technologies and their different applications in varying climates. Second, the benefits from cool pavement are indirect. Third, institutional complexities surround pavement type selection throughout a metropolitan area, and more information on the economics of cool pavements, as well as funding mechanisms to support these technologies, are needed.

Reducing the urban heat island effect can benefit air quality, lower air conditioning needs, and enhance human health and comfort. Using cool pavements also helps to improve water quality, noise, safety, and nighttime illumination.

Cool pavements can be achieved with existing paving technologies and do not require new materials. Possible mechanisms for creating a cool pavement that have been studied to date are a) increased surface reflectance, which reduces the solar radiation absorbed by the pavement; b) increased permeability, which cools the pavement through evaporation of water; and c) a composite structure for noise reduction, which also has been found to emit lower levels of heat at night. Several conventional paving technologies now exist that can apply these mechanisms. For example, greater reflectance can be provided by conventional concrete, roller-compacted concrete, concrete-over-asphalt ("whitetopping" and "ultra-thin whitetopping"), asphalt concrete and asphalt chip seals with light-colored aggregate, and asphalt pavements with modified color. Porous pavements can be built with asphalt concrete, portland cement concrete, or unbound surfaces such as stone, brick, or grass. The composite structure used for noise reduction plus nighttime temperature benefits comprises a rubber asphalt surfacing over conventional concrete slabs. It should be noted that specific pavement technologies with cool attributes will not be appropriate for all uses; some may be better suited to light traffic areas, for instance; others to areas where noise management is considered crucial. In addition, certain paving technologies may not always be appropriate or feasible in a particular region of the country – whether technically, economically, organizationally, or institutionally.

The makeup of the U.S. paving industry will have an important influence on the way pavement owners consider the use of cool pavements. Far from being a monolithic industry with homogenous characteristics, it is broken down into multiple actors, public and private, that vary in goals, services offered, institutional and economic structure, and show considerable geographic variations as well. State and local agencies have primary responsibility for the majority of public pavement facilities; private facilities comprise a wide variety of commercial, residential, and industrial roadways and lots.

While all of the technologies mentioned above are now available, local agencies often lack the information and incentives to apply these in a coordinated and consistent way throughout their metropolitan areas. For a given project, pavement selection is generally made independently of environmental concerns. However, transportation professionals are looking for innovative ways to deal with environmental issues, and the marriage of cool pavement benefits to the attainment of other policy objectives (such as improved groundwater quality by using porous pavements in parking areas) could potentially provide incentives to use cool pavement technologies. Such an approach also may allow cool pavement projects to leverage funds geared towards these other policy objectives.

Through its Heat Island Reduction Initiative, the U.S. Environmental Protection Agency (EPA) has looked at how pavements might reduce urban temperatures and improve air quality. While the research has provided useful, many questions remain regarding pavements' effect on urban climate and air and water quality as well as on the cost effectiveness of the various technology options. Therefore, the EPA has commissioned this report to capture the state of knowledge and activity on cool pavements. This report is intended to present straightforward information to help decision-makers – to the degree possible – select the best pavements for their current needs. Further, this document is meant to help advance the issue by presenting information on research needs and next steps.

Potential research opportunities to advance and promote cool pavements exist in several areas:

- To demonstrate the cool pavement behavior of conventional and innovative pavement materials and designs in facilities such as highways or boulevards, large parking lots, and terminals;
- To understand better, both theoretically and empirically, the contributions of cool pavements to reducing the urban heat island and improving air and water quality, and how to better account for complicating factors in actual urban settings such as shadows from nearby structures, changes in pavement characteristics over time, and absorption by nearby buildings of solar radiation reflected from the pavement surface; and

- To understand and deal with the organizational and institutional factors affecting pavement decisions by local agencies, including information dissemination, development of case studies; potential roles of planning bodies such as Metropolitan Planning Organizations (MPOs) in providing information, regional coordination, and funding assistance; and ways to leverage existing funding (e.g., for safety, air quality, ground water protection, etc.) to help meet cool pavement objectives as well.

1.0 Introduction

Pavements are critical to transportation in all of its aspects – walking, riding in passenger vehicles, carrying goods in commercial vehicles, providing mobile services, and parking. They account for a significant percentage of the land surface in an urban area. Analyses in cities such as Chicago, Houston, Sacramento, and Salt Lake City have shown that pavements for both travel and parking can account for 29 to 39 percent of the land surface in an urban area.[1] A large portion of this is due to parking; in the Houston, Texas, metropolitan area, the parking facilities account for approximately 60 percent of the transportation land use.[2]

By altering landcover, pavements have important localized environmental effects in urban areas. This report focuses on the contributions pavements make to the urban heat island. As with roofing materials, paving materials can reach 150° F in daytime, radiating away this excess heat during both day and night into the air in the urban canopy layer (as well heating stormwater that reaches the pavement surface).[3] Due to the large area covered by pavements in urban areas, they are an important element to consider in heat island mitigation.

This contribution can be reduced by using "cool pavements." Cool pavements can be achieved with existing paving technologies and do not require new materials. Their "cool" nature comes about by the attention given to the choice of materials and engineering design. The use of cool pavements is meant to reduce pavement temperature by increasing pavement reflectivity or controlling temperature by other means, with the selected technique(s) applied as appropriate throughout the urban area. Specific pavement technologies with cool attributes will not be appropriate for all uses; some may be better suited to light traffic areas, for instance; others to areas where noise management is considered crucial. In addition, certain paving technologies may not always be appropriate or feasible in a particular region of the country – whether technically, economically, organizationally, or institutionally – and local pavement engineers and owner agencies may not be sufficiently familiar with cool pavements to apply them confidently.

This report gives additional information on cool pavement technology and options for implementation. It describes the types of pavements now in use throughout the United States, the candidates for cool pavements within this context, and some of the elements that go into decisions on pavement selection at the state and local levels. Pavement type selection, design, and construction are influenced by a number of technical, economic, organizational, and institutional factors. Understanding how these factors are perceived by public- and private-sector facility owners can help those wishing to develop a more effective approach to implementing cool pavement policies, long-range plans, programs, and projects.

2.0 Benefits of Cool Pavements

As part of a heat island reduction strategy, cool pavements contribute to the general benefits of heat island mitigation, including increased comfort, decreased energy use, and likely improved air quality. Cool pavements also can be one component of a larger sustainable pavements program, or a "green" transportation infrastructure.

Cool pavements can contribute to local as well as regional comfort improvements. For instance, they help make large paved areas such as parking lots more comfortable for users. Shopping centers may feel this enhances the shopping experience.

Quantifying the heat island mitigation benefits of cool pavements is complicated by several factors in a real urban setting. The reflectivity of pavement surfaces changes over time; buildings, trees, and vehicles cast shadows; some of the reflected light could be reabsorbed by surrounding structures, negating the effect of the cooler pavement; and the degree of cooling afforded by permeable pavements is not well quantified. There may be offsetting effects or tradeoffs in the several mechanisms at work, all complicating the estimate of the benefits that cool pavements can yield.

The benefits of cool pavements are not limited to heat island reduction. There also are a number of ancillary benefits that can be gained from the use of cool pavement technologies, which can make their use worthwhile in their own right or as additional factors contributing to sustainable or green pavement initiatives. These additional benefits of cool pavements include:

- **Water quality.** Cool pavements can create improvements in water quality in two ways:
  - Permeable roadway pavements and especially parking facilities of all types (asphalt, concrete, and reinforced grass and gravel paving systems) can address water quality problems by reducing the percentage of land covered by impervious surfaces. When combined with water treatment wetlands, these pavements help to act as filters, improving water quality and providing greater groundwater protection. These improvements can translate into savings for urban areas by reducing the need to construct separate sewers or expanded water treatment facilities.
  - Both permeable and non-permeable cool pavements can help water quality through reduced heating of runoff. Laboratory tests with permeable pavers have shown reductions in runoff temperatures of two to four degrees Celsius in comparison to conventional asphalt paving.[4]
- **Noise.** The open pores of permeable pavements have been shown to significantly reduce tire noise.

- **Safety.** Permeable roadway pavements can enhance safety by reducing water spray from moving vehicles and increasing traction through better water drainage.
- **Nighttime illumination.** More reflective pavements can enhance visibility at night, potentially reducing lighting requirements and saving both money and energy. European road designers often take pavement color into account when planning lighting needs.[5] Better illumination from lighter pavements is sometimes considered valuable at private establishments as well, for security or customer appeal. Some sources cite nighttime illumination enhancements of 10 to 30 percent with more reflective pavements.

In designing a cool pavement policy, it is important to consider the differing characteristics of pavements in selecting the appropriate one for each situation. For instance, high-albedo pavements, which reflect away more solar radiation, will absorb less heat than darker pavements and thus stay cooler. However, they may not be appropriate in places where people will be uncomfortably exposed to the reflected radiation for long periods, as in a children's playground. In contrast, other pavements may take longer to heat during the day, but release excess heat at night – effectively transferring some of the day's heat to the evening. This may be appropriate in situations where the main concern is daytime heat or air pollution (such as ozone formation). In some sense, one can think of this as deciding how best to "manage" the urban climate. The information provided in this report can provide some of the background necessary to begin considering these issues.

3.0 Pavement Assets in the United States

Understanding the types and distribution of pavements now in use in the United States will set the stage for discussing both the candidate technologies for cool pavements and the industries that provide the labor skills, equipment, and materials needed to produce and install this infrastructure.

3.1 Pavement Coverage in Urban Areas

As noted in the introduction, pavements account for a substantial portion of the land cover in urban areas. Table 3.1 illustrates this point for selected American cities. Of the cities shown here, pavement coverage ranges from 29 percent of the land area in Houston to 45 percent in Sacramento. The data in Table 3.1 also show that land use and pavement coverage vary within this range, depending on the urban form of each city.

Table 3.1 Land Cover Percentages in Four Urban Areas

Urban Area	Pavement	Vegetation	Roofs	Other	Total
Sacramento	45%	20%	20%	15%	100%
Chicago	37	27	25	11	100
Salt Lake City	36	33	22	9	100
Houston	29	37	21	12	100

Source: Rose, L.S., H. Akbari, and H. Taha, "Characterizing the Fabric of the Urban Environment: A Case Study of Greater Houston, Texas," Lawrence Berkeley National Laboratory Report LBNL-51448, January 2003.

Of the area covered by pavement, roads account for 33 percent of pavement coverage in Houston and up to 59 percent in Sacramento, as shown in Table 3.2. Parking areas account for similar or greater percentages of pavement cover in the cities analyzed here, ranging from 29 percent in Sacramento to 60 percent in Houston. Sidewalks are less significant, ranging from seven percent of pavement area in Houston to 16 percent in Salt Lake City.

Table 3.2 Percentage of Pavement Area by Type of Use

Urban Area	Roads	Parking	Sidewalks	Total
Sacramento	59%	29%	12%	100%
Chicago	50	42	8	100
Salt Lake City	48	35	16	100
Houston	33	60	7	100

Source: Rose, L.S., H. Akbari, and H. Taha, "Characterizing the Fabric of the Urban Environment: A Case Study of Greater Houston, Texas," Lawrence Berkeley National Laboratory Report LBNL-51448, January 2003; Rose, L.S., and H. Akbari, "Characterizing the Fabric of the Urban Environment: A Case Study of Metropolitan Chicago, Illinois," Lawrence Berkeley National Laboratory Report LBNL-49275, October 2001; Rose, L.S., and H. Akbari, "Characterizing the Fabric of the Urban Environment: A Case Study of Salt Lake City, Utah," Lawrence Berkeley National Laboratory Report LBNL-47851, February 2001.

3.2 Types of Pavement Surfaces

Pavements are on-ground structures for riding, walking, and parking. Different materials are used in pavement construction; these are generally classified by the type of surface, also called the wearing course:

- "Flexible" pavements are built with asphalt. Asphalt concrete pavement (ACP), or hot-mix asphalt (HMA), is used on highways, roads, and streets. It consists of an asphalt binder mixed with stone, referred to as aggregate. For simplicity, these pavements are commonly referred to as "asphalt."
- "Rigid" pavements are built with portland cement concrete (PCC). The concrete consists of portland cement mixed with water and aggregate, and cured until it is strong enough to carry traffic. Conventional PCC pavement is placed in fixed forms or by machines that include traveling forms ("slipform paving") to create the pavement slabs; a variant of this material is roller-compacted concrete, which is rolled like asphalt. For simplicity, these pavements are commonly referred to as "concrete."
- Other types of conventional pavement in use include bituminous surface treatments, road mixes, and macadam construction. These pavements are relatively thin and are mixed in place. In contrast with the examples above, these pavements are used on roads with lower traffic volumes and loads. They are referred to as "low type" or "intermediate type" in classifications of pavement construction.
- The examples above all produce hard or bound surfaces. It also is possible to build traffic-bearing surfaces with unbound or "unpaved" materials. Gravel roads are one example, but are used mainly in rural areas. Another example is the use of grass, gravel, or crushed rock. These materials may be reinforced by a lattice or grid made of plastic, concrete, or other material. Unbound surfaces can be used for parking areas in urban settings.

As pavements wear, they require resurfacing to correct distress, restore surface smoothness and skid resistance, and restore or add strength to handle future traffic loads. Both asphalt and concrete materials are used in resurfacing.

- Asphalt may be resurfaced with asphalt (these are still considered "asphalt" pavements).
- An asphalt surface over a concrete slab produces a "composite" pavement.
- Concrete may be resurfaced with concrete (these are still considered "concrete" pavements).
- Concrete placed over asphalt also is referred to as "whitetopping." A variant of this technology is a relatively thin concrete resurfacing that is bonded to the underlying asphalt layer (ultra-thin whitetopping, or UTW).

Pavement type is thus characterized by the type of material used in new construction, and by the materials in subsequent resurfacing. Resurfacing is considered to restore or add pavement structural strength. Both new construction and resurfacing provide opportunities for installing materials consistent with cool pavements.

In addition to new construction and resurfacing, pavement surface treatments are available for preventive maintenance. Preventive maintenance treatments extend the life of the pavement and correct minor distress, but do not add structural strength. The following preventive maintenance treatments may have use in cool pavement techniques:

- Chip seals for asphalt pavements consist of rock chips bound in liquid asphalt, distributed over the pavement surface. A chip seal does not add strength, but rejuvenates the surface to counteract the effects of aging and to forestall cracking.
- Slurry seals (asphalt-water emulsions) are another example of preventive treatments. A slurry seal is used to rejuvenate an aged asphalt surface and to seal minor cracking.
- Microsurfacing is a relatively thin asphalt overlay that includes advanced polymers in the asphalt binder.[6]

These examples are sufficient to provide an overview of paving technology in the United States. Other examples of treatments that are relevant to cool pavements will be given later in this report.

3.3 Pavement Distribution on the Federal-Aid System

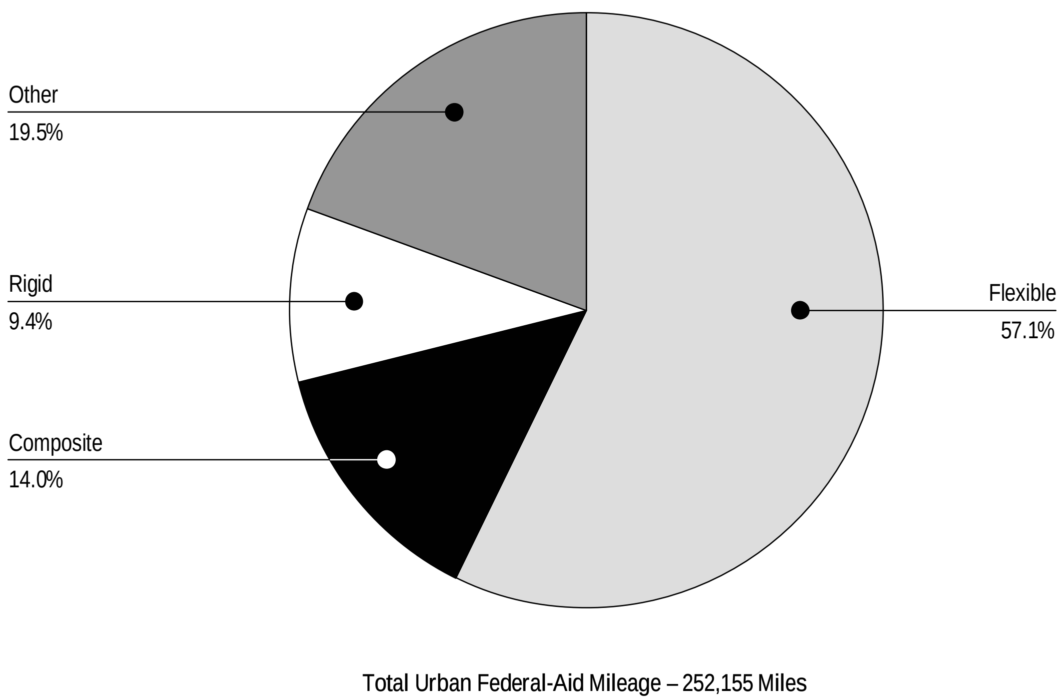
The Federal-aid system comprises a network of highways that are significant to intrastate and interstate travel. It includes the Interstate highways and other highways and arterials designated as the National Highway System (NHS).

While the Federal government finances major shares of construction and rehabilitation on the Federal-aid system, the operational responsibility for these highways falls primarily to state departments of transportation (DOTs).[a]

Figure 3.1 shows the distribution of pavement type used on urban Federal-aid highways.[7] The predominant surface type is asphalt, represented by three segments of the pie chart in Figure 3.1:

- Highways surfaced with flexible pavement;
- Highways with composite pavement; and
- A portion of the highways with "other surfaces" that are constructed from bituminous materials.

Figure 3.1 Pavement Distribution on Urban Federal-Aid Highways
2001



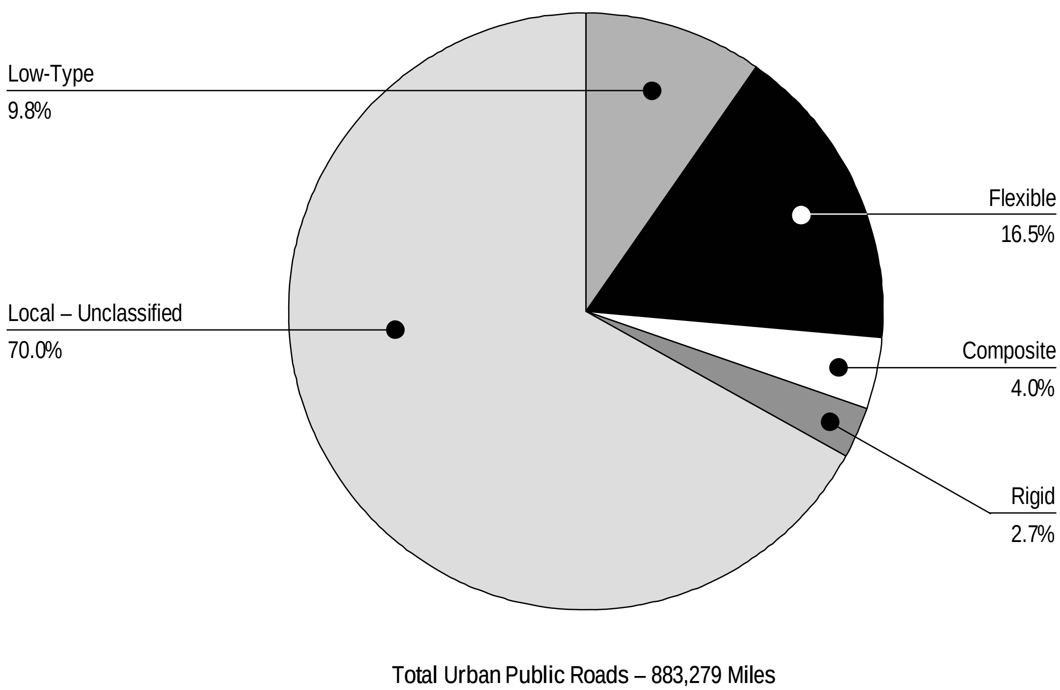
[a] A relatively small portion of the Federal-aid system is under municipal control. The Federal government does directly manage roads in national parks and other Federal lands, but the length of these routes is likewise small in comparison to the highway system managed by the state DOTs. While Federal-aid roads comprise a small portion of total pavement in an urban area, they include some of the most heavily traveled routes, with the most complete data availability.

Certain pavement types may dominate in a particular state and highway classification. Considering urban Interstate and other urban NHS highways, for example, Iowa's pavements are mostly concrete; Massachusetts uses mostly asphalt; and Illinois' pavements are mostly composite.[8]

3.4 PAVEMENT DISTRIBUTION ON ALL PUBLIC ROADS

Figure 3.2 shows a similar distribution of pavement type for all U.S. urban public roads.[9] The pavements on state highways are identified explicitly and are primarily surfaced with asphalt; the composition of pavements on local roads is not classified in this source. However, pavement distributions obtained from selected states confirms information from the asphalt industry that most local pavements that are hard surfaced are asphalt.[10] Low-type pavements in Figure 3.2 include unpaved roads, gravel roads, and low- or intermediate-type surfaces.

Figure 3.2 Pavement Distribution on Urban Public Roads
2001



3.5 OTHER FACILITIES

Pavement practices in other facilities encompass a range of materials, and there are no general rules as to which materials are used.

- Various materials are used in airfield runways, taxiways, and aprons, sometimes in combination with one another. At airfields serving heavy aircraft or major general aviation airports, hard surfaces may be paved with concrete or asphalt. While some airports may use a single material type throughout, it is not unusual to see both these materials used; e.g., concrete runways with asphalt taxiways and concrete aprons, or asphalt runways and taxiways with concrete aprons. Small general aviation airports may have grass runways and taxiways.
- Parking lots may be paved with asphalt or concrete, or have grass or reinforced, permeable surfaces. Parking garage decks are typically concrete. As noted in Table 3.2, parking lots constitute a substantial portion of total pavement surface area in urban areas, on the order of 30 to 60 percent of pavements.

Sidewalks or walkways may be built of concrete, asphalt, or other materials; e.g., brick, stone blocks, paving blocks, gravel, etc. Bicycle paths are typically paved with asphalt or concrete.

4.0 Pavements and the Urban Climate

4.1 GENERAL CONCEPTS

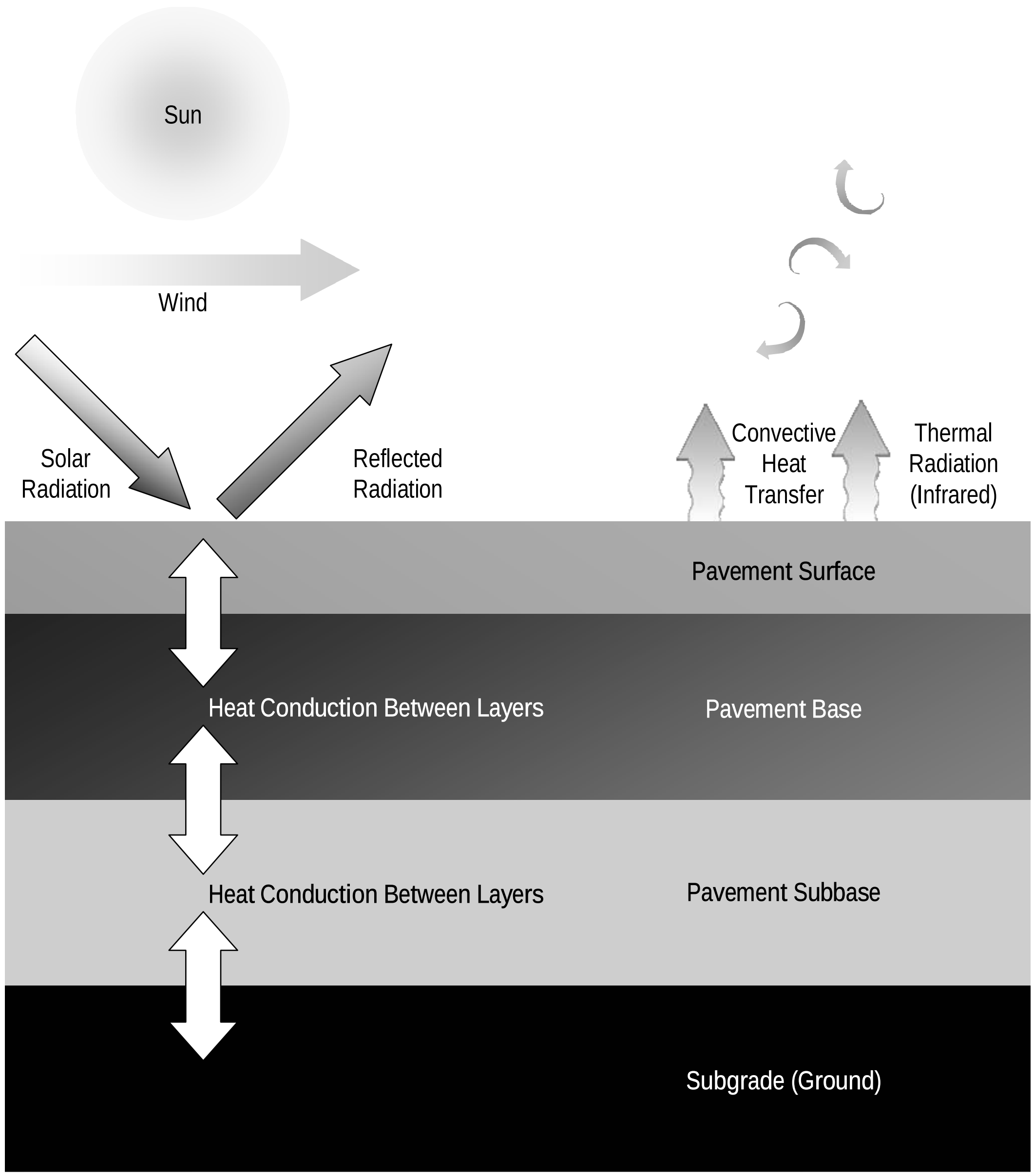
There are several types of heat islands, each with different mechanisms of formation, characteristics, and impacts. Urban heat island studies have to date focused on air temperatures within the **urban canopy layer** (UCL),[11] or the atmosphere below the level of building rooftops, where we live. With the introduction of remote sensing technologies, several researchers also have focused on surface heat islands. Actions to control the heat island effect lie primarily within the canopy and surface layers. The relationship of pavements to these two heat islands is discussed in this report.

By altering the surface energy balance, pavements contribute to the urban heat island. The material properties of pavements cause them to absorb and store a larger amount of heat than vegetated landcover. In addition, the impervious nature of most pavements reduces cooling due to evaporation in comparison to vegetation. As a result, pavements become considerably hotter than ambient canopy temperature and radiate this excess heat into the canopy layer throughout the day and into the night. (Conversely, pavements can contribute to an urban "cool" island early in the morning, as they will take longer to heat in the morning due to their heat storage capacity.) Figure 4.1 depicts a schematic pavement cross-section and the heat-related processes that can affect the pavement structure.

Cool pavement strategies seek to control the temperature of the pavement (and hence its ability to transfer heat to the air above) by controlling one or more of the material properties that influence the way pavements absorb, store, and radiate heat. These include:

- **Albedo.** Albedo, or solar reflectance, represents the ability of a surface to reflect short-wave radiation (visible light, for the most part); a higher albedo signifies greater ability to reflect light away. Thus, greater albedo reduces the amount of solar energy absorbed by a pavement and keeps it cooler, in the same way that a white car stays cooler in the summertime than a black car. Generally, albedo is correlated with color – lighter colors have higher albedos.
- **Permeability.** By allowing water and water vapor to pass through them (or be stored within the voids of the pavement), permeable (or pervious) pavements can take advantage of the cooling effect of evaporation.

Figure 4.1 Heat-Related Characteristics and Processes in a Pavement



- **Conductivity.** This measures the rate at which heat is transferred throughout the pavement. A pavement with low conductivity will get hot at the surface quickly, but will not store as much heat as one with higher conductivity.
- **Emissivity.** Emissivity is a measure of the rate at which an object can radiate away heat from its surface; objects with higher emissivity will radiate heat away faster.

- **Thickness.** The thickness of a pavement will influence how much heat it can store. A thinner pavement will heat faster in the day, but also cool more quickly at night. The effective "thickness" of a pavement will depend in part on how well heat can be conducted from surface layers to base layers.
- **Convective airflow.** Both the "roughness" of a pavement and its porosity can influence how quickly it can be cooled by convective airflow; generally, porous pavements cool faster than conventional pavements.

4.2 Mechanisms of Cool Pavements

Given current pavement technology, there are three ways to reduce pavement's contribution to the urban heat island: by providing a surface that reflects a greater amount of solar radiation; by increasing the ability of the pavement to cool at night; or by allowing a pavement to cool through evaporation by designing and building it as a porous structure.

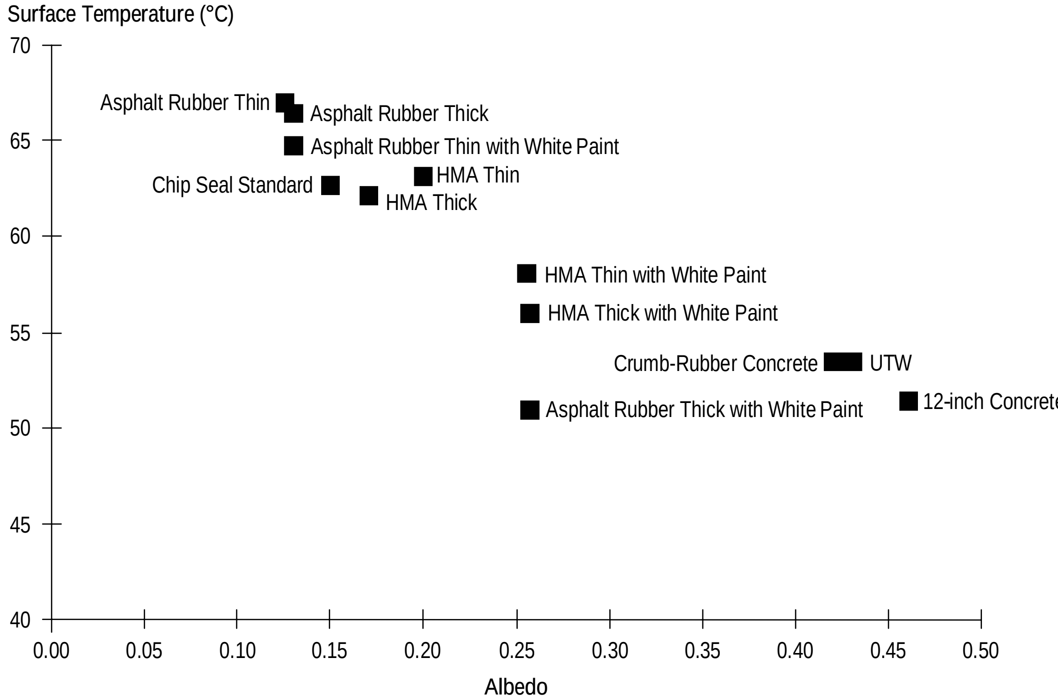
Albedo

Albedo is measured as the ratio of incident to reflected radiation. Conventional paving materials have albedos ranging from 0.05 to 0.40 when new. Albedo changes over time, due to changing materials properties and the accumulation of dirt and grime on the pavement surface. Thus, while concrete and asphalt pavements have different albedo values when new, the values approach each other once pavements are put in service.

The cool pavement mechanism is based on the idea that by increasing the reflectance of the pavement surface, less sunlight will be absorbed, lowering the daytime temperature of the pavement. This lowered temperature would result in lower air temperature near ground level. The correlation between albedo and pavement temperature is shown in Figure 4.2 for several pavement surfaces in Phoenix, Arizona.[12] (Different results might be obtained for different solar, wind, and other weather conditions.) Methods to adjust the reflectance of pavement surfaces must account for several practical matters:

- Pavement is a combination of materials, primarily aggregate (crushed rock or gravel and sand) and a binder to hold the aggregate in place. The binders most commonly used are asphalt and portland cement. The reflectance of a pavement surface depends upon the reflectance characteristics of its materials and the degree to which each material is exposed at the pavement surface. For example, new concrete pavements have relatively high reflectance because of the light color of the portland cement, but reflectance may be reduced if paved with exposed aggregate, as is done for decorative reasons in sidewalks and patios. New asphalt pavements, with a black binder, are generally much less reflective; however, asphalt pavements with light-colored aggregate (e.g., limestone) may appear very light in color.

Figure 4.2 Surface Temperature and Albedo for Selected Types of Pavements in Phoenix, Arizona



Source: Redrawn from data by Jay S. Golden and Kamil Kaloush, SMART Program, and Arizona State University, July 24, 2004.

- Pavement materials change over time due to aging and use. For example, asphalt oxidizes, which lightens its color and increases its reflectance over a period of roughly five to 10 years. However, if allowed to continue, the asphalt effectively "dries out," becomes brittle, and loses its ability to bind the aggregate, leading to a distress referred to as raveling. If a concrete surface becomes dirty and stained, its reflectance decreases over time. Thus, while concrete pavements generally have higher reflectance than asphalt pavements when they are new, over time their albedo values become closer.
- The surface characteristics that affect reflectance also affect the appearance of pavements, and appearance is important to facility owners and motorists for many reasons. Certainly, the contrast in color between pavement surface and lane striping or message markings is important to daytime and nighttime visibility in dry and wet conditions, and affects safety. While owners of facilities where nighttime illumination is important may prefer a lighter pavement color, others like the "crispness" of black pavement with white striping in their parking lots. Some perceive color as a measure of "newness." These subjective perceptions, discussed in the literature and revealed as well in interviews during this study, are hard to generalize, and may lead to unforeseen public responses to attempts to adjust pavement color for reflectance.

There are several ways in which pavement albedo may be adjusted: for new pavements, by selecting a binder or aggregate of different color or altering the binder color; and for existing or new pavements, by coating the pavement with a seal or surface of a lighter color. Technologies that can help achieve a higher albedo are discussed in Section 5.0.

Nighttime Radiational Cooling

A pavement that can lower its temperature quickly during nighttime cooling can reduce the nighttime heat island effect. A consortium led by Arizona State University (ASU) is now experimenting with a composite pavement that has a nighttime temperature lower than that of adjacent PCC pavements. This effect is accomplished by using a rubberized asphalt layer over a PCC base. While this pavement design has been adopted to reduce tire-pavement noise, it also provides a cool pavement benefit and an environmental benefit through the use of recycled materials.[13]

Porosity or Permeability

A porous or permeable ground surface that allows water to percolate through it can exert a cooling effect through evaporation of water in the pavement voids or from beneath (depending on the type of surface and thickness). In addition, permeable surfaces are sometimes more conducive to cooling from convective airflow.

Permeable surfaces have been used to date to control stormwater runoff; the evaporative cooling effect also could be used for heat island reduction. Both asphalt and concrete pavements can be built with porous surfaces, and unbound surfaces (e.g., grass, gravel) can be constructed using grids for reinforcement. These approaches are discussed further in Section 5.0.

4.3 Effect of Urban Geometry

Before proceeding with the description of candidate cool pavement technologies, it is useful to discuss one other aspect of the urban setting that influences the performance of cool pavements: the three-dimensional urban geometry, or "urban canyon" effect created by tall buildings at the urban core. The urban canyon has two opposing effects: it can increase the heat island effect by significantly reducing nighttime radiational cooling, but it also can decrease urban temperatures by shading pavements during the day.[14]

The ability of a surface to cool at night by emitting longwave radiation into the sky depends on its "sky-view factor" – the proportion of its viewing hemisphere that is occupied by sky rather than surrounding buildings. A pavement surrounded by tall buildings will have less exposure to sky, so that the buildings will block or absorb the heat emitted by the pavement, preventing the heat from escaping the canopy air layer and exacerbating the heat island effect.

The sky-view factor can be approximated as the ratio of building height to street width (H/W), so that the maximum nighttime heat island intensity, measured as the difference between an urban area and a nearby rural area, can be expressed as:[15]

$$\Delta T_{u-r(\max)} = 7.45 + 3.97(\ln H/W)$$

For instance, assume that a downtown area has a 72-foot wide street (four travel lanes and two parking lanes of 12 feet each), 12-foot sidewalks, and 125-foot buildings on either side (about 10 stories). The heat island effect (expressed as the peak difference between urban and rural temperatures) calculated using the above equation is a maximum temperature difference of about 8.5° C. A low-rise neighborhood with the same street widths but 40-foot tall buildings (about three stories) will show a heat island intensity of only 4.0° C. It should be noted that this low-rise case is more typical of most U.S. cities, which spread horizontally more than vertically.

At the same time, buildings might shade a pavement during the day, limiting the effect of the relative "coolness" of the pavement on the heat island. The net effect of urban canyons will, therefore, also depend on the angle of the sun. In lower latitudes, where the sun is more directly overhead, the effect of the sky-view factor will be more important in affecting nighttime cooling than daytime shading.

The proportion of a city with tall buildings and the specific geometry of this street canyon effect can vary depending on the urban form and the degree to which a city has "built up rather than out." Nonetheless, in most cities, the street canyon effect will be most prominent in downtowns and commercial districts with higher proportions of taller buildings set close to each other. Areas of commercial land use generally comprise 15 to 20 percent of land cover in urban areas, although not all commercial use may occupy tall buildings.[16]

4.4 Additional Factors

Significant research has been conducted on many of the factors outlined above. For example, the role of pavement albedo has been researched extensively by the Heat Island Group at the Lawrence Berkeley National Laboratory.[17] Pavement characteristics that can provide cooling mechanisms for retained heat have been addressed, for example, for porous pavements that allow water infiltration,[18] and for pavement materials and structures that release longwave radiation through nighttime cooling.[19] In attempting to apply these findings to actual urban environments, there are several additional details that should be considered:

- Pavements are not standardized, manufactured products. They vary in structural cross-section and materials composition. Most importantly, pavements must meet several criteria regarding strength, durability, and safety, as well as feasible initial and life-cycle cost. Cool pavement behavior is but one of many factors that potentially could influence the selection and design of a pavement.

- The most suitable mechanisms for cool pavements may differ by region. For example, permeability might be a less effective cooling mechanism in desert climates than in wetter settings.
- The relationship between surface temperatures and air temperatures in urban areas depend heavily on local conditions and are physically complex. One should carefully consider the effect of local conditions in applying a relationship developed for one city to another city having different climate, geography, and urban form.
- Actual physical situations are complex and may involve offsetting factors that prevent simple "rules-of-thumb" guidelines for practitioners. For example, increased levels of air pollution increase the atmospheric absorption of solar radiation (therefore reducing the radiation that reaches the ground, which would reduce the temperature rise due to solar radiation and therefore reduce the daytime heat island effect). It also, however, increases the atmospheric radiation during the night, which would increase the nighttime heat island effect (or reduce nighttime cooling). A similar set of offsetting implications relates to urban geometry.

Future research in the field may shed light on many of these issues.

5.0 Types of Cool Pavements

5.1 Candidate Technologies

Several candidate technologies for cool pavement have been investigated in past research, including options for new pavement construction, reconstruction, and maintenance and rehabilitation activities.[20] Brief descriptions of these technologies are given below, including additional suggestions discussed in interviews with paving industry representatives. It is clear from these interviews that the industry associations will be responsive in supporting development and application of cool pavement technologies if their clients demand these options. This review is not intended to be exhaustive, but rather to outline the basic technologies involved.

Both the asphalt and the concrete industries stress the importance of competent design, construction, and inspection of paving projects, including those that are using technologies consistent for cool pavements.[b] This guidance is a matter of good practice generally and of being responsive to client and customer needs, and is not limited to cool pavements alone. All of these technologies depend upon the proper proportioning of cement, aggregate, and other constituents, and good control over the characteristics of these materials (e.g., in the size distribution of the aggregates). Lack of care in specifying and enforcing materials properties can lead to poor performance, which – if associated with a local cool pavement initiative – could contribute to a reluctance to consider future cool pavements and a loss of credibility for the initiative.

Conventional Portland Cement Concrete Pavement

Conventional PCC pavement has been proposed as a cool pavement because of its light color and reflectivity. It is used in new construction and reconstruction. The degree of surface reflectivity is affected by both the color of the cement and the type and color of aggregate (particularly as the cement surface becomes worn and the aggregate is exposed).[21]

Concrete Additives

Additives are routinely used in concrete to enhance its placement during construction or its performance during its service life.

[b] These comments are reflected both in the literature describing technologies and in personal communications with industry representatives.

- One example is the use of slag cement in combination with portland cement. Slag is a byproduct of processing iron or copper ore in a blast furnace. It is obtained from the surface of the molten ore, granulated, and ground to produce a cement that replaces a portion of the portland cement in a concrete mixture. It has several benefits to concrete workability and performance (e.g., improved strength, resistance to aggressive chemicals, better ability to place concrete in hot weather). Among these benefits is a lighter color, which can enhance reflectivity of the finished pavement.[22] In addition, by reducing the amount of portland cement used, slag cement reduces greenhouse gas emissions and energy use in the production of concrete.[23]

- Fly ash also can be used as a replacement for portland cement in concrete mixtures. Fly ash is a powdery byproduct of burning coal. While fly ash provides several benefits to concrete (e.g., improved workability, strength, durability, resistance to chemical attack), there is no mention in the reviewed literature of special characteristics that would favor cool pavements. In particular, fly ash color varies considerably, ranging from light tan to black depending on the source; any reflectivity benefits also would be source specific.[24,25] It does have other environmental benefits; as with slag cement, the use of fly ash reduces greenhouse gas emissions and energy use. A potential drawback is that fly ash mixes initially gain strength more slowly than typical mixes; however, they generally reach higher final strengths.[26] Federal agencies are required to allow the use of fly ash in construction projects;[27] in addition, the California Department of Transportation (Caltrans) mandates a minimum of 25 percent fly ash.[28]

Whitetopping and Ultra-Thin Whitetopping

Whitetopping consists of a concrete pavement applied over an existing asphalt pavement as a form of maintenance or resurfacing. Conventional whitetopping is more than four inches thick. UTW is a newer form of this process in which a two- to four-inch thickness of concrete, usually high strength and fiber reinforced, is placed over an asphalt surface that has been milled.[29] The UTW is different from conventional whitetopping in that it relies on bonding with the asphalt surface for strength, and joint spacing is much shorter (typically two to six feet for UTW, in comparison to five to 25 feet for conventional whitetopping). As a potential cool paving technology, UTW provides the color and reflectance of concrete over an existing asphalt surface. It has been used on a number of projects across the country for resurfacing road segments, intersections, and parking lots.[30]

Roller-Compacted Concrete Pavement

Roller-compacted concrete is a specially mixed and placed form of concrete. It employs a very stiff mix that is placed with techniques and equipment much like that used for asphalt pavement. While it results in a strong pavement, its surface is not finished or textured, as is conventional concrete pavement. It is used for heavy hauling roads where speed is not a factor, bulk commodity storage areas, intermodal container facilities, automotive manufacturing plant parking areas, military facilities, and warehouse floors. Parts of its surface may become abraded over time. However, it is economical, with initial cost lower than that of conventional concrete, and competitive with asphalt concrete.[c]

Light Aggregate in Asphalt Concrete Pavement

The reflectance of ACP can be increased by using light-colored aggregate such as limestone. This type of aggregate is available naturally in parts of the country (e.g., Houston area, Florida) and is used in conventional pavement construction and reconstruction. In these locations, the incremental cost of this technology is nil. In other locations, however, the cost to transport such aggregate to the job site is prohibitively expensive.

Chip Seals with Light Aggregate

Chip seals are a frequently used preventive maintenance technique on asphalt pavements[31] (see Section 3.0 for a description of chip seals). Use of light-colored aggregate in these seals could increase the albedo of asphalt-paved surfaces. The cost of such treatment depends on the local availability of suitable aggregate, as noted earlier for ACP. Chip seals are traditionally associated with roads carrying light traffic volumes because of the tendency of the chips (stones) to loosen and be propelled by the action of moving vehicles toward other vehicles, potentially resulting in windshield damage. While Texas has had experience in applying chip seals to high-volume highways (including Interstate highways),[32] the trend now is to use another preventive maintenance treatment (microsurfacing) in lieu of chip seals on these high-volume roads.[33]

Porous Pavement and Surfaces

Porous pavement and permeable surfaces have been investigated as mechanisms for stormwater discharge control and ground water management in urbanized areas. Both concrete and asphalt pavements can be built as porous surfaces on roads and parking lots.

A porous asphalt surface can improve skid resistance and reduce traffic noise, rutting, and splash due to ponded water on the surface. Noise reduction benefits may decline over time,[34] however, and there may be reduced strength and

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[c] Roller-compacted concrete has been used, for example, in the Fort McHenry Shipyard Facility in Baltimore, and in parking areas at manufacturing facilities for the Saturn Corporation in Spring Hill, Tennessee; for Honda in Lincoln, Alabama; and for Mercedes Benz in Vance, Alabama. Sources include the following: Piggott, R.W., P.E., "Roller-Compacted Concrete Pavements – A Study of Long-Term Performance," Research & Development, Portland Cement Association, RP366, 1999; *RCC, Get Used to It!*, Portland Cement Association, undated; Personal communication with Halsted, G.E., Portland Cement Association, Georgia.

durability in comparison to conventional surfaces.[35] The extent to which they can be used on high-speed, high-volume roadways needs more investigation. Permeable friction courses laid on top of an impermeable base have been used successfully in Texas[d] on interstates (e.g., I-35 in San Antonio) to improve traction and visibility in wet weather, as well as reduce noise.[36] Pervious concrete may be used where reductions in stormwater runoff are desirable; it is appropriate for low-speed traffic (less than 35 miles per hour).[37]

Opinions differ on whether porous pavements present a problem in winter. As long as the pavement remains free draining, there should be no problem due to freezing and thawing. However, if water becomes trapped in the pavement voids, expansion during freezing may degrade the pavement layer. Because road sand may clog the pavement pores, other methods of snow and ice control (e.g., use of chemicals) may be needed with porous pavements.[38]

Other types of permeable surfaces can be built using plastic grids or masonry blocks in filled with grass or gravel. This type of "unbound" surface can be used in several applications: driveways, shoulders, parking lots, bicycle trails, pedestrian and golf paths, equestrian trails, and slope stabilization.[39]

Color Pigments and Seals

Pigments and seals are available to change the color of an asphalt surface to make it lighter.[40] However, these products are expensive, and tend to be used only in special situations where color is a dominant paving criterion. (Pigments also are available for concrete pavements; however, because concrete pavements are already light-colored, pigments are unlikely to improve their "coolness".)

Rubberized Asphalt

A composite pavement design with a rubberized asphalt layer over a PCC base is now being used in the Phoenix, Arizona, area. The primary purpose of these pavements is to reduce tire-pavement noise, but current research indicates that they are cooler at night than adjacent PCC.[41] To determine their potential benefits in reducing the heat island, these pavements will be instrumented through an ongoing program by ASU. However, preliminary indications from satellite photos of different types of pavements in the Phoenix metropolitan area suggest promising results from a cool pavement perspective. Because the program has just gotten underway, detailed data are not yet available.

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[d] The permeable friction course generally used in Texas is laid down 1.5 to 2.0 inches thick on top of an impermeable layer. It has 14 percent air voids, and relies on the high speed of passing vehicles to keep this air voids from plugging with dirt and other matter. For pavement specifications used in Texas, see ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standard/s342.pdf.

5.2 AIR QUALITY IMPACTS OF PAVEMENT MANUFACTURE AND PLACEMENT

Urban areas considering the use of cool pavements will likely be interested in the "upstream" environmental impacts of manufacturing and placing different types of pavements, to gain a more holistic understanding of the net benefits of using cool pavements. Rather than attempting an exhaustive environmental life-cycle analysis of all the inputs and processes involved in pavement manufacture, we have focused on the air quality impacts directly due to manufacturing and placing asphalt and PCC pavements. These would likely be the most significant concern to urban areas considering the impact of a cool pavement initiative in their regions. Other concerns not addressed here might include impacts on water quality and usage, as well as recycling of industrial wastes or pavement materials.

The properties and manufacturing processes of PCC and asphalt result in differing emission impacts for the two materials. With the exception of carbon dioxide (CO_2), most emissions have readily available control technologies that already are in use at many plants.

Emissions Related to PCC Manufacture and Placement

Concrete's environmental impacts arise during the manufacture of portland cement, the binder for PCC. The production of cement releases substantial quantities of CO_2 from both fuel combustion and the chemical reaction that decomposes the calcium-containing raw material into lime (CaO) and CO_2 (the "calcining" process). On a global scale, cement production accounts for 2.4 percent of total industrial and energy-related CO_2 emissions.[42] Moreover, the United States is the third largest cement producer in the world. Only about one-third of U.S. cement production is meant for pavements, however.[43]

Cement kilns are used to transform the raw materials into an intermediate product called "clinker," at temperatures of around 1,500° C. Once the clinker has cooled, gypsum (up to five percent) and specialty chemicals are added to turn the product into portland cement. The kiln is generally heated with coal, natural gas, and, less commonly, oil. Typically, the calcining process produces about one-half ton of CO_2 for every ton of portland cement. CO_2 emissions from energy consumption vary greatly depending on the process and fuel used, but range from an additional one-quarter ton to one-half ton of CO_2 emissions per ton of portland cement.

Some abatement possibilities exist for CO_2 emissions. Many plants can and do incorporate energy-saving features that make use of waste heat from the kiln to preheat materials or assist other processes. The use of slag cement or fly ash as a substitute for portland cement also could reduce CO_2 emissions by about one ton per ton of slag cement or fly ash used.[44] However, slag cement can typically only replace 25 to 50 percent of the portland cement in a concrete mix;[45] fly ash can typically replace 15 to 30 percent.[46]

Combustion of fuel to heat the kiln also results in the emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and sulfur dioxide (SO_2). Only very small quantities of volatile organic compounds (VOC) are released. Particulate matter (PM) emissions for post-1971 facilities are limited by Federal regulation. There are essentially no emissions from concrete paving operations (beyond fugitive dust or other emissions associated with construction vehicles and operations).

Emissions Related to Asphalt Manufacture and Placement

Asphalt cement is manufactured at much lower temperatures (on the order of several hundred degrees Fahrenheit). CO_2 emissions due to fuel combustion are correspondingly lower, and it is not produced by any chemical reactions involved in asphalt production. The majority of HMA plants use relatively clean-burning natural gas to heat the raw materials, with the remainder using fuel oil. Emissions from asphalt plants include PM, other combustion products such as NO_x and SO_2, CO, and small amounts of VOCs and hazardous air pollutants (HAP).

Asphalt pavements also release VOCs during application and use. However, only "cutback" (sometimes known as "cold-mix") asphalts are considered a significant source of VOCs.[47] These asphalts are thinned with volatile distillates such as naphtha and kerosene. They are generally used only for quick patches and, in most cities, their use is banned entirely or during the ozone season. Depending on the mix, these asphalts can produce evaporative VOC emissions of five to 32 percent of the weight of the asphalt applied (e.g., one ton of cutback asphalt would produce from 100 to 640 pounds of VOC emissions). There also may be VOC emissions from the solvents used in other maintenance procedures, such as sealcoats, that may be subject to regulation at Federal, state, or local levels.[48]

6.0 Considerations in Selecting Pavements

Multiple considerations come into play when pavement owners select the type of pavement to place. To craft an effective cool pavement effort, it is important to understand the perspectives of pavement owners and suppliers, and how cost and environmental considerations impact their decisions. In many cases, pavement selection is governed by the perspective, needs, and past experience of the entity involved: state authorities have different capabilities and needs as compared to local authorities; private sector owners have different perspectives as well. The relative cost of various pavements is a very important factor in these decisions. On the other hand, environmental factors often have a limited role in the pavement selection process. This section provides greater detail on these considerations.

6.1 Perspectives of Pavement Owners and Suppliers

Pavement owners deal with decisions on pavement selection in ways that reflect their agencies' experience and that meet their needs, capabilities, requirements, and available funding. A decision to consider cool pavements would be made in this context. Pavements represent a long-term investment, and pavement owners, therefore, are not likely to consider cool pavements unless they can expect performance and cost that are competitive with conventional pavements. They may not always use life-cycle cost in their evaluation – decision-makers on a tight budget may pay more attention to initial cost. Pavement performance – a measure of the quality of experience provided to the transportation user (structural integrity, rideability, materials durability, etc.) – also is a priority for pavement owners. For pavement owners to be willing to use them, cool pavement techniques need to sustain or improve on performance. Pavement owners and producers may perceive the use of less common pavements as an extra cost and performance risk.

However, pavement selection is affected by more than just cost and performance. Local government agencies (more so than state DOTs) also are influenced by local history and practice regarding the types of pavements to be used. Private developers likewise have additional considerations, such as the timeframe for which they expect to own a given property, and their responses to local regulations and standards.

The remainder of this section provides an overview of the perspectives of public-sector owners, private-sector owners, and pavement suppliers/producers, as well as the implications for cool pavement efforts.

Public-Sector Owners

Public-sector owners encompass agencies at all levels of government that provide transportation services. Transportation, road, aviation, and public works departments at the county and municipal levels and DOTs, departments of roads, and departments of aviation at the state levels are the owners of prime interest for cool pavements. There also are quasi-public authorities that build and operate turnpikes, ports, and airports. Finally, there are state and local facilities-management entities that control development and maintenance of public spaces and parking facilities and lots; these entities also should be considered in developing pavement strategies. These owner groups represent a range of interests, capabilities, and requirements for pavements. Significant variations also may exist within groups: e.g., in their capabilities to perform pavement management functions.

National Level

The Federal government also has a role in pavement systems at the state and local levels, represented primarily by the Federal Highway Administration (FHWA). The FHWA is not a system “owner” per se but, through its roles as the agent for distributing Federal funds and providing technical expertise, it exerts a considerable influence on activities in the Federal-aid system and, through a trickle-down effect, on state and local systems as well. It also plays an important role in funding or conducting pavement research. There are, in general, a number of intergovernmental relationships that exist among Federal, state, and local agencies, ranging from financial aid to technology transfer, technical assistance, sharing of management systems and data, and adoption of standards. The FHWA’s Local Technical Assistance Programs (LTAP) are one example of formal mechanisms to provide assistance to local agencies in a state.

Another player at the national level is the American Association of State Highway and Transportation Officials (AASHTO), representing the state DOTs. AASHTO works at the Federal level in lobbying for programs and budgets to support state transportation needs. It collaborates with the FHWA and other organizations in sponsoring research and hosting conferences and workshops serving the transportation community. It also plays a role in researching and establishing standards and evaluation methods for transportation facility design, maintenance, and operations.

State DOTs

State DOTs manage the Federal and state highway systems within their jurisdictions. State DOTs may not be the main agencies that are considered in heat island reduction strategies. Nonetheless, their expertise and their roles in providing local aid give them influence with local agencies, and much data on the performance of different paving materials come from DOT experience. Furthermore, their strong technical and analytic capabilities provide a benchmark for comparison with other organizations:

- DOTs take a long-term, life-cycle view of pavement investment options and impacts on performance and costs. A life-cycle analysis is required for Federal-aid pavement projects, and sometimes may be required by state statute (e.g., Washington, Michigan). Nonetheless, DOTs face short-term budget constraints and are aware of initial cost in making pavement investments.
- State DOTs have long been engaged in computer applications to help manage pavement networks. Pavement management systems have been in place for about 30 years, with corresponding attention to data collection and analysis of historical cost and performance trends.
- Field data collection and analysis is undertaken periodically, often with specialized equipment to measure surface irregularities. Some states use vans that provide several data inputs: e.g., surface irregularities, extent and severity of cracking, and a videolog of the pavement surface. These data are processed to provide performance measures and indexes of pavement condition and serviceability.
- DOTs have in-house materials laboratories to conduct tests, analyze field data, and recommend changes in design, construction, or maintenance practice.
- DOTs may apply Federal funding to research programs related to their transportation activities. These programs identify and diagnose problems, review current practice, investigate new practices, and provide recommendations on ways to improve management, service delivery, and system performance. For large-scale efforts or where geographic or organizational diversity would benefit a research effort, agencies may group their financial and staff resources in "pooled-fund" efforts, and may solicit additional assistance from the FHWA or other sources.
- DOTs also participate in national research efforts that benefit the transportation industry as a whole. One longstanding example is the ongoing National Cooperative Highway Research Program (NCHRP) that has focused on a wide range of transportation construction, maintenance, operational, and management topics. The five-year Strategic Highway Research Program (SHRP) that was completed in the 1990s is another example; a new, or "Future," Strategic Highway Research Program (F-SHRP) is included in the current Transportation Reauthorization bill now before Congress.
- DOTs also avail themselves of Federal assistance provided by the FHWA division offices in each state. The DOTs, in turn, provide assistance to local agencies through Federally funded LTAP Centers. These centers provide ongoing technical partnering, technology transfer, and research opportunities with local governments, educational institutions, professional associations,

and the private sector. The work programs for these centers are managed and approved by the states, with concurrence of the Federal government. This is an excellent and locally trusted route to introducing new concepts and technologies to local agencies and providing training in these technical areas.

To be sure, DOT practices vary by state, as do pavement priorities and criteria for selection. DOTs' pavement management systems help analyze the technical and cost factors affecting these decisions, among them composition of the state road system (proportion of urban and rural routes, trucking needs, traffic volume, etc.); soil and climatic conditions; local supply economics; and forecast funding available. Nonetheless, pavements are a very significant part of a DOT's highway program budget, and they are a very visible component of the road system to the public, its political leaders, and the local construction industries alike. It is therefore natural to assume that cool pavements will likewise require political sensitivity on the part of public agencies in determining the relative costs and benefits of cool pavement options, and demonstrating fairness to competing industries in selecting cool pavement approaches.

Local Agencies

Local agencies are more difficult to characterize generally – their capabilities and practices vary considerably. Some have pavement management systems and analytic procedures, which may have been developed with the assistance of a state DOT, a regional planning agency, or a city or county professional association. If used properly, these management tools enable agencies to identify and rank needs, and potentially to consider investment strategies that minimize pavement life-cycle costs. Other jurisdictions base decisions more on historical precedents and standard practices and designs. Our assessment of the procedures used by many local agencies, based on interviews conducted in this study, is that they reflect the following characteristics:

- While local agencies understand concepts of long-term performance and cost effectiveness, the variability in annual funding and shortfalls in comparison to needs impede a long-term investment strategy and drive agencies to "worst-first" approaches.
- Agencies also try to "stretch" available dollars across the greatest number of road miles by selecting treatments that provide an immediate fix and relatively low cost. The downside of this approach is that pavement service life is shortened from the level that could be attained with an economical, preventive maintenance approach.
- Factors considered in the short term in selecting pavements include the initial cost of the pavement treatment, the improvement in condition that is gained, the importance of the road being considered, and political decisions on road priority and need for work. The order in which these are prioritized depends greatly on local considerations. In one city, as an example, the mayor put a

strong emphasis on minimizing traffic delays from construction, which in turn influences the city's pavement selection.[49]

- Past precedent is an important shaper of current decisions. Particularly on lower-volume streets, agencies stay with the same pavement design standards for decades simply because they work. Alternate designs that have failed in the past are not likely to be considered without good reason.
- Subjective perceptions of appearance may shape decisions in certain situations. For instance, pavement engineers in one city sometimes use a coloring agent (often carbon black) to create darker asphalt concrete for primarily aesthetic reasons.[50]
- Agencies are aware of new technologies from conferences and from contractors or vendors presenting new products. They are most aware of products that meet some currently perceived issue in maintaining the city's streets.

These factors complicate the decision process and preclude use of a single measure, such as life-cycle cost, as a guide to determining which cool pavement solutions are preferred for implementation. Life-cycle cost effectiveness is, of course, very important – a pavement that is not economical over the long term will likely not be selected in any case. The point being made here is that even if a cool paving technology is cost effective in comparison to conventional options, that fact alone may not be sufficient to convince local governments to use it. More broadly based benefits, coupled with strong demonstration of performance, may be needed.

All Governmental Levels

At the national, state, and local levels of government, the ability to manage open spaces and parking facilities provides a unique opportunity to leverage the pavement expertise of transportation-facilities providers in selecting or influencing suitable pavements for other uses. This is true particularly where agencies that manage open spaces or parking facilities lack detailed expertise in pavement issues. The ability to implement facilities-management strategies and pavement techniques based on the experience of the transportation sector enables governments to extend the cool pavement concept beyond the travel ways. It also supports efforts to influence the private sector in its pavement strategies.

Private-Sector Owners

Private-sector owners comprise developers of commercial and residential construction; corporations with large offices and plants that require paving for parking areas, sidewalks and paths; and firms that build or operate parking facilities, warehouse facilities, and shipping terminals. For many of these firms, paving is a secondary function for which they may have only limited in-house expertise. They have incentives and perceptions of cost that differ from those of public-sector agencies, providing yet another approach to pavement selection.

- Initial cost is very important to private developers, especially if they are not likely to retain ownership of the facility for very long (e.g., streets and sidewalks in a residential subdivision, or paid parking lots on property awaiting redevelopment). In recognition of the incentives this creates, some cities set minimum pavement standards if the locality will be taking responsibility for upkeep of the street.[e]
- If ownership is longer term, then performance and life-cycle costs may be considered, but initial cost is still important.
- Major facilities – such as very large parking areas and port or warehouse facilities – would typically be analyzed in terms of technology options and their relative performance and life-cycle costs.
- Private-sector owners respond to regulatory requirements, but the cost of the proposed solution will still drive decisions.
- Private firms also will consider subjective factors such as the complexity of construction and perceived problems during pavement service life. One company returned to asphalt for long-term parking lots due to problems it experienced in the construction and maintenance of a concrete parking lot, despite analyses indicating that concrete was the most economical option.[51]
- Subjective perceptions of appearance may shape pavement selection decisions even if they cost more. Parking lot companies place priority on the "look" of the parking lot in determining when maintenance is needed.[52] Both the asphalt and the concrete industries cited examples where "the other industry's product" was selected because of appearance.

Suppliers/Producers of Pavements

The U.S. paving industry comprises several groups of organizations, many of which themselves can be said to constitute individual "industries." These groups encompass engineering and other technical services; contractors; vendors and suppliers; and professional and trade associations. Each group has a distinct set of services they provide to clients or customers. It is the relationships and interactions among these industry groups and pavement owners that results in a pavement "product." Cool pavements, if they are to be accepted and used widely, must likewise become a recognized "product" of these industries. The major industry groups are introduced below to develop a broad picture of the industry overall.

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[e] In Winston-Salem, North Carolina, the City additionally required that every subdivision be built to city pavement standards, even if the streets were meant to remain private, in the event that the City might acquire responsibility in the future. (Personal communication with Hyde, S., City of Winston-Salem, September 2003.)

Engineering and Other Technical Services

The materials and techniques suitable for cool pavement must be engineered structures; i.e., they must be designed, built, inspected, and maintained to standards that ensure satisfactory, economical performance. Industry groups that provide these needed services include pavement consulting engineers, inspectors, and testing laboratories. These groups may be hired by owner agencies or, in some instances, by contractors.

Over the long term, the state-of-the-art is updated through research and demonstration of new materials and techniques. Research institutions within public agencies, publicly or privately sponsored research organizations, and academia provide these services, sometimes in cooperation with owner agencies to be able to conduct demonstration projects in the field. Successful innovations are communicated through the industry via conferences and workshops, word of mouth, periodicals issued by owner agencies and professional and trade associations, and industry marketing efforts.

Contractors

Construction contractors build the pavements that are specified by owners. They must interpret the owner's specifications and requirements, envision a construction approach that will meet technical requirements at acceptable cost, bid the job – typically on a lump-sum, lowest-cost-wins criterion – and build the pavement satisfactorily and economically. Contractors require a good deal of know-how to keep abreast of new developments; understand owner requirements; manage the construction site safely (including traffic control) and in conformity with local ordinances and environmental regulations; coordinate the inputs of subcontractors, vendors, and suppliers; deal with utility companies and abutters to the construction site; and respond to changes in anticipated site conditions and weather. Though contractors are generally knowledgeable on advances in technology, many state and local agencies noted a significant learning curve in the application of unfamiliar pavement technologies or techniques.

Contractors are a diverse group, difficult to generalize. They range in size from small, local firms to large, regional or multistate operations, and thus represent a spectrum of project experience, skills, and equipment. While some contractors specialize in a particular pavement material (asphalt or concrete) or technique (e.g., HMA paving, chip sealing), others engage in both asphalt and concrete paving. Contractors perform not only new construction, but also rehabilitation (e.g., pavement resurfacing or major repairs) and maintenance.

Vendors and Suppliers

Vendors and suppliers provide the equipment, materials, additives, and information regarding these products that contractors need to build pavements properly and economically. Vendors and suppliers are highly focused on specific products and practices, some of which can be proprietary (e.g., Koch Pavement

Solution's NovaChip). Paving equipment is specialized to the type of material being placed; e.g., concrete slipform pavers or asphalt pavement "lay-down" spreaders. Basic materials are aggregate (crushed stone) and binder or cement (specific grade of asphalt or portland cement). Additives for asphalt and for concrete may be used to enhance materials characteristics during placement (e.g., to improve workability or control the heat produced by concrete while curing) or during service life (e.g., to increase durability). Job requirements and relative costs determine their use.

While paving and mixing equipment manufacturers may be national or international in their business operations, materials suppliers tend to be local or regional, given the relatively high cost of transporting bulk paving materials. It is for this reason that access to a local source of aggregate is critical to economical paving.

Professional and Trade Associations

A large number of professional and trade associations reflect virtually all aspects of the paving industry, including groups, products, and practices. These associations typically provide their members technical support, information about research findings and innovations, and advocacy of industry positions in the political and public information arenas. They are prominent participants in discussions of public policy issues that affect their members. Because they view their membership as their clients, they reflect positions that align with members' interests – a point that is important for any cool pavement initiative. Many, but not all, associations have a national organization comprising branches in states or regions. In cases where a national organization exists, there is a trend toward an increasing vertical linkage and communication within the organization; i.e., elevating local or regional issues, concerns, or positions to a national level for debate. Section 7.0, "Where to Get More Information" lists several relevant trade organizations.

Implications for the Use of Cool Pavements

The interactions among these actors have several important implications for cool pavement efforts. Pavements are a highly visible, long-term investment. Pavement owners therefore are not likely to consider cool pavements unless they have reason to believe that they will provide performance and cost that are competitive with conventional pavements.

The existing literature has framed the potential for cool pavements in terms of the competitive life-cycle costs of cool pavement approaches, especially given presumed performance improvements from lower in-service temperatures. In practice, however, life-cycle cost may be overshadowed by initial cost in evaluations by pavement owners, particularly where budgets are tight. In addition, pavements not in common use represent an extra cost and performance risk for pavement owners and producers. The industry tends to be skeptical about success in new pavements unless conclusively demonstrated. Promising research and trials in laboratories and field experimental sites are often followed by demonstration projects encompassing as wide a range of geographical conditions as practicable before new pavement technologies come into wider use.

The need to serve the customer – the transportation user – is paramount for pavement owners. Pavement performance is gauged in a number of ways – structural integrity, skid resistance, surface visual quality, rideability, materials durability – all of which must be maintained over periods of typically 10 to 30 years. For pavement owners to be willing to use them, cool pavement techniques need to sustain or improve on performance so as not to jeopardize motorists or passengers.

In addition to the more easily quantified cost and performance considerations, county and municipal governments are affected (more strongly than are state DOTs) by local history and practice regarding the types of pavements to be used. Private developers likewise have additional considerations in the timeframes in which they will hold interests in the infrastructures they plan to build, and their responses to local regulations and standards. Thus, the decision on the type of pavement to build is affected by several criteria, not only performance and cost.

Finally, a note is in order on the diversity in preferred practices throughout the paving industry. While all its members share some basic interests and concerns, the industry overall is not monolithic. Local economic conditions, material availability, competitive forces, historical precedents, owners' requirements, and other factors all affect decisions on pavement selection; preferred strategies for pavement design, construction, maintenance, and rehabilitation; and industry responses to these trends. Each region will need to recognize and accommodate this diversity of views in formulating an approach to cool pavements. For a cool pavement effort to be successful, the benefits of the approach must be appealing to a sufficiently broad range of industry participants.

Given these factors, it seems that the benefits of cool pavements can be most compelling to different industry groups if the benefits of using this technology cut across a number of dimensions – e.g., cost effectiveness, better performance and safety, increased customer satisfaction, better visual quality, and demonstrated environmental improvements – not only a stronger case for heat island reduction, but also improvements in other environmental measures such as noise reduction or improved runoff and ground water characteristics. Combining a cool-pavement benefit with proven benefits in other characteristics of pavement performance improves the likelihood that the technology will be recognized and tried. This program management approach is discussed in greater detail in Section 7.0.

6.2 Cost Considerations

The costs of competing pavement technologies are an important factor in selecting the type of pavement or maintenance technique to employ. Developing comparable data on costs is complicated, however, by differences in practice among agencies nationwide and by local economic factors. In addition, similar units have different meanings for each pavement technology; a ton of asphalt and a ton of concrete will not produce the same amount of road. Costs also depend heavily on the overall design of an individual roadway; a road constructed to bear heavy truck traffic would be expected to cost significantly more per square yard of pavement surface than one built for light residential use. Finally, local availability of materials will strongly influence the cost of certain cool paving technologies, especially those involving light-colored aggregates; it is cost prohibitive to ship aggregate very far.

For these reasons, it is difficult to meaningfully compare costs between candidate technologies without a full consideration of project type and location. Ultimately, local pavement contractors and engineers are the ones who can generate meaningful costs. Nonetheless, it is useful to know general cost ranges for potential pavement technologies.

Unit Costs for Pavement Technologies

Unit costs of some different types of pavements based on state DOT bid data are shown in Table 6.1.[f] In cases where multiple bid items correspond to a technology (e.g., different types of HMA or of concrete), Table 6.1 gives both the price of the most prevalent bid item (based on total bid quantity reported) and the spread in unit costs among all relevant bid items reported. The weighted average unit cost is weighted by the quantity of asphalt or PCC reported by each state. Note that only the price of the most prevalent bid item, rather than the range also shown in the table, was used in calculating the weighted average unit cost.

While these data are useful to obtain a rough idea of relative unit costs, they must be used with care:

- Units of each item differ among tons, square yards (SY), and cubic yards (CY). The units shown are the ones most commonly used for each item.
- Specifications of materials, slab/layer thickness, site conditions, and other design parameters may vary among states and among projects within a state.
- The definitions of bid items may vary among agencies regarding what is included; e.g., whether preparation work, installation of reinforcing, or ancillary items are included within the bid item shown.
- There may be differences due to economies of scale between large highway projects and more modest-scale parking facilities.
- Considerable variation in unit price is evident from Table 6.1, within states as well as among states.

[f] DOTs were selected on the basis of bid data availability on their web sites.

Table 6.1 Bid Unit Costs of Selected Pavement Technologies

Paving Technology[g]	Units	CO	MA	NY	OR	TN	UT	WI	WY	Weighted Average[h]
HOT-MIX ASPHALT										
Most prevalent bid item	Ton	$44	$42	$57	$24	$33	$35		$20	$26/ton
Range	Ton	$35-$184	$42-$75	$42-$110	$20-$63	$28-$240		$29-$62	$20-$23	
PORTLAND CEMENT CONCRETE										
Plain Jointed										
Most prevalent bid item	SY		$32		$41	$35			$44	$40/SY
Range	SY				$41-$82	$35-$40	$40-$44	$21-$48	$34-$44	
Reinforced										
Most prevalent bid item	CY			$286	$392					$381/CY
Range	CY			$286-$725	$392-$758					
Ultra-Thin Whitetopping	CY			$763		$398				$445/CY

Sources: Colorado DOT, YR2001 Cost Data Book (Maintenance) (May 2002).
Massachusetts Highway Department, Weighted Average Bid Prices (2002).
New York State DOT, Weighted Average Bid Price Book (2003).
Oregon DOT, Highway Construction Average Unit Bid Prices (January 2003).
Tennessee DOT, Average Unit Price Report (2003).
Utah DOT, Statewide Standard Item Average Prices and Total Quantities (October 2003).
Wisconsin DOT, Average Unit Price List (2002).
Wyoming DOT, Average Unit Bid Prices for 2002 English (i.e., English units as opposed to metric).

Notes: See accompanying text for important clarifications regarding the costs and items included in this table.
Definitions of bid items and pavement specifications may vary from state to state.
SY = square yards.
CY = cubic yards.

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[g] Definition of bid item may vary by state and project, depending on material specifications and what work is included.

[h] Based on most prevalent bid item price, rather than the price range.

An alternate presentation is therefore given in Table 6.2. This table combines information from several sources:

- Bid construction costs from Table 6.1 are converted to commensurate units of dollars per square yard per inch thickness of pavement surface for easier comparison.
- Costs of maintenance and rehabilitation treatments are shown in dollars per square yard as obtained from other sources.[53,54]
- Estimated performance lives are estimated using information from the Cool Houston Plan.[55]

Table 6.2 Comparative Unit Costs of Selected Pavement Treatments

Treatment	Unit	Unit Cost[i], $/SY/in or $/SY	Estimated Service Life, Years
Hot-mix asphalt	SY/in	$1.00-$1.50	7-20
Plain-jointed portland cement concrete	SY/in	$3.00-$5.00	15-35
Reinforced concrete	SY/in	$7.00-$13.00	15-35
Whitetopping	SY/in	$3.00-$5.00	10-15
Ultra-thin whitetopping (refer to text)	SY/in	$40.00-$60.00	Relatively new technique
Slurry seals	SY	$0.90	2-8
Microsurfacing	SY	$1.25	5-10
Chip seals	SY	$0.85	2-8
Thin hot-mix overlay	SY	$1.75	2-12

Sources: As noted in text.

Notes: See accompanying text for important clarifications regarding the costs and items included in this table.
SY = square yard.

While the costs give a rough comparison among different paving treatments, care must again be used because these costs are subject to considerable variation due to the variability inherent in the data in Table 6.1, local economics, different materials properties, and assumptions of the pavement thickness used to estimate the construction items. The costs are estimates for performing the treatment, and are not converted to a life-cycle basis. The costs of UTW shown in Tables 6.1 and 6.2 are considerably higher than those of other surfaces. It is not certain how much of this is due to the material itself or to the inclusion of related work within this bid item. This technique is typically described as cost effective

[i] Note that costs will vary considerably by region and by the specifications of particular pavement designs (for example, pavement thickness).

in the literature. While Table 6.2 indicates that UTW is a relatively new technique, in-service performance to date on installed projects as reported in the literature has been good.

The costs of porous pavements require additional explanation:

- According to the FHWA, the cost of porous asphalt is approximately 10 to 15 percent higher than that of regular asphalt, and porous concrete is about 25 percent more expensive than regular concrete.[56] These comparisons pertain to the surface layer only.
- The cost of porous pavements reported in project summaries may include the entire drainage structure that lies under and adjacent to the pavement surface. These costs are considerably higher; e.g., $50 to $75 per square yard.
- Porous pavement cost comparisons, particularly for parking lots, emphasize that the higher project unit costs (for the surface layer and for underlying and adjacent works) are offset by savings in other drainage features such as culvert pipes. Thus, the project overall may be cost effective, even if the pavement component is somewhat higher than a conventional pavement.

6.3 Factoring Environmental Issues into Pavement Decisions

Environmental Perspectives of Paving Industries

Both the asphalt and the concrete industries are proud of the recognition they have received for their environmental advances. Both industries, for example, are involved in recycling of their respective materials, and both have developed porous or permeable pavements. The asphalt industry is proud of its record in reducing gaseous emissions and dust from asphalt plants, and the EPA itself no longer classifies these plants as major sources of HAPs.[57] The concrete industry is similarly proud of its work in energy and CO_2 reduction. While environmental awareness will remain an important component of the industries' transportation work, products will likely continue to be developed and marketed primarily on the basis of improved performance and cost.

Environmental Regulation of Projects Involving Paving

Transportation projects are subject to Federal, state, and, in some cases, local environmental regulations. The Federal regulations are based on the National Environmental Policy Act of 1969 (NEPA), which applies particularly to new construction and reconstruction or major improvements of existing facilities. NEPA serves as the regulatory and procedural umbrella for many project-related environmental analyses and concerns, including public involvement, Coast Guard permits, Corps of Engineer permits, aquifer protection, wetlands preservation, threatened and endangered species, coastal zone consistency, air quality conformity, historic preservation, environmental justice, noise abatement, sustainable development, and community impact assessment.

The NEPA areas most associated with addressing the urban heat island effect are public involvement, air quality impacts, noise mitigation, secondary and cumulative impacts analysis, and (indirectly) groundwater protection. These activities are typically dealt with in an early stage of project development, which some agencies refer to as "early preliminary engineering" (EPE). The intent of environmental reviews at this stage is to get an approval called the Record of Decision (ROD) that will allow the project to move forward to design in the "preliminary engineering" (PE) phase. Pavement design is not started until the PE phase is reached and, thus, typically occurs *after* the project's environmental issues have been addressed. None of the areas of concern addressed by the existing NEPA processes considers the type of pavement either as a potential mitigation step or as a required design activity.[j] As a practical matter, the primary environmental concerns for pavement managers and project design engineers are in dealing with stormwater management (under National Pollutant Discharge Elimination System, or NPDES, regulations) and dust control during construction. Emissions at the pavement manufacturing plant are not their responsibilities, and emissions from the pavement itself are considered negligible. With this background in mind, the important points to note with respect to environmental regulation of highway projects and its influence on pavements are that:

- Pavement design and construction requirements are typically not affected by other project design considerations or environmental mitigation steps up to that point – pavement is not considered as a means to mitigate environmental impacts of a given project, nor are the environmental impacts of a particular type of pavement considered in planning the project;
- Pavement design is typically a stand-alone component of project design; and
- Pavement construction is almost invariably an individual component of a construction bid.

As a result, the existing environmental regulatory framework for public-sector road projects exerts little direct influence on *pavement type selection* – and is thus not in a position today to promote cool pavement approaches. Because pavements are a stand-alone component of project design and construction, however,

[j] However, our interviews indicate that some state DOTs (particularly Arizona) are now reviewing pavement type in the context of tire-pavement noise, primarily in the context of resurfacing existing pavements. Nonetheless, as far as the NEPA process concerned, current FHWA policy generally does not allow the use of "pavement type or surface texture" as a noise abatement measure. The FHWA has issued guidance on quiet pavement pilot programs, however (http://www.fhwa.dot.gov/environment/noise/qpppmem.htm). For FHWA regulations, see 23 CFR Part 772, at http://www.fhwa.dot.gov/environment/23cfr772.htm.

they could provide an opportunity to undertake cool pavement initiatives in the future without disrupting the overall design and construction process.

It should be noted that transportation professionals in state and local governments and private-sector contractors **are** interested in pursuing promising new solutions to air quality, noise abatement, stormwater management, and other societal concerns. Chicago has made a conscious effort to "green" its roads with landscaped medians that are aesthetically pleasing and absorb stormwater runoff.[58] To help comply with the Clean Water Act, Winston-Salem has instituted a street-sweeping program to reduce runoff contamination.[59] Dane County, Wisconsin, now requires developments to reduce thermal pollution of runoff from impervious surfaces.[60] At the state level, a few attempts have been made to encourage environmental considerations in pavements. Georgia considered passing permeable pavement legislation at one point to address groundwater concerns;[61] and the North Carolina DOT has recently begun examining the heat island issue.

These factors suggest that one avenue to encourage and potentially fund the use of cool pavement technology is through programs that address other environmental concerns (e.g., ground water management) or societal issues (e.g., safety). Transportation Enhancement,[k] safety, and possibly other Federal programs are thus potential funding sources that could lead to a by-product application of cool pavement technology. Complementary state programs also may exist to provide further assistance to local governments. As an example, a safety project to reconstruct an intersection (e.g., to add turning lanes or install new traffic signals) could be coupled with a new or resurfaced pavement (such as UTW) that provides greater reflectance. Similarly, potential air quality benefits for using a cool pavement treatment as a stand-alone or as part of an already eligible Transportation Enhancement project might allow it to compete more aggressively for funds and expedite deployment of the technique.

The crafting of approaches like these must take account of the roles of different levels of government and intergovernmental relationships. For example:

- The FHWA reviews project designs and specifications only for projects on the Federal-aid system – not a major component of a local street grid.
- States do not exert jurisdiction over cities and counties in project design and construction, except where urban state highways are maintained by local jurisdictions. Local governments may choose to apply state standards to their systems, but this is a matter of influence rather than jurisdiction.

[k] The Transportation Enhancement program sets aside a portion of highway funds for bicycle, pedestrian, scenic, and other non-traditional projects.

- Cities and counties exercise limited jurisdiction over private-sector paving, but do have some strong levers they can employ:
  - Local governments can specify minimum standards and specifications that pavements must meet.
  - Local governments can extend the requirements of the permitting process for private paving projects, which now governs primarily the access of a property to the street.
  - Local governments can institute regulations limiting impervious surfaces if there is a rationale for stormwater runoff and groundwater management. Such regulations would encourage consideration of porous or permeable pavements.

While these approaches offer promising avenues to "piggyback" the application of cool pavement designs and technologies on other types of benefits accruing from a project, the rationale for using cool pavements can be much stronger if the benefits of the approach are understood on its own merits. **More available information and a clear demonstration of benefits will help produce wider recognition, acceptance, and use of cool pavement.** Better communication is one aspect of this issue; the other is the clear demonstration in the field of the advantages of cool pavements, as discussed earlier from the perspective of performance. This issue revealed itself during the interviews and investigations for this report as follows:

- Many stakeholders who were interviewed had not heard of the idea.
- Web sites typically used by transportation professionals (such as those for the FHWA and AASHTO) do not mention cool pavements. By contrast, other environmental issues are well covered; e.g., air quality, runoff and ground water, noise impacts, visual quality afforded by highways.
- The fact that there are several contributing factors to the heat island effect clouds the role of pavements and the potential benefits to be gained by using cool pavements.
- The computer models now in use need further refinement to conclusively (and quantitatively) demonstrate the air quality benefits of cool pavements.

Promoting Cool Pavements with Other Environmental Actions

Answers to the issues posed above can come from additional research, as well as from experiments by communities and private firms that are willing to undertake a cool pavement initiative or, more broadly, a pro-environmental or "green" initiative. While these efforts must address the technical questions regarding benefits of cool pavements, and technological matters about the materials and techniques most suitable to providing economical solutions, there also are institutional issues that bear investigation to see if there are ways to promote the concept among a wider set of communities. Potential mechanisms that could be used over the long term to encourage the use of technology consistent with cool pavements include the following:

- Zoning regulations;
- Economic development initiatives that entail linkage payments or requirements (e.g., payments by developers, required as a condition of construction approval that could be used to fund cool pavement in that project or elsewhere);
- Permitting and approval of site development plans;
- Water quality regulations and permits, including those for stormwater contamination, thermal pollution, and groundwater protection;
- Air quality regulations;
- Minimum pavement specifications, standards (e.g., for cross-section and materials), and minimum thresholds of service life or performance;
- The concept of a "utility district" that might be applied to infrastructure (e.g., a statutorily established district within which guidelines could favor cool pavements, backed by fees paid by the beneficiaries of these improvements); and
- Tax incentives for long-term pavement performance.

Again, these institutional mechanisms are possible ways to encourage the consideration of cool pavements. For them to be meaningful, however, the rationale for cool pavements also must be in place; i.e., documentation of the need, available technology, cost feasibility, and demonstrated benefits.

7.0 Information on Implementing Cool Pavements

7.1 Marrying Cool Pavements to Other Policy Objectives

In many cases, the rational for using cool pavements can be strengthened if married to other, already existing policy objectives. Pavements, whether built for roadways, airport landings and taxiways, or parking facilities, are a highly visible and long-term capital investment. The decision on the type of pavement that is appropriate in each instance is related to the need to maintain the investment for the expected life of the investment. As such, agencies will be more willing to justify the cost and risk of cooler pavements designs if their benefits can be compounded with the benefits of meeting other policy goals, especially if they address existing legislative or regulatory requirements. By recognizing this linkage, agencies can promote cool pavements under more recognizable and accepted mechanisms. This approach also expands the list of possible funding categories available to the practitioner to meet agency capital needs.

The policy objectives listed below are existing examples with which urban areas are already grappling, for regulatory or other reasons. In many cases, cool pavements could be a logical component of the solutions. Some policy objectives that could find co-benefits with cool pavements include:

- **Air quality mitigation.** Elevated air temperatures can exacerbate air quality problems. To the extent that cooler pavements can help mitigate that, urban areas may see a benefit to using them as much as possible. EPA has issued a policy on incorporating emerging measures into state implementation plans (SIP) that specifically includes heat island reduction programs and cool pavements as candidates for the policy.[62] The policy limits these measures to six percent of total reductions needed for the SIP. As of June 2005, no state has used this policy to include cool pavements in its SIP.
- **Water quality improvement.** Permeable roadway pavements and especially parking facilities of all types (asphalt, concrete, and reinforced grass and gravel pave systems) can address water quality problems by reducing the percentage of land covered by impervious surfaces. Many cities already are required to address stormwater management problems under the Clean Water Act, as with street sweeping programs, etc. In addition, cities with combined sewers (where storm drains connect to the regular sewer system) may find permeable pavements a viable method of reducing combined sewer overflows (in which untreated sewage is released directly to the environment) during storm events. Given the alternatives (constructing separate sewers,

expanding sewage treatment plants, building storage tanks), it may even be cost effective in comparison to the alternatives.

As well as reducing storm runoff, permeable, porous pavements when combined with water treatment wetlands, help to act as filters, sifting dust and dirt out of the stormwater. This improves water quality by filtering the water and improving groundwater protection. Even non-permeable cool pavements could help water quality through reduced heating of runoff.

- **Noise reduction.** The open pores of permeable pavements have been shown to significantly reduce tire noise. Road noise is increasingly a concern in many areas because of the aging of the Interstate system and other high-classification roads, the need to rebuild or expand these systems, and the growth of residential dwellings next to these facilities. At this time, the problem is usually addressed with very expensive noise barriers. In addition, although the FHWA currently does not allow the use of quieter pavements as a noise mitigation measure, it has issued guidance to state DOTs interested in conducting quiet pavement research or in developing Quiet Pavement Pilot Programs (QPPP).[63] One potential problem noted by the FHWA is the tendency for the pavement pores to fill with detritus over time, reducing their effectiveness in noise mitigation.
- **Safety improvement.** Permeable pavements reduce water splash (particularly from trucks) and provide better traction in wet weather. In fact, permeable surface layers (sometimes called "open-graded friction courses") have been used in a number of locations for this purpose. (These were generally not built with permeable base layers to allow water to drain all the way through, as safety and traction were the primary goals.)
- **Context-sensitive design.** The context-sensitive design process considers the total community and physical environment in which a project is to be constructed. This process/policy is being widely applied by transportation agencies across the country to preserve and enhance environmental resources while maintaining traveler safety and mobility. As well as accruing the environmental benefits of cool pavements, a context-sensitive design might take advantage of the aesthetics associated with cool pavements (such as lighter colored aggregates, pavement coloration, paving blocks, the natural look of reinforced grass parking facilities or gravel pavements) to help a project better fit into its environment. This concern for the aesthetics of a pavement can often be seen in "streetscape" projects, which aim to encourage downtown revitalization by creating more pedestrian- and community-friendly environments. In these cases, bricks, pavers, textured pavements, or different colored pavements are often used to mark zones such as pedestrian crossings, or to make surroundings more appealing visually.

Table 7.1 lists selected examples of instances in which pavements that could be considered "cool pavements" have been used to implement some of the policies listed above. In most cases, urban heat island mitigation was not a primary factor in choosing these pavements, or even necessarily a co-benefit that was explicitly considered.

Table 7.1 Examples of Cool Pavements Complementing Other Policy Objectives

Policy Objective	Location	Project
Water Quality	Ford Motor Company Rouge Center, near Detroit, MI	A 16-acre parking lot was constructed with porous pavements over large stone storage basins, as part of the facility's stormwater management system.
	Houston, TX	A 317,000 square foot Grasspave (reinforced turf structure) parking lot was constructed at Reliant Stadium, both to mitigate stormwater and "green" the stadium area. It also serves as a venue for outdoor festivals and rodeos.[64]
	Atlanta, GA	The City of Atlanta built a porous concrete parking lot at its Department of Corrections.[65]
	Eugene, OR	The City of Eugene constructed a porous asphalt parking lot at its equipment maintenance facility, using the Oregon DOT's asphalt mix design for an open-graded friction course.[66]
	Chicago, IL	The City of Chicago reconstructed a 10,000 square foot alley with a gravel pave system for both stormwater and heat island benefits.[67]
Noise Reduction	Phoenix area, AZ	As part of its QPPP, the Arizona DOT has been experimenting with the use of asphalt rubber friction course (also called crumb-rubber) atop a concrete slab. It has plans to install these on sections of interstates and other high-volume roadways throughout the area, with a noise-monitoring program to assess benefits over time.[68]
Safety Improvement	San Antonio, TX	A section of I-35 was repaved with a permeable friction courses (laid on top of an impermeable base) to improve traction and visibility in wet weather.
Context-Sensitive Design	Burlington, VT	The North Street Revitalization Project made use of painted, textured asphalts at crosswalks, and considered use of tinted asphalt mixes.[69]
	Washington, D.C.	In a recent reconstruction of Pennsylvania Avenue in front of the White House, the roadway was repaved with a reddish asphalt to create a more "natural" look.[70]

7.2 POTENTIAL FUNDING SOURCES

In successfully marrying cool pavements to the policy objectives discussed above, one may be able to leverage existing funding sources for these projects. Though heat island mitigation is not in itself an eligibility criterion for existing Federal funding programs, for example, it may be perceived as an additional benefit of projects that are eligible for funding based on the other objectives shown in Table 7.1. It could serve as an additional determining factor in the final project selection process by an agency. Clearly, the development of state and local policies to address heat island issues will be facilitated by using the funding programs described below, which will allow these techniques to be added to the regular toolbox of the pavement professionals. The funding sources described below have not to date been used on a systematic basis for cool pavement projects. Doing so would represent a new and innovative use of these funds.

The information below is only an introduction to some possible funding sources. It is important to note that to successfully receive grant funding, any project would need to first meet the eligibility criteria. Nonetheless, the sources may provide an opportunity for projects involving cool paving technologies to be funded as part of regular project selection and implementation strategies and programs. The status of these programs may change under the reauthorization of the present Federal transportation enabling legislation.

Transportation Enhancement Funds

Administered by the FHWA, this program sets aside a percentage of surface transportation funds for a specific set of (seven) activities known as transportation enhancements. These provide funds for bicycle and pedestrian projects, scenic programs, historic preservation, roadway facility beautification, and environmental mitigation to address water pollution due to highway runoff. Permeable pavements could possibly qualify for the latter funding eligibility criterion. Other cool pavement technologies could augment a project that meets eligibility rules for one of the other categories, if unable to solely qualify; they could easily be included in streetscape projects as well as for aesthetic qualities. The program distributes more than $500 million per year. For general information, visit: http://www.fhwa.dot.gov/environment/te/index.htm. For a list of eligible activities, see: http://www.fhwa.dot.gov/environment/te/guidance.htm#qualifying.

Scenic Byways Program

This FHWA program provides funding to establish and improve scenic byways. Eligible improvements must enhance the scenic byway visitor's experience in some way. Ordinary maintenance is not funded. Although this program is not specifically focused on the environment, funds may be used to protect resources "directly related to the byway or its intrinsic qualities." Because the program does not fund ordinary repaving projects, cool pavements are most applicable in the context of parking lots provided for scenic byway facilities (such as visitor centers or viewpoints). The program distributes about $25 million per year. For more information, visit http://www.bywaysonline.org.

Transportation and Community and System Preservation Pilot Program

Administered by the FHWA with the Federal Transit Administration (FTA), Federal Railroad Administration (FRA), and EPA, this program grants funds to states, local governments, and metropolitan planning organizations (MPOs) to plan and implement smart growth strategies. Among these, it includes grants to reduce the environmental impacts of and harmonize transportation projects in the community. This program would allow a better integration of metropolitan area long-range transportation and land use decision-making concerns that are central to the routine implementation of cool pavement techniques. Many streetscape projects also have been funded by this program, including the Burlington and Houston streetscape projects described above. The program distributes about $25 million per year. For more information, visit: http://www.fhwa.dot.gov/tcsp/index.html.

Safety- and Operations-Related Programs

Programs that can fund safety and operations work, such as the **Highway Safety Program** itself, or the flexible **Surface Transportation Program (STP),** could fund pavement construction using techniques like UTW where appropriate – e.g., in intersection reconstruction. Similarly, the use of permeable pavements to improve safety in wet weather could be eligible for these funds.

Context-Sensitive Design

Not a specific program but instead a design concept process, the idea of context-sensitive design considers the total community and physical environment in which a project is to be constructed as critical to a successful transportation investment. This policy is being widely applied by transportation agencies across the country to preserve and enhance environmental and community resources while maintaining traveler safety and mobility. The design concepts involved are eligible to be applied in all Federal funding categories. For more information, visit http://www.fhwa.dot.gov/csd/history.htm.

7.3 Local Policies to Promote Cool Pavements

Policy-Makers

As shown in this report, the decision to select a particular pavement type is a complex process involving issues as diverse as initial cost, historical precedent, length of facility ownership, and perceived product durability. A diverse set of agencies are making these decisions, including state DOTs; city and county governmental and road agencies; airport, port, and toll authorities; and private developers. Of these, the agencies at the city and county level are the ones that can have the most immediate impact on promoting the cool pavement concept. These have the most direct enabling influences on integrating land use and transportation decision-making in urban areas.

In urbanized areas, MPOs are the most important structure for integrating the wants and needs of local municipalities. MPOs were created by Federal transportation legislation to provide coordinated, comprehensive, and cooperative policy, planning, and programming direction for the expenditure of Federal transportation funds in these urban areas. Many of the projects that are eligible for funding through the Federal programs discussed above are directly reviewed and approved by the MPO itself. In fact, final program and project decisions must be consistent with the Long-Range Transportation Plan for the MPO area. This Long-Range Transportation Plan is required by the FHWA to allow the expenditure of Federal transportation funds.[71] This planning requirement provides an excellent opportunity to develop policies that would highlight and embed the cool pavement concept to address heat island issues. Because the MPO is composed of the local agencies that have direct responsibility for local project initiation, it is well situated to positively influence cool pavement implementation.

Developing urban area policy guidance and information tools that speak to the funding eligibility opportunities and local case examples can promote the use of cool pavement technologies within the context of local governmental controls of capital budgeting and land use regulations. This policy direction can be most helpful as local units coordinate and leverage their local transportation-related facilities investment with areawide Federal project funding.

Specific Actions

Cities and counties have direct control over the capital facilities budgets that can be used to facilitate cool pavement designs for local streets, intersection improvements, and parking facilities. They also are often substantial partners in local airport, toll, and port facility operations. This can extend their influence to other use activities, and puts substantial amounts of pavement under their decision-making control. In these cases, cool pavements can be implemented by direct decision-making on the part of the local agencies; cool pavements could become a standard tool to consider in planning paving-related projects.

However, there also are good options for promoting cool pavement use by the private sector. There are a number of potential mechanisms that the MPO could encourage local units to use in order to encourage the use of cool pavements, including the following:

- Minimum pavement specifications and standards (e.g., for cross-section and materials) for pavements expected to eventually come under municipal control (as in residential subdivisions).
- Permitting and approval of site development plans. This a powerful tool to reflect long-term city or county transportation, environmental, and

community planning goal and objectives for the area. For instance, local governments can extend the requirements of the permitting process for private paving projects. Currently, these govern primarily the access of a property to the street to parking facilities as part of larger local development policy consideration, but it could equally govern the nature of the pavement itself.

- Groundwater protection regulations that are tied to new or existing clean-up concerns. For instance, local governments can institute regulations limiting impervious surfaces as part of rationale for stormwater runoff and groundwater management throughout the urban area. Such regulations would encourage consideration of porous or permeable pavements.
- Economic development initiative that entail linkage payments or requirements (e.g., payments by developers, required as a condition of construction approval, that could be used to fund cool pavement in that project or elsewhere).
- The concept of a "utility district" that might be applied to infrastructure; e.g., a statutorily established district within which guidelines could favor cool pavements, backed by fees paid by the beneficiaries of these improvements.
- Tax incentives for long-term pavement performance. Similar to the utility district, this should be tied to meeting long-term planning goals and the anticipation that property values will be enhanced and public maintenance requirements will be minimal.

For those interested in further background on the potential role of MPOs, a summary of interviews conducted with several MPOs is provided in Appendix A.

7.4 Current Initiatives

Several initiatives relating to cool pavements and urban heat island reduction are already underway. Examples include the following:

- **LEED for Sustainable Buildings**. The U.S. Green Building Council has developed national standards for sustainable buildings, called the Leadership in Energy and Environmental Design (LEED) Green Building Rating System. The system provides a framework for assessing building performance from an environmental perspective, by granting credits for actions related to sustainable site development, energy efficiency, water quality impacts, use of recycled materials, etc. A building requires 26 points to acquire basic certification, and more for higher levels of certification (up to a maximum of 69). For the installation of cool pavements to qualify for the heat island reduction credit (one point), the site must use materials with an albedo of at least 0.3 for 30 percent of the site's non-roof impervious surfaces. One credit also may be given for open-grid pavement, in which less than 50 percent of the pavement surface is made of impermeable materials. In addition, use of porous pavements can gain one point in the stormwater management category.[72]

- **Cool Houston!** The Cool Houston Plan, developed by HARC, proposes actions to mitigate the urban heat island by remaking the surface of the region. It takes advantage of the following situations: a) many rooftops and paved surfaces are replaced every year; b) it focuses on those surfaces that are most likely to change, rather than all such areas in the urban region; and c) it proposes actions that are feasible and beneficial to property owners and the community at large. Cool pavements is one component of the plan; others are cool roofing and tree planting.[73]
- **Atlanta Cool Communities**. Atlanta's Cool Community program is a non-profit advocacy program that addresses heat island issues in the Atlanta metropolitan area. It focuses on cool roofing and tree planting as well as cool paving as ways to improve air and water quality and conserve energy. Atlanta's Cool Communities has formed a coalition of public and private organizations to support these efforts, including representatives from state, city, and county agencies, non-profits, a local power company, and cement and concrete associations.[74]
- **Sustainable Materials and Renewable Technologies (SMART) Program**. A consortium of public- and private-sector groups, academic institutions, and other stakeholders within the Greater Phoenix area have begun to study ways to mitigate the urban heat island in that region. This effort includes researchers from ASU, the Massachusetts Institute of Technology (MIT), Cambridge University, Tec de Monterrey, the Indian Institute of Technology (IIT) – Delhi, and the University of Cape Town.[75]

7.5 Where to Get More Information

As a market for cool pavements cannot be said to exist in the same way as for cool roofing products, information resources are more limited. However, there are a number of organizations that could provide useful information for those wishing to plan a cool pavement initiative.

Many national and state-level trade associations provide general information on pavements:

- The **National Asphalt Paving Association** web site (http://www.hotmix.org) contains information on asphalt technologies, environmental issues, and links to state asphalt paving associations (http://www.hotmix.org/view_article.php?ID=63).
- The **Asphalt Paving Alliance** is another source of information on asphalt pavements and includes some information on noise reduction (http://www.asphaltalliance.com/).
- The **American Concrete Paving Association** (ACPA) web site (http://www.cement.org) provides general information about concrete pavements. It also provides links to its state and regional chapters (see http://www.pavement.com/chaplinks/chapters/chapmap.html).

- The **Portland Cement Association** web site (http://www.pavement.com) also provides general information about concrete pavements.
- The **Georgia Concrete & Products Association** web site (http://www.gcpa.org/) provides links to information on heat islands and on permeable pavements.

Similarly, several web sites provide insight into the public sector:

- The **FHWA's Office of Pavement Technology** provides very useful links to pavement technology information (http://www.fhwa.dot.gov/pavement/about.htm).
- The **FHWA's Office of Planning, Environment, and Realty** provides comprehensive information regarding transportation planning and the environment (http://www.fhwa.dot.gov/hep/index.htm).
- The **AASHTO Center for Environmental Excellence** web site (http://environment.transportation.org/) contains a substantial amount of information regarding environmental issues and transportation projects.
- The **AMPO** web site (http://www.ampo.org/) has links to one's local MPO and discussions of the environmental and other issues faced by MPOs.

Several cities and research institutions have created cool paving research or implementation plans. Their web sites yield useful insights into questions regarding cool pavements benefits and implementation. These include:

- The **Consortium for the Study of Rapidly Urbanizing Regions** at ASU (http://ces.asu.edu/csrur/index.htm)
- The **Houston Advanced Research Council** (HARC), at http://www.harc.edu/harc/Projects/CoolHouston/HeatIsland/. HARC has produced a Cool Paving Plan, viewable at http://www.harc.edu/harc/Projects/CoolHouston/About/Documents/CoolPavingPlan.pdf.

Finally, to get detailed information on the costs and viability of cool pavements designs in urban areas and for specific types of projects, state, local, or private developers should contact local paving associations or contractors. Cool pavement project costs and properties vary considerably from region to region, and ultimately the local practitioners are the only ones who can generate accurate costs. Cool pavement project designs can utilize all types of construction material to achieve the desired results, and costs will vary considerably on this basis as well.

8.0 Research Needs

8.1 Potential Future Research

Additional research on cool pavements can develop a wider body of knowledge and experience as to how cool pavements behave, what designs and technologies are feasible, where and how they can best be applied, and what are their benefits. This section presents a discussion of research needs that could help advance the field of cool pavements. The ideas presented here can be applied by public- and private-sector organizations as well as academic researchers.

Within a broad context, the research could extend to the technical, economic, organizational, and institutional aspects of cool pavements:

- Technical research would focus on refinements to promising materials; design and construction approaches that enhance the capability for heat island reduction; and processes describing the impacts of cool pavements.
- Research in the economic area could refine information on initial costs of techniques and life-cycle performance and costs; ways to make techniques more economical to use; and estimates of the benefits of cool pavements to society.
- Organizational research could focus on ways to increase awareness of cool pavements and promote their use in public- and private-sector agencies, including training programs.
- Institutional research could focus on ways to communicate success stories, conduct technology transfer, and address the barriers to use.

Table 8.1 is an example of a framework for compiling the results of existing research and identifying gaps in knowledge that can be addressed in future studies, particularly in the technical and economic areas. "Filling in the blanks" in such a framework would help identify where needed work should be focused.

Specific action items growing out of cool pavement research could take many forms. The following list presents a sample of the types of projects that could help advance the field. As noted above, a wide range of public, private, and academic organizations could implement these projects.

Table 8.1 Framework for Identifying Information Needed to Assess the Benefits of Cool Pavements

Variable	Inputs to Calculation	Issues, Concerns, Factors to Consider
External Inputs		
Incoming sunlight (solar radiation)	Amount of radiation reaching Earth	
Sunlight reaching the surface	Amount of radiation absorbed by atmosphere, clouds, etc.	
Precipitation	Latent heat transfer, soil moisture content	
Effect of Urban Form		
Shading	Shading by buildings, trees, and vehicles	These factors will vary by pavement location and time of day.
Sky-view factor	Percent of sky "visible" to the pavement (not blocked by structures, trees, etc.)	Affects ability of pavement to cool through longwave radiation by potentially directing heat back at pavement.
Adjacent properties	Percent of reflected light that is absorbed by surrounding structures rather than going out to space	This will vary by pavement location and time of day. However, it could have an important impact on the overall effectiveness of a heat island strategy.
Effect of Pavement Material Properties		
Percent of solar radiation reflected by pavement	Actual pavement albedo	Albedo of in-use pavements will be affected by aging, dirt, and surface wetness.
Effect of permeability on pavement temperature	Porosity of pavement and water content of pavement and base below it	Will need data on how much permeability reduces pavement temperature under a variety of moisture and soil conditions. Again, data from in-use pavements is best.
Effect of rate of heat absorption and radiation on pavement temperature	Thermal conductivity, heat capacity, emissivity, thickness, and other properties	Will influence "time lag" in how a pavement contributes to the heat island in daytime versus nighttime. Again, data from in-use pavements is best.
Impact on the Urban Heat Island		
Contribution to local heat island (i.e., change in temperature of air directly above pavement)	Amount of heat radiated and convected to the air above a paved area	Field data collected above a variety of paved areas that are in use (with vehicles, etc.) will be most useful.
Contribution to regional heat island (change in city's temperature)	Percent of regional heat island effect due to pavements alone	Will be difficult to directly measure in the real world due to the scale of the problem. Models can address this but will need to be fairly detailed to capture the steps outlined above.
Diurnal effects (time of day impacts)	Heat storage and release by time over the course of a 24-hour period	Complex issue to address, depending on many competing materials properties.

Variable	Inputs to Calculation	Issues, Concerns, Factors to Consider
Other Environmental Benefits		
Effect on evaporative gasoline emissions from parked vehicles (i.e., VOC emissions)	Degree to which cooler pavement temperatures result in cooler vehicle temperatures	As well as incorporating an understanding of local air temperature changes from cool pavements, actual field measurements of evaporative emissions or gasoline tank temperatures would be effective.
Effect on ozone formation	Percent decrease in ozone formation from reduced temperature; percent increase in ozone formation from increased reflected light	May be difficult to measure directly the effect of heat island reduction, but advanced air quality models may be able to estimate.
Effect on runoff	Decreased heating of runoff due to cooler pavements	Potentially important ancillary benefit.
Effect on noise	Noise reductions from permeable pavements	Potentially important ancillary benefit. Need to determine whether benefits decrease as pavement wears over time.
Effect on nighttime illumination	Additional illumination provided at night by pavements with higher albedo	Could help reduce energy usage and lighting costs.
Cost and performance Implications		
Life cycle costs of cool pavements	Initial, maintenance, rehabilitation, and disposal costs	Factors to consider include frequency of maintenance, life expectancy.
Effect on performance characteristics	Skid resistance, noise, safety, durability, etc.	Cool pavements must meet appropriate standards for their intended uses.
Expected usage	Applicability of pavement for different uses	Some pavements may only be appropriate for light-duty use, as in parking lots or lightly traveled roadways.

Guide Materials

- **Develop a practical guide that describes the cooling mechanisms for various pavement designs based on their thermal characteristics and behaviors.** This guide would help translate the various heat-related characteristics and processes into non-technical, easy-to-understand terms and descriptions for use by pavement engineers, public works officials, and decision-makers. Such a guide would help these individuals to understand in a detailed but practical sense how different pavement configurations could work as cool pavements and where they might work best. The guide would help answer basic questions: Which pavements are relatively cooler during the day versus the night? On balance, which pavements (based on their diurnal behaviors) might be best suited for a particular climate? How do thick surfaces behave in comparison to thin surfaces for the same material?
- **Document the heat island-related characteristics of various pavements in a comprehensive technical report.** This report would capture daily temperature profiles and relevant mechanisms of heat transfer and temperature gain or loss for pavements of different materials, structure, and surface characteristics. The goal would be to understand the full heating and cooling cycle of different types of pavement over a 24-hour period, to assess the net gain from use of "cooler" pavements – and to understand which pavements really are "cooler" in given situations when looked at on a 24-hour basis.

Case Studies and Field Tests

- **Conduct long-term tests at specific pavement sites to document initial and long-term performance as a cool pavement.**
  - Initially, this work could focus on pavements alone; e.g., large, unshaded parking lots, to isolate the behavior of the pavement materials and structure.
  - Later, other variables could be introduced, related to urban location, adjacent land use, different "street canyon" geometry, etc.
- **Conduct case studies of porous pavements as a cool pavement to demonstrate:**
  - Pavement longevity;
  - Ability to retain porosity over time; and
  - Degree of heat reduction.
- **Conduct research to develop an easy data collection methodology to determine the percent area of the urban fabric devoted to paved surfaces, and the characteristics of these surfaces (i.e., urban canyon geometry, percent shaded by vegetation, etc.).** This information is basic to future estimates of cool pavement impacts and benefits.

Institutional Capacity Building

- **Take full advantage of ongoing work in markets where cool paving strategies are understood, accepted, and underway.** Collect information from different locales to:
  - Develop and disseminate success stories;
  - Build a database of experience that documents successful cases, enables an objective comparison among sites, and provides benchmarks for impacts that can be expected in other locations;
  - Refine and validate modeling capabilities to provide more definitive analyses of potential cool pavement impacts;
  - Experiment with different supporting and reinforcing institutional mechanisms, in collaboration with participating local governments, to identify the factors that motivate local decision-makers and the pavement industry; and
  - Develop a body of technical and performance data that can serve as "toolboxes" for engineers and contractors, providing guidance on cool pavement selection, anticipated performance, and cost.
- **Build industry acceptance of a cool paving rationale.**
  - Sponsor and encourage research on cool pavement materials and processes under field conditions.
  - Sponsor and encourage demonstration projects where promising materials technologies are applied by selected agencies under realistic construction conditions.
  - Investigate and document corollary benefits that might accompany the greater use of "cool" pavement techniques. For example, the benefits of porous pavements for groundwater quality tend to be known and accepted, and Arizona has had good experience with the heat-reducing characteristics of composite pavements originally intended for noise reduction. However, the implications of pavements of different colors and albedo values for safety and energy savings (in nighttime illumination), for example, are not as well known and documented.
  - Build partnerships with the FHWA, state and local agencies, AASHTO, TRB, and NCHRP to identify projects that relate to heat island reduction objectives, and if appropriate, participate in oversight.
- **Work with transportation funding agencies to build into existing programs funding eligibility and incentives for agencies to apply technologies consistent with cool pavements.**

8.2 Conclusions and Next Steps

The ideas presented here are only means as a sampling of the types of activities that could expand the body of knowledge and experience for cool pavements. As discussed above, these needs encompass not just technical pavement and construction research, but also institutional research and public information. To further explore this, EPA will be hosting a workshop on June 27, 2005 to discuss research and institutional needs and possible "next steps" to bring the field to a greater level of maturity. Results from this workshop will be posted on EPA's web site.

9.0 References

[1] Akbari, H., L. Rose, and H. Taha, "Characterizing the Fabric of the Urban Environment: A Case Study of Sacramento, California," Lawrence Berkeley National Laboratory, U.S. Department of Energy, LBNL-44688, 1999; and Rose, L., H. Akbari, and H. Taha, "Characterizing the Fabric of Urban Environment: A Case Study of Metropolitan Houston, Texas," Lawrence Berkeley National Laboratory, LBNL-51448, 2003.

[2] Rose, L., H. Akbari, and H. Taha, "Characterizing the Fabric of Urban Environment: A Case Study of Metropolitan Houston, Texas," Lawrence Berkeley National Laboratory, LBNL-51448, 2003.

[3] Pomerantz, M., B. Pon, H. Akbari, and S.C. Chang, "The Effect of Pavements' Temperatures on Air Temperatures in Large Cities," Lawrence Berkeley National Laboratory, LBNL-43442, April 2000. This is also discussed further in Environmental Protection Agency's heat Island Guidebook (forthcoming).

[4] James, W., "Green Roads: Research into Permeable Pavers," *Stormwater*, pp. 48-50, March/April 2002. Available at http://www.forester.net/sw_0203_green.html. See also http://www.lid-stormwater.net/permeable_pavers/permpavers_benefits.htm.

[5] U.S. Department of Transportation, Federal Highway Administration. *European Road Lighting Technologies*, International Technology Exchange Program: September 2001.

[6] For additional information on these treatments, see Geoffroy, D.N., P.E., *Cost-Effective Preventive Pavement Maintenance*, National Cooperative Highway Research Program, Synthesis of Highway Practice 223, 1996; also http://www.slurry.org/mswhat.htm.

[7] *Highway Statistics 2001*, Federal Highway Administration, Table HM-31, October 2002 (2001 data).

[8] Ibid.

[9] Ibid., Table HM-12.

[10] Pavement type classifications for local roads are included in the web sites of DOTs in Georgia, Idaho, Iowa, Massachusetts, and Minnesota. These are selected states; other DOTs may include this information as well.

[11] Oke, T.R., "The Energetic Basis of the Urban Heat Island," *Quarterly Journal of the Royal Meteorological Society*, Vol. 108, pp. 1-24, 1982. As cited in "International Association for Urban Climate Teaching Resources: The Urban Canopy Layer Heat Island," p. 15.

[12] Figure provided by Jay S. Golden, Director, Sustainable Systems Program for Urban Climate & Materials, Center for Environmental Studies, Arizona State University.

[13] Golden, J.S., "A Sustainable Systems Approach to the Hysteresis Lag Effect of Surface Materials & Urban Heat Islands," Arizona State University, Tempe, Arizona, p. 2.

[14] Oke, T.R., "Canyon geometry and the nocturnal heat island: Comparison of scale model and field observations," *International Journal of Climatology,* Vol. 1, pp. 237-254, 1981. As cited in "International Association for Urban Climate Teaching Resources: The Urban Canopy Layer Heat Island," p. 17-18.

[15] International Association for Urban Climate Teaching Resources: The Urban Canopy Layer Heat Island, p. 18.

[16] Akbari, H. and L. Rose, October 2001, "Characterizing the Fabric of the Urban Environment: A Case Study of Metropolitan Chicago, Illinois," Lawrence Berkeley National Laboratory, University of California at Berkeley, LBNL-49275.

[17] See, for example: Pomerantz, M., H. Akbari, A. Chen, H. Taha, and A.H. Rosenfeld, "Paving Materials for Heat Island Mitigation," Lawrence Berkeley National Laboratory, LBNL-38074, 1997; Levinson, R. and H. Akbari, "Effects of Composition and Exposure on the Solar Reflectance of Portland Cement Concrete," Lawrence Berkeley National Laboratory, LBNL-48334, December 2001; Pomerantz, M., B. Pon, H. Akbari, and S.C. Chang, "The Effect of Pavements' Temperatures on Air Temperatures in Large Cities," Lawrence Berkeley National Laboratory, LBNL-43442, April 2000; Ting, M., J. Koomey, and M. Pomerantz, "Preliminary Evaluation of the Lifecycle Costs and Market Barriers of Reflective Pavements," Lawrence Berkeley National Laboratory, LBNL-45864, November 2001; and Pomerantz, M., H. Akbari, and J.T. Harvey, "Cooler Reflective Pavements Give Benefits Beyond Energy Savings: Durability and Illumination," Lawrence Berkeley National Laboratory and the Institute of Transportation Studies, University of California at Berkeley, undated.

[18] See for example: Booth, D.B., J. Leavitt, and K. Peterson, "The University of Washington Permeable Pavement Demonstration Project – Background and First-Year Field Results," Center for Urban Water Resources Management, Department of Civil Engineering, University of Washington, undated; Booth, D.B. and J. Leavitt, "Field Evaluation of Permeable Pavement Systems for Improved Stormwater Management," Journal of the American Planning Association, Summer 1999, pp. 314-325; Brown, D.C., "Porous Asphalt Pavement Rescues Parking Lots," Asphalt Contractor, January 1996, pp. 70-72; "Oregon Likes Porous Pavements," Asphalt Contractor, January 1996, pp. 70-76; Brown, D.C., "Porous Pavement," Pit & Quarry, May 1995, p. 26; and Kuennen, T., "Voids Add Value to Pervious Concrete," Better Roads, August 2003.

[19] See for example: International Association for Urban Climate Teaching Resources: The Urban Canopy Layer Heat Island, pp. 16-18; Asaeda, T., Vu Thanh Ca, and A. Wake, "Heat Storage of Pavement and Its Effect on the Lower Atmosphere," Atmospheric Environment, Vol. 30, No. 3, 1996, pp. 413-427; and Asaeda, T. and Vu Thanh Ca, "Characteristics of Permeable Pavement During Hot Summer Weather and Impact on the Thermal Environment," Building and Environment 35, 2000, pp. 363-375.

[20] Ting, M., J. Koomey, and M. Pomerantz, *Preliminary Evaluation of the Lifecycle Costs and Market Barriers of Reflective Pavements*, Energy Analysis Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, November 2001; Pomerantz, M., H. Akbari, and J.T. Harvey, "Durability and Visibility of Cooler Reflective Pavements, Environmental Energy Technologies Division," Lawrence Berkeley National Laboratory, April 2000.

[21] Levinson, R. and H. Akbari, "Effects of Composition and Exposure on the Solar Reflectance of Portland Cement Concrete," Heat Island Group, Lawrence Berkeley National Laboratory, December 2001.

[22] "Slag Cement and Concrete Pavements," *Concrete Pavement Executive Briefs,* American Concrete Pavement Association.

[23] "Slag Cement and the Environment," *Slag Cement in Concrete No. 22,* Slag Cement Association. http://www.slagcement.org/image/123800_c_sU128801_s_i185550/No22_Environmental_Benefits.pdf

[24] "Fly Ash Facts for Highway Engineers," Federal Highway Administration, FHWA-IF-03-019, June 2003.

[25] Marceau, M.L., J. Gajda, and M. VanGeem, "Use of Fly Ash in Concrete; Normal and High Volume Ranges," Portland Cement Association, PCA R&D Serial No. 2604, 2002.

[26] Shell, S., "Better Concrete, Cooler World," *Engineering News Record*, p. 57, August 9, 1999.

[27] 40 CFR Part 247: Comprehensive Guideline for Procurement of Products Containing Recovered Materials; Final Rule. In Federal Register, May 1, 1995, pp. 21369-21376.

[28] ISG Resources, Inc., "Performance Building Materials from Coal Combustion Products: Technical Overview."

[29] Ultra-Thin Whitetopping, *Concrete Information*, American Concrete Paving Association.

[30] A partial list of whitetopping projects throughout the United States is given in *Whitetopping – State-of-the-Practice*, Engineering Bulletin, American Concrete Pavement Association. A partial list of UTW projects throughout the United States is given in *Ultra-Thin Whitetopping*, Concrete Information, American Concrete Pavement Association.

[31] Geoffroy, D.N., P.E., *Cost-Effective Preventive Pavement Maintenance*, National Cooperative Highway Research Program, Synthesis of Highway Practice 223, 1996.

[32] Personal communication with O'Leary, B., Prime Materials and Supply Corp., Houston, Texas.

[33] Personal communication with Smith, R., Texas Transportation Institute, Texas A&M University.

[34] Herman, L.A., "Analysis of Strategies to Control Traffic Noise at the Source: Implications for Policy-Makers," Transportation Research Record 1626, 1998, pp. 41-48.

[35] See, for example, the following: "Oregon Likes Porous Pavements," *Asphalt Contractor*, January 1996, pp. 72-76; "Porous Asphalt Pavement Rescues Parking Lots," Asphalt Contractor, January 1996, pp. 71-72.

[36] E-mail from Raine, W., Texas Department of Transportation, to Wong, E., Environmental Protection Agency, March 2003.

[37] Portland Cement Pervious Association (PCPA), *Standards and Recommendations for Design Criteria, Testing, Inspections, Certifications, and Specifications*, 2003.

[38] See, for example, the following sources: "NEMO: Non-point Education for Municipal Officials: Reducing Runoff," University of Connecticut, http://nemo.uconn.edu/reducing_runoff/questions.htm#6; http://www.gcpa.org/pervious_q&a.htm; http://www.americantrails.org/resources/trailbuilding/PermPavers.PDF.

[39] Booth, D.B., J. Leavitt, and K. Peterson, "The University of Washington Permeable Pavement Demonstration Project: Background and First-Year Results," Center for Urban Water Resources Management, Department of Civil Engineering, University of Washington, undated.

[40] See product literature from AsphaColor Corporation at www.asphacolor.com; also from www.btinternet.com.

[41] Golden, J.S., "A Sustainable Systems Approach to the Hysteresis Lag Effect of Surface Materials & Urban Heat Islands," Arizona State University, Tempe, Arizona, p. 2.

[42] Environmental Protection Agency, 2003. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001.* EPA 430R03004.

[43] Portland Cement Association, 2004. "2000 Apparent Use of Cement by Market." http://www.cement.org/market/.

[44] Pew Center on Global Climate Change, 2003. "Innovative Policy Solutions to Global Climate Change In Brief, Number 6: Taking Climate Change into Account in U.S. Transportation." http://www.pewclimate.org/docUploads/ustransp%5Fbrief%2Epdf.

[45] "Slag Cement and the Environment," *Slag Cement in Concrete No. 22,* Slag Cement Association. http://www.slagcement.org/image/123800_c_sU128801_s_i185550/No22_Environmental_Benefits.pdf

[46] Federal Highway Administration, 2003. *Fly Ash Facts for Highway Engineers: Fourth Edition*. Washington, D.C.: FHWA-1F-03-019, June.

[47] Environmental Protection Agency, 1995. *Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources.* http://www.epa.gov/ttn/chief/ap42/.

[48] April 2005. Personal communication with Salman, D., Office of Air Quality Planning and Standards, Environmental Protection Agency.

[49] September 2003. Personal communication with Worthington, B., Bureau of Highways, Chicago Department of Transportation.

[50] October 2003. Personal communication with Khan, W., D.C. Department of Transportation. While others also cite the use of carbon black for aesthetic purposes (e.g., its use to make slurry seals blacker in color: California Pavement Maintenance Company, "Pavement Maintenance – Slurry Seal: How Slurry Seal is Made" http://www.cpmamerica.com/slurry_seal.htm), the material also benefits pavement performance in substantive ways; e.g., to stiffen the asphalt mastic for increased durability in certain types of pavements (see Washington State Department of Transportation, "Tech Notes: Stone Matrix Asphalt," September 2000. http://www.wsdot.wa.gov/biz/mats/pavement/SMA%20Tech%20Note.pdf) and to resist aging (Texas Department of Transportation, "FHWA Priority Technology Project (PTP): Crumb Rubber Hot Mix in Odessa," 2004, http://www.dot.state.tx.us/GSD/recycle/projects.htm); (All States Asphalt, Inc., "Asphalt-Rubber," http://www.allstatesasphalt.com/nf-sv-6.htm).

[51] September 2003. Personal communication with Chavez, S., (Vice-President) and Inser, G., (Atlanta City Manager) of the Parking Company of America.

[52] Ibid.

[53] Stidger, R.W., "New Practices for Managing Pavement Life," *Better Roads*, April 2002; Kuennen, T., "Voids Add Value To Pervious Concrete," *Better Roads*, August 2003; and Means, R.S., *Heavy Construction Cost Data*, 2004.

[54] Geoffroy, D.N., P.E., "Cost-Effective Preventive Pavement Maintenance," National Cooperative Highway Research Program, Synthesis of Highway Practice 223, National Academy Press, 1996.

[55] Houston Advanced Research Center (HARC), "Cool Houston! A Plan for Cooling the Region," July 2004.

[56] Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring; Fact Sheet – Porous Pavements, www.fhwa.dot.gov/environment/ultraurb/3fs15.htm.

[57] Asphalt Education Partnership, 2004. "Common Myths About Asphalt." http://www.beyondroads.com/index.cfm?fuseaction=page&filename=commonMyths.html.

[58] September 2003. Personal communication with Worthington, B., Bureau of Highways, Chicago Department of Transportation.

[59] September 2003. Personal communication with Hyde, S., City of Winston-Salem, North Carolina.

[60] "Beating the Heat: Mitigating Thermal Impacts," *EPA Nonpoint Source News-Notes*, September 2003, Issue #72, pp. 23-26.

[61] September 2003. Personal communication with Rabun, J.T., Pavement Engineer, Georgia Department of Transportation.

[62] Environmental Protection Agency, "Incorporating Emerging and Voluntary Measures in a State Implementation Plan (SIP)," Office of Air and Radiation, September 2004. http://www.epa.gov/ttn/oarpg/t1/memoranda/evm_ievm_g.pdf.

[63] Federal Highway Administration Memorandum, "INFORMATION: Highway Traffic Noise – Guidance on Quiet Pavement Pilot Programs and Tire/Pavement Noise Research," from Shrouds, J., Director, Office of Natural and Human Environment, January 19, 2005. http://www.fhwa.dot.gov/environment/noise/qpppmem.htm.

[64] Hun-Dorris, T., "Advances in Porous Pavement," *Stormwater*, March/April 2005. http://www.stormh2o.com/sw_0503_advances.html.

[65] Atlanta Cool Communities, "Pervious Pavements for a More Livable Environment," http://www.coolcommunities.org/cool_pavements.htm.

[66] Brown, Dan, "Thinking Green with Porous Asphalt," *Hot Mix Asphalt Technology (HMAT),* May/June 2003, pp. 14 – 17.

[67] Environmental Protection Agency, "Asphalt Alley Reconstruction," http://www.epa.gov/heatisland/pilot/chic_activities.html#7.

[68] Arizona Department of Transportation (ADOT), "Quiet Pavement Pilot Program," April 16, 2003. http://www.fhwa.dot.gov/environment/noise/qpppadot.htm.

[69] Personal communication with Merriman, K., City of Burlington, January 2004.

[70] The White House, "Pennsylvania Avenue Project," http://www.whitehouse.gov/pennproject/.

[71] U.S. Code Title 23, Part 450, Sections 214 and 322.

[72] For more information on LEED, see http://www.usgbc.org/leed/leed_main.asp.

[73] Houston Advanced Research Center (HARC), Cool Houston! A Plan for Cooling the Region, July 2004.

[74] More information can be found on the program's web site at http://www.coolcommunities.org.

[75] Golden, J.S., "A Sustainable Systems Approach to the Hysteresis Lag Effect of Surface Materials & Urban Heat Islands," Arizona State University, Tempe, Arizona, undated. See also www.urbanSMART.org and www.urbanheat.org.

Appendix A

Engaging MPOs and Other Organizations

A. Engaging MPOs and Other Organizations

Interviews were conducted with several MPOs and other organizations to assess their views on cool pavements and their willingness to participate in "spreading the word" and implementation. Discussions were held with representatives of the following groups:

- Three MPOs: the Maricopa Association of Governments (MAG) representing the Phoenix, Arizona, region; the South East Michigan Council of Governments (SEMCOG), representing the seven counties in and around the City of Detroit; and the Tri-County Regional Planning Commission (Tri-County), representing the three counties of Ingham, Clinton, and Eaton in Central Michigan.[1]
- The director of the national Association of Metropolitan Planning Organizations (AMPO).[1]
- A representative of the Houston Advanced Research Center (HARC), who recently completed the "Cool Houston!" plan, worked on heat island issues with the Dallas-Fort Worth MPO, and conducted workshops with the Austin and San Antonio Councils of Government (COGs).[1]
- A representative of the Metropolitan Partnership for Energy, a non-profit group that works with the City of San Antonio and the Alamo Area COG.[1]

These interviews indicated the following:

- While all of these individuals were familiar with environmental initiatives such as use of porous pavements to improve groundwater quality, the level of knowledge of cool pavements and heat islands varied, depending upon the agency's involvement with this technique or with related topics such as environmental impacts of land use. Even when there was no prior awareness, however, individuals were able to offer opinions on a cool pavement initiative once the idea was explained to them.
- The MPO representatives stated that, to their knowledge, cool pavement aspects are not considered in pavement project development or pavement selection processes within their regions. Other factors such as historical precedent and initial and life-cycle costs are the main considerations.
- All interviewees noted that cool pavements would receive greater attention if they helped regions to meet air quality goals or improve water quality. Air quality tended to be emphasized by the MPOs, perhaps because air quality and transportation analyses are typically done within the same group of the MPO organization.

- Most of the interviewees emphasized that the ability to leverage existing monies (e.g., for air quality, water quality, system enhancement, etc.) for use on cool pavements is critical to their implementation. There is no additional money available to fund cool pavements as a separate program, so incentives to apply cool paving techniques to help meet air quality, water quality, or other policy goals is needed.
- One MPO suggested other contexts in which cool pavements could be considered; e.g., in ongoing discussions of the impact of pavement selection on land use decisions, site design, urban street design standards (the Institute of Transportation Engineers (ITE) is now developing a new local street guide), context-sensitive design concepts, the American Planning Association's (APA) shared-parking-management concepts, and other Smart Growth initiatives. Again, the MPO could play an active role in helping to promote cool pavements if there were a clear linkage to Federally funded programs. If there were a solid connection between cool pavements and the mitigation of environmental issues, the concept of "pavement type" could become a routine checklist item that an agency would need to satisfy for NEPA approval of projects.
- The MPOs and AMPO were willing to receive informational articles on cool pavements for the benefit of their members. Some indicated their willingness to participate in a workshop discussion if sufficient interest developed among their members.

These findings reinforce the value of developing an interest in cool pavements at a national level with the FHWA, AASHTO, AMPO, Transportation Research Board (TRB)/NCHRP, and other groups. For instance, the FHWA and key AASHTO committees could help to secure eligibility for Federal funding of cool pavements that can be applied to meet other, existing program goals (e.g., air or water quality, safety, highway enhancements, etc.). Federal backing of cool pavements is critical to MPO engagement of the issue with their local constituents.

Cool pavement is a road surface that uses additives to reflect solar radiation unlike conventional dark pavement.Â The EPA reports "that if pavement reflectance throughout a city were increased from 10 to 35 percent, the air temperature could potentially be reduced by 1Â°F (0.6Â°C)."[2] Existing dark pavement can be altered to increase albedo through whitetopping or by adding reflective coats and seals. Evaluation of cool pavement strategies for mitigating heat island and improving outdoor thermal environment. Dissertation, University of California at Davis.Google Scholar. Li, H., Harvey, J., Holland, T., & Kayhanjan.Â Cool pavements. Reducing urban heat islands: compendium of strategies. Washington, DC: EPA.Google Scholar.