Sustainable Pavement Solutions for O'ahu

An Exploration into the Use of Reclaimed Asphalt Pavement (RAP),
Warm Mix Asphalt (WMA) and other Sustainable Strategies
for O'ahu's Hot Mix Asphalt (HMA) Pavements

Warm mix asphalt
paved on Farrington Highway for HDOT, 5 October 2006

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Executive Summary

This report was prepared at the request of the Hawai'i Community Foundation and for the purpose of exploring and recommending sustainable solutions for the hot mix asphalt (HMA) pavement industry on O'ahu. Principal findings are as follows:

The O'ahu Hot Mix Asphalt (HMA) Industry

About 750,000 tons of HMA will be produced on O'ahu in 2010, primarily by two contractors: Grace Pacific Corp. (70%) and Jas. W. Glover, Ltd. (30%). The majority of work on O'ahu is for the City & County of Honolulu (60%), HDOT (15%), the military (15%) and others (10%). This can change from year-to-year based on individual agency funding and contracting.

Reclaimed Asphalt Pavement (RAP)

- About 100,000 tons of RAP will be used in new HMA mixtures on O'ahu in 2010
- Current RAP inventory in stockpiles is around 800,000 tons and growing
- Update the 1986 City & County of Honolulu specifications and make them consistent with HDOT specifications
- Allow the use of RAP in unbound aggregate base layers up to 50%, which is consistent with UH research findings.

Warm Mix Asphalt (WMA)

- Implement a permissive WMA specification for HDOT and Honolulu.
- Equip all Hawai'i (and O'ahu) HMA plants with WMA technology. Likely this means the widespread adoption of plant foaming technologies.
- Advertise Hawai'i as the first 100% WMA state in the U.S.

Other Sustainable Options for HMA on O'ahu

- **Use local materials**. Especially avoid importing aggregate from long distances. The energy use and CO_2 emissions associated with an HMA pavement constructed using aggregate from British Columbia is *4-5 times more* than a pavement constructed using local aggregate.
- **Rescind the mandate to include glass cullet in HMA**. Its impact on HMA quality is neutral to slightly negative and its highest and best use is in the making of glass.
- **Develop and use stone matrix asphalt (SMA), a long-lasting HMA surfacing**. HDOT paved a test section of SMA in 2004 but nothing has been paved since.
- **Adopt a standard accounting practice that accurately reflects all sustainability efforts put into O'ahu roadways**. A rating system like Greenroads could provide a means of (1) quantifying what is being done, (2) setting goals for improvement, and (3) effectively communicating sustainability efforts to the public and their benefits.

Potential Impacts of Sustainability Options for O'ahu

- In 2010 O'ahu HMA paving will use about 465 TJ (terrajoules) of energy and produce about 50,000 tonnes (metric tons) of greenhouse gases. This is equivalent to the energy use and greenhouse gas output for all households in Kailua town (pop. 36,000).

- Figure 1 shows a general estimate of the reduction in energy use associated with the sustainable solutions investigated in this report. Greenhouse gas reductions are similar.

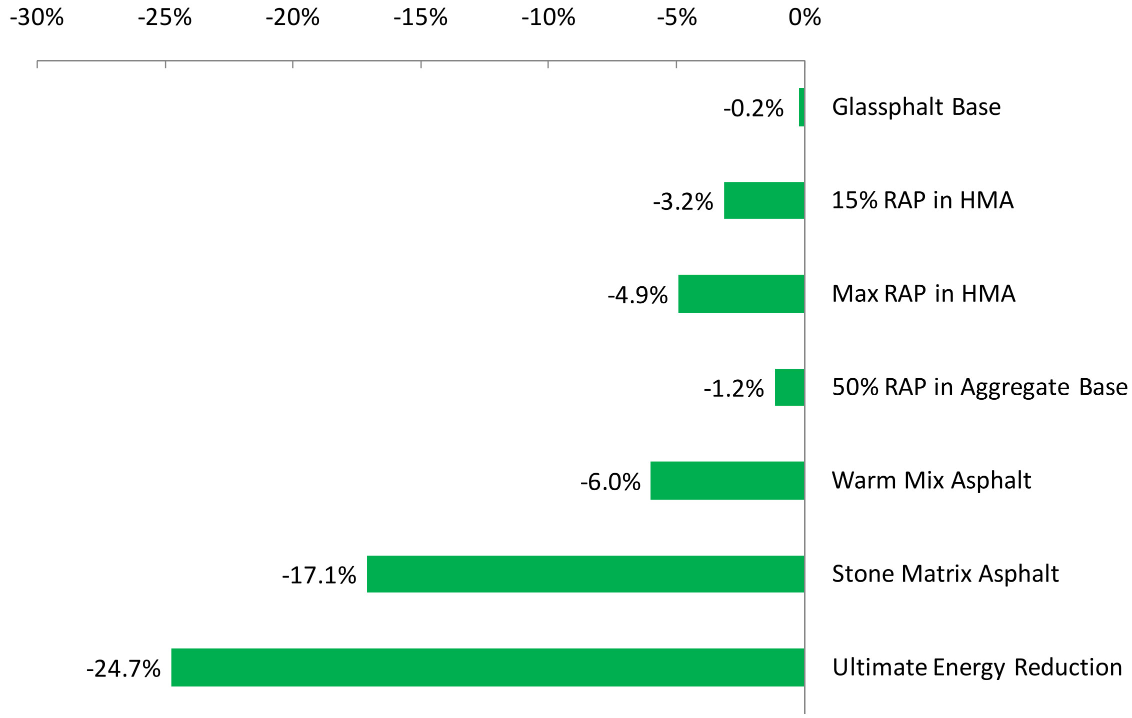

Figure 1. Average yearly energy reduction for HMA paving on O'ahu when compared to the baseline "all virgin materials" option. "Ultimate Energy Reduction" is a combination of these strategies: SMA surface course, 40% RAP in HMA base course, 50% RAP in aggregate base course and WMA used in all instances.

It is clear that the sustainable solutions examined in this report have significantly varying impacts in energy use and greenhouse gas emissions. Decisions regarding which ones to pursue should consider this. Current practice is most nearly reflected by the "15% RAP in HMA" option in Figure 1.

Sustainability Plan

There are many options for making HMA pavements more sustainable in the long-run; far more than can reasonably be implemented given Hawai'i's isolated location and limited resources. Given this, a coherent strategy to evaluate options and implementing a limited number of the most promising ones would be beneficial. This plan could, as a minimum, include:

- A written strategy for making pavements more sustainable in the State of Hawai'i.
- Identified metrics that will best indicate the extent to which this plan is being executed.
- Clearly defined goals and desired end results based on key metrics.
- A means to update and maintain the plan current and in compliance with higher-level plans and directives.

1 Purpose and Scope of Report

This report was prepared at the request of the Hawai'i Community Foundation and for the purpose of exploring and recommending sustainable solutions for the hot mix asphalt (HMA) pavement industry on O'ahu. The impetus for the report was a Yale University Center for Industrial Ecology report titled, *Linking Waste and Material Flows on the Island of Oahu, Hawai'i: The Search for Sustainable Solutions* (2009). The Yale report identified "asphalt" as one area of potential opportunity to improve the amount of material recycled. This report explores that issue and also takes the opportunity to identify other potential sustainable solutions that could be applied to the HMA pavement industry. Note that this report is specific to the Island of O'ahu but many, if not all, the recommendations are relevant throughout the State of Hawai'i.

2 Sustainability Defined

Any document dealing with "sustainability" should precisely define the term. This report defines "sustainability" as *a system characteristic that reflects the system's capacity to support natural laws and human values*. "Natural laws" refers to three basic principles that must be upheld to maintain earth's ecosystem as discussed by Robért (2000). These are summarized:

1. Do not extract substances from the earth at a faster pace than their slow redeposit and reintegration into the earth.
2. Do not produce substances at a faster pace than they can be broken down and integrated into nature near its current equilibrium.
3. Do not degrade ecosystems because our health and prosperity depend on their proper functioning.

"Human values" refers to equity and economy. Equity is interpreted as a primarily human concept of meeting nine fundamental human needs: subsistence, protection, affection, understanding, participation, leisure, creation, identity and freedom (Max-Neef et al. 1991). Economy is broadly interpreted as management of human, manufactured, natural and financial capital (Hawken et al. 1999). Thus, by this definition economy refers to project finance but it also refers to items such as forest resources management and carbon cap and-trade schemes.

In total, this definition contains the key elements of *ecology*, *equity* and *economy* and is essentially consistent but more actionable on a project scale than the often quoted United Nations 1987 Brundtland Commission report excerpt: "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (A/RES/42/187). It is also compatible with the Millennium Ecosystem Assessment (2005).

3 The HMA Industry on O'ahu

The HMA industry on O'ahu largely consists of three owner agencies (Hawai'i DOT, City & County of Honolulu and the military) and two producers (Grace Pacific Corp. and Jas. W. Glover, Ltd.). Some smaller contractors place HMA but still purchase the material from Grace or Glover.

Table 1 provides a snapshot of the HMA industry on O'ahu for 2010 This should not be taken as a yearly average over time because amounts vary from year-to-year based on government funding levels and work actually put out for bid. Nonetheless, the statistics for 2010 provide a reasonable estimate of a year of HMA work on O'ahu. Appendix A contains a brief background on HMA for more information on processes and terms.

Table 1. Approximate HMA Industry Statistics for 2010

Item	Amount[1]
Hawai'i HMA Market Size:	1.2 million tons for 2010 (approximate)
O'ahu HMA Market	
Total Size:	750,000 tons (approximate) or about 60% of Hawai'i total
Distribution by Producer: (who makes the HMA)	70% Grace Pacific Corp. 30% Jas. W. Glover, Ltd.
Distribution by Owner:	60% City & County of Honolulu 15% HDOT 15% Military 10% Private/Other
Distribution by Job Type:	85% Roads and Streets 15% Airfields, parking lots and other
Distribution by Thickness:	75% thin overlays (1-2 inches thick total) 25% thicker reconstruction (3-15 inches thick total)
RAP[2] on O'ahu	Unknown tonnage generated yearly About 100,000 tons used in new HMA material[3] About 800,000 tons of RAP in stockpiles[4]

Notes:
1. Percentages are based on tons placed.
2. RAP = Reclaimed Asphalt Pavement (common term for recycled HMA)
3. The rough amount of RAP that will be incorporated into new HMA in 2010
4. The rough amount or RAP existing in stockpiles on O'ahu as of October 2010. According to Grace Pacific and Jas. W. Glover reports, these stockpiles are growing in size indicating that the RAP usage rate is below the RAP generation rate.

3.1 Sources and Disposal of Paving Materials

Asphalt cement source. Currently, O'ahu gets the bulk of its asphalt cement from Asphalt Hawai'i, a joint venture between Jas. W. Glover and Grace Pacific. Asphalt Hawai'i buys asphalt cement on the open market and is currently getting it from Irving Oil, a refinery located in New Brunswick, Canada (the actual crude oil comes from Saudi Arabia). This joint venture was formed based on the following events: (1) one of the two previous asphalt cement refiners on O'ahu (Chevron) announced they would stop producing asphalt cement, and (2) the remaining refiner (Tesoro) could not meet demand. These events led to O'ahu to effectively running out of asphalt cement in 2006 and essentially halting most pavement construction on the island. To ensure a reliable supply, Jas. W. Glover and Grace Pacific entered into a joint venture to procure their own asphalt cement. While procuring asphalt cement from nearly 8,000 miles away rather than locally may seem extreme, the actual raw material (crude oil) is likely to come from afar in both instances anyway. Therefore, what results is really just a shift in who bears the burden of transport from source to refiner and not a huge added transportation cost. In late 2010 Grace Pacific acquired Mid Pac Petroleum; however this is not likely to have an impact on asphalt supply in Hawai'i or on O'ahu.

Aggregate sources. Larger aggregate sizes are sourced from O'ahu quarries while smaller aggregate sizes (sand) are generally imported from Maui and British Columbia. Sand is imported because local sand tends to be of low quality for use in HMA. For a period of time larger aggregate was also imported to O'ahu because of delays in permitting Grace Pacific Corp.'s Makakilo quarry expansion. The permitting process began in 2005 but before the permit was approved in 2008, the existing permitted quarry area was exhausted and Grace Pacific began importing aggregate from Texada Island, British Columbia by barge. With the new permit, Makakilo can now again produce aggregate and the importation of aggregate from British Columbia has stopped.

HMA sources and disposition. The HMA for paving on O'ahu is produced entirely on O'ahu at one of the three island plants. A vast majority of old HMA (call "reclaimed asphalt pavement" or RAP for short) is recycled on O'ahu with almost all of it going back to the three island plants to be used as RAP. The Yale report cites the PVT landfill in Nanakuli as estimating 8% of their 200,000 tons of construction and demolition (C&D) waste to be HMA (this is about 16,000 tons). Although unverified, this material is likely to come from local contractors removing small sections of pavement in non-paving contracts. Paving contractors rarely landfill RAP since it has real value to them; often upwards of $30/ton. Because of this value, the idea of public ownership of RAP has, from time-to-time, come up in the U.S. and elsewhere. Typically, this idea can be viewed as more trouble than it is worth (e.g., administrative and storage costs in excess of value). However, for some organizations it is encouraged. For instance, the Unified Facilities Criteria (UFC) Standard Practice for Pavement Recycling (UFC 3-250-07) states that recycled material (RAP and recycled aggregate) should be stockpiled for use on other Government projects and that if ownership is transferred to the contractor, credit should be given to the Government for its value. It does not specify how such credit is to be given. Ultimately, the reasoning for contractor ownership of RAP is that most public agencies are not equipped to handle the logistics and processing of this material (i.e., transport, storage, crushing and delivery). In most cases, creating the logistics infrastructure for RAP ownership would cost more than it would save. Contractors, conversely, already have such infrastructure in place so the marginal cost for RAP logistics is comparatively small.

3.2 Hawai'i Asphalt Paving Industry (HAPI)

The Hawai'i Asphalt Paving Industry (HAPI) is the state industry trade group. HAPI generally represents contractor and producer points-of-view. The author, Steve Muench, has worked informally with HAPI since 2002 and has delivered about 10 of seminars that they have sponsored. Grace Pacific and Jas. W. Glover are the two largest contributing members to HAPI. HAPI opinion is cited in this report when an industry perspective needs to be included.

4 Use of Reclaimed Asphalt Pavement (RAP) in HMA on O’ahu

Reclaimed asphalt pavement (RAP) is commonly used in HMA mixtures on O’ahu. The use of RAP is governed by owner specifications. This section reviews the generation of RAP, specifications, the overall amount and quality of RAP available for use on O’ahu, and the potential for O’ahu to use more RAP in pavement structures.

4.1 RAP Generation and Disposition

RAP is recycled HMA. The bulk of it is generated by cold-planing off the surface of an existing pavement (Figure 2). Typically, this material (in the form of small 2-inch or less chunks) becomes the property of the contractor doing the work and is transported to a HMA plant or quarry where it is stored in a temporary stockpile for future use. RAP is usually screened and crushed before being included as a component in new HMA. RAP can also be blended with virgin aggregate to be used as a base course, however this application is not the highest and best use because it does not take advantage of the asphalt cement present in the RAP. Therefore, contractors generally prefer to use RAP as a component in new HMA but will also use it as a substitute for unbound aggregate if economics dictate. Using RAP in any capacity allows the contractor to reduce the amount of virgin (new) materials by an equal amount, which can save the contractor money. As a result, RAP is generally viewed as a commodity and is not discarded to landfill without careful thought. The HMA industry often touts RAP as one of, if not the most, recycled materials in the U.S. One estimate, that is almost always quoted, states that 80% of HMA is recycled (Bloomquist et al. 1993).

Figure 2. Cold-planing off about 4 inches of old HMA in the Manoa area in 2003.

4.2 Specifications

Several key specifying agencies generally control the amount of RAP allowed to be used. HDOT, Honolulu, FAA and military standard specifications are briefly discussed here.

HDOT. The current specification, dated 2005, and special provisions allow the following amounts of RAP:

- 20% in "hot mix asphalt (HMA) pavement" – usually used as the surface course (generally the top two inches of a pavement structure.
- 40% in "hot mix asphalt base (HMAB)" – usually used as the base course. The specification actually allows 30% for batch plants and 40% for drum mix plants, however there are currently no batch plants on O'ahu.
- 20% in "hot mix glassphalt base (HMGB)" – required to be used as base material in lieu of HMAB if (1) glass cullet is available, and (2) the market price is equal to or less than aggregate. HMGB also includes 10% glass cullet as an aggregate substitute.

Honolulu. The current specification, dated 1986, does not allow the use of RAP in HMA. However, special provisions can, and typically are, added to allow 20% RAP in the surface course and 40% RAP in the base course similar to HDOT. Overall, RAP use is inconsistent through-out the City and County of Honolulu: sometimes the RAP special provision can be left out, purposefully or not, which causes some confusion amongst contractors bidding Honolulu work and can result in Honolulu jobs being paved with 100% virgin mix (no RAP) even when RAP would be an appropriate addition. The core issue is that the current standard specifications are now over 24 years old and need to be updated. Based on their comments, HAPI and Honolulu both favor an update. HAPI favors an update that would closely replicate HDOT specifications where appropriate.

Federal Aviation Administration (FAA). While HDOT administers Hawai'i airports, specifications are largely dictated by the FAA. FAA specifications (found as FAA Advisory Circular AC 150/5370-10), issued in 2009, do not allow RAP in surface mixes (usually the top 2-3 inches) except for shoulders, but allows 30% in other mixtures.

Military. Unified Facilities Guide Specification (UFGS) Section 32 12 15, dated May 2010, does not allow RAP in surface mixes (usually the top 2-3 inches) except for shoulders, but allows 30% in other mixtures. This is the same as FAA specification.

4.3 RAP on O'ahu

The amount of available RAP on O'ahu is large (800,000 tons) and growing in size. It is difficult to estimate the total quantity of RAP generated on O'ahu each year or in any specific year since RAP is typically inventoried only as it is used in new HMA and not as it is generated. For 2010, its use in new HMA on O'ahu is on the order of about 100,000 tons (based on estimates from Grace and Glover). Newcomb and Jones (2008) report that actual RAP use as a percentage in Hawai'i is about 15% for surface courses and 20% for base courses. It is important to note that there are two main RAP material streams on O'ahu:

- **Pure or "Clean" RAP**. Comes directly from milling up old HMA pavement. Contractors usually store this RAP on site at the HMA plant and use it when allowed. Current industry estimates are on the order of 400,000 tons of clean RAP stockpiled on O'ahu.

- **Co-mingled RAP**. Comes from demolition and milling jobs where the old HMA pavement is combined in the demolition process with underlying material such as unbound aggregate and soil. This often occurs when a contractor removes a depth of material that extends beyond the existing pavement depth using only one cold-planer pass. An option, which would likely increase cost, would be to mill the clean RAP in one pass and then return and mill the co-mingled material in a second pass. This increase in construction cost may, however, be offset by the additional clean RAP available for use. Current industry estimates are on the order of 400,000 tons of co-mingled RAP stockpiled on O'ahu.

Estimates from Grace and Glover suggest that clean RAP is used reasonably but with growing inventory suggesting there is room for greater use. Co-mingled RAP is only used infrequently since the non-RAP materials (aggregate and soil) are not allowed to be included (and should not be included) in new HMA. Therefore, stockpiles of co-mingled RAP are growing at a greater rate because it cannot be effectively used.

4.4 Can O'ahu Use More RAP?

O'ahu can use more RAP that it currently does. Nationwide, RAP use is on the increase. A recent article (Newcomb and Jones 2010) surveying U.S. RAP use (the survey was by Cecil Jones, North Carolina DOT) reported 27 state DOTs that have increased their allowable RAP percentages since 2007 (Hawai'i is one of them), 44 states that permit more than 25% RAP in HMA mixtures (Hawai'i is one of them), and 24 state DOTs that actually use more than 20% RAP in HMA layers (Hawai'i is one of them). RAP can also be included in other non-HMA applications such as backfills and embankments (Ooi et al. 2010). For example, a 2007/2008 Army project on Drum Road (connects Schofield Barracks with the North Shore) used 50% RAP in the sub-base material only (not a hard-surface pavement).

RAP inventory is growing. Current industry sentiment is that allowable RAP percentages in HMA mixtures in Hawai'i specifications are acceptable. However, RAP inventory is growing. A reasonable solution would be to increase RAP content allowed in surface courses to 25% and to allow RAP to be included in unbound aggregate base courses at 50% so long as it is fully mixed at a central processing facility (see Ooi et al. 2010 and McGarrah and Matsumoto 2010, included in the Appendixes). Many states have had success with the former and currently allow the latter. The overall mindset should shift from the amount of RAP in HMA to the amount of RAP in the entire pavement structure, which would include aggregate base course.

4.5 Issues with Higher RAP Use

Using more RAP can be a rather complex undertaking. Currently, HDOT is sponsoring research at the University of Hawai'i to address technical aspects of this idea (Ooi et al. 2010). Specific issues are:

- **For high RAP HMA (e.g., 30% and above) RAP must be treated in a fundamentally different way**. Current specifications are written to essentially treat RAP as a contaminant in virgin HMA: as long as the fraction or RAP is kept low it can be of relatively poor quality and will not affect mixture performance. However, at higher RAP percentages (e.g., 30% or more) RAP needs to be of higher quality meaning it must be more precisely graded, sorted and stored. This means a greater investment on the contractor's part in RAP crushers, separate storage of different sized stockpiles and better tracking of RAP origin. This investment by the contractor is significant, and will likely not be made until specifying agencies make a similar commitment to using high RAP mixtures and paying for the required infrastructure in the form of a higher price per ton of mix.

- **A practical limit to RAP use in HMA based on plant physics is 50-60%**. In general, RAP is added to a drum mix plant away from the direct heating flame. It is heated to the proper temperature (usually between 300 and 350°F for the entire mix including the RAP) by directly heating the virgin aggregate in the HMA to a much hotter temperature and then letting these aggregate heat the RAP. The more RAP in a mix the less virgin aggregate. Therefore, there is a practical limit to the RAP content of a new HMA mixture at around 50-60%. While higher RAP content mixtures have been successfully made, they generally involved special considerations.
- **A practical limit to RAP used in HMA based on quality control is 30-40%**. At these percentages RAP begins to control mixture qualities and its lack of homogeneity can cause variations in mixture quality that are difficult to control. As a result, contractors will sometimes limit the RAP content of HMAB for HDOT to 30% (even thought 40% is allowed) in order to control HMA mixture quality.
- **To better use RAP at consistently high percentages, the HMA plant needs to be tuned**. At high RAP percentages (30% and above) the ideal configuration of an HMA plant changes. Plant operators must make a decision on how they tune their plant, which usually results in tuning for low to no RAP content that is consistent with current use.
- **Higher percentages of RAP (e.g., above about 25%) in HMA likely require a softer asphalt cement**. Currently, Hawai'i only uses one grade of asphalt cement: PG 64-16. The stiffer aged binder in RAP requires a softer virgin binder as an offset to create a workable mixture. Asphalt Hawai'i is committed to supplying PG 58-28 to the O'ahu market by mid to late 2011. This should help improve high-RAP mixes.
- **RAP in aggregate base course changes its properties**. The draft research report by Ooi et al. (2010) from UH is an excellent summary of material properties and provides outstanding recommendations for using RAP, recycled concrete aggregate (RCA) and recycled glass (RG) in non-HMA layers.

4.6 RAP Recommendations for O'ahu

- Implement results from UH preliminary research findings. In regards to RAP, the report recommends the following: none in untreated permeable base; 50% in untreated base, subbase, backfills and embankment; 100% in non-critical trench backfill and drainage fill. In addition to the UH work, this report includes a literature review on including RAP in aggregate base material. Appendix B contains a sample specification from New Jersey.

- Consider slightly raising the allowable RAP fraction in HMA surface courses. The exact percentage needs to be determined through proper investigation.
- Maintain the allowable RAP fraction in HMA base courses at 40%.
- Update the 1986 Honolulu specifications. Industry sentiment is to closely aligned Honolulu and HDOT specifications. This is a major effort and would likely be the most involved of these recommendations.
- Leave national specifications (FAA and UFGS) unchanged. National specifications will not change based on Hawai'i input alone. Lobbying for changes would not be a productive use of effort.

In all instances of recommended change, the change should only be made through close consultation between HDOT, Honolulu and industry. Such consultation *could* consist of the following general schedule:

- Phase 1: Form a dedicated task force consisting of members from HDOT, Honolulu and industry (perhaps 1 representative for each). This task force would carefully consider the change (and relevant research) and recommend a course of action. An initial few (1 to 3) pilot projects incorporating the change would be built and then reviewed by the task force for performance and possible changes in implementation. The task force issues a report detailing the change and results of the pilot projects.
- Phase 2: The task force would recommend an initial specification to HDOT and Honolulu for use in an additional 1-3 projects. This would test the specification language and use by all parties. Changes could be made based on feedback. Task force issues a report based on the experiences of these projects.
- Phase 3: Change applicable HDOT and Honolulu specifications/procedures based on task force recommendations.

5 Use of Warm Mix Asphalt on O'ahu

This section describes warm mix asphalt (WMA), its previous use in Hawai'i, the experiences of other agencies using WMA, issues with WMA use on O'ahu and recommendations for WMA use on O'ahu.

5.1 Warm Mix Asphalt Defined

WMA is the generic term for any process or additive used that allows the asphalt cement to adequately coat the aggregate material in the HMA manufacturing facility at a temperature significantly less than the asphalt cement manufacturer's recommended temperature. This reduction in temperature, usually on the order of 25-150°F, results in lower fuel consumption and fewer emissions by the HMA plant, better compaction of the HMA mixture and less worker exposure to fumes at the jobsite. Currently, there are over 30 different methods to produce WMA, most of which fall into four major categories:

1. **Plant foaming**. A small device that allows mixing of water and asphalt before injection into the drum is added (Figures 3 and 4). This foams the asphalt upon entry into the drum allowing full aggregate coating at lower temperatures.
2. **Additive foaming**. The same foaming is accomplished by adding a small amount of material to the drum that contains entrapped water. When added the water turns to steam and the same foaming action occurs.
3. **Additive organics**. Adding a wax to the drum that melts at mixing temperatures, effectively creating a lubricant and then solidifies at in-service temperatures providing a beneficial stiffening agent during pavement use.
4. **Chemical surfactants**. Various chemical surfactant packages. Surfactants lower the surface tension of liquids and, in this instance, act as foaming agents.

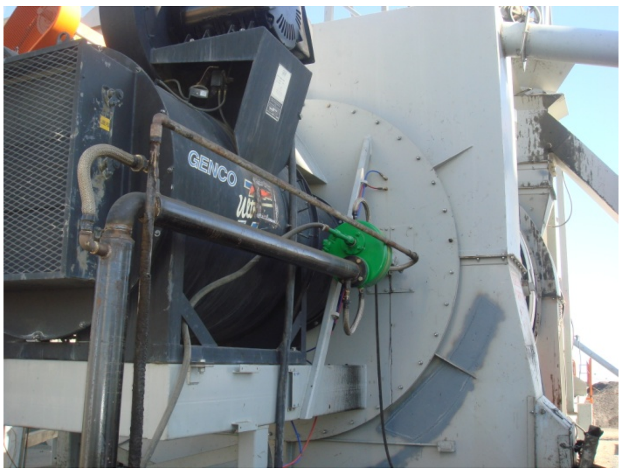

Figure 3. Gencor Green Machine foaming device installed (green in picture).

Figure 4. Gencor Green Machine control box.

In many states there is sentiment in favor of using WMA on a widespread basis. Currently the plant foaming technology looks to be most favored by industry. This is because conversion of existing HMA plants using a WMA plant foaming device is not complex and represents a definable one-time expense that can result in fuel savings in the long-run. Several companies make plant foaming add-on kits and market them in the $50,000 range. They are relatively small, can be installed quickly and use relatively little water (1-2 lbs of water per ton of WMA).

5.2 O'ahu Efforts to Date

In 2006 Grace Pacific paved a portion of Farrington Highway using the Sasobit WMA additive. They successfully lowered the HMA mixing temperature by approximately 50°F without adverse effects. Although not quantified, emissions at the plant appeared to be less, compaction at the site appeared to be equal or better and fumes at the site appeared to be less.

In 2008 there was some sentiment in HDOT and industry to pursue a federal grant to convert all HMA plants in the state to WMA capability using the plant foaming method. This would have made Hawai'i the first all-WMA state in the U.S. Ultimately, this never came to fruition.

5.3 Selected Experiences of other Agencies

Many other agencies in the U.S. and worldwide have experimented with WMA use and a significant portion of them are moving or have moved to allowing WMA use at the discretion of the contractor. While research is still ongoing on the long-term performance of WMA pavements, results to date are almost unanimously positive. Worldwide experience with WMA dates back to the early 1990s in Europe. Some examples of current agency use and experience:

Texas DOT (TxDOT). The foremost agency in WMA use in the U.S. Moved quickly to implementation from test projects and in 2009 paved over 1 million tons of WMA. TxDOT allows WMA on all projects and requires it on some projects. Special Provision 341-020 is used to specify WMA (see Appendix D). TxDOT handles WMA technologies as they would any other product. Technologies must be pre-approved by TxDOT for use (see Appendix E). The current pre-approved list and procedures for approval are here: ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/mpl/wma.pdf. TxDOT has a wealth of experience with WMA and should be consulted of considering adopting WMA.

Washington State DOT (WSDOT). Have used several WMA technologies in a test project capacity. 2010 Standard Specifications allow contractors to use WMA at their discretion as long as the additive/process is approved by the engineer.

City of Seattle. Have used several WMA technologies in a test project capacity. They are moving towards a permissive specification.

The WMA technical working group (TWG), a group of agency and industry experts, published a guide specification in 2008 that can be adopted by specifying agencies (http://www.warmmixasphalt.com/submissions/93_20081209_WMA%20Guide%20Specification%20version%201.07%20Final_WMATWG.pdf). This is also reprinted in Appendix C.

The general trend in WMA seems to be towards agencies having a permissive specification (allows use of pre-approved WMA additives/processes at the contractor's discretion) and contractors installing plant foaming devices. It is the author's view that WMA will be a standard industry method within the next 5-10 years.

5.4 Issues with WMA use on O'ahu

HAPI views WMA use in Hawai'i (and O'ahu) as an all-or-nothing venture. Generally, it is inconvenient (but not impossible) for a HMA plant to switch back-and-forth between HMA and WMA for individual small jobs. Thus, if a plant started producing WMA in the morning it would like to produce it all day long. If so, those requiring non-WMA mixtures would have to go to another plant. If, however, all specifying agencies allow WMA then plants could commit to producing all WMA and this would not be an issue. Additionally, Asphalt Hawai'i is capable of mixing in some WMA additives at the terminal, which would eliminate the need for any special equipment at individual plants. Also, some plants and types of WMA more readily lend themselves to quick switching than others. HAPI also strongly favors a permissive specification that would allow WMA to be used at the contractor's discretion. Of course, such a specification would likely involve a pre-approved product list.

5.5 WMA Recommendations for O'ahu

- Implement a permissive WMA specification for HDOT and Honolulu. This would likely tip the balance in favor of using WMA on most all HDOT and Honolulu projects. Appendix C is a sample specification from the WMA TWG and Appendix D is TxDOT Special Provision 341-020.
- Establish a pre-approved WMA technology list based on the same methods TxDOT uses.
- Equip all Hawai'i (and O'ahu) HMA plants with WMA technology. This likely means adoption of plant foaming technologies.
- Advertise Hawai'i as the first 100% WMA state in the U.S.

As with RAP recommended changes, WMA change should only be made through close consultation between HDOT, Honolulu and industry. The recommended general schedule for RAP could also be used for WMA.

6 Other Sustainable Options for HMA on O'ahu

Beyond RAP and WMA, there are other viable sustainable HMA options for O'ahu.

6.1 Use Local Materials

Use local materials to the extent possible in HMA. Importing aggregate results in an especially high energy and emissions cost that should not be tolerated. Specifying agencies should carefully consider the effects of existing specifications that essentially dictate the import of sand for HMA. These effects should be weighed against the possible negative effects on HMA quality of relaxing those specifications.

6.2 No Glass Cullet in Pavement Materials

The mandate to use glass cullet in HMGB is not practical and should be rescinded. HAPI, HDOT and Honolulu have all expressed this sentiment and are in relative agreement. Reasons are:

1. **Glass cullet is rarely used**. HMGB need only be used if the price of glass cullet is equal to or less than aggregate. This is rarely the case.
2. **Glass cullet can make HMA worse**. Its effect on HMA qualities is generally neutral to slightly negative (West et al. 1993). In rather simplistic terms, the problem is that asphalt does not stick to glass. Therefore, asphalt properties that rely on this "sticking" are generally not as good. Some of this can be overcome using an anti-strip additive but there may still be some negative consequences.
3. **The best use of glass cullet is in making new glass containers**. In a 2003 study, Enviros (an environmental consultant) calculated that recycling glass as a feedstock for new glass saved 315 kg of CO_2 for every tonne of recycled glass, while using glass as an aggregate replacement *required an additional* 2 kg of CO_2 for every tonne of recycled glass. Even though glass must be shipped to North America, sorted and cleaned to be

recycled into new glass containers, the benefits still far outweigh its use in pavement materials.

4. **Glass cullet in HMA limits recycling options**. Glass cullet is not allowed in the surface course of HDOT or Honolulu mixes. This can effectively prevent RAP use at all in the surface course unless the exclusion of glass cullet in the surface course is relaxed. Currently, this exclusion is not always relaxed. What this amounts to is a specification that requires including a waste product in new material that effectively excludes that material from being recycled.

6.3 Develop and Use Stone Matrix Asphalt

Stone matrix asphalt (SMA) is a specialty surface course mixture that was developed some 30 years ago in Europe to combat the effects of studded tire wear and provide a longer-lasting HMA pavement surface. Since then, SMA has been used all over the world and is in regular use in many states. As a premium mix, it tends to cost more initially, but its extended life more than compensates for this initial premium. Using SMA has the potential to reduce the overall amount of paving materials consumed on O'ahu because SMA-surfaced roadways would have to be resurfaced less often. As with most new material ventures, industry requires a commitment from agencies to pave substantial tonnage of the material before they are likely to invest in material supply lines and equipment to support the effort. Otherwise, they stand to lose money. SMA is likely to require a modified asphalt binder, which is not currently supplied on O'ahu.

One trial project to date. HDOT paved an initial trial section of SMA on the Moanalua Freeway in 2004, which appears to be performing adequately. To date, however, no other SMA has been paved on O'ahu roads and development of SMA is not a current priority within HDOT.

7 Impacts of Sustainable Options for O'ahu

So far, sustainable solutions have been discussed without regard to their impact on sustainability. However, impact is an important quality to consider when determining which solutions to pursue given limited resources. This section describes the relative impact of the sustainable solutions previously discussed *in regards to energy and greenhouse gases only*. Ideally, impact addresses all three principles of sustainability (ecology, equity and economy), however in principle this is difficult to do entirely objectively without an agreed upon metric. The issue of a more universal metric and its use is addressed in Section 7.4.

7.1 Method of Quantifying Impacts: Life Cycle Inventory

The Excel-based software program PaLATE (Consortium on Green Design and Manufacturing. 2007), as modified by the University of Washington (UW) was used to evaluate the energy use and CO_2 emissions associated with different sustainable solutions. It must be stressed that the version modified by the University UW (available for free at www.greenroads.us) must be used. It is a complete rebuild of the original version, which had numerous defects rendering it essentially useless. PaLATE uses a method called "life cycle assessment" (LCA) to determine these numbers. The U.S. Environmental Protection Agency (EPA 2010) describes LCA as, "…a technique to assess the environmental aspects and potential impacts associated with a product, process, or service." For this study, a limited life cycle inventory (a compilation of energy and greenhouse gas emissions) is presented for HMA pavements that covers the life of a pavement from the gathering of raw materials up to and including placement of the HMA. It does not cover operational use (i.e., traffic) and end-of-life disposition. Even though results are approximate at best, this limited LCI can provide insight into the relative magnitude of impact each sustainable solution might have.

Assumptions made for this LCI. This LCI makes a number of broad assumptions. Importantly, changes in these assumptions that are less than an order of magnitude (a factor of 10) are not likely to change the general conclusions reached. Assumptions are:

- 50-year analysis period
- 750,000 tons of HMA paved on O'ahu in 2010
- About the same amount of HMA tonnage for each of the next 50 years
- The standard unit analyzed is 1 lane-mile of pavement (1 mile of pavement, 12 ft. wide)
- Pavement structures, materials and tonnages analyzed are as seen in Table 2.

Table 2. Pavement Structures, Materials and Tonnages used in the LCI

Paving Action	Preservation Mill-and-Fill	New or Reconstructed Low-Volume Pavement	New or Reconstructed High-Volume Pavement
Total HMA Tonnage	562,500 (75% of O'ahu total)	112,500 tons (15% of O'ahu total)	75,000 tons (10% of O'ahu total)
Cold Plane Depth	1.5 inches	none	none
Surface Course	1.5 inches	2.0 inches	2.0 inches
HMA Base Course	none	4.0 inches	8.0 inches
Aggregate Base Course	none	6.0 inches	6.0 inches

Note that these are rough assumptions and are not intended to precisely reflect paving practices in a given year. Rather, they are meant to give a broad idea of what is typically done. Sustainable solutions investigated are:

- **All virgin materials**. All materials are new; no recycled materials are used.
- **Glassphalt HMA base**. Recycled glass cutlet is used in place of 10% of the aggregate in the HMA base material.
- **15% RAP in all HMA**. All HMA (surface and base) contains 15% RAP. *Current HDOT and Honolulu practice is closest to this sustainable solution*.
- **Max RAP in all HMA**. HMA surface course contains 20% and HMA base course contains 40% RAP. This is the maximum allowed by current specifications.
- **50% RAP in aggregate base**. Aggregate base contains 50% RAP. This is consistent with Ooi et al. (2010) recommendations.
- **Warm mix asphalt**. All HMA is produced using WMA technology. It is broadly assumed this will result in a 20% reduction in energy used by the HMA plant.

- **Stone matrix asphalt**. SMA is used as the surface course. It is assumed this will result in one fewer overlays over the 50-year analysis period due to SMA's better durability.
- **Ultimate energy reduction**. Uses a SMA surface course with no RAP, 40% RAP in the HMA base, 25% RAP in the aggregate base and WMA. Represents the highest practical energy reduction over virgin material use alone.

7.2 Results

Calculations were made for all sustainable solutions for mill-and-fill, low-volume and high-volume pavement structures. Tables 3 and 4 show example outputs for a low-volume pavement (designated "New or Reconstructed Low-Volume Pavement" in Table 2). Complete calculations and Excel worksheets are available on request.

Table 3. LCI Energy Results for 1 Lane-Mile of Low-Volume Pavement

Option	Initial Construction Energy (TJ)	Mill-and-Fill Rehabs in 50 Years	Mill-and-Fill Energy (TJ)	Total 50-year Energy (TJ)
All virgin materials	1.40	4	0.40	3.00
Glassphalt HMA base	1.38	4	0.40	2.99
15% RAP in all HMA	1.35	4	0.39	2.91
Max RAP in all HMA	1.30	4	0.38	2.84
50% RAP in aggregate base	1.32	4	0.40	2.93
Warm Mix Asphalt	1.36	4	0.37	2.85
Stone matrix asphalt	1.42	3	0.42	2.66
Ultimate energy reduction	1.17	3	0.39	2.33

Note: as an example of how costly non-local materials can be, the same all-virgin materials HMA constructed using aggregate from British Columbia uses about 17.2 TJ over 50 yrs.

Table 4. LCI CO_2e Results for 1 Lane-Mile of Low-Volume Pavement

Option	Initial Construction CO_2e (kg)	Mill-and-Fill Rehabs in 50 Years	Mill-and-Fill CO_2e (kg)	Total 50-year CO_2e (kg)
All virgin materials	295,683	4	30,730	418,603
Glassphalt HMA base	294,848	4	30,730	417,768
15% RAP in all HMA	291,891	4	29,606	410,315
Max RAP in all HMA	287,208	4	29,175	403,908
50% RAP in aggregate base	287,695	4	30,730	410,615
Warm Mix Asphalt	292,978	4	28,692	407,746
Stone matrix asphalt	297,279	3	31,771	392,592
Ultimate energy reduction	275,003	3	29,739	364,220

Note: as an example of how costly non-local materials can be, the same all-virgin materials HMA constructed using aggregate from British Columbia emits about 1,400,000 kg over 50 yrs.

7.3 *Implications for O'ahu*

It is estimated that HMA paving on O'ahu in 2010 will use approximately 465 TJ (terrajoules) of energy and generated 50,000 tonnes (metric tons) of CO_2e (CO_2 equivalent – a measure of total greenhouse gas (GHG) production) for 2010. To put this in perspective, the average U.S. household consumes about 11,000 kWh (0.039 TJ) of energy and produces about 3.08 tonnes of CO_2e in a typical year. This means that HMA paving on O'ahu in 2010 consumed the equivalent of about 12,000 households of energy and emitted the equivalent of 16,000 households of GHG. Given the U.S. Census Bureau's average persons per household of 2.59 this represents the energy and GHG associated with everyone in Kailua (pop. 36,000). Figures 5 and 6 estimate the percentage reduction in energy use and CO_2e that could be achieved on O'ahu for each sustainable solution if fully adopted and implemented. For comparison, a shift to using "max RAP in HMA" saves about 200 households worth of energy and CO_2e, while the "ultimate energy reduction" solution saves about 2,500 households worth of the same.

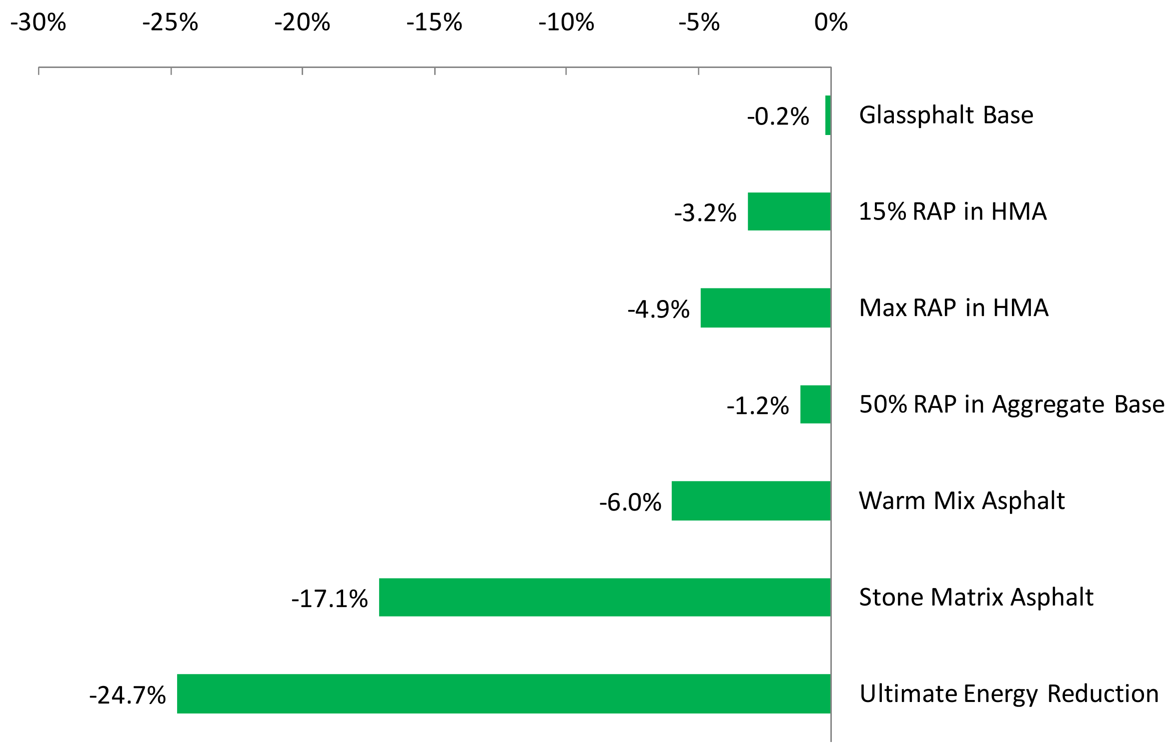

Figure 5. Average yearly energy reduction for HMA paving on O'ahu when compared to the baseline "all virgin materials" option.

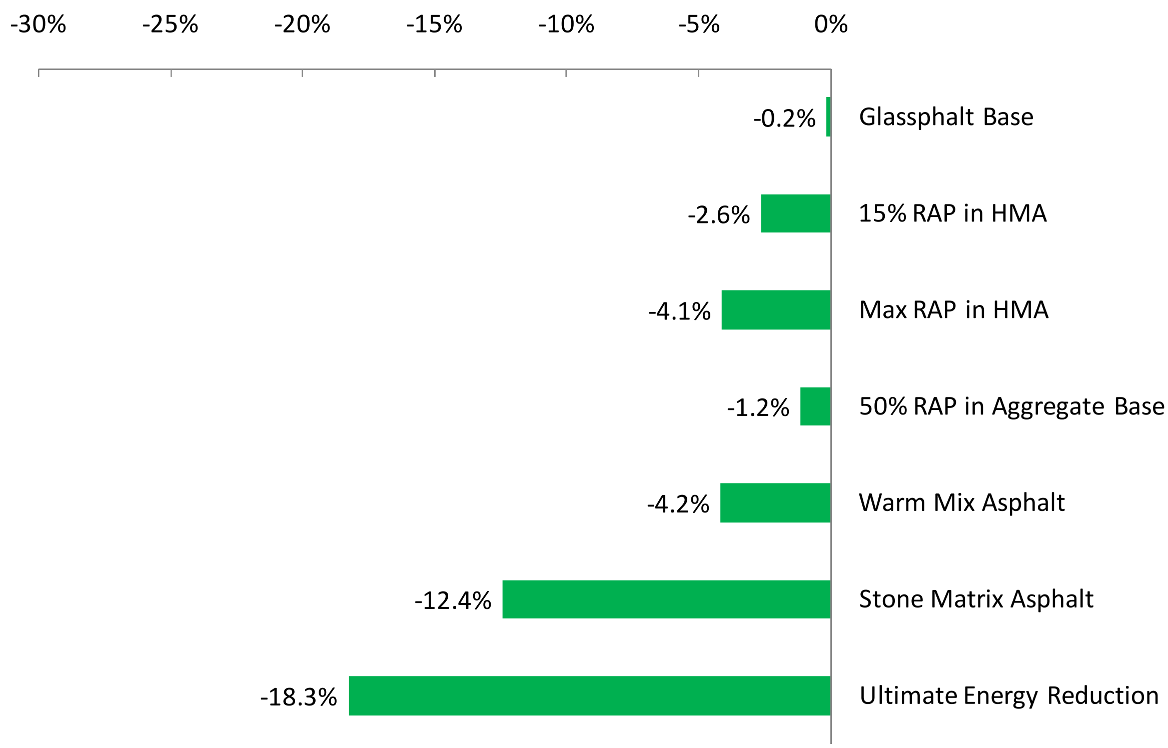

Figure 6. Average yearly CO_2 emissions reduction for HMA paving on O'ahu when compared to the baseline "all virgin materials" option.

Figures 5 and 6 show that in order to make substantial reductions in energy and emissions (on the order of 10% or more) a new paving material must be mastered (SMA) or a combination of several sustainable solutions must be implemented together. Smaller changes that are easier to accomplish (e.g., increasing RAP use or WMA alone) can reduce energy use and CO_2 emissions but not by more than several percentage points over current amounts.

7.4 Considering the Whole System: Greenroads

So far, this sustainability exploration has focused on specific items such as RAP and WMA. While these individual items can have real impact, sustainability is a system characteristic and decisions are best made when considering the whole system. A reasonable system to consider is that of the entire roadway including things like ecological impact, access and mobility, safety, construction, materials, etc. Unfortunately, this can be difficult to do in a consistent way because these items do not have a common science, language or even engineering units. For instance, how does one compare a scenic view with 20% RAP use? In the field of infrastructure, rating systems have evolved as helpful tools in this instance. A rating system, if properly designed and calibrated could be used by owner agencies, designers, contractors and public officials to holistically consider sustainability in a straightforward and understandable manner. This review recommends Greenroads, a rating system developed by the University of Washington (including Steve Muench, the lead author) and CH2M HILL.

About Greenroads. Greenroads is a sustainability performance metric for roadways that awards points for more sustainable practices. A concise listing of Greenroads credits can be found at the end of this Introduction. Fundamentally, Greenroads is a metric that helps quantify the sustainable attributes of a roadway project. This quantification can be used to:

- Define what project attributes contribute to roadway sustainability.
- Provide a sustainability accounting tool for roadway projects.
- Communicate sustainable project attributes to stakeholders.
- Manage and improve roadway sustainability.
- Grant "certification" based on achieving a minimum number of points.

More on Greenroads is available at: www.greenroads.us.

8 Sustainability Plan

Most of the sustainable solutions investigated have either been tried once (e.g., SMA) or are in some stage of investigation for possible adoption (e.g., more RAP, WMA). They are not new nor do they push the boundaries of engineering. In most instances the major impediment to improved sustainability today is human will and organization. Certainly there will be more sustainable technology in the future but there is ample room for improvement now if we are able to effectively harness our current ability and apply it in a systematic and organized manner.

Why a plan can help. Owner agencies on O'ahu are already investigating or have thought about all the sustainable solutions discussed in this report. Thus, the major recommendations of this report are all implementation-based; take action in an organized manner. This may be difficult because this exploration did not uncover any coherent sustainability plan at the local owner-agency level that systematically deals with pavement or HMA. At the highest level, plans do exist: the State has the *Hawai'i 2050 Sustainability Plan* (2008) and Honolulu has the report from the Mayor's Energy & Sustainability Task Force *Working toward the 21st Century Ahupua'a* (2009). However since they are high-level, these plans do not address pavements in particular. Without a general strategy to address sustainability the tendency is to address it in a piecemeal and reactive manner. When something is proposed or a question asked, it is investigated and answered. Especially in light of the small size and limited resources of the Island of O'ahu (for that matter the State of Hawai'i), a pavement sustainability strategy set forth by a combined group of government and industry could lay out specific priority solutions, expected impacts and a timetable for their implementation.

Contents of a sustainability plan. As a starting point, a sustainable pavement statewide strategy could take high-level documents and translate goals and metrics to be applied to pavements. The document should be short, direct and action oriented and should reflect the combined views of government and industry. It should contain a basic plan, metrics for measuring progress and goals related to those metrics. The plan could be reviewed and updated on a recurring basis so that it does not become dated and useless.

9 Recommendations Summary

The following is a short list of the most impactful recommendations from this exploration:

- Update the 1986 City & County of Honolulu Standard Specifications.
- Allow RAP to be included in unbound aggregate base layers up to 50% (Ooi et al. 2010).
- Implement a permissive WMA specification for HDOT and Honolulu.
- Equip all Hawai'i (and O'ahu) HMA plants with WMA technology.
- Advertise Hawai'i as the first 100% WMA state in the U.S.
- Use local materials.
- Do not require glass cullet to be included in roadway materials.
- Develop expertise in and use stone matrix asphalt (SMA) as a surface course.
- Try out and consider adopting the Greenroads sustainability rating system.
- Develop and implement a pavement sustainability plan.

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Appendixes for:

Sustainable Pavement Solutions for O'ahu

An Exploration into the Use of Reclaimed Asphalt Pavement (RAP),
Warm Mix Asphalt (WMA) and other Sustainable Strategies
for O'ahu's Hot Mix Asphalt (HMA) Pavements

Kailua Road Paving
12 August 2008

Steve Muench
with assistance from Denise Muramoto

2 February 2011

Table of Contents

Appendix A: A Brief Overview of Hot Mix Asphalt

Hot mix asphalt (HMA) is a conglomerate material made from asphalt cement, a refined oil product, and crushed rock, or aggregate (Figures 1 and 2). Asphalt essentially serves as the glue that holds the aggregate together. By weight, HMA is about 5% asphalt cement and 95% aggregate. By volume, it is roughly 10% asphalt cement, 85% aggregate and 5% air. HMA is made at a production plant (Figure 3) by heating aggregate and then adding asphalt cement. During construction HMA is hot (typically 300-350°F when made and 175-300°F when placed) and somewhat fluid but then becomes stiff and solid at normal roadway temperatures (below about 150°F). HMA is relatively heavy and cheap on a weight basis, thus it is almost always made locally (i.e., within 50 miles of the construction site) otherwise transportation costs would become unbearably high. HMA is placed by an asphalt paver (Figure 4) and then compacted by one or several rollers. Proper compaction is critical in getting the HMA to last and perform well. A typical HMA pavement consists of a layer or layers of HMA placed on top of a layer or layers of aggregate base material. HMA thicknesses can range from 2-4 inches (for low traffic pavements and parking lots) up to 12-15 inches (for high traffic pavements with lots of heavy trucks). If properly designed and constructed a HMA pavement surface (the top 1-3 inches) must be replaced every 10-20 years but the rest of the structure can remain in place almost indefinitely. Most paved roads in the U.S. (over 90%) and in Hawai'i (over 95%) are surfaced with HMA.

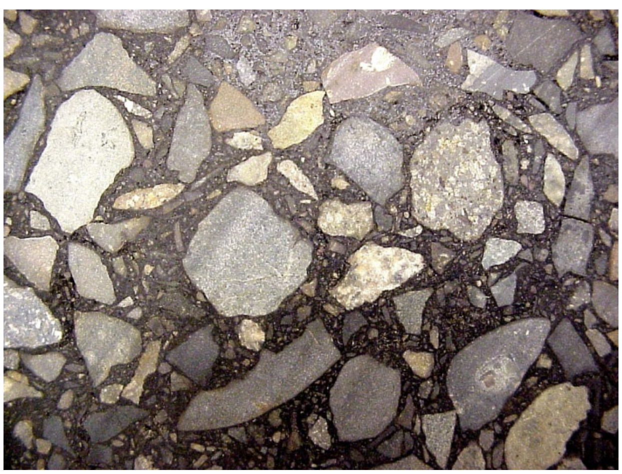

Figure 1. Close-up of hot mix asphalt (HMA).

Figure 2. HMA core taken from Makakilo Drive.

Figure 3. Grace Pacific's Campbell Industrial Park HMA plant when it was still located at their Makakilo quarry (aerial picture from Bing Maps).

Figure 4. HDOT Farrington Highway paving HMA paver in October 2006.

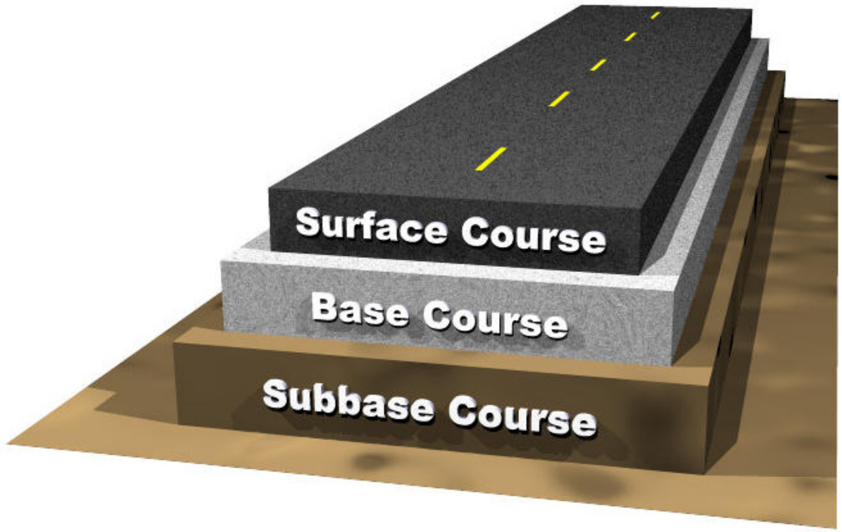

Figure 5. Typical HMA pavement structure.

Appendix B: RAP in Base Course Guidance and Specifications

Reviews of RAP in Base Courses

This study updated the Washington State DOT's (WSDOT) Research Report WA-RD 713.1 (2007) titled *Evaluation of Current Practices of Reclaimed Asphalt Pavement/Virgin Aggregate as Base Course Material***.** The original 2007 report can be found at: http://www.wsdot.wa.gov/Research/Reports/700/713.1.htm. The update is included with this report.

NJDOT *Standard Specifications for Road and Bridge Construction 2007* (Section 901)

901.10.03 Virgin and RAP Mixture

The Contractor may also produce DGA by mixing a maximum of 50 percent RAP conforming to 901.05.04 with previously approved virgin DGA.

Use a method of mixing that will ensure that the blended mixture is homogeneous with regard to particle size and composition. Ensure that the blended mixture meets the following requirements:

1. **Composition.** Ensure that the composition, as determined according to NJDOT A-3, conforms to the requirements specified in Table 901.10.03-1.

Table 901.10.03-1 Composition Requirements for Virgin DGA and RAP Mixture

Aggregate Property	Percent by Weight Maximum
RAP	50
Concrete	5
Brick, schist, and other friable material	4
Reactive material	0
Wood	0.1

2. **Plasticity and Gradation.** Use a blended material that is non-plastic when the portion passing the No. 40 sieve is tested according to AASHTO T 90. Ensure that the DGA containing RAP conforms to the gradation for DGA as specified in 901.10.01, except that the percent passing the No. 200 sieve is 0 to 10 percent when tested according to NJDOT A-6.

3. **Density Control.** Perform density control as specified in 302.03.01, except for the method for determining the dry density. After determining the wet density according to AASHTO T 310 (Direct Transmission Mode), the ME will take a 1000-gram sample of the DGA for subsequent weighing, drying, and reweighing in the laboratory to determine the moisture content. The ME will calculate the dry density using the wet density measured according to AASHTO T 310 and the moisture content measured from the lab tested sample. The ME will use the dry densities to determine the Q statistic for acceptance of the density.

Appendix C: Guide Specification for WMA

Online at:
http://www.warmmixasphalt.com/submissions/93_20081209_WMA%20Guide%20Specification%20version%201.07%20Final_WMATWG.pdf

Warm Mix Asphalt (WMA) Guide Specification for Highway Construction

Division 400 - Asphalt Pavements and Surface Treatments

SECTION 4XX - WARM MIX ASPHALT (WMA) PAVEMENT

Warm mix asphalt (WMA) is the generic term used to describe the reduction in production, paving, and compaction temperatures achieved through the application of one of several WMA technologies.

Some modifications to HMA plants may be necessary to accommodate the WMA technologies as noted in Section 4XX.03 Construction.

Production and paving temperatures may need to be increased for higher reclaimed asphalt pavement (RAP) contents, increased haul distances, decreased ambient temperatures, or other WMA project specific conditions.

All provisions for the production and placement of conventional HMA mixtures as stipulated in [*applicable Agency specification*] are in force except as noted below.

4XX.01 Description

Construct one or more courses of plant produced warm mix asphalt (WMA) pavement on a prepared foundation, using virgin aggregate or a combination of virgin and/or reclaimed aggregate material (RAM) and prescribed manufactured WMA additives and/or WMA plant process modifications. Use of RAP materials, consisting of cold milled, crushed, or processed bituminous asphalt mixture; and reclaimed asphalt shingles (RAS) are permitted at the current [*Agency specified*] percentages, provided that the mixture meets all the requirements of these specifications.

4XX.02 Material

WMA may be produced by one or a combination of several technologies involving HMA plant foaming processes and equipment, mineral additives, or chemicals that allow the reduction of mix production temperatures to within 185°F to 275°F. *(Note: The upper temperature range is appropriate for modified asphalt binders and WMA mixtures which include higher percentages of reclaimed asphalt pavement.)*

Provide materials as specified in:

Aggregate	Subsection XXX
Liquid Antistrips	Subsection XXX
Asphalt Binder	Subsection XXX
HMA Additives	Subsection XXX
Lime for Asphalt Mixtures	Subsection XXX
Mineral Filler	Subsection XXX
Reclaimed Asphalt Pavement	Subsection XXX
Reclaimed Aggregate Material	Subsection XXX
Reclaimed Asphalt Shingles	Subsection XXX

4XX.03 Construction

A. *Mix Design*. Develop and submit a job mix formula for each mixture according to AASHTO R 35 or [*Agency specified procedure*]. Each job mix formula must be capable of being produced, placed, and compacted as specified. Apply all mix design requirements for HMA to the development of the WMA mix design.

(Note to Contracting Agency: Recommended mix design practices specific to WMA have not been established. Job mix formulas for WMA mixtures are currently developed with conventional HMA mix design practices and the WMA technology process or additives are included afterward. The Contracting Agency and WMA producer must ensure the WMA technology does not adversely affect the asphalt binder performance grade and WMA mixture performance during the development and verification of the WMA job mix formula. All acceptance and performance testing must be conducted with the WMA technology added. A specific WMA mix design recommended practice is expected upon the completion of the National Cooperative Highway Research Program (NCHRP) Project 09-43 "Mix Design Practices for Warm Mix Asphalt" detailed at www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=977.)

Submit a written job mix formula for review and approval at least [XX] calendar days before production, or when sources of asphalt binder, aggregates, WMA additives, or other components of the mix change.

Submit the following information:

1. All information required in the report section of AASHTO R 35 or [*Agency specified procedure*].
2. WMA technology and/or WMA additives information.
3. WMA technology manufacturer's established recommendations for usage.
4. WMA technology manufacturer's established target rate for water and additives, the acceptable variation for production, and documentation showing the impact of excessive production variation.
5. WMA technology material safety data sheets (MSDS).
6. Documentation of past WMA technology field applications including project type, project owner, tonnage, location, mix design, mixture volumetrics, field density, and performance; or documentation of WMA technology listing on [*Agency specified*] approved products list.
7. Temperature range for mixing.
8. Temperature range for compacting.
9. Asphalt binder performance grade test data over the range of WMA additive percentages proposed for use.
10. WMA mixture performance test results [*as required by the Contracting Agency*].
11. Laboratory test data, samples and sources of all mixture components, and asphalt binder viscosity-temperature relationships.

(Note to Contracting Agency: Some WMA technologies may alter the asphalt binder grade and conventional performance grading may not be suitable to quantify the WMA technology effects.)

B. *Additives*. Use anti-stripping additives, silicone additives, WMA additives, and WMA technologies as specified. Comply with approved mix design quantities. Confirm the addition rate through field tests performed during production.

(Note to Contracting Agency: Silicon additives are historically used as both an antifoam and defoamer to inhibit foaming in asphalt binder applications. Ensure silicon additive compatibility when asphalt binder foaming processes are used to produce WMA.)

Comply with the manufacturer's recommendations for incorporating additives and WMA technologies into the mix. Comply with manufacturer's recommendations regarding receiving, storage, and delivery of additives.

Maintain supplier recommendations on file at the asphalt mixing plant and make available for reference while producing WMA.

C. *Sampling*. Perform sampling according to the following standards:

1. *Aggregate*. AASHTO T 2 or [*Agency specified procedure*].
2. *Asphalt Binder*. AASHTO T 40 or [*Agency specified procedure*].
3. *Warm Mix Asphalt (WMA) Plant Mix*. AASHTO T 168 or [*Agency specified procedure*].

D. *Weather Limitations*.

1. Place WMA mixtures only on dry, unfrozen surfaces and only when weather conditions allow for proper production, placement, handling, and compacting.

2. Meet [*agency specified*] placement temperatures.

(*Note to Contracting Agency: The minimum HMA delivery, placement, and compaction temperatures should be reviewed to accommodate the WMA reduced temperature and achieve workability and density requirements. Documentation that demonstrates a proven history of the WMA technology's ability to be placed and compacted at the reduced temperatures may be required. A test strip or initial production verification requirement can be used to demonstrate placement and compaction at the reduced temperature. Minimum ambient paving temperature requirements may be lowered 20°F from normal temperature requirements. Do not lower ambient paving temperatures to below freezing.*)

E. *Equipment*. Use equipment and WMA technologies capable of producing an asphalt mixture that meet specification requirements and is workable at the minimum placement and compaction temperature desired, regardless of storage or haul distance considerations.

1. *Asphalt Mixing Plant*. Meet AASHTO M 156 or [*as further modified by the Agency*].

Modify the asphalt mixing plant as required by the manufacturer to introduce the WMA technology.

Plant modifications may include additional plant instrumentation, the installation of asphalt binder foaming systems and/or WMA additive delivery systems, tuning the plant burner and adjusting the flights in order to operate at lower production temperatures and/or reduced tonnage.

(Note: Implementation of best management practices in the control of aggregate moisture content prior to introduction to the drying or mixing drum is highly recommended in order to achieve the maximum benefit of WMA technology.)

(*Note to Contracting Agency: It may be beneficial to produce an HMA mixture at conventional HMA temperatures immediately before WMA production at the lower temperatures in order to bring the plant up to temperature and ensure proper baghouse operating temperature. The following references published by the National Asphalt Pavement Association detail specifics related to plant modifications and operational changes in order to maximize the benefits of WMA production, especially regarding reduced fuel usage and reduced emissions:*
Quality Improvement Series 125 (QIP 125), "Warm Mix Asphalt: Best Practices",

Quality Improvement Series 126 (QIP 126), "Energy Conservation in Hot Mix Asphalt Production," and Environmental Council 101 (EC-101), "Best Management Practices to Minimize Emissions During HMA Construction")

All metering devices will meet the current [*Agency specified*] requirement for liquid or mineral additives. Document the integration of plant controls and interlocks when using WMA additive metering devices.

2. *Hauling Equipment*. Furnish equipment with tight, clean, smooth metal beds to haul WMA mixture. Keep beds free of petroleum oils, solvents, or other materials that would adversely affect the mixture. Apply a thin coat of approved release agent to beds as necessary to prevent mixture sticking. Do not use petroleum derivatives or other coating material that contaminates or alters the characteristics of the mix.

Be prepared to cover and insulate hauling beds. Equip each truck with a waterproof and windproof cover of suitable material and sufficient size to protect the mix from the weather. Securely fasten covers when necessary to maintain temperature. Ensure that covers do not allow water to enter the bed, paver, or mix transfer device during mix unloading. Use insulated truck beds when necessary to maintain temperature.

3. *Asphalt Pavers*. Provide self-propelled asphalt pavers with activated, heated, adjustable, vibratory screed assemblies to spread and finish to the specified section widths and thicknesses. Provide full width screw augers and provide auger extensions to ensure the paver's distribution system places the mixture uniformly, maintaining a consistent head of material in front of the screed. Screed or strike-off the surface without segregating, tearing, shoving, or gouging the mixture.

Operate the paver at consistent speeds and in a manner that results in an even, continuous layer. Avoid and minimize stop and start operation or allowing the paver to remain stationary during operation.

Equip pavers with automatic screed controls with sensors capable of continuously sensing grade, sensing the transverse slope of the screed, and providing the automatic signals that operate the screed to maintain grade and transverse slope. Control the screed to maintain the grade and transverse slope according to plan.

The Contractor may operate equipment manually in irregularly shaped, narrow, and minor areas.

If automatic controls fail, operate equipment manually only for the remainder of the work day and only if specified results are obtained.

Suspend paving if the specified surface tolerances are not met. Resume only after correcting the situation.

4. *Rollers*. Use rollers as required to achieve [*Agency specified*] pavement density and capable of reversing direction without shoving or tearing the mixture.

Operate rollers according to manufacturer's recommendations. Only use vibratory rollers equipped with separate energy and propulsion controls. Select equipment that will not crush the aggregate or displace the mixture.

F. *Mixing and Holding*. Heat the asphalt binder within the specified temperature range. Ensure a continuous supply of heated asphalt binder to the mixer.

Heat and dry aggregates to the required temperature. Avoid damaging or contaminating the aggregate.

Combine and mix the dried aggregates and asphalt binder to meet the job mix formula. Ensure a minimum of 95 percent uniform coating of aggregates according to AASHTO T 195 or [*Agency specified procedure*].

Correct procedures if storing or holding causes segregation, excessive heat loss, or a reduced quality mixture. Properly dispose of mixture which does not meet specifications.

G. *Preparing Base or Existing Surface*. Clear surface of debris and deleterious material. Apply and cure tack coat before placing the WMA. Apply a tack coat on all surfaces, curbs, gutters, manholes, or other structure surfaces, that will be in contact with the WMA.

Repair damaged areas of the base or existing surface. Restore the existing surface or base to a uniform grade and cross section before placing the mix.

H. *Pre-paving Requirements*. Prior to placing any WMA mix, produce a sufficient amount of WMA mix to properly calibrate the plant and procedures using the mix design approved for mainline construction. The Engineer will sample and test the WMA mix thus produced for the following:

1. voids in mineral aggregate (VMA);
2. asphalt binder content;
3. gradation;
4. air voids; and
5. tensile strength ratio (or Hamburg wheel tracking test for moisture damage)

Heat WMA field samples, transported to the laboratory, to the field production temperature, or lower, when reheating is required for WMA mixture testing.

(Note: Field produced WMA loose mix samples which are immediately compacted and tested, without reheating, may produce lower voids in mineral aggregate and lower air voids test results when compared to reheated samples. This should be validated during the test strip or initial production lot. One possible remedy is to cool the WMA sample to room temperature and reheat to a temperature that is less than or equal to the WMA field production temperature before laboratory compaction. This will minimize the WMA technology's effects on the test results and ensures the sample is not excessively aged.)

Place no WMA mixture that fails to meet specification requirements. WMA mixture not meeting the requirements may be used in the construction of temporary facilities when approved by the Engineer.

Construct a control strip or initial production lot with production materials and equipment. Select compacting methods to meet the specified density. The Engineer will take random loose mix and core samples to verify compliance with job mix and specification requirements. Reconstruct the test strip or initial production lot if the job mix formula, the compacting method, or compacting equipment changes, or if results do not meet specifications.

I. *Spreading and Finishing*. Spread and finish the mixture with asphalt pavers to specified grade and thickness.

Hand place material in areas inaccessible to mechanical spreading and finishing equipment.
Maintain a consistent supply of mixture to ensure uninterrupted paving.

Minimize inconvenience to traffic and protect existing and finished surfaces. Leave only short lane sections, normally less than [26 ft (8 m)], where the abutting lane is not placed the same day, or according to [*Agency specified*] traffic safety requirements.

J. *Compacting*. Compact immediately after spreading and before the WMA mixture falls below the minimum job mix design compaction temperature. Discontinue paving if unable to achieve the specified density before the mixture cools below the minimum recommended WMA job mix design compaction temperature.

Provide the number, weight, type, and sequence of rollers necessary to compact the mixture without displacing, cracking, or shoving. Roll the WMA mixture parallel to the centerline. Begin rolling superelevated curves at the low side and continue to the high side, overlapping longitudinal passes parallel to the centerline.

Maintain a uniform roller speed with the drive wheels nearest the paver. Operate vibratory rollers uniformly at the manufacturer's recommended speed and frequency.

Continue rolling to eliminate all roller marks and to achieve the minimum [*Agency specified*] percent of theoretical maximum density or the recommended [*Agency specified*] percent of laboratory density as determined according to [*Agency-specified method*].

(Note to Contracting Agency: Air void and density requirements are important to provide long term performance of asphalt pavements. Due to the potential for increased workability of WMA mixtures and therefore increased density, it is important to monitor rolling operations to ensure excessive compaction does not occur and minimum air void requirements and/or the upper limit on percent of maximum density are not exceeded.)

Maintain the line and grade of the edge during rolling.

Prevent the mixture from adhering to the rollers by using very small quantities of detergent or other approved release material.

Hand compact areas inaccessible to rollers.

The Engineer will take random tests of the compacted pavement to verify specification compliance. At no cost to the Agency, remove and replace mixture that does not meet specification requirements or that becomes contaminated with foreign materials. Remove defective materials for the full thickness of the course by saw cutting the sides perpendicular and parallel to the direction of traffic. Coat saw cut edges with bituminous materials and replace the defective material with specification materials.

K. *Joints*. Protect ends of a freshly laid mixture from damage by rollers. Form transverse joints to expose the full depth of the course. Apply a tack coat on transverse and longitudinal joint contact surfaces immediately before paving. Construct all longitudinal joints within 12 in. (300 mm) of the lane lines. Offset longitudinal and transverse joints on succeeding lifts 6 inches (150 mm) to 12 inches (300 mm) from the joint in the layer immediately below. Create the longitudinal joint in the top layer along the centerline of two-lane highways or at the lane lines of roadways with more than two lanes.

L. *Surface Tests*. The Engineer will test pavement surfaces to verify compliance with [*Agency specified*] smoothness and texture requirements.

Correct pavement surfaces that do not meet specification requirements by cold milling, diamond grinding, overlaying, or removing and replacing according to the following:

a. *Diamond Grinding.* Diamond grind final pavement surfaces exposed to vehicle traffic to the required surface tolerance and cross section. Remove and dispose of all waste material.

b. Cold Milling. Cold mill intermediate pavement surfaces to the required surface tolerance and cross section. Remove and dispose of all waste materials.

c. *Overlaying*. Use specification materials for overlays. Overlay the full width of the underlying pavement surface. Place a minimum recommended overlay thickness of [1.6 in. (40 mm)]. Use only one overlay.

d. *Removing and Replacing*. Replace rejected areas with WMA pavement materials that meet specification requirements. Test the corrected surface area. Complete all corrections before determining pavement thickness.

4XX.04 Measurement

The Engineer will measure work acceptably completed as specified in Subsection XXX and as follows:

A. The Engineer will base quantities of asphalt binder on the theoretical mass incorporated into accepted product as verified by samples taken according to Subsection XXX.

4XX.05 Payment

Include costs of plant startup operations, considering both labor and materials, in the price bid for the mixture in place.

The Agency will pay for accepted quantities at the contract unit price as follows:

Pay Item Pay Unit
(A) Asphalt Binder ton (Mg), gal (L)
(B) WMA Plant Mix—Type _____ ton (Mg), yd^2 (m^2)

Such payment is full compensation for furnishing all materials, equipment, labor, and incidentals to complete the work as specified.

Appendix D: TxDOT Special Provision 341-020

2004 Specifications

SPECIAL PROVISION

341---020

Dense-Graded Hot-Mix Asphalt (QC/QA)

For this project, Item 341, "Dense-Graded Hot-Mix Asphalt (QC/QA)," of the Standard Specifications, is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 341.2. Materials, Section A. Aggregate is voided and replaced by the following:

A. **Aggregate.** Furnish aggregates from sources that conform to the requirements shown in Table 1, and as specified in this Section, unless otherwise shown on the plans. Provide aggregate stockpiles that meet the definition in this Section for either a coarse aggregate or fine aggregate. Aggregate from RAP is not required to meet Table 1 requirements unless otherwise shown on the plans. Supply mechanically crushed gravel or stone aggregates that meet the definitions in Tex-100-E. The Engineer will designate the plant or the quarry as the sampling location. Samples must be from materials produced for the project. The Engineer will establish the surface aggregate classification (SAC) and perform Los Angeles abrasion, magnesium sulfate soundness, and Micro-Deval tests. Perform all other aggregate quality tests listed in Table 1. Document all test results on the mixture design report. The Engineer may perform tests on independent or split samples to verify Contractor test results. Stockpile aggregates for each source and type separately. Determine aggregate gradations for mixture design and production testing based on the washed sieve analysis given in Tex-200-F, Part II. Do not add material to an approved stockpile from sources that do not meet the aggregate quality requirements of the Department's *Bituminous Rated Source Quality Catalog* (BRSQC) unless otherwise approved.

Article 341.2. Materials, Section A. Aggregate, Section 1. Coarse Aggregate. The second paragraph is voided and replaced by the following:

Provide coarse aggregate with at least the minimum SAC as shown on the plans. SAC requirements apply only to aggregates used on the surface of travel lanes. When shown on the plans, SAC requirements apply to aggregates used on surfaces other than travel lanes. The SAC for sources on the Department's Aggregate Quality Monitoring Program (AQMP) is listed in the BRSQC.

Article 341.2. Materials, Section A. Aggregate, Section 2. RAP is voided and replaced by the following:

2. **RAP.** RAP is salvaged, milled, pulverized, broken, or crushed asphalt pavement. Crush or break RAP so that 100% of the particles pass the 2-in. sieve.

Use of Contractor-owned RAP including HMA plant waste is permitted, unless otherwise noted in the plans. Department-owned RAP stockpiles are available for the Contractor's use when the stockpile locations are shown on the plans. Department-owned RAP generated through required work on the Contract is available for the Contractor's use when shown on the plans. Perform any necessary tests to ensure Contractor or Department-owned RAP is appropriate for use. Unless otherwise shown on the plans, the Department will not perform any tests or assume any liability for the quality of the Department-owned RAP. When shown on the plans, the contractor will retain ownership of RAP generated on the project.

Fractionated RAP is defined as having two or more RAP stockpiles, whereas the RAP is divided into coarse and fine fractions. The coarse RAP stockpile will contain only material retained by processing over a 3/8 in. screen or 1/2 in. screen, unless otherwise approved. The fine RAP stockpile will contain only material passing the 3/8 in. screen or 1/2 in. screen, unless otherwise approved. The Engineer may allow the Contractor to use an alternate to the 3/8 in. screen or 1/2 in. screen to fractionate the RAP. The maximum percentages of fractionated RAP may be comprised of coarse or fine fractionated RAP or the combination of both coarse and fine fractionated RAP. Utilize a separate cold feed bin for each stockpile of fractionated RAP used.

Determine asphalt content and gradation of RAP stockpiles for mixture design purposes. Perform other tests on RAP when shown on the plans. Use no more than 10% unfractionated RAP in surface mixtures and no more than 20% unfractionated RAP in non-surface mixtures that are placed within 8 in. of the final riding surface. Use no more than 30% unfractionated RAP in non-surface mixtures that are placed 8 in. or more from the final riding surface. Use no more than 20% fractionated RAP in surface mixtures and no more than 30% fractionated RAP in non-surface mixtures that are placed within 8 in. of the final riding surface. Use no more than 40% fractionated RAP in non-surface mixtures that are placed 8 in. or more from the final riding surface. "Surface" mixtures are defined as mixtures that will be the final lift or riding surface of the pavement structure. "Non-Surface" mixtures are defined as mixtures that will be an intermediate or base layer in the pavement structure. The allowable percentages shown above may be decreased or increased when shown on the plans. Do not use Department or Contractor owned RAP contaminated with dirt or other objectionable materials. Do not use Department or Contractor owned RAP if the decantation value exceeds 5% and the plasticity index is greater than 8. Test the stockpiled RAP for decantation in accordance with Tex-406-A, Part I. Determine the plasticity index in accordance with Tex-106-E if the decantation value exceeds 5%. The decantation and plasticity index requirements do not apply to RAP samples with asphalt removed by extraction.

Do not intermingle Contractor-owned RAP stockpiles with Department-owned RAP stockpiles. Remove unused Contractor-owned RAP material from the project site upon completion of the project. Return unused Department-owned RAP to the designated stockpile location.

Article 341.2. Materials, Section F. Additives is supplemented by the following:

Warm Mix Asphalt (WMA) is defined as additives or processes that allow a reduction in the temperature at which asphalt mixtures are produced and placed. WMA is allowed for use at the Contractor's option unless otherwise shown on the plans. The use of WMA is required when shown on plans. When WMA is required by the plans, produce an asphalt mixture within the temperature range of 215ºF and 275ºF. When WMA is not required as shown on plans, produce an asphalt mixture within the temperature range of 215ºF and 350ºF. Unless otherwise directed, use only WMA additives or processes listed on the Department's approved list maintained by the Construction Division.

Article 341.4. Construction, Section D. Mixture Design. The first paragraph and Table 7 are voided and replaced by the following:

The Contractor may elect to design the mixture using a Texas Gyratory Compactor (TGC) or a Superpave Gyratory Compactor (SGC), unless otherwise shown on the plans. Use the typical weight design example given in Tex-204-F, Part I when using a TGC or the Superpave mixture design procedure given in Tex-204-F, Part IV when using a SGC. Design the mixture to meet the requirements listed in Tables 1, 2, 3, 6, 7, and 8. When using the TGC, design the mixture at a 96.0% target laboratory-molded density or as noted in Table 7. When using the SGC, design the mixture at 75 gyrations (Ndesign). Use only a target laboratory-molded density of 96.0% when using the SGC to design the mixture; however, adjustments can be made to the Ndes value as noted in Table 7.

Use an approved laboratory to perform the Hamburg Wheel test and provide results with the mixture design or provide the laboratory mixture and request that the Department perform the Hamburg Wheel test. The Construction Division maintains a list of approved laboratories. The Engineer will be allowed 10 working days to provide the Contractor with Hamburg Wheel test results on the laboratory mixture design.

Table 7
Laboratory Mixture Design Properties

Mixture Property	Test Method	Requirement
Target laboratory-molded density, %	Tex-207-F	96.0[1]
Design gyrations (Ndesign)	Tex-241-F	75 gyrations[2]
Tensile strength (dry), psi	Tex-226-F	85-200[3]
Boil test[4]	Tex-530-C	-

1. May be adjusted within a range of 96.0–97.5% when shown on the plans or allowed by the Engineer when using the TGC (Tex-204-F, Part I).
2. May be adjusted within a range of 50–100 gyrations when shown on the plans or allowed by the Engineer when using the SGC (Tex-204-F, Part IV).
3. May exceed 200 psi when approved and may be waived when approved.
4. Used to establish baseline for comparison to production results. May be waived when approved.

Article 341.4. Construction, Section D. Mixture Design, Section 2. Job-Mix Formula Approval. The first paragraph is voided and replaced by the following:

2. Job-Mix Formula Approval. The job-mix formula (JMF) is the combined aggregate gradation and target asphalt percentage used to establish target values for hot mix production. JMF1 is the original laboratory mixture design used to produce the trial batch. When WMA is used, JMF1 may be designed and submitted to the Engineer without including the WMA additive. When WMA is used, document the additive or process used and recommend rate on the JMF1 submittal. The Engineer and the Contractor will verify JMF1 based on plant-produced mixture from the trial batch, unless otherwise approved. The Engineer may accept an existing mixture design previously used on a Department project and may waive the trial batch to verify JMF1.

Article 341.4. Construction, Section D. Mixture Design, Section 2. Job-Mix Formula Approval, Section a. Contractor's Responsibilities, Section (1) Providing Texas Gyratory Compactor is voided and replaced by the following:

(1) Providing Gyratory Compactor. Use a Texas Gyratory Compactor (TGC) calibrated in accordance with Tex-914-K when electing or required to design the mixture in accordance with Tex-204-F, Part I, for molding production samples. Furnish a Superpave gyratory compactor (SGC) calibrated in accordance with Tex-241-F when electing or required to design the mixture in accordance with Tex-204-F, Part IV, for molding production samples. If the SGC is used, locate the SGC at the Engineer's field laboratory and make the SGC available to the Engineer for use in molding production samples.

Article 341.4. Construction, Section D. Mixture Design, Section 2. Job-Mix Formula Approval, Section a. Contractor's Responsibilities, Section (2) Gyratory Compactor Correlation Factors is voided and replaced by the following:

(2) Gyratory Compactor Correlation Factors. Use Tex-206-F, Part II, to perform a gyratory compactor correlation when the Engineer uses a different gyratory compactor. Apply the correlation factor to all subsequent production test results.

Article 341.4. Construction, Section D. Mixture Design, Section 2. Job-Mix Formula Approval, Section a. Contractor's Responsibilities, Section (6) Ignition Oven Correction Factors is voided and replaced by the following:

(6) Ignition Oven Correction Factors. Determine the aggregate and asphalt correction factors from the ignition oven in accordance with Tex-236-F. Provide the Engineer with split samples of the mixtures, including all additives (except water) and blank samples used to determine the correction factors. Correction factors established from a previously approved mixture design may be used for the current mixture design, provided that the mixture design and ignition oven are the same as previously used, unless otherwise directed.

Article 341.4. Construction, Section D. Mixture Design, Section 2. Job-Mix Formula Approval, Section a. Contractor's Responsibilities, Section (8) Trial Batch Approval is voided and replaced by the following:

(8) Trial Batch Approval. Upon receiving conditional approval of JMF1 from the Engineer, provide a plant-produced trial batch including the WMA additive or process, if applicable for verification testing of JMF1 and development of JMF2.

Article 341.4. Construction, Section D. Mixture Design, Section 2. Job-Mix Formula Approval, Section a. Contractor's Responsibilities, Table 9 is voided and replaced by the following:

Table 9
Operational Tolerances

Description	Test Method	Allowable Difference from Current JMF Target	Allowable Difference between Contractor and Engineer[1]
Individual % retained for #8 sieve and larger	Tex-200-F or Tex-236-F	±5.0[2]	±5.0
Individual % retained for sieves smaller than #8 and larger than #200		±3.0[2]	±3.0
% passing the #200 sieve		±2.0[2]	±1.6
Asphalt content, %	Tex-236-F	±0.3[3]	±0.3
Laboratory-molded density, %	Tex-207-F	±1.0	±1.0
In-place air voids, %		N/A	±1.0
Laboratory-molded bulk specific gravity		N/A	±0.020
VMA, %, min		Note 4	N/A
Theoretical maximum specific (Rice) gravity	Tex-227-F	N/A	±0.020

1. Contractor may request referee testing only when values exceed these tolerances.
2. When within these tolerances, mixture production gradations may fall outside the master grading limits; however, the % passing the #200 will be considered out of tolerance when outside the master grading limits.
3. Tolerance between trial batch test results and JMF1 is not allowed to exceed 0.5%, unless otherwise directed. Tolerance between JMF1 and JMF2 is allowed to exceed ± 0.3%.
4. Test and verify that Table 6 requirements are met.

Article 341.4. Construction, Section D. Mixture Design, Section 2, Job-Mix Formula Approval, Section b. Engineer's Responsibilities, Section (1) Gyratory Compactor is voided and replaced by the following:

(1) Gyratory Compactor. For mixtures designed in accordance with Tex-204-F, Part I, the Engineer will use a Department TGC, calibrated in accordance with Tex-914-K, to mold samples for trial batch and production testing. The Engineer will make the Department TGC and the Department field laboratory available to the Contractor for molding verification samples, if requested by the Contractor.

For mixtures designed in accordance with Tex-204-F, Part IV, the Engineer will use a Department SGC, calibrated in accordance with Tex-241-F, to mold samples for laboratory mixture design verification. For molding trial batch and production specimens, the Engineer will use the Contractor-provided SGC at the field laboratory or provide and use a Department SGC at an alternate location. The Engineer will make the Contractor-provided SGC in the Department field laboratory available to the Contractor for molding verification samples.

Article 341.4. Construction, Section E. Production Operations, Section 2. Mixing and Discharge of Materials is supplemented with the following:

When WMA is specified on the plans, produce the mixture and monitor the temperature of the material in the truck before shipping to ensure that it does not exceed 275ºF or is less than 215ºF. When WMA is specified, the Department will not pay for or allow placement of any WMA produced at more than 275ºF or less than 215ºF, unless otherwise directed.

Article 341.4. Construction, Section G. Placement Operations is voided and replaced by the following:

G. Placement Operations. Collect haul tickets from each load of mixture delivered to the project and provide the Department's copy to the Engineer approximately every hour, or as directed by the Engineer. Measure and record the temperature of the mixture as discharged from the truck or material transfer device prior to entering the paver and an approximate station number on each ticket. Unless otherwise directed, calculate the daily and cumulative yield for the specified lift and provide to the Engineer at the end of paving operations for each day. The Engineer may suspend production if the Contractor fails to produce haul tickets and yield calculations by the end of paving operations for each day.

Prepare the surface by removing raised pavement markers and objectionable material such as moisture, dirt, sand, leaves, and other loose impediments from the surface before placing mixture. Remove vegetation from pavement edges. Place the mixture to meet the typical section requirements and produce a smooth, finished surface with a uniform appearance and texture. Offset longitudinal joints of successive courses of hot mix by at least 6 in. Place mixture so longitudinal joints on the surface course coincide with lane lines, or as directed. Ensure that all finished surfaces will drain properly. Place mixture within the compacted lift thickness shown in Table 10, unless otherwise shown on the plans or allowed.

Article 341.4. Construction, Section G. Placement Operations, Section 1. Weather Conditions is voided and replaced with the following:

1. Weather Conditions. Place mixture when the roadway surface temperature is equal to or higher than the temperatures listed in Table 10A, unless otherwise approved or as shown on the plans. Measure the roadway surface temperature with a handheld infrared thermometer. The Engineer may allow mixture placement to begin prior to the roadway surface reaching the required temperature requirements if conditions are such that the roadway surface will reach the required temperature within 2 hrs. of beginning placement operations. Unless otherwise shown on the plans, place mixtures only when weather conditions and moisture conditions of the roadway surface are suitable in the opinion of the Engineer.

Article 341.4. Construction, Section G. Placement Operations, Section 1. Weather Conditions is supplemented by the following:

Table 10A
Minimum Pavement Surface Temperatures

	Minimum Pavement Surface Temperatures in Degrees Fahrenheit	
High Temperature Binder Grade	**Subsurface Layers or Night Paving Operations**	**Surface Layers Placed in Daylight Operations**
PG 64 or lower	45	50
PG 70	55[1]	60[1]
PG 76 or higher	60[1]	60[1]

1. Contractors may pave at temperatures 10°F lower than the values shown in Table 10A when utilizing a paving process including WMA or equipment that eliminates thermal segregation. In such cases, the contractor must use either an infrared bar attached to the paver, a hand held thermal camera, or a hand held infrared thermometer operated in accordance with Tex-244-F to demonstrate to the satisfaction of the Engineer that the uncompacted mat has no more than 10°F of thermal segregation.

Article 341.4. Construction, Section G. Placement Operations, Section 3. Lay-Down Operations. The first paragraph is voided and not replaced.

Article 341.4. Construction, Section G. Placement Operations, Section 3. Lay-Down Operations. Table 11 is voided and not replaced.

Article 341.4. Construction, Section I. Acceptance Plan, Section 1. Referee Testing. The second paragraph is voided and replaced with the following:

The Construction Division will determine the laboratory-molded density based on the molded specific gravity and the maximum theoretical specific gravity of the referee sample. The in-place air voids will be determined based on the bulk specific gravity of the cores, as determined by the referee laboratory, and the Engineer's average maximum theoretical specific gravity for the lot. With the exception of "remove and replace" conditions, referee test results are final and will establish pay adjustment factors for the sublot in question. The Contractor may decline referee testing and accept the Engineer's test results when the placement pay adjustment factor for any sublot results in a "remove and replace" condition. Sublots subject to be removed and replaced will be further evaluated in accordance with Article 341.6, "Payment."

Article 341.4. Construction, Section I. Acceptance Plan, Section 2. Production Acceptance, Section c. Production Testing. The first paragraph is voided and replaced with the following:

The Contractor and Engineer must perform production tests in accordance with Table 12. The Contractor has the option to verify the Engineer's test results on split samples provided by the Engineer. The Engineer may use asphalt content results from quality control testing performed by the Contractor to determine VMA. Determine compliance with operational tolerances listed in Table 9 for all sublots.

Article 341.4. Construction, Section I. Acceptance Plan, Section 3. Placement Acceptance, Section a. Placement Lot, Section (2) Incomplete Placement Lots is voided and replaced by the following:

(2) Incomplete Placement Lots. An incomplete placement lot consists of the area placed as described in Section 341.4.I.2.a(2), "Incomplete Production Lot," excluding miscellaneous areas as defined in Section 341.4.I.3.a(4), "Miscellaneous Areas." Placement sampling is required if the random sample plan for production resulted in a sample being obtained from an incomplete production sublot.

Article 341.4. Construction, Section I. Acceptance Plan, Section 3. Placement Acceptance, Section b. Placement Sampling. The third and fifth paragraphs are voided and replaced by the following:

Unless otherwise determined, the Engineer will witness the coring operation and measurement of the core thickness. Unless otherwise approved, obtain the cores within 1 working day of the time the placement sublot is completed. Obtain two 6-in. diameter cores side by side from within 1 ft. of the random location provided for the placement sublot. Mark the cores for identification, measure and record the untrimmed core height, and provide the information to the Engineer.

Visually inspect each core and verify that the current paving layer is bonded to the underlying layer. If an adequate bond does not exist between the current and underlying layer, take corrective action to ensure that an adequate bond will be achieved during subsequent placement operations. For Type D and Type F mixtures, 4-in. diameter cores are allowed.

If the core heights exceed the minimum untrimmed values listed in Table 10, trim and deliver the cores to the Engineer within 1 working day following placement operations, unless otherwise approved. Trim the bottom or top of the core only when necessary to remove any foreign matter and to provide a level and smooth surface for testing. Foreign matter is another paving layer, such as hot mix, surface treatment, subgrade, or base material. Trim no more than 1/2 in. of material. Do not trim the core if the surface is level and there is not foreign matter bonded to the surface of the core.

Article 341.4. Construction, Section I. Acceptance Plan, Section 3. Placement Acceptance, Section c. Placement Testing is voided and replaced by the following:

c. Placement Testing. Perform placement tests in accordance with Table 12. After the Engineer returns the cores, the Contractor has the option to test the cores to verify the Engineer's test results for in-place air voids. The allowable differences between the Contractor's and Engineer's test results are listed in Table 9.

Article 341.6. Payment. The first paragraph is voided and replaced by the following:

The work performed and materials furnished in accordance with this Item and measured as provided under Article 341.5, "Measurement," will be paid for at the unit price bid for "Dense-Graded Hot-Mix Asphalt (QC/QA)" of the type, surface aggregate classification, and binder specified. When shown on the plans, "level up" may be specified. Pay adjustments for bonuses and penalties will be applied as determined in this Item except for level ups where a pay adjustment factor of 1.000 will be assigned for all production and placement sublots. These prices are full compensation for surface preparation, materials including tack coat, placement, equipment, labor, tools, and incidentals.

Article 341.6. Payment, Section A. Production Pay Adjustment Factors is supplemented by the following:

When WMA is specified on the plans, at the Contractor's request the Engineer has the option to assign all sublots a production pay adjustment factor of 1.000. When the Engineer elects to assign all sublots a production pay adjustment factor of 1.000, control mixture production to yield a laboratory-molded density with an absolute deviation no greater than 1.0 percent from the target laboratory-molded density as defined in Table 7 or as shown on plans, as tested by the Engineer. The Engineer may suspend production and shipment of mixture if the laboratory-molded density deviates more than 1.0 percent from the target laboratory-molded density for two consecutive sublots.

Article 341.6. Payment, Section B. Placement Pay Adjustment Factors, Section 2. Placement Sublots Subject to Removal and Replacement is voided and replaced by the following:

2. Placement Sublots Subject to Removal and Replacement. If after referee testing the placement pay adjustment factor for any sublot results in a "remove and replace" condition as listed in Table 15, the Engineer will choose the location of two cores to be taken within 3 ft. of the original failing core location. The Contractor will obtain the cores in the presence of the Engineer. The Engineer will take immediate possession of the untrimmed cores and submit the untrimmed cores to the Materials and Pavements Section of the Construction Division, where they will be trimmed and tested for bulk specific gravity within 10 working days of receipt. The average bulk specific gravity of the cores will be divided by the Engineer's average maximum theoretical specific gravity for that lot to determine the new pay adjustment factor of the sublot in question. If the new pay adjustment factor is 0.700 or greater, the new pay adjustment factor will apply to that sublot. If the new pay adjustment factor is less than 0.700, no payment will be made for the sublot. Remove and replace the failing sublot. Replacement material meeting the requirements of this Item will be paid for in accordance with this Article.

Appendix E: TxDOT Approved WMA Additives

Available at: http://www.txdot.gov/txdot_library/publications/producer_list.htm

Warm Mix Asphalt (WMA)

The following Warm Mix Asphalt (WMA) additives and processes are pre-approved for use on department projects. Contact Dale Rand, P.E. of the Flexible Pavements Branch of CST/M&P at (512) 506-5836 for any information and status.

Approval requires the submittal of documentation from a minimum of 3 construction projects using the WMA technology, preferably a minimum of 1 in the State of Texas. Documentation must include a mixture design with mechanical property test results and Quality Control/Quality Assurance (QC/QA) test results measured during production. The following information must be included with the documentation:

- Contact Name & Telephone Number;
- Product Name & Supplier;
- Dates of construction for each project;
- Project Control-Section-Job (CSJ) Number for each project, if available; and
- Location and Highway for each project submitted.

WMA Technology	Process Type	WMA Supplier
Advera (Synthetic Zeolite)	Chemical Additive	PQ Corporation
Aspha-Min (Synthetic Zeolite)	Chemical Additive	Aspha-Min
Double Barrel Green	Foaming Process	Astec Industries, Inc.
Evotherm	Chemical Additive	MeadWestvaco Asphalt Innovations
Redi-Set WMX	Chemical Additive	Akzo Nobel Surfactants
Sasobit	Organic Additive	Sasol Wax Americas, Inc.
Terex	Foaming Process	Terex Roadbuilding
Maxam	Foaming Process	Maxam Equipment
Ultrafoam GX	Foaming Process	Gencor Industries