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

Steve Muench
with assistance from Denise Muramoto

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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.

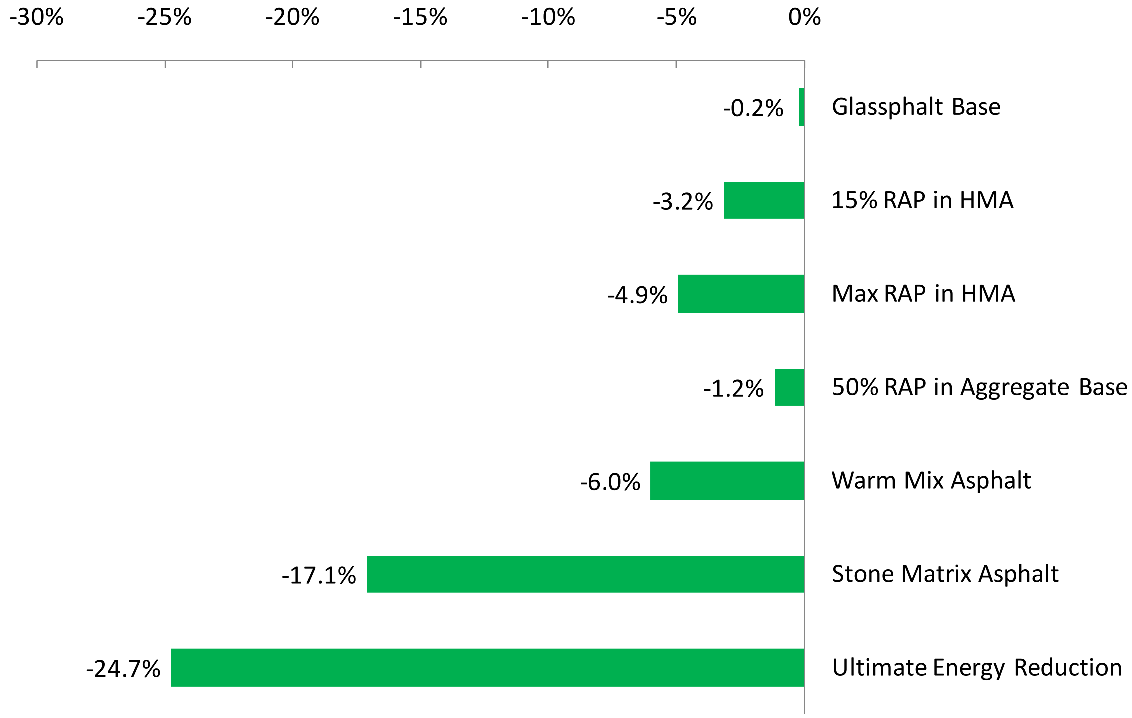

Figure 1. Average yearly energy reduction for HMA paving on O'ahu when compared to the baseline "all virgin materials" option. "Ultimate Energy Reduction" is a combination of these strategies: SMA surface course, 40% RAP in HMA base course, 50% RAP in aggregate base course and WMA used in all instances.

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.

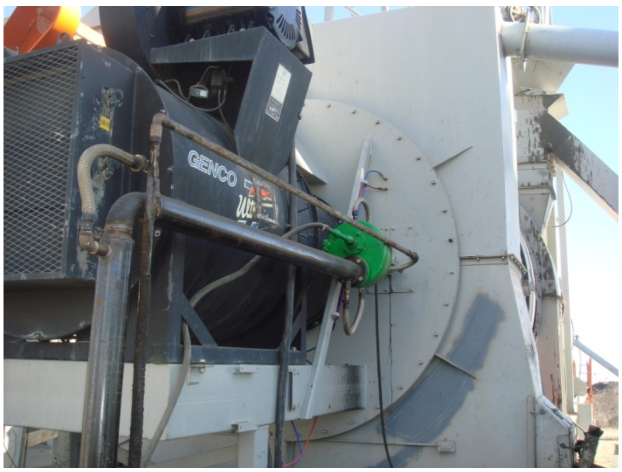

Figure 3. Gencor Green Machine foaming device installed (green in picture).

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.

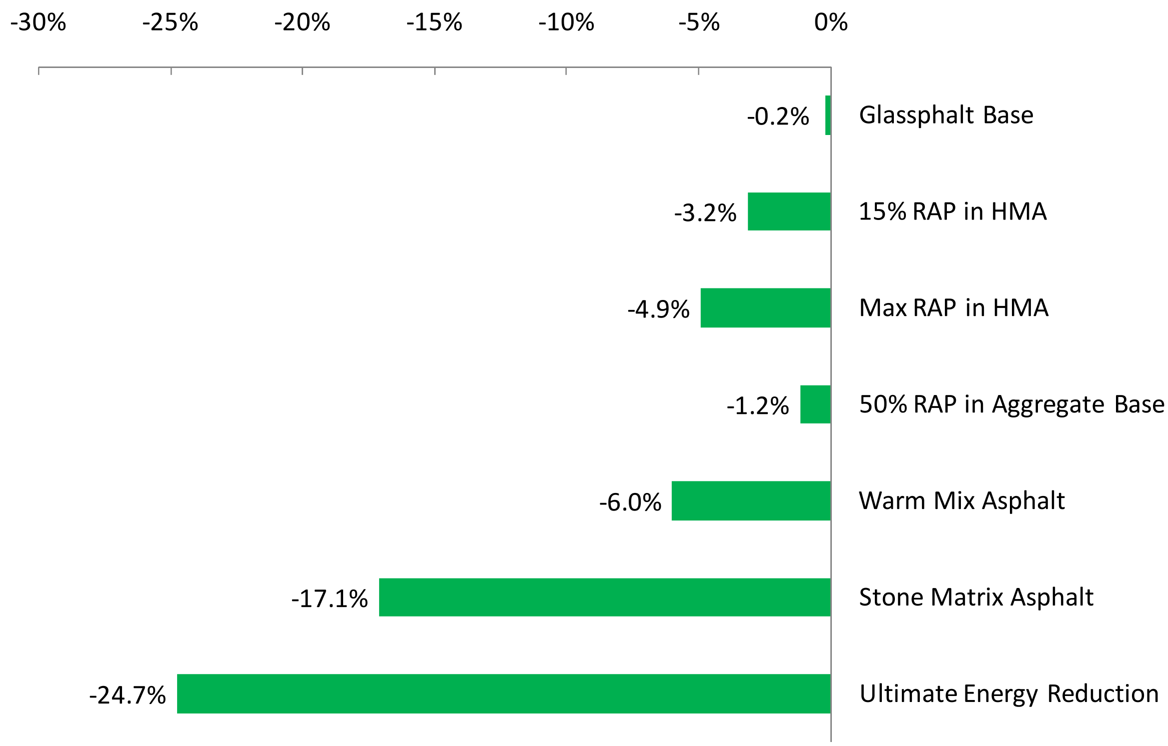

Figure 5. Average yearly energy reduction for HMA paving on O'ahu when compared to the baseline "all virgin materials" option.

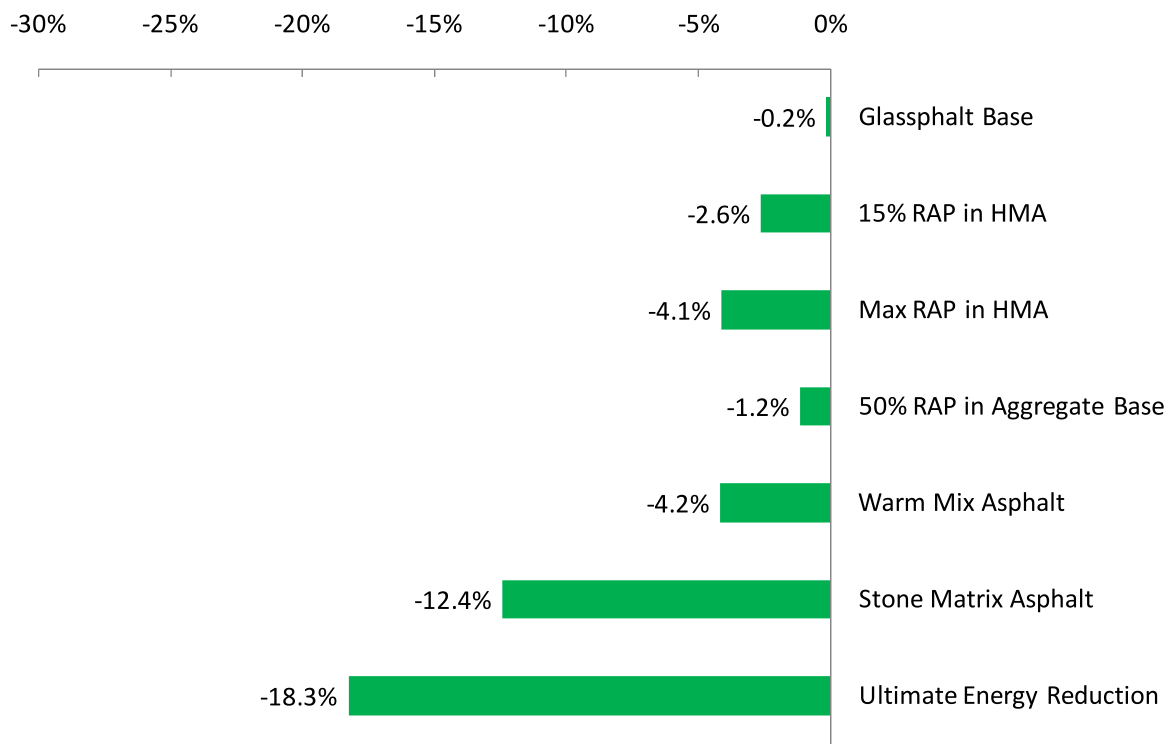

Figure 6. Average yearly CO_2 emissions reduction for HMA paving on O'ahu when compared to the baseline "all virgin materials" option.

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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