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Green Up Pavement Rehabilitation Design Tool

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GREEN UP PAVEMENT REHABILITATION DESIGN TOOL

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16. Abstract

While designers produce pavement rehabilitation recommendations every day, for projects of all sizes, most designers have little information on the environmental impact of their recommendations. This research developed a new decision tool, called the "Green Up Pavement Rehabilitation Design Tool," to allow the comparison of different rehabilitation solutions in terms of greenhouse gas emissions and to encourage sustainable practices such as materials recycling and the use of permeable, cool, and quiet pavement surfaces The project aligns with the major goal of California Senate Bill 1, which is "to address deferred maintenance on the state highway system and the local street and road system," by providing a rehabilitation strategy selection tool as well as an educational tool to promote sustainable pavement practices. The Green Up graphic and the overall methodology were finalized in consultation with representatives of the portland cement concrete and asphalt industries in California. For designers interested in learning more, the tool includes fact sheets about sustainable pavement rehabilitation strategies and links to additional online resources.

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EXECUTIVE SUMMARY

The majority of California's streets and highways are in need of repair and rehabilitation. A vast transportation infrastructure built primarily in the 1950s and 1960s has reached and, in many cases, exceeded its original design life. Rehabilitation strategies are in general selected based on cost, past experience with the proposed strategy, and materials availability. Sustainability considerations are rarely included, unless specifically required by the owner.

Green Up is a pavement rehabilitation decision tool that uses symbols and colors to illustrate the sustainable aspects of proposed pavement rehabilitation strategies. The intended audience consists primarily of pavement, materials, and geotechnical engineers that develop or evaluate pavement rehabilitation recommendations as part of their job responsibilities. In addition, Green Up provides designers with succinct educational content as well as links to outside resources about sustainable materials and pavement rehabilitation strategies.

The Green Up graphic is produced starting from factors such as quantities of materials involved in the rehabilitation process, the intended use of the materials imported or exported from the job site, surface properties, and pavement life extension as a result of rehabilitation. The tool also illustrates the cradle-to-gate global warming potential of the virgin materials used. An example of the use of the Green Up graphic to compare two candidate rehabilitation strategies is given in Figure 1.

To serve as a link between the Green Up tool and outside experts, several fact sheets or info pages have been developed to succinctly give additional information on sustainable pavement materials and practices and to direct the users to outside resources from industry, public agencies, and academia.

The original methodology used to produce the Green Up graphic was proposed by Andrei (2014) and it did not include a global warming potential component. The scope of this project was to improve the existing methodology by adding an environmental impact component based on environmental product declarations and by developing several fact sheets about important aspects of sustainable pavements. While developing an online application remains to be accomplished in a future project, an Excel macro has been produced in parallel with this report to create correct illustrations of the Green Up graphic and to add links to the info pages included in this report. The Excel macro consists of a spreadsheet with command buttons and check boxes that can be used to produce the Green Up graphic. The associated code has been written in Visual Basic for Applications and is included with the Excel file. In addition to the Excel macro, which will serve as a mockup for the online application, guidelines on the desired features of the online application were sought and are summarized in the last chapter of the report.

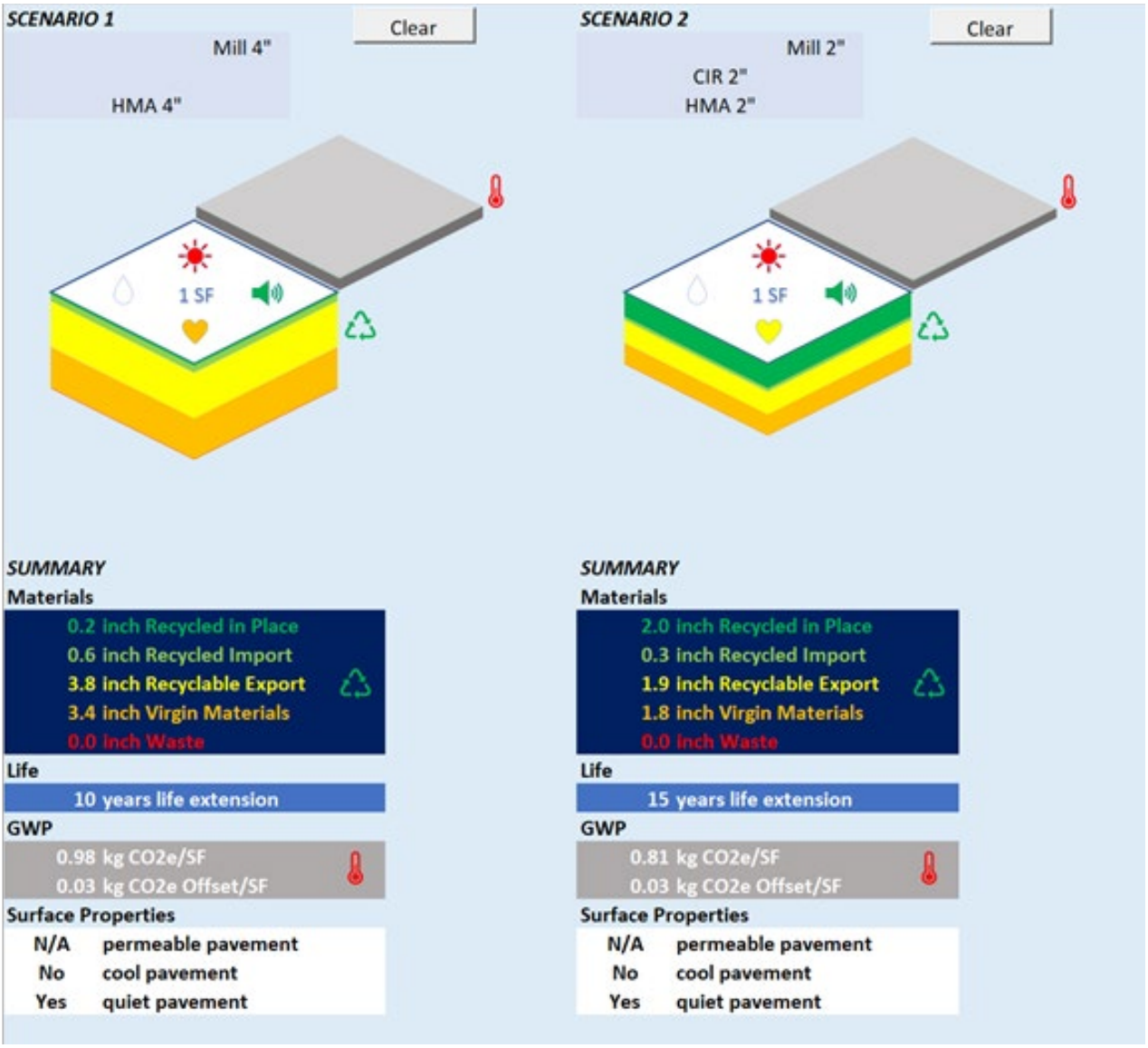

Figure 1. Comparison of Pavement Rehabilitation Scenarios Using Green Up

Given the time and budget constraints of this project, the project team coordinated with industry representatives to select a number of rehabilitation activities and strategies:

- Surface removal/demolition
- Diamond grinding
- Cold planing (milling)
- Crack and seat
- Cold in-place recycling
- Full depth reclamation (with cement or with emulsified asphalt)

- Jointed plain concrete
- Hot mix asphalt concrete
- Permeable pavement (pervious concrete or porous asphalt)
- Cool pavement
- Quiet pavement

The methodology allows for more rehabilitation treatments or strategies to be included in the future. Adding information on base materials for example will allow for the use of the tool not only for rehabilitation but also for new design/construction projects.

An evaluation copy of the Green Up macro is available for download on the website of the Pavement Recycling and Reclaiming Center at Cal Poly Pomona (PRRCenter.org). The fact sheets developed in this study can also be accessed on this site under the “Learn” menu item. It is the authors intention to host the future Green Up online app also on this web site.

I. BACKGROUND

PROJECT GOALS

The goal of this project was to develop a pavement rehabilitation strategy selection tool that will allow designers to explore and compare various strategies in terms of life, cost, and overall environmental impact. The tool includes a strong educational component providing information about "green" pavement rehabilitation strategies and links to relevant academic, public, and industry web sites. The main criteria of comparison between different strategies are the responsible use of materials (minimizing waste and increasing recycling and reusing), reducing global warming potential (in terms of carbon footprint as documented by relevant Environmental Product Declarations), and other key properties such as life extension, permeable surface, quiet surface (noise), and cool surface (heat island effect).

Project Alignment with SB1 Goals and Consortium Research Objectives

The project aligns with the major goal of California Senate Bill 1 (SB1), which is "to address deferred maintenance on the state highway system and the local street and road system," by providing a rehabilitation strategy selection tool as well as an educational tool to promote sustainable pavement practices.[1]

Recycling and reusing materials are specifically included in the Green Up tool among the major comparison criteria. The second major criterion is based on Environmental Product Declarations (EPDs), which are used to estimate the global warming potential of different strategies. Directly related to this aim, section 2030 (e) of the bill reads:

> To the extent deemed cost effective, and where feasible, in the context of both the project scope and the risk level for the asset due to global climate change, the department and cities and counties receiving funds under the program shall include features in the projects funded by the program to better adapt the asset to withstand the negative effects of climate change and make the asset more resilient to impacts such as fires, floods, and sea level rise.

The Green Up tool includes pavement surface considerations such as "permeable" to mitigate storm water and "cool" to mitigate the heat island effect, where both issues are accentuated by climate change.

The project aligns primarily with Objective 2 of the California State University Transportation Consortium (CSUTC) to "develop tools and approaches, such as life-cycle cost analysis, that will identify cost-effective materials and methods to facilitate road and bridge rehabilitation/maintenance decision-making and improve the long-term benefits of transportation investments." Green Up will help designers make informed decisions and include environmental impacts in their decision processes. Based on the idea that longer-lasting pavements are more sustainable, Green Up includes the design life of the pavement as one of the comparison criteria between rehabilitation alternatives.

Sustainability Rating Systems for Pavements

In recent years, the civil engineering community has become more receptive to sustainability and sustainable design. Consequently, rating systems have been developed to encourage and reward the use of sustainable practices. Some of the most well-known "green" rating systems are those developed by the Leadership in Energy and Environmental Design or LEED program.[2] In the LEED rating systems, sustainable practices are rewarded with credits: the more credits earned, the higher the LEED certification rewarded. Specific to pavements, LEED includes a range of applicable credits sorted into the following major categories:

- Storm water management and the recommended use of permeable pavements
- Heat island effect reduction and the recommended use of pavement surfaces with high Surface Reflective Index (SRI)
- Recycled content in infrastructure and the recommended use of recyclable materials
- Construction waste management and the recommendation to divert recyclable materials from disposal

Other credits are available in LEED: for example, for providing bike lanes, carpool lanes, building "walkable" streets, and so on. However, pavement rehabilitation recommendations are usually developed by materials or geotechnical engineers who have little say in the geometric aspects of the design, and their recommendations are limited to materials, thickness, and the demolition and construction technologies to be used.

Another successful rating system developed specifically for roadways and transportation infrastructure is Greenroads.[3] This rating system includes eleven prerequisites for certification:

- Environmental review process
- Lifecycle cost analysis
- Lifecycle inventory
- Quality control plan
- Noise mitigation plan
- Waste management plan
- Pollution prevention plan
- Low impact development
- Pavement management system

- Site maintenance plan
- Educational outreach

Both LEED and Greenroads are complex systems and require registration and documentation of a project before it can be evaluated and certified—a process that most designers cannot afford in terms of both time and money. In California, for example, more than 80% of roads are managed by cities and counties which do not have the financial resources of a state department of transportation. According to a 2013 study, the overall condition of these local roads is "at risk" and continues to deteriorate.[4] In other words, these pavements are in dire need of maintenance and rehabilitation. The same study found that the funding available for maintenance and rehabilitation is only about a third of what is needed to prevent further deterioration. As a result, rehabilitation projects are often limited to restoring the structural and functional properties of the pavement "on a budget." For such projects, it is impractical to use the rather complex LEED or Greenroads rating systems. These rating systems seem to be more appropriate for projects with larger budgets and greater publicity.

The Green Up system was first proposed by Andrei in 2014 to fill the need for a simple, fast, and readily available tool to evaluate and compare the sustainable aspects of different pavement rehabilitation scenarios.[5] While limited in scope, in comparison with other, more complex systems, Green Up allows a designer to explore and learn about key sustainable pavement rehabilitation practices such as recycling, reducing waste, reducing greenhouse gas emissions, and providing permeable, cool, and quiet riding surfaces. It was the goal of this project to revise and update the originally proposed Green Up system and to produce a decision tool that will have industry-wide acceptance and support.

PROJECT OBJECTIVES

The following objectives were identified during the proposal stage.

Objective 1: Review Metrics and Comparison Criteria

In collaboration with industry representatives, the following Green Up criteria and metrics were reviewed with the purpose of achieving consensus on the general comparison criteria to be included and the design of the Greenup graphics. The original proposed metrics included:

- Distribution of materials, by weight, into the following sub-categories, in order of most to least sustainable:

  1. Recycled In-Place
  2. Recycled Import
  3. Virgin

4. Recyclable Export

5. Waste

- Global warming potential (GWP) as documented by current Environmental Product Declarations (EPDs) for a cradle-to-gate analysis

- Surface characteristics:

  1. Permeability

  2. Solar Reflectivity

  3. Noise

- Life Cycle Cost Analysis in a simplified form where alternatives will be compared on a cost-per-year basis to account for differences in the overall performance life of different strategies

Instead of producing a score or ranking to compare rehabilitation strategies, the Green Up tool produces a graphic, as illustrated in Figure 2. Colors are used to illustrate the sustainable features of a given design. Green is used for the most sustainable practices. Red and dark gray indicate the least sustainable practices. Relative ratios of materials used below the pavement surface are shown to the right of the recycling symbol. Surface characteristics are shown on the diamonds with symbols for permeability (water drop symbol), solar reflectivity (sun symbol), noise (speaker symbol), and life cycle cost (heart symbol). Global warming potential is illustrated by the gray cloud with the thermometer symbol. Producing this graphic for each design scenario will allow designers to compare alternatives and learn about ways to “green up” their design recommendations. When the user clicks on any of the symbols of the Green Up graphic, they will be shown their current inputs as well as a link to additional information on how to include more sustainable practices for a given strategy or material.

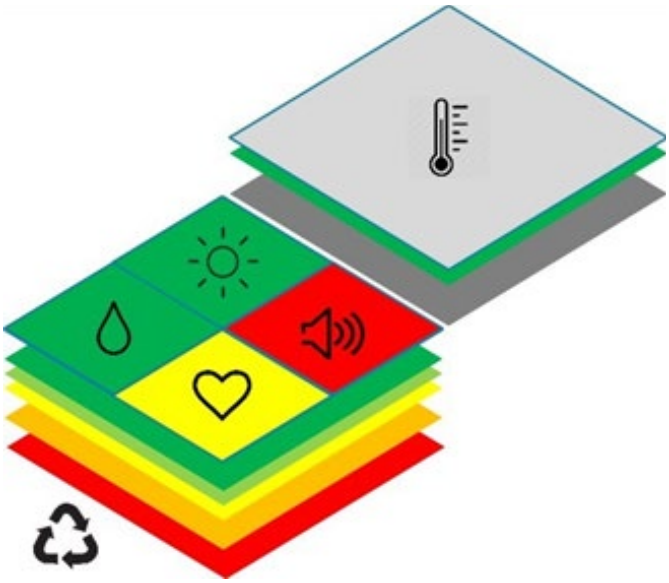

Figure 2. Originally Proposed Green Up Graphic Example

Representatives of the following trade associations were invited to participate and provide feedback on both the criteria for comparison, as well as the Green Up graphic itself:

- California-Nevada Cement Association (CNCA)
- California Asphalt Pavement Association (CalAPA)
- Asphalt Recycling and Reclaiming Association (ARRA)
- International Grooving and Grinding Association (IGGA)

Objective 2: User Inputs

The second objective of the project was to gather and analyze the user inputs necessary to make the decision tool functional for the following common pavement rehabilitation strategies:

- Asphalt Concrete
- Cold Planing
- Cold In-Place/Central Plant Recycling
- Full-Depth Reclamation
- Overlay
- Portland Cement Concrete
- Grooving and Grinding

- Partial and Full-Depth Repair
- Slab Replacement
- In-Place Recycling

Objective 3: Educational Content

The third objective of the project was to develop content for educational web pages that will provide the first level of additional information when designers want to learn more about a certain material or pavement rehabilitation strategy. The same content will be useful to civil engineering students studying pavement design, construction, and maintenance/ rehabilitation. The proposed flow of information which corresponds to the level of detail that will be provided to users/designers is illustrated in Figure 3.

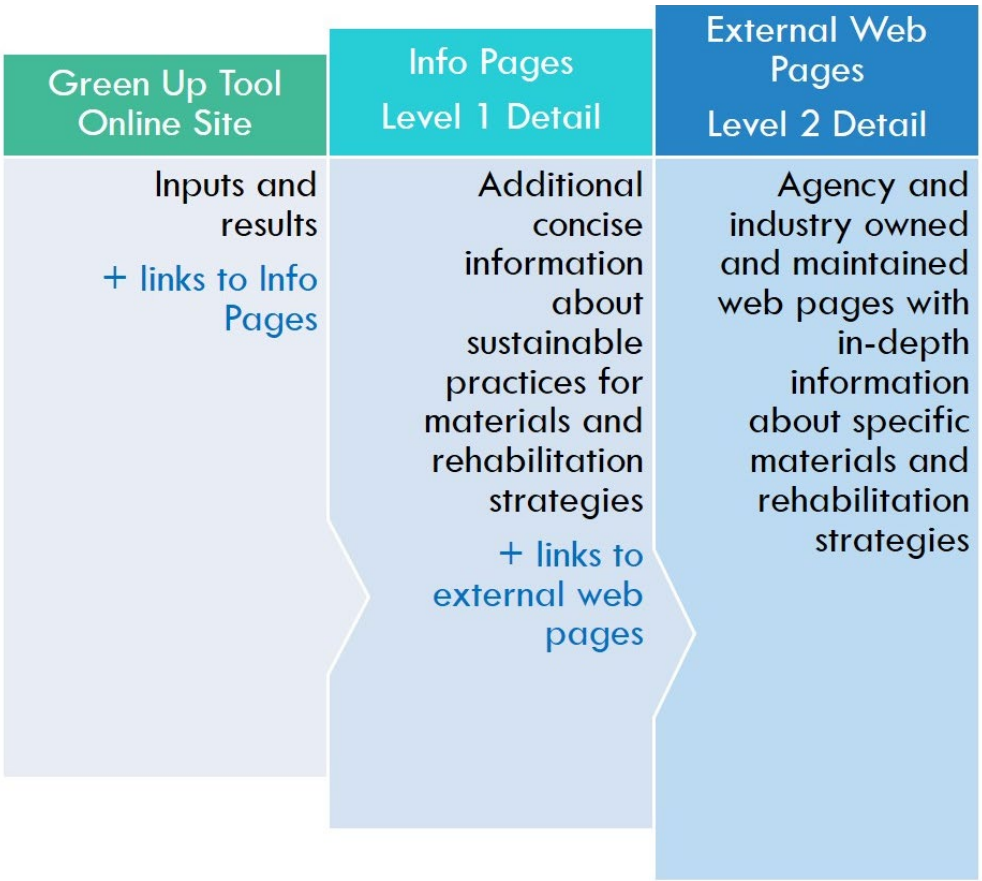

Figure 3. Levels of Educational Content

Additional information will be provided on the Green Up page in the form of pop-up balloons to help users input the correct information. In addition, links to web pages with Level 1 Detail will be provided. These web pages will be hosted and maintained by the project team, and the content will be developed for this project. Included on the Level 1 Detail pages will be links to resources from industry, public agencies, and academia. Access to these pages will allow designers to get in touch with agency and industry representatives to download relevant standards and specifications, to access more detailed global warming potential

calculators and EPDs, or to get in touch with material producers or contractors who can provide more direct help with a specific material or rehabilitation strategy.

The Green Up tool is therefore intended to be not only a decision analysis tool, but also a portal to several levels of information about sustainable pavement rehabilitation practices. Today's engineering students are tomorrow's designers. This younger generation expects to find the information they need online, and they appreciate a tiered level of detail whereby they can dive into more information when they have the time to invest in the learning process. The Green Up tool is designed with future generations in mind as a platform which will be easily updated and appended with videos, animations, and additional means of delivering information to help the learning process.

Objective 4: Application Functionality

The fourth objective of the project is to finalize the design of the user interface and to clearly describe the functions that online users should have access to once Green Up is made available online, such as:

- Saving design scenarios
- Selecting design scenarios for comparison and displaying the Green Up graphics next to each other
- Printing reports for each scenario
- Printing reports for each comparison
- Sharing scenarios with other designers and having the ability to chat and comment to promote a learning community

This information will be compiled so that later it can be conveyed to a programmer who will build the online solution. Programming and deployment of the solution were not included in the scope of this project.

II. GREEN UP REHABILITATION ACTIVITIES AND SUSTAINABILITY METRICS

REHABILITATION ACTIVITIES

The first objective of this project was to determine the metrics and the rehabilitation activities to be included in the initial iteration of the Green Up decision tool. Rehabilitation activities generally begin with partial-depth or full-depth removal of the existing surface. Then, a new surface is placed, or the existing pavement may be recycled in place or reclaimed to repair existing distress and restore carrying capacity before placement of the new surface. A limited number of rehabilitation treatments were selected in consultation with CNCA and CalAPA for this first version of Green Up:

1. Jointed Plain Concrete Pavement (JPCP)
2. Hot Mix Asphalt (HMA)
3. Removal/demolition of existing JPCP or HMA surface
4. Diamond Grinding JPCP
5. Cold Planning/Milling HMA
6. Crack and Seat JPCP
7. Cold In-Place Recycling (CIR)
8. Full Depth Reclamation (FDR) with cement or with asphalt emulsion

In addition to the above rehabilitation activities, it was agreed to include the following sustainable pavement strategies:

1. Permeable Pavement with pervious concrete or porous asphalt
2. Cool Pavement
3. Quiet Pavement
4. Long-Life Pavement

More rehabilitation treatments and strategies are available and will be added to future versions of the Green Up tool. Due to the inherent time and budget constraints for this project, only the above 12 treatments/strategies were included at this time.

SUSTAINABILITY METRICS

The following metrics or comparison criteria were selected for implementation in Green Up.

Materials Recycling

Both portland cement concrete and asphalt concrete consist primarily of aggregates—more than 80% by weight in concrete and around 95% in asphalt concrete. Unbound bases and treated bases are also essentially aggregate. Recycling and reclaiming this natural, non-renewable resource make perfect sense.

Materials categories in Green Up have been created to encourage recycling and discourage the use of virgin materials or the disposal of materials from existing pavements as waste. For each rehabilitation activity or technology, materials are placed into the following categories, in the order of most to least sustainable (the color used to represent these quantities in the Green Up graphic is shown in parentheses):

1. Recycled In-Place (green)
   Recycling in place is ranked as most sustainable in Green Up because it involves the reuse of existing materials at the job site, thus minimizing waste and transportation greenhouse gas emissions; it also reduces the need for new (virgin) materials, thus minimizing the carbon footprint associated with mining, processing, transporting, mixing, and placing virgin materials. It should be noted that besides emissions, the heavy trucks travelling to and from the job site will also add load repetitions and incremental damage to existing pavements as well as possibly contributing to traffic congestion.

2. Recycled Import (light green)
   Recycled import includes materials such as reclaimed asphalt pavement (RAP), recycled concrete aggregate (RCA), crumb rubber, fly ash, and slag.

3. Recyclable Export (yellow)
   Recyclable export includes materials that will be removed from the site but not disposed of. These materials include reclaimed asphalt pavement (RAP) or recycled concrete aggregate (RCA).

4. Virgin (orange)
   This category includes virgin materials, such as portland cement, virgin asphalt binder, and virgin aggregates.

5. Waste (red)
   This category includes materials that will likely be disposed of and cannot be reused or recycled.

The above ranking of materials into categories is subjective and was developed specifically for use with the Green Up tool. The categories should not be used as the sole consideration in choosing a rehabilitation solution. As with any rehabilitation treatment or strategy, project selection is key, and it is assumed that Green Up users will choose the right treatment for the right pavement at the right time in the life cycle of that pavement.

Global Warming Potential

In order to add a global warming potential (GWP) dimension to Green Up, users will be asked to input 100-year GWP values as documented by current Environmental Product Declaration (EPD) for a cradle-to-gate analysis. Since greenhouse gases can remain in the atmosphere for various periods of time, ranging from a few years to thousands of years—depending on the gas—a 100-year period is chosen as a reference for comparison. In addition, because greenhouse gases have different potential to contribute to global warming, their environmental impact is compared to that of carbon dioxide (CO_2)—the most abundant greenhouse gas in the atmosphere—and the global warming potential is expressed in units of weight of CO_2 equivalent or CO_2e. In Green Up, users will enter 100-year GWP values for the different rehabilitation strategies used and a volume proportional to the total weight of CO_2e for a given rehabilitation alternative will be calculated and shown in the form of a gray cloud.

The construction phase and the use phase of the project's life cycle are not included. While it is recognized that these phases are very important,[6] accurately estimating the corresponding carbon footprint for the construction and use phases of a project would require a significant amount of additional project-specific information and a more complex analysis, which is beyond the scope of Green Up.

Green Up also gives users the option to report carbon offsets, if any, or learn about options to offset the project's carbon footprint. Offsets will be shown in green in the same area as the carbon footprint. The same units, CO_2 equivalent (100 years), will be used for carbon offsets.

Sustainable Strategies

A white diamond representing one square foot of pavement is shown on the center of the Green Up graphic. Four symbols are shown on this white diamond to illustrate four sustainable strategies:

1. Permeable Pavement
   Users will have the option to select whether a permeable surface is used, such as pervious concrete or porous asphalt. A water drop symbol will be shown on the left side of the white diamond in one of the following colors: green (permeable surface), red (impermeable surface), or white (not applicable).

2. Cool Pavement
   Users will have the option to select whether the pavement surface qualifies as cool surface, such as a new portland cement concrete surface. A sun symbol will be shown on the top side of the white diamond in one of the following colors: green (cool surface), red (regular surface), or white (not applicable).

3. Quiet Pavement
   Users will have the option to select whether the pavement surface is quieter, such as rubberized asphalt concrete or a diamond ground portland cement concrete surface. A speaker symbol will be shown on the right side of the white diamond in one of the following colors: green (quieter surface), red (regular surface), or white (not applicable).

4. Long-Life Pavement
   The fourth symbol shown on the white diamond is a heart, which is used to illustrate life extension. The following colors will be used: red (0 to 7 years), orange (8 to 14 years), yellow (15 to 22 years), light green (23 to 29 years), and green (30 years or more).

The goal is to encourage designers to use or learn more about these sustainable aspects of pavements and hopefully include these strategies in their rehabilitation solutions when appropriate. The “not applicable” option indicates that a certain strategy may not apply to a specific project. For example, traffic noise may not be an issue for a road passing through an uninhabited, remote rural area.

III. GREEN UP INPUTS

Green Up is intended to be an easy to use practical tool, that should not take more than 5 to 10 minutes for an experienced user to enter inputs and generate the Green Up graphic for two or more design alternatives. The number of inputs should therefore also be reduced to a minimum and default values should be provided where possible.

The first step in using the tool is to select the rehabilitation activities that will be employed in one rehabilitation scenario, e.g., mill and overlay. Next, the user will enter the thickness of each activity. Rehabilitation activities will come with default values which the user will have the ability to customize if necessary.

Key inputs for each rehabilitation activity or treatment were identified by examining the main items typically reported in job mix formulas and specifications. The project team used a variety of sources but gave priority to standards and specifications used in California (Caltrans Standard Specifications and Greenbook).

Default values or ranges of values were also sought and identified for each material. This information will be useful when Green Up users do not have mix design information readily available.

In order to develop the Green Up graphic, materials were placed into five different categories, as described in more detail in the previous chapter:

1. Recycled In-Place (green)

2. Recycled Import (light green)

3. Recyclable Export (yellow)

4. Virgin (orange)

5. Waste (red)

Following are summaries of inputs, corresponding Green Up categories, and default values or ranges of values for the initial eight rehabilitation activities included in Green Up.

SURFACE REMOVAL

Demolition and removal of the existing pavement surface, be it asphalt or concrete, is normally achieved with heavy machinery and results in debris of different sizes and irregular geometry. The demolition debris can be recycled as aggregate for unbound base layers or as aggregate for new asphalt concrete or portland cement concrete.

In Green Up, all the material that has the potential to be recovered and reused qualifies as Recyclable Export. Some of the debris, however, may be contaminated with fines from the existing underlying layers and may be difficult to recycle as aggregate. This portion of

the demolition debris, which will likely end up in a landfill or at a dump site, qualifies as Waste. According to a recent study by the Environmental Protection Agency (EPA, 2018), construction and demolition debris waste for concrete and asphalt concrete in the United States amounts to 3% or less of the weight of material placed. Using this information, inputs and default values for surface removal are given in Table 1.

Table 1. Surface Removal Inputs and Defaults

Input	Description	Default Value
Thickness	Average depth of pavement to be removed, in inches	User Input
Recycled In-Place	Percent demolition debris that will be reused at the site, %	0
Recyclable Export	Percent demolition debris that will be stored for future processing and use as recycled aggregate, %	97
Waste	Percent demolition debris that will be disposed of, % (note that this is a calculated value, not a user input)	3

DIAMOND GRINDING

Diamond grinding consists of the removal of a thin layer of the pavement surface material (up to 7 mm) using closely spaced diamond saw blades. It is used primarily on jointed plain concrete pavement (JPCP) to correct faulting between slabs and restore the longitudinal and transversal profile. Diamond grinding also results in a surface texture that improves friction and reduces tire-pavement noise.[7]

In Green Up, users can enter the thickness for diamond grinding as well as the percent concrete grinding residue (CGR) that will be reused or diverted from landfills. Best management practices for CGR are available from the International Grooving and Grinding Association (IGGA, 2013). Default values are given in Table 2. A diamond ground surface will qualify as a Quiet surface, which will be illustrated by a green-colored speaker symbol in the Green Up graphic.

COLD PLANING

Cold planing or milling consists of the partial or full removal of an existing asphalt concrete surface using a rotary cutting drum and specialized equipment. Milling equipment can also be used to excavate and remove base and subbase materials.[8] When limited to the asphalt concrete surface, cold planing produces RAP or Reclaimed Asphalt Pavement, which in Green Up qualifies as Recycled In-Place if reused at the site or Recyclable Export if transported to a plant for future use as recycled aggregate. Default values for cold planing are given in Table 3.

Table 2. Diamond Grinding Inputs and Defaults

Input	Description	Default Value
Thickness	Average depth of treatment, in inches	User Input
Recyclable Export	Percent concrete grinding residue that will be stored for future processing and use as recycled aggregate, %	50

Waste	Percent demolition debris that will be disposed of, % (note that this is a calculated value, not a user input)	50

Table 3. Cold Planing Inputs and Defaults

Input	Description	Default Value
Thickness	Average depth of treatment, in inches	User Input
Recycled In-Place	Percent demolition debris that will be reused at the site, %	5
Recyclable Export	Percent demolition debris that will be stored for future processing and use as recycled aggregate, %	94
Waste	Percent demolition debris that will be disposed of, % (note that this is a calculated value, not a user input)	1

A comparison of the Green Up graphic for Surface Removal, Diamond Grinding, and Cold Planing is shown in Figure 4. Please note that the graphics do not reflect one complete rehabilitation solution, such as “mill and fill,” but only the individual contribution of each specific rehabilitation activity.

CRACK AND SEAT (CS)

Cracking and seating an existing concrete pavement involve the controlled cracking of slabs into smaller areas with the purpose of preventing reflective cracking in an HMA overlay. CS is a feasible alternative when there is significant damage in the existing pavement, when the pavement profile can be raised to higher elevation with an overlay, and where underground utilities will not be damaged by the vibrations produced during CS operations. In Green Up, the entire thickness of concrete subject to cracking and seating qualifies as Recycled In-Place. Therefore, treatment thickness is the only input value.

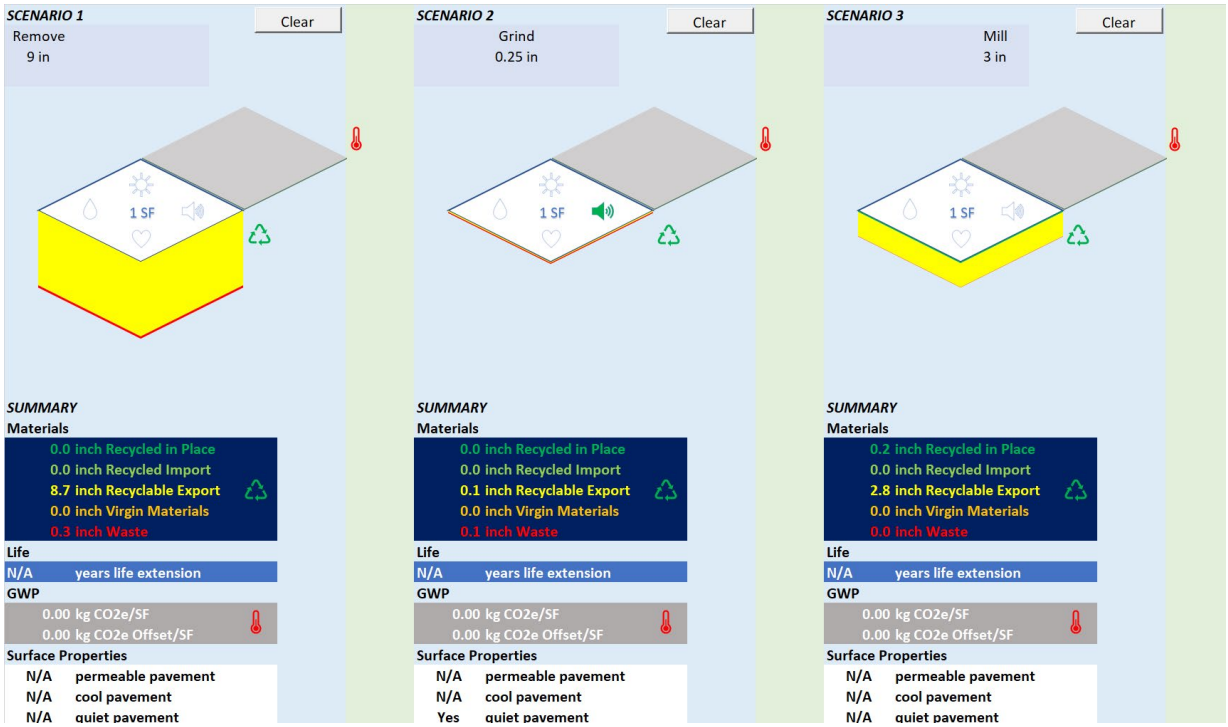

Figure 4. Green Up Graphic for 9 in. Removal, 0.25 in. Grinding, 3 in. Mill.

This figure was generated using Green Up Macro v101.xlsm

COLD IN-PLACE RECYCLING (CIR)

Cold in-place recycling consists of cold planing or milling an existing asphalt concrete surface to a specified depth followed by mixing the produced RAP with emulsified asphalt, then placing and compacting the fresh CIR mix in-place. The typical depth is 2 to 4 inches, depending on the equipment used and the condition and hardness of the existing pavement surface. CIR is normally followed by HMA overlay. In Green Up, the entire CIR treatment thickness qualifies as Recycled In-Place. This categorization is, however, adjusted for the asphalt residue in the asphalt emulsion and portland cement, which are considered virgin materials. CIR inputs and default values are given in Table 4.

EPDs for asphalt emulsions are not available in the United States at the time of this report. For this initial version of Green Up, the Asphalt Institute EPD for asphalt cement was used together with percent asphalt residue to produce a rough estimate of the global warming potential of the emulsion. This is only an approximation, and users will have an opportunity to enter more accurate values for asphalt emulsions once U.S.-based EPDs become available in the future.

Table 4. Cold In-Place Recycling Inputs and Defaults

Input	Description	Default Value
Thickness	Average depth of treatment, in inches	User Input
Emulsion Content	Percent asphalt emulsion, % by weight of mix	3.5
Asphalt Residue	Percent asphalt cement in the emulsion, % by weight of emulsion	65
Portland Cement	Percent portland cement, % by weight of mix	0
G_{mb}	Bulk specific gravity of the compacted CIR mix	2.45
EPD for Asphalt Cement	Environmental Product Declaration for asphalt cement	AI LCA 3/2019
Declared Unit	Declared unit for asphalt cement EPD	Metric Ton
Asphalt GWP	Cradle-to-gate global warming potential in kg CO_2 eq (100 years) per declared unit	637
EPD for Portland Cement	Environmental Product Declaration for portland cement	PCA #035
Declared Unit	Declared unit for portland cement EPD	Metric Ton
Cement GWP	Cradle-to-gate global warming potential in kg CO_2 eq (100 years) per declared unit	1040

Example Green Up graphics for Crack and Seat and CIR are shown in Figure 5. Please note that the graphics do not reflect one complete rehabilitation solution, such as “crack, seat, and overlay,” but only the individual contribution of each specific rehabilitation activity.

FULL DEPTH RECLAMATION (FDR)

Full depth reclamation is an in-place recycling technology whereby the entire thickness of the existing asphalt concrete and a portion of the underlying layers are pulverized and mixed into a new, distress-free base-like material. New aggregate, foamed or emulsified asphalt, cement or other chemical stabilization agents can be added to give the new material more strength and stability. The newly produced material is then compacted and

covered with an overlay or thin surface treatment. Green Up includes two alternatives for FDR: with asphalt emulsion and with cement. Figure 6 shows the Green Up graphic for 9 inches of FDR with cement, and the same treatment thickness with asphalt emulsion. Note that the graphics do not reflect a complete rehabilitation solution. Default values and inputs for FDR are given in Table 5.

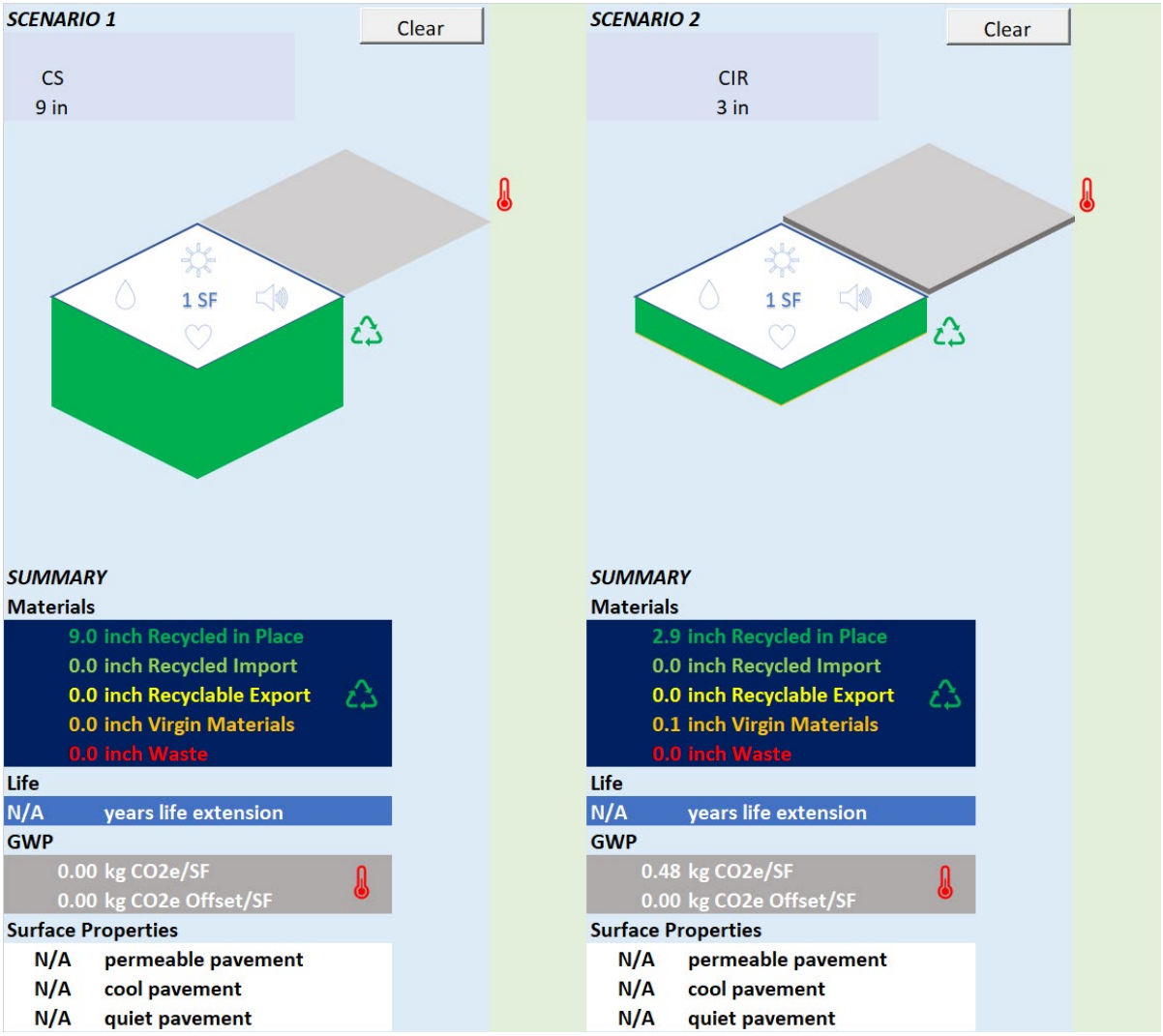

Figure 5. Green Up Graphic for 9 in. CS, 3 in. CIR

This figure was generated using Green Up Macro v101.xlsm

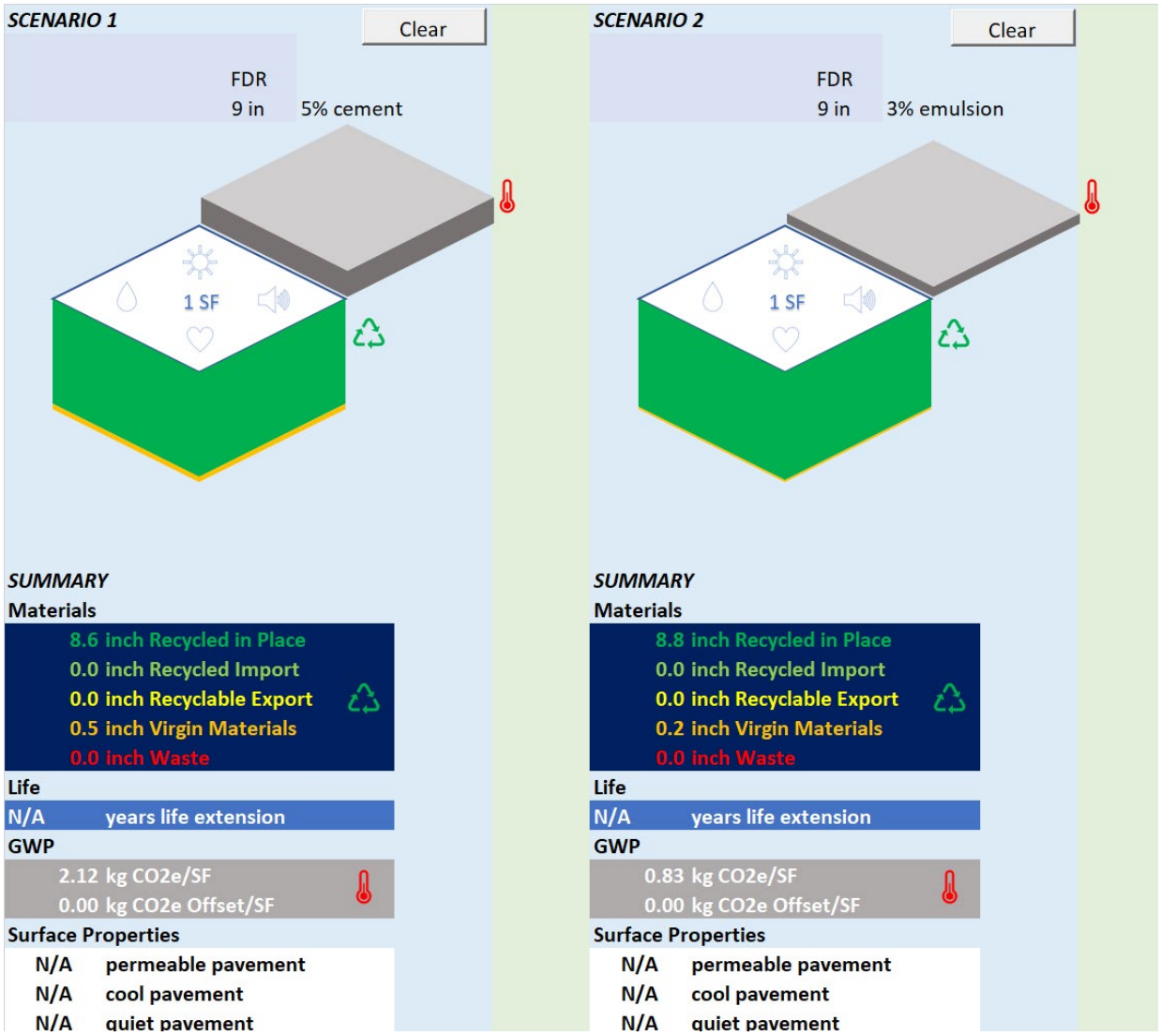

Figure 6. Green Up Graphic for 9 in. FDR with Cement, 9 in. FDR with Asphalt Emulsion

This figure was generated using Green Up Macro v101.xlsm

Table 5. Cold In-Place Recycling Inputs and Defaults

Input	Description	Default Value
Thickness	Average depth of treatment, in inches	User Input
Emulsion Content	Percent asphalt emulsion, % by weight of mix	3.0 for FDR with emulsion
Asphalt Residue	Percent asphalt cement in the emulsion, % by weight of emulsion	65
Portland Cement	Percent portland cement, % by weight of mix	5.0 for FDR with cement
G_{mb}	Bulk specific gravity of the compacted CIR mix	2.00
EPD for Asphalt Cement	Environmental Product Declaration for asphalt cement	AI LCA 3/2019
Declared Unit	Declared unit for asphalt cement EPD	Metric Ton
Asphalt GWP	Cradle-to-gate global warming potential in kg CO_2 eq (100 years) per declared unit	637
EPD for Portland Cement	Environmental Product Declaration for portland cement	PCA #035
Declared Unit	Declared unit for portland cement EPD	Metric Ton
Cement GWP	Cradle-to-gate global warming potential in kg CO_2 eq (100 years) per declared unit	1040

Since EPDs for FDR are not available at the time of this report, the global warming potential for each scenario is estimated based on EPDs for portland cement and asphalt cement and the amount of cement or asphalt in the FDR mix. FDR with cement followed by overlay can extend the life of an existing pavement structure by 15 to 20 years.[9] Similar results were reported by Bergeron for FDR with asphalt emulsion.[10]

JOINTED PLAIN CONCRETE PAVEMENT (JPCP)

Inputs and default values for JPCP are shown in Table 6. Note that all values can be adjusted by users, but these are the values that will be included by default.

In Green Up, JPCP will be assumed to be a cool surface by default due to the lighter color and higher albedo of regular concrete. Users who want to include pervious concrete will have the option to indicate that the surface is permeable, and they can adjust the mix design to reflect a pervious concrete mix. Virgin aggregates and cement will contribute to the total amount of virgin materials. Recycled aggregate, fly ash, slag, and silica fume will contribute to the recycled import category. Several JPCP scenarios are illustrated in Figure 7.

Table 6. JPCP Inputs and Defaults

Input	Description	Default Value
Thickness	Average layer thickness, in inches	User Input
Surface or Base	Users select whether the concrete will serve as the surface of the pavement	Yes/No
Pervious	If a surface, users select whether the surface is permeable	Yes/No
Cool	If a surface, users select whether the surface is cool	Yes/No
Quiet	If a surface, users select whether the surface is quiet	Yes/No
Portland Cement	Amount of portland cement, in lb/yd^3	445
Fly Ash	Amount of fly ash, in lb/yd^3	85
Slag Cement	Amount of granulated blast furnace slag (GGBFS), in lb/yd^3	0
Silica Fume	Amount of silica fume, in lb/yd^3	0
Virgin Aggregate	Amount of coarse and fine virgin aggregate, in lb/yd^3	3186
Recycled Aggregate	Amount of coarse and fine recycled aggregate, in lb/yd^3	0
EPD	Reference environmental product declaration	NRMCAEPD: 10003
Mix ID	Reference mix in the EPD	1412570
Declared Unit	Declared unit in the EPD	1m^3
GWP	Cradle-to-gate global warming potential in kg CO_2 eq (100 years) per declared unit	462

Life extension, which is represented by the color of the heart symbol, was not included in these scenarios, since this factor would depend on the existing pavement structure, future traffic, etc. The scope of Figure 7 is to illustrate the contribution of the JPCP layer alone or in combination with diamond grinding to the Green Up graphic.

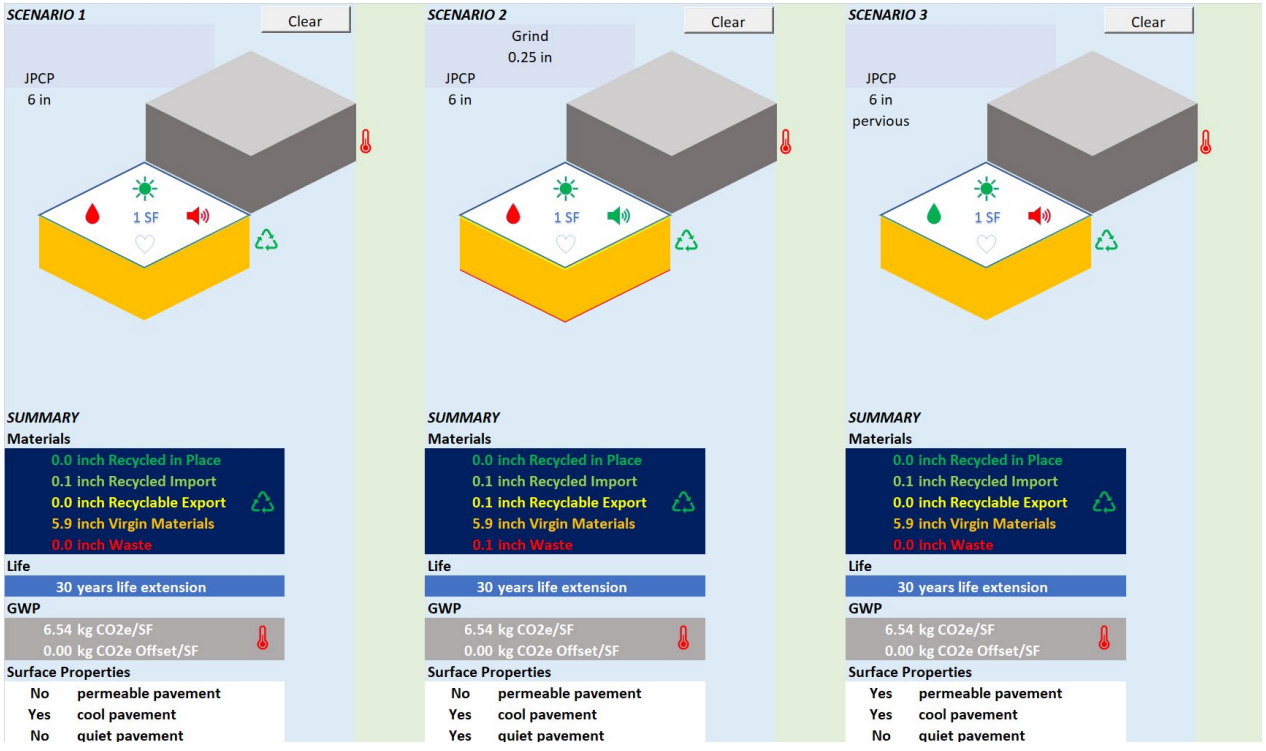

Figure 7. Green Up Graphic for 6 in. JPCP, JPCP + Diamond Grinding, and Pervious Concrete

This figure was generated using Green Up Macro v101.xlsm

HOT MIX ASPHALT (HMA)

Inputs and default values for HMA are shown in Table 7. Note that all values can be adjusted by users, but these are the values that will be included by default. In Green Up, the amount of asphalt cement and virgin aggregate will contribute to the total amount of virgin materials reported. Rubber and RAP will contribute to the recycled import category. In the user interface, a checkbox is included for warm mix technology. Although checking the box will not influence the appearance of the Green Up graphic, users will have access to an info page on warm mix and its advantages. Several HMA scenarios are presented in Figure 8.

Similar to Figure 6, life extension was not included in these scenarios since the scope of Figure 8 is to illustrate the contribution of the HMA layer alone to the Green Up graphic.

Table 7. HMA Inputs and Defaults

Input	Description	Default Value
Thickness	Average layer thickness, in inches	User Input
Surface or Base	Users select whether the concrete will serve as the surface of the pavement	Yes/No
Pervious	If a surface, users select whether the surface is permeable	Yes/No
Cool	If a surface, users select whether the surface is cool	Yes/No
Quiet	If a surface, users select whether the surface is quiet	Yes/No
Warm Mix	Users select whether warm mix technology will be used	Yes/No
Virgin Aggregate	Amount of virgin aggregate, % by weight of total dry aggregate	85
RAP	Amount of recycled aggregate, % by weight of total dry aggregate	15
Asphalt Cement	Amount of asphalt cement, % by weight of HMA mix	5.5
Rubber	Amount of crumb rubber modifier, % by weight of asphalt binder	8
G_{mb}	Bulk specific gravity of the compacted HMA mix	2.35
EPD	Reference environmental product declaration	Emerald 19.55.52.9
Mix ID	Reference mix in the EPD	2018-TM-004D-VSS-64-10-R0
Declared Unit	Declared unit in the EPD	1 U.S. Short Ton
GWP	Cradle-to-gate global warming potential in kg CO_2 eq (100 years) per declared unit	38.5

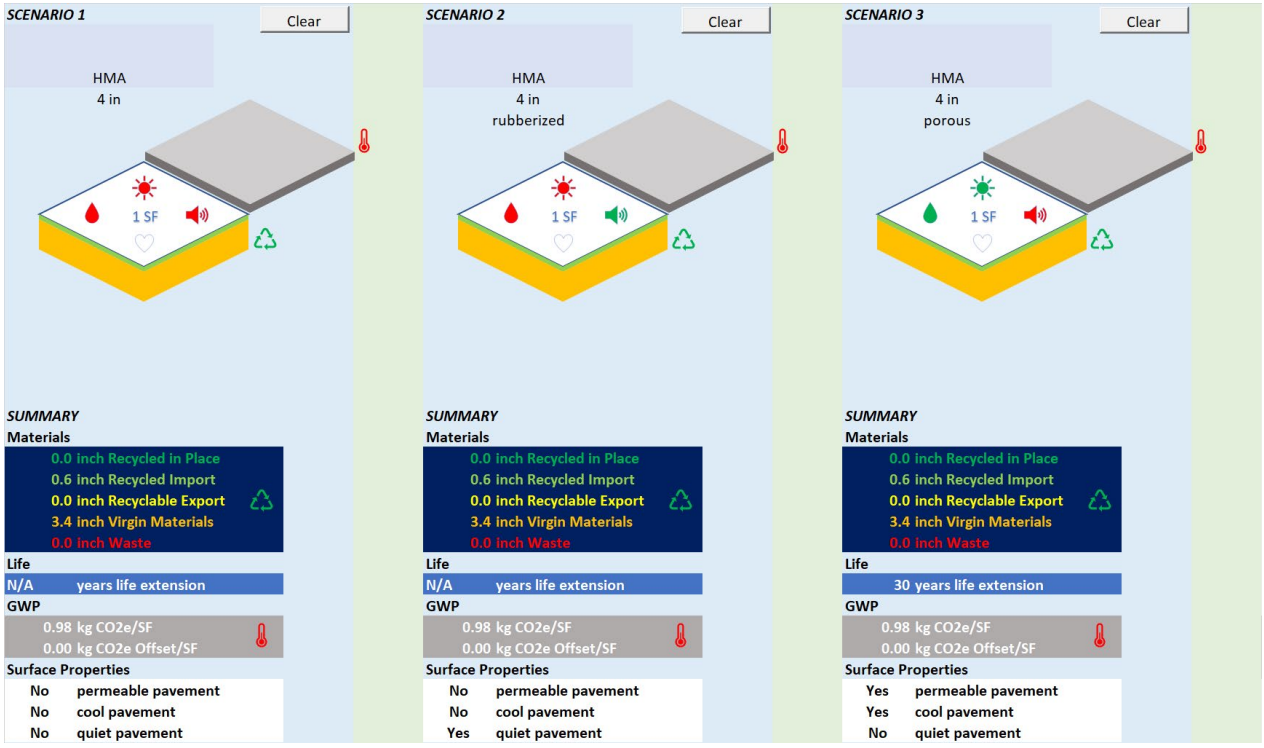

Figure 8. Green Up Graphic for 4 in. HMA, Rubberized HMA, and Porous Asphalt

This figure was generated using Green Up Macro v101.xlsm

GENERAL PROJECT INPUTS

In addition to the above rehabilitation activities, users will be asked to enter the following general project inputs:

- Estimated Life Extension

  Users can input life extension in years and will be advised to use additional resources such as PavementDesigner.org or PaveXpressDesign.com to more accurately estimate life extension for a given rehabilitation scenario. The information is used to give a different color to the heart symbol, as already described in the previous chapter. An info-page on long-life pavement will be provided to help users learn about the benefits of designing and building durable, long-lasting pavement structures.

  The info-page will also provide links to life cycle cost analysis resources which designers may want to include in their overall decision process.

- Carbon Offsets

  Users can input carbon offsets in kilograms of CO_2e (100-year GWP). Offsets are divided by the entire project area to calculate and show in the Green Up graphic the corresponding offset per square foot of project. Users will have access to an info-page on global warming potential and carbon offsets to help them decide whether they should pursue this strategy for a specific project or not.

- Permeable Pavement

  Users can indicate whether permeable pavement would be beneficial and applicable for their specific project. When the entire pavement structure is not permeable or when the pavement is subject to heavy traffic, using a permeable surface may not be recommended. Users will have access to an info-page on permeable pavements to help them decide whether they should pursue this strategy for a specific project or not.

- Tire-Pavement Noise

  Tire-pavement noise may not be an issue on pavements that are far from residential areas or in other situations where sound pollution is not an issue. Users will have access to an info-page on quieter pavements to help them decide whether they should pursue this strategy for a specific project or not.

- Heat Island Effect

  The urban heat island effect may not be an issue in rural areas or for pavements that are shaded by trees or other structures. Users will have access to an info-page on cool pavements to help them decide whether they should pursue this strategy for a specific project or not.

IV. GREEN UP GRAPHIC

This section of the report describes how the Green Up graphic is constructed based on user inputs. The Green Up graphic consists of three major areas: materials, carbon footprint, and surface/structure properties. Materials information is used to develop the colored layers below the surface which are shown next to the recycling symbol. The global warming component is used to develop the gray cloud above and to the right of the surface. Lastly, surface characteristics are used to determine the colors of the four symbols shown on the surface, as illustrated below:

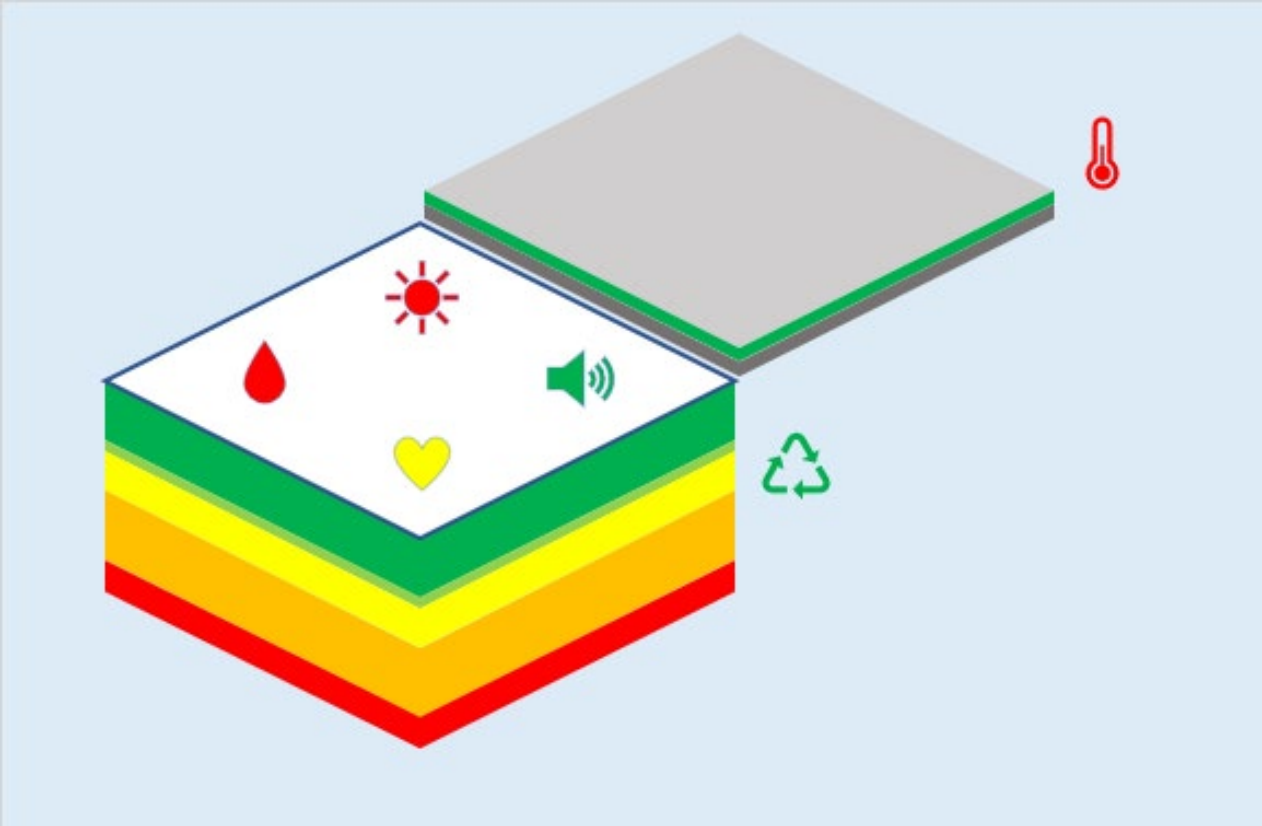

Figure 9. Green Up Graphic Example

This figure was generated using Green Up Macro v101.xlsm

For calculation purposes, the surface represents one square foot of project, or an area of 1 ft^2.

Materials

For the materials category, a 1:1 scale in inches is used, relative to the dimensions of the surface. For each rehabilitation scenario, the corresponding thickness of material in each of the five categories listed below is calculated. Totals per category are calculated and the total thickness in inches per category of materials is show in the following order, from the top (surface) down:

- Recycled In-Place (green), in inches (zG)

- Recycled Import (light green), in inches (*zLG*)
- Recyclable Export (yellow), in inches (*zY*)
- Virgin (orange), in inches (*zO*)
- Waste (red), in inches (*zR*)

To calculate the thickness corresponding to each color (category), the following equations are used:

$$zG = \sum_i t_i \times pG_i$$

$$zLG = \sum_i t_i \times pLG_i$$

$$zY = \sum_i t_i \times pY_i$$

$$zO = \sum_i t_i \times pO_i$$

$$zR = \sum_i t_i \times pR_i$$

Where:

i = indicates the i^{th} rehabilitation treatment

t_i = thickness of i^{th} rehabilitation treatment

pG_i = percent by weight of material recycled in place for the i^{th} rehabilitation treatment

pLG_i = percent by weight of material that qualifies as recycled import for the i^{th} rehabilitation treatment (for example, RAP in HMA or fly ash in JPCP)

pY_i = percent by weight of virgin material for the i^{th} rehabilitation treatment

pR_i = percent by weight of waste for the i^{th} rehabilitation treatment

Carbon Footprint

For the global warming potential category, the cradle-to-gate global warming potential for a given material is used to calculate the corresponding global warming potential per square foot of project area. In all cases, GWP from EPDs is transformed into kilograms of CO_2e per 1,000 kg material. This step gives a ratio of CO_2e to total weight of material. This ratio is then multiplied by the weight of material in one square foot of pavement and the corresponding thickness.

For portland cement concrete, a unit weight of 150 pcf (2,407 kg/m^3) was assumed. To calculate the corresponding amount of CO_2e for one square foot of concrete at a given thickness *h*, the following equation was used:

$$GWP/SF = GWP\ kg/m^3 / 2{,}407\ kg/m^3 \times 68.1\ kg/ft^3 \times 1ft^2 \times h(in.) / 12$$

For asphalt concrete, the bulk specific gravity of the compacted mix (2.35) is used to transform GWP from kilograms of CO_2e per U.S. short ton into kilograms of CO_2e per square foot of HMA at a given thickness *h* using the following equation:

$$GWP/SF = (GWP\ kg/USton \times 1.102\ mton/USton) / (2.35 \times 1{,}000\ kg/m^3) \times 66.5\ kg/ft^3 \times 1ft^2 \times h\ in. / 12$$

For CIR and FDR, global warming potential is estimated based on the amount of asphalt cement and portland cement used in the mix. A dry density of 2,000 kg/m^3 was assumed for FDR. The following equations are used:

$$GWPcement/SF = GWPc\ kg/mton / 2{,}000\ kg/m^3 \times 56.6\ kg/ft^3 \times 1ft^2 \times h\ in. / 12 \times \%cement$$

$$GWPasphalt/SF = GWPa\ kg/mton / 2{,}000\ kg/m^3 \times 56.6\ kg/ft^3 \times 1ft^2 \times h\ in. / 12 \times \%asphalt$$

Carbon offsets, if any, will be specified as a total quantity of CO_2e (100 years). This amount is divided by the project area (in square feet) to obtain the thickness of the green carbon offset layer to be shown at the top of the GWP cloud graphic, as illustrated earlier in Figure 9.

Surface Properties

The colors of the surface symbols will be dictated by user inputs, as illustrated in Figure 10.

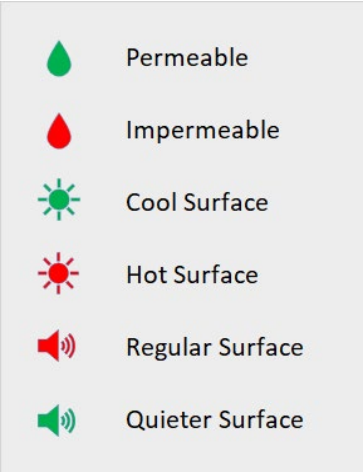

Figure 10. Legend for Surface Properties

In addition to the selections made by the users, the following automatic selections will be made:

- Diamond grinding will produce a quiet surface
- Rubberized asphalt will produce a quiet surface
- Pervious concrete will also qualify as cool pavement
- Porous asphalt will also qualify as cool pavement

Life Extension

Users will need to input the estimated pavement life extension corresponding to the recommended rehabilitation strategy. The color of the heart symbol shown on the Green Up graphic is selected according to the following formula:

$$LifeColor = Integer\left(\frac{Years}{7.5} + 1\right)$$

Where:

Years = user input, life extension for the recommended rehabilitation solution

LifeColor = numerical value corresponding to the following colors:

1 = red (less than 8 years life extension)

2 = orange (8 to 14 years life extension)

3 = yellow (15 to 22 years life extension)

4 = light green (23 to 29 years life extension)

5 = green (30 years or longer life extension)

The corresponding time scale and colors that will be used for the life diamond in the Green Up graphic are illustrated in Figure 11:

Figure 11. Color Code for the Life Component of Green Up

Most rehabilitation solutions will likely result in a life extension of less than 15 years, but the purpose of Green Up is to encourage designers to strive for longer life extensions and therefore more sustainable solutions.

V. EDUCATIONAL CONTENT

Several info pages have been developed in support of the Green Up tool. The purpose of these pages is to provide concise additional information about a topic of interest together with links to resources from industry, agencies, and academia where users can learn more about the topic or find relevant contacts. When Green Up is made available online, these info-pages will also be available as web pages. The following info pages have been developed and are included in this chapter:

- Long-life pavement
- Carbon offsets
- Quiet pavement
- Urban heat island
- Cool pavement
- Permeable pavement
- Pervious concrete
- Porous asphalt
- Warm mix

Besides serving as a resource for designers, these fact pages will also be a good resource for decision makers or engineering students who are not intimately familiar with pavement rehabilitation activities and strategies and need an introduction to the concepts and key aspects of these processes.

On the following pages, each of the concepts from the above bullet list is expanded in the form of a fact sheet.

LONG-LIFE PAVEMENTS

What is it?

Pavements can last longer than the generally accepted 20 to 40 year life spans for new construction when designed to maintain their structural integrity over time and when properly and periodically maintained. In general, long-life design strategies ensure that the pavement structure remains free of internal distress over time as long as the surface is periodically maintained.

Long-life rigid pavement design can be achieved by increasing the thickness of concrete or by using continuously reinforced concrete or steel fiber reinforced concrete. While the

initial cost will be higher than for conventional 40 years design, the long-term cost savings will likely be significant.

The concept of “perpetual pavement” is used for flexible and composite pavements which draw their strength primarily from layers of hot mix asphalt concrete. To maintain integrity over time, these layers of asphalt are thick enough to prevent bottom-up alligator cracking from initiating at the bottom of the asphalt concrete structural layer. A sacrificial surface layer is normally used to provide friction and protect the pavement core from the elements.

Why use it?

The more durable the pavement structure, the less frequent and costly will be the maintenance and rehabilitation activities needed to keep the pavement open and functional. User costs will also be minimized by reducing the frequency and duration of traffic closures. When a pavement reaches the end of its life, strong and durable structures will provide a solid foundation for re-construction and a good material source for recycling and reclaiming.

How to use it?

It is generally more sustainable to find long-term solutions and to strive for longer design lives. In Green Up, users can input the expected life extension for a specific rehabilitation scenario which will be reflected in the color of the heart symbol, ranging from red for short-term solutions to green for strategies that will extend the life of the structure by 30 years or longer. Consider design alternatives that result in longer life extensions.

Where to learn more and who to contact?

To estimate the life extension for a specific rehabilitation strategy, the following resources are available for free, online:

- PavementDesigner.org for rigid pavements
- PaveXpressDesign.com for flexible pavements

To design a “perpetual” flexible pavement:

- PerRoad software and online help and guidance

European research on steel fiber reinforced roller-compacted concrete for long-life pavements:

- ECOLANES Project 315030

Life cycle cost analysis (LCCA) resources:

- FHWA LCCA web page and RealCost software application

CARBON OFFSETS

What is it?

Pavement maintenance and rehabilitation activities generate greenhouse gas emissions that contribute to global warming. Emissions can be offset or by supporting projects that avoid or reduce greenhouse gas emissions. Such projects include: the capture and sequestration of greenhouse gases, investing in renewable energy sources, or improved forest management.

Why use it?

When a direct reduction in emissions is not possible, carbon offsets can be purchased to indirectly reduce the overall negative impact of the project on the environment.

How to use it?

Consider purchasing carbon offset credits to reduce the overall carbon footprint of your project. In Green Up, carbon offsets are subtracted from the grey GWP cloud schematically shown on the right side of the Green Up graphic.

Where to learn more and who to contact?

The Environmental Protection Agency's web page on carbon offsets and other carbon footprint reduction instruments can be found at the following URL:

- EPA carbon footprint reduction instruments

Carbon offsets can be purchased from a range of vendors. Consult a business directory or conduct an online search to find and contact vendors in your area. For example, at the time of this report, Carbonfund.org offers to offset 1 metric ton of CO_2eq for $10. Another vendor, Cooleffect.org, estimates the average cost to offset 1 metric ton of CO_2eq at $8.37.

QUIET PAVEMENT

What is it?

The term "quiet pavement" or "quieter pavement" is used for pavements where the noise levels from tire/pavement interaction are reduced in comparison with traditional pavements. Noise reduction is usually achieved by controlling the texture of the pavement surface to absorb some of the noise produced by moving vehicles.

Why use it?

Noise pollution is a significant problem in residential areas, and many public agencies have criteria for mandating noise mitigation measures such as sound walls when noise levels raise above a certain threshold. Using a quieter pavement surface can reduce noise levels by 3–5 decibels (dB), which translates into a 50% reduction in noise energy or the

equivalent of doubling the distance between the source of the noise and the receptor.

How to use it?

Consider diamond grinding for concrete pavements. Consider using rubberized asphalt concrete, open graded friction course, or stone matrix asphalt.

Where to learn more and who to contact?

The Federal Highway Administration's Sustainable Pavements Program article on tire-pavement noise:

- FHWA Tire-Pavement Noise article

International Grooving and Grinding Association:

- IGGA Technical Information page

Asphalt Pavement Alliance web page on tire-pavement noise:

- APA Noise page

URBAN HEAT ISLAND

What is it?

An urban heat island (UHI) is a metropolitan area that is significantly warmer than its surrounding rural areas. The modification of the land surface by urban development, which uses materials that effectively retain heat, is the main cause of the UHI. Paved streets, parking lots, and sidewalks, amount to about one third of the area of the average city and therefore have a significant contribution to the heat island effect. A secondary contributor to the UHI is waste heat generated by energy usage. Research into the effects of elevated urban temperatures on air quality, energy consumption, and human health has resulted in scientific, legislative, health, and municipal stakeholders implementing various strategies to mitigate this effect.

How to mitigate?

One method to reduce UHI focuses on retrofitting urban infrastructure, such as roofs and roads, with high-albedo or reflective materials. Albedo refers a surface's capacity to reflect solar radiation and is defined as the ratio of the reflected radiation from the surface to the incident radiation upon it. The greater the albedo (i.e. reflectivity), the less the radiative energy absorbed by the surface. Other mitigation strategies include the use of urban vegetation, such as shade trees, and pervious surfaces. Shade trees provide direct shade to buildings and pedestrians, while also improving the thermal environment through evapotranspiration processes and increasing albedo. Impervious surfaces lead to runoff of available moisture and limit the ability of cities to be cooled by evapotranspiration processes.

Where to learn more and who to contact?

Check out the Green Up info pages on Cool Pavement and Permeable Pavement.

Environmental Protection Agency web page on urban heat islands:

- EPA Heat Island Effect web page

Lawrence Berkeley National Laboratory:

- Berkeley Lab Heat Island Group page

COOL PAVEMENTS

What is it?

Like conventional dark roofs, dark pavements get hot in the sun because they absorb 80–95% of sunlight. Hot pavements aggravate urban heat islands by warming the local air and contribute to global warming by radiating heat into the atmosphere. When temperatures in Southern California rise above 100 degrees Fahrenheit, surface temperatures on its asphalt roads can climb to 150. Solar reflective “cool” pavements stay cooler in the sun than traditional pavements. Pavement reflectance can be enhanced by using reflective aggregate, a reflective or clear binder, or a reflective surface coating.

Why use it?

Some of the benefits of cool pavements include energy savings and emissions reductions; improved comfort and health; increased driver safety; improved air quality; reduced street lighting costs; reduced power plant emissions; improved water quality; and slowed climate change. Cool pavements lower the outside air temperature, allowing air conditioners to cool buildings with less energy while also reducing the need for electric street lighting at night. Cool pavements also reduce heat-related illnesses while slowing the formation of smog and improving pedestrian comfort. Light-colored pavements reflect streetlights and vehicle headlights at night, which increases driving visibility and reduces the costs of street lighting at night.

In some instances, cool pavements may reflect more heat and light onto adjacent buildings, making those buildings hotter. Also, the carbon footprint of the reflective paints used to make an originally low albedo pavement more reflective may be higher than the amount of carbon that would be saved by slightly lowering ambient temperatures for adjacent buildings. An important challenge is to create cool pavement materials that reduce life-cycle energy, carbon, and cost for the entire neighborhood where the pavement is located.

How to use it?

Consider using pervious concrete or porous asphalt to also provide a cool surface. Consider using a light-colored pavement surface, like concrete. Consider using specially formulated paints to increase the albedo of a darker pavement surface.

Where to learn more and who to contact?

Environmental Protection Agency cool pavement compendium:

- EPA Cool Pavement Compendium document

Lawrence Berkeley National Laboratory:

- Berkeley Lab Cool Pavements page

City of Los Angeles Cool Pavement Pilot Project:

- Cool Pavement Pilot Project

PERMEABLE PAVEMENTS

What is it?

Permeable pavement structures allow rainwater to infiltrate through the pavement surface as well as underlying layers to ultimately reach the subgrade soil. If the subgrade has adequate permeability, then the water can further infiltrate into the soil and reach the ground water. Otherwise, a drainage system may be installed to divert the water accumulated in the structure to a different location.

Traditional pavement structures are designed to prevent water from entering the pavement and to drain any water from inside the structure to the sides and away from the structure and the subgrade soil. In a structure designed to be impermeable, any accumulation of water will lead to premature failure. Therefore, permeable surfaces must be supported by permeable structures which are specifically designed to function when water infiltrates the structure. Permeable structures will normally be thicker to give water a place to be stored and will use materials with good drainage properties and which are less sensitive to changes in moisture. To ensure infiltration of water into the subgrade, it is not uncommon to leave the subgrade soil uncompacted and instead use a very thick base/subbase section to provide structural support for the surface layer.

Why use it?

In general, the benefits of permeable pavements include restoration of the ground water reserves; less consumed energy and natural resources; low-impact infrastructure; and a cost-effective method for stormwater mitigation by eliminating the use of drainage structures.

How to use it?

Consider using pervious concrete or porous asphalt on a specially designed permeable pavement structure. Permeable structures are best suited for parking lots or low traffic roads.

Where to learn more and who to contact?

The Environmental Protection Agency has a cool pavement compendium which includes information on permeable pavement:

- EPA Cool Pavement Compendium document

American Society of Civil Engineers Permeable Pavements Manual:

- Presentation about the manual

National Ready Mix Concrete Association:

- Pervious Pavement web site includes design guidelines

National Asphalt Pavement Association:

- Porous Asphalt web page includes links to design guidelines

PERVIOUS CONCRETE

What is it?

Pervious concrete is portland cement concrete with open-graded aggregate. The void space of pervious concrete is typically between 15 and 25%. Like all permeable pavements, the surface will accept sediment, thereby decreasing its infiltration rate over time.

Why use it?

Rooftops and roads represent the leading alteration in water movement across the landscape, and this alteration can have severe consequences, especially in disturbing runoff processes. As water flows over roofs and paved areas, it picks up pollutants which are transported and later deposited into bodies of water, causing those bodies to become polluted. Fully permeable pavements are sustainable and cost-effective alternatives to traditional, impervious pavements, as they eliminate the need to construct of drainage pipes or trenches for collecting stormwater, while also being able to reduce stormwater runoff and pollutants from urbanized areas.

How to use it?

Consider using pervious concrete on a specially designed permeable pavement structure. Permeable structures are best suited for parking lots or low traffic roads.

Where to learn more and who to contact?

Green Up page on permeable pavement structures:

- Green Up Permeable Pavement Info Page

National Ready Mix Concrete Association:

- Pervious Pavement web site

POROUS ASPHALT

What is it?

Porous asphalt consists of a special open-graded surface course bounded by asphalt cement, followed by a larger stone bed over the subgrade. It is designed to manage and treat stormwater runoff. The open-graded section in a typical installation ranges from 3 to 7 inches thick with a void ratio between 15% to 20%. Common applications for porous asphalt include parking areas, walkways, trails, and roads. After the water drains through the open-graded section and stone bed, it slowly infiltrates into the soil. The stone bed size and depth must be designed so that the water level never rises back into the asphalt layer.

How is this sustainable?

Porous asphalt is considered a cool pavement because of the open structure design. It also helps reduce demands on storm sewer systems by replenishing water tables and aquifers instead of directing rainfall to storm sewers.

Although porous asphalt is a great “green” alternative to conventional paving techniques, the initial costs are often higher due to the special underlying stone bed.

Where to learn more and who to contact?

Green Up page on permeable pavement structures:

- Green Up Permeable Pavement Info-Page

National Asphalt Pavement Association:

- Porous Asphalt web page includes links to design guidelines

Federal Highway Administration Tech Brief

- Porous Asphalt Pavements with Stone Reservoirs

WARM MIX ASPHALT

What is it?

Warm Mix Asphalt (WMA) is a technology that allows Hot Mix Asphalt (HMA) to be mixed and placed at lower temperatures. This technology can reduce paving costs, extend the

paving season, improve asphalt compaction, allow for increased haul distances, and improve working conditions by reducing exposure to fuel emissions, fumes, and odors.

WMA technology reduces the viscosity of the asphalt binder with additives (water-based, organic, chemical, or hybrids) so that binders and aggregates can be mixed at lower temperatures. The reduction in viscosity also allows the mixture to be easily manipulated and compacted at lower temperatures.

How is this sustainable?

Since WMA is applied at a low temperature, less fuel is needed for its production. The consumption of fuel is typically reduced by 20% compared to HMA production. Because cooling directly affects asphalt durability, cold ambient temperatures adversely affect HMA. Since WMA cools more slowly than HMA, it may be placed at lower temperatures, extending the paving season. WMA is also more easily compacted, therefore saving time and labor.

The production and application of WMA produces less smoke and dust than ordinary HMA. Consider this method if the application is in closed areas such as tunnels. WMA also produces fewer emissions. This allows for WMA to be placed on days with low air quality.

Where to learn more and who to contact?

Federal Highway Administration resources:

- FHWA warm mix article
- FHWA warm mix technologies and research

National Asphalt Pavement Association:

- NAPA warm mix web site

VI. GREEN UP EXAMPLES

The development of an online application was not included in the scope of this project. However, the project team developed a mockup application using Microsoft Excel and Visual Basic for Applications (VBA). The Excel macro can be used to perform all calculations and produce the Green Up graphic as described in Chapter IV. It does not have all the functionality that would be desired from the online app and it is not in any way ready for distribution as an alternative to the online app. However, using the Excel macro, the project team was able to experiment with and illustrate how the Green Up graphic could be used to compare different rehabilitation scenarios. Following are two examples: one for rigid pavement rehabilitation and the other for flexible pavement rehabilitation.

RIGID PAVEMENT REHABILITATION EXAMPLE

For this first example, we assumed an existing jointed plain concrete pavement (JPCP) in need of rehabilitation. PavementDesigner.org was used to model the pavement structure and to input the desired life extension in order to estimate the required thickness of rehabilitation treatment. The following assumptions were made:

- The pavement is in an urban area where heat island and noise should be mitigated
- The pavement is a major arterial roadway and permeable pavement is not an option
- The existing JPCP is 9 inches thick and with a fair amount of distress; therefore, diamond grinding alone is not an option

Using PavementDesigner.org, we obtained a recommended thickness of 2 inches for a bonded concrete on concrete overlay and an estimated life extension of 30 years or more. This is Scenario 1 in our comparison which is illustrated in Figure 12.

In Scenario 2, we use the same structure and assumptions, but we add diamond grinding after the 2 inch overlay in order to make it a quiet surface.

Scenario 3 is to remove the existing concrete slabs and replace them with new concrete slabs of the same thickness (9 inches). A comparison of the three scenarios is illustrated in Figure 12.

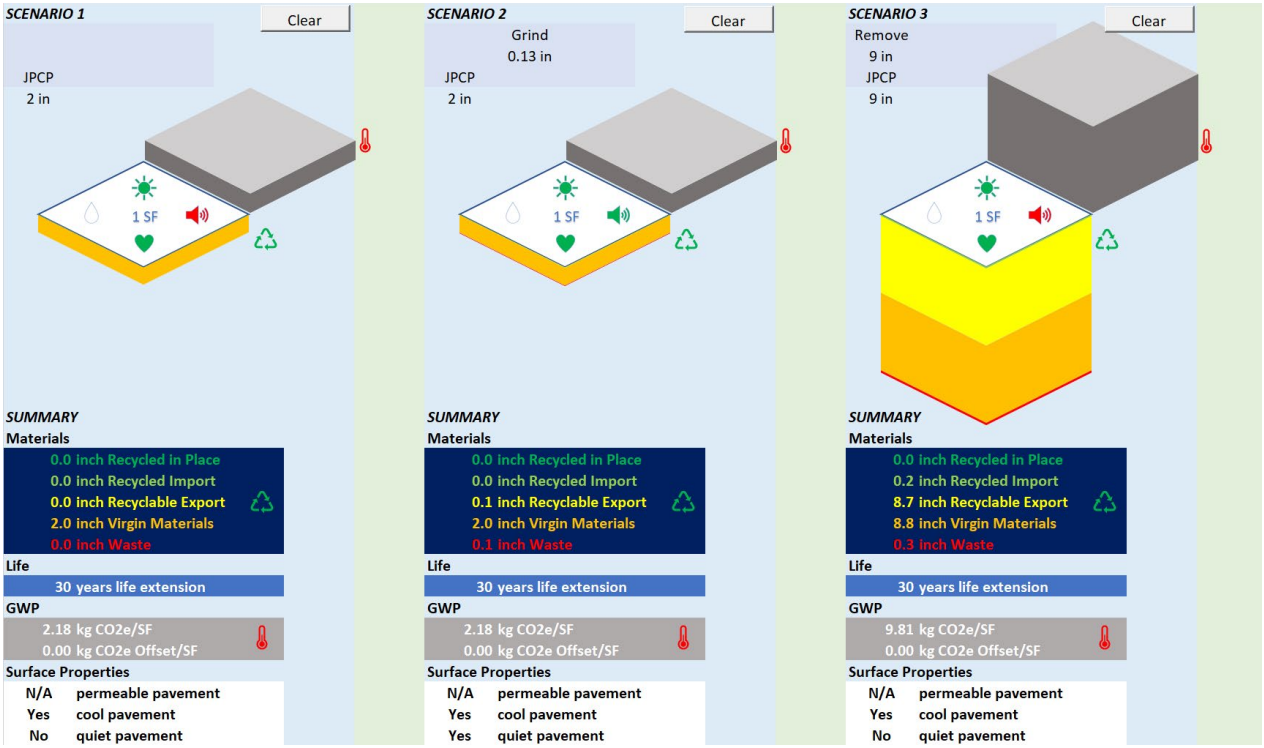

Figure 12. Rigid Pavement Rehabilitation Example

This figure was generated using Green Up Macro v101.xlsm

Green Up users will be able to compare the different rehabilitation scenarios and make an informed decision or choose to explore more rehabilitation scenarios. Life cycle cost information for each scenario, if available, should also be included in the decision process.

FLEXIBLE PAVEMENT REHABILITATION CASE STUDY

For the flexible pavement example, we assumed a collector street with 6 inches of HMA on top of a granular base. The following assumptions were made:

- The pavement is in an urban area where heat island and noise should be mitigated
- The pavement is a collector street and permeable pavement is not an option
- The existing HMA is 6 inches thick and with a fair amount of distress; raising the pavement elevations is not an option due to existing curb and utilities

The following rehabilitation scenarios were explored:

- Remove 6 inch and fill with HMA 6 inch
- Mill 2 inch, CIR 3 inch, Overlay with rubberized HMA 2 inch
- Mill 2 inch, FDR with asphalt emulsion 12 inch, overlay with rubberized HMA 2 inch

The resulting Green Up graphics are show in Figure 13.

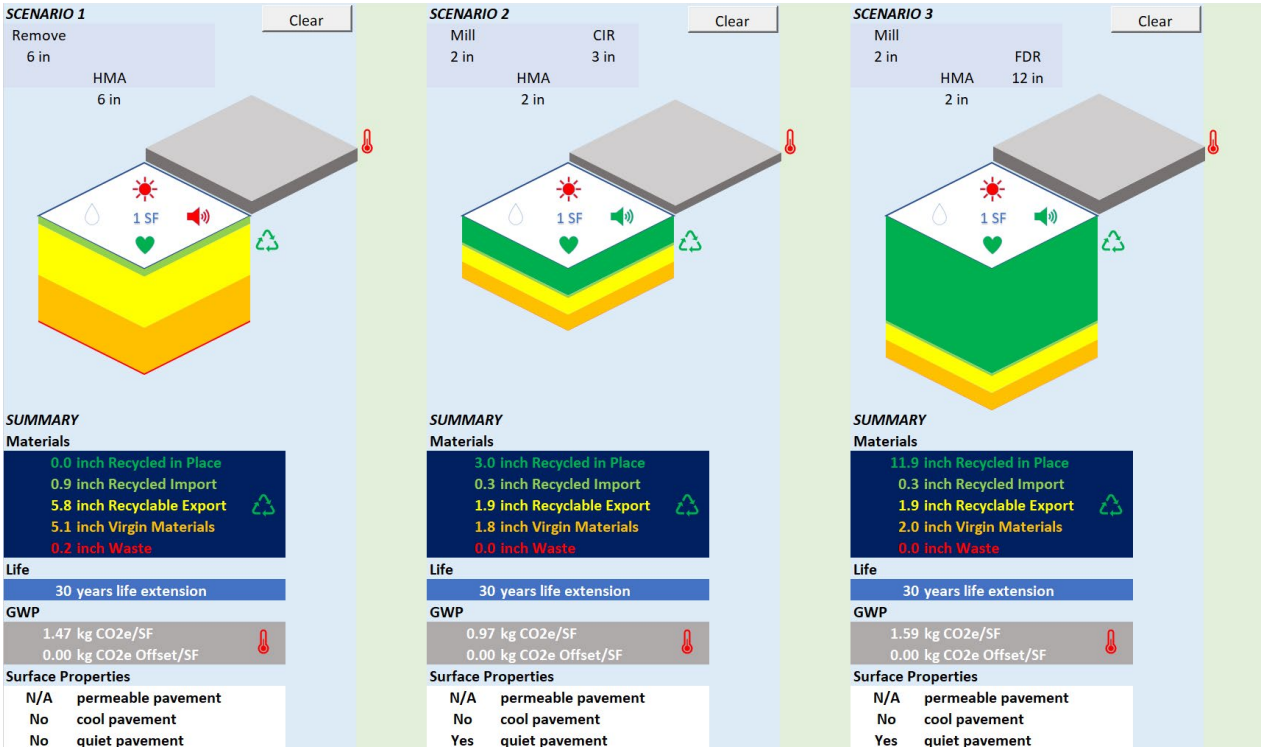

Figure 13. Flexible Pavement Rehabilitation Example.

This figure was generated using Green Up Macro v101.xlsm

As illustrated in Figure 13, the three scenarios will have different impacts on the environment. Scenarios 1 and 3 will generate about 1.5 kilograms CO_2e per square foot of project while Scenario 2 will have a lower impact at only 1.0 kilogram CO_2e per square foot. In terms of materials, Scenarios 2 and 3 reuse a larger volume of materials in comparison with Scenario 1, which relies almost entirely on virgin materials. All scenarios will contribute to the heat island effect, but Scenarios 2 and 3 use a quieter surface.

In general, agencies and consultants choose rehabilitation solutions based on cost, availability of materials, and past experience with a given rehabilitation strategy. Green Up will provide some input to the decision process by illustrating the sustainable aspects of the different solutions, as shown in Figures 12 and 13.

VII. APPLICATION FUNCTIONALITY

The next step for Green Up will be to make the application available for free online. Following are some of the desired features of the future online application:

- Users should have the ability to create a username and password to login or continue as a guest.
- Example scenarios should be available for demonstration purposes to help new users learn how to use Green Up and know what to expect.
- Registered users should have the ability to save scenarios and choose which ones to compare from all saved scenarios.
- Users should have the ability to produce a report and print or save in PDF format a rehabilitation scenario and the corresponding Green Up graphic.
- When hovering with the mouse over an area of the Green Up graphic, relevant options and suggestions for improving the sustainability of a proposed solution will be offered.
- Registered users should have the ability to produce a report that includes up to three different rehabilitation scenarios.
- Reports should include both the Green Up graphic and numerical summaries of the quantities used in developing the graphic.
- Users should have the option to share scenarios via common social media links.
- A blog and users' forum will be maintained to allow users to provide feedback, share their experiences with the site and the tool, and actively contribute to further developments of the Green Up tool.
- Potential integration with other online tools such as PavementDesigner.org and PaveXpressDesign.com should be explored. This would allow users of other online tools to add the Green Up graphic to their rehabilitation analysis.

In consultation with industry representatives, it was agreed that the online tool will be a work in progress and that application features will be added or removed primarily based on feedback from users. As a minimum, users should be able to produce the graphic, and reports and should have the ability to compare up to three scenarios side-by-side.

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