Consortium on Green Design and Manufacturing
University of California, Berkeley

PaLATE

Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE)

User Manual
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Glossary:

CIR = cold in-place recycling
GWP = global warming potential
HIPR = hot in-place recycling
HTP = human toxicity potential
NPV = net present value
RAP = reclaimed asphalt pavement
RCM = recycled concrete material
UCRF = uniform capital recovery factor

Introduction

This tool has three types of worksheets: Input, Output and Data. The User is expected to enter data in the Input worksheets only. Table 1 presents the structure of PaLATE, the name of each sheet, and its content. The first sheet, "Introduction," contains this file.

MS Excel Sheet Name		Content
1.	Introduction	introduction
2.	Design	input
3.	Initial Construction	
4.	Maintenance	
5.	Equipment	
6.	Costs	
7.	Cost Results	output
8.	Environmental Results	
9.	References	data
10.	Data →	
11.	Densities	
12.	Equipment (Details)	
13.	EMF transport	
14.	Fumes	
15.	Leachate	
16.	Cost Data	
17.	Conversions	
18.	Diagrams	

Table 1: Tool structure and content of each sheet

There is a life-cycle diagram at the top of each input worksheet that highlights in red the stage in which the user is working. The user adds data in each stage at his/her discretion, and in addition, default values or a range of values are provided for the user's convenience.

PaLATE does not take into account emissions during the user phase of the pavement, i.e., emissions from automobiles. For this, please use another tool, such as the U.S. EPA's MOBILE 6.2.

Next, a description of PaLATE based on its components is provided.

1) Input data

Design, initial construction, maintenance, equipment, and costs are sheets in PaLATE that accept data from the user. Most cells with numbers or zeros are subject to values inserted by the user. Gray shaded cells do not accept data entry.

1.1. Design

This page takes user input on the width, length and depth of the different layers of the pavement. Volumes for each layer are calculated and can be used as a guide for volume inputs on other worksheets. The layers available are:

- Wearing course 1
- Wearing course 2
- Wearing course 4
- Subbase 1
- Subbase 2
- Subbase 3
- Subbase 4

The layers are represented in a color-coded diagram of the assumed roadway design, and the same colors are used in the following pages to guide the user throughout the analysis.

It is not necessary to fill in information for all layers. The user may choose only one of them to carry out a simplified analysis. The user also inputs the volume of embankment and shoulder material to be analyzed, if applicable.

Densities for various construction materials used in PaLATE are also reported on this page. There is a column with "suggested density ranges or values (tons/yd3)." However, the user is encouraged to customize the values in the "Actual Density" column.

The period of analysis is entered to denote the years of service life of the pavement, and to calculate life-cycle costs in present value terms. The discount rate is entered in the sheet "Costs."

Only fill in data about the layers you are interested in analyzing. Leave irrelevant layers blank.

After changing any value in PaLATE, we recommend that the user saves the file under a different name (using "Save As") to avoid losing the original information in the tool.

1.2. Initial construction

This worksheet should only be used if the effects of initial construction are assessed. That is, if the user is interested in the assessment of maintenance options she/he should fill in the maintenance page and set to zero all entry cells in the “Initial Construction” page. In addition to the seven potential pavement layers, data about embankments and shoulders could be inserted here.

Each wearing course mix (asphalt or Portland cement concrete) needs to be disaggregated into its basic materials in order to account for transportation emissions in the supply chain. The "Total" in each pavement layer denotes the transportation of the wearing course mix to the construction site.

For the subbase layers as well as embankments and shoulders, transportation distances are entered for each basic material. The "Total" indicates the total volume of subbase materials in each subbase layer.

For each layer, enter/select data about materials usage and transportation: volume, transportation distance, and transportation mode. For a particular material for each layer, if multiple transportation modes are used, select the most prevalent one.

For the wearing courses, if the project uses milled old pavement (reclaimed asphalt pavement – RAP, or recycled concrete pavement - RCM), enter the volume used and the transportation distance from the old pavement site to the processing (asphalt or concrete) plant under "RAP transport" or "RCM transport." If RAP or RCM is reused on-site, enter 0 for transport distance.

For the subbases, "RAP to recycling plant" and "RCM to recycling plant" include milling or demolition of the old pavement. Enter volume used and the transportation distance from the old pavement site to the processing (asphalt or concrete) plant. For "RAP from recycling plant to site" and "RCM from recycling plant to site," indicate the transportation distance between the processing (crushing) plant and the current project site. The volumes for these two categories are linked to their respective counterparts: "RAP to recycling plant" and "RCM to recycling plant."

As a general rule, the environmental impacts are counted against the user of the materials, not the producer. For example, the user of reclaimed asphalt pavement - RAP will be accountable for the environmental impacts from the milling and transportation rather than the contractor that milled the old pavement and produced RAP.

If the pavement is constructed on a site where old pavement exists, enter data about waste materials sent to a landfill. The densities for materials can also be changed on this page, but the linked formulae will be lost from the “Design” sheet if the user saves the file.

1.3. Maintenance

This worksheet solicits data about maintenance options throughout the lifetime of the road (as identified on the “Design” sheet): wearing course reconstruction, full-depth reclamation, hot in-place recycling, cold in-place recycling, patching, microsurfacing, crack sealing, whitetopping, rubblization, as well as embankment and shoulder reconstruction.

Each wearing course mix (asphalt or Portland cement concrete) needs to be disaggregated into its basic materials in order to account for transportation emissions in the supply chain. The "Total" denotes the transportation of the wearing course mix to the construction site.

For the subbase layers as well as embankments and shoulders, transportation distances are entered for each basic material. The "Total" indicates the total volume of subbase materials in each subbase layer.

For each layer, enter/select data about materials usage and transportation: volume, transportation distance, and transportation mode. For a particular material for each layer, if multiple transportation modes are used, select the most dominant one.

For the wearing courses, if the project uses milled old pavement (reclaimed asphalt pavement - RAP or recycled concrete pavement - RCM), enter the volume used and the transportation distance from the old pavement site to the processing (asphalt or concrete) plant under "RAP transport" or "RCM transport." If RAP or RCM is reused on-site, enter 0 for transport distance.

For the subbases, "RAP to recycling plant" and "RCM to recycling plant" include milling or demolition of the old pavement. Enter volume used and the transportation distance from the old pavement site to the processing (asphalt or concrete) plant. For "RAP from recycling plant to site" and "RCM from recycling plant to site," indicate the transportation distance between the processing (crushing) plant and the current project site. The volumes for these two categories are linked to their respective counterparts: "RAP to recycling plant" and "RCM to recycling plant."

If old pavement is removed from the site, enter data about waste materials sent to a landfill. It is not recommended to change the densities for materials on this page because the links to the “Design” sheet will be lost if the user saves the file.

Full depth reclamation: If FDR is used, enter the volumes reclaimed from each layer in the "Process - Full depth reclamation" category for each layer.

1.4. Equipment

The user is provided with default equipment types for each process. The information is classified according to a list of construction and maintenance activities. Each equipment type has a brand/model, engine capacity, productivity, fuel consumption, fuel type, additional fuel consumption, and fuel type.

Modify equipment model choice as needed, or disable equipment type by process by selecting "None" from the pull-down menu. Equipment model specifications should not be modified on this worksheet. If the User wishes to insert a different model type, select "other" and insert the relevant data (equipment type, horsepower, productivity, fuel consumption, fuel type) in the "Equipment (Details)" worksheet (see 3.4.).

1.5. Costs

This worksheet calculates the net present value (NPV) of initial construction and scheduled maintenance, as well as the annualized cost over the period of analysis.

Enter the discount rate in the blue table AND fill out EITHER the green table OR the orange table for the Base Scenario. (The orange table starts in cell AY12.) The green table calculates the NPV based on the cost of the activities whereas the orange table uses a different approach and calculates the NPV based on the cost of materials, equipment, and labor. Table 2 shows the inputs for each of the models.

Activity based approach	Material based approach
• Installed Asphalt Paving Cost • Installed Concrete Paving Cost • Installed Subbase & Embankment Construction Cost • HIPR Cost • CIR Cost • Patching Cost • Microsurfacing Cost • Crack Sealing Cost • Whitetopping Cost • Rubblization Cost • Full-depth Reclamation Cost • RAP from site to landfill (transportation & disposal cost) • RCM from site to landfill (transportation & disposal cost) • RAP from site to recycling facility (transportation & handling/processing revenue [-] or cost [+]) • RCM from site to recycling facility (transportation & handling/processing revenue [-] or cost [+])	• Virgin Aggregate • Bitumen • Cement • Concrete Additives • Asphalt Emulsion • RAP from Asphalt plant • HIPR • CIR • RCM from Concrete Plant • Coal Fly Ash • Coal Bottom Ash • Blast Furnace Slag • Recycled Tires/ Crumb Rubber • Glass Cullet • Water • Steel Reinforcing Bars • RAP from site to landfill • RCM from site to landfill • Rock • Gravel • Sand • Soil • Labor • Equipment • Overhead & Profit

Table 2: Inputs needed for the cost calculation modules

The green table should be used for entering the total installed costs of the ready-mixed materials (including materials, equipment, labor, and overhead and profit) by year over the period of analysis.

The orange table should be used for entering the cost of each material that comprise the ready-mixed materials by year over the period of analysis. In addition to the material cost, the cost of labor, equipment, and overhead and profit should be entered for each year.

In the column headings, typical cost ranges are provided, and as a reminder, the total volumes originally entered in the "Initial Construction" and "Maintenance" worksheets. Specify volumes for each relevant year and material and/or process.

If the user wishes to compare cost scenarios, both the Base Scenario and the Alternative Scenario tables should be completed. The two scenarios allow for the use of two different discount rates (The Alternative Scenario tables start in cells B70 and AY70.)

If waste material is sent to a landfill, specify the state where the landfill is located. An expected tipping fee [Biocycle 2001] is provided for RAP and RCM landfilling in the appropriate columns.

2. Output

The output pages contain the results of the analysis. PaLATE reports environmental results and economic results separately.

2.1. Cost Results

Cost results are depicted in bar graphs (ready to be printed on separate pages). NPV is broken down by phase (Initial construction & Maintenance) by materials, labor, and equipment costs.

2.2. Environmental Results

Detailed results are given in tables by road layer and by life-cycle phase, and the grand totals are summarized in a more aggregated way (Table 3).

Initial Construction	Materials Production
	Materials Transportation
	Processes (Equipment)
Maintenance	Materials Production
	Materials Transportation
	Processes (Equipment)

Table 3: Life-cycle phases included in the grand totals table

The “Environmental Results” worksheet presents the life-cycle inventory of the following categories:

- Energy [MJ]
- Water Consumption [kg]
- CO_2 [Mg] emissions = Global Warming Potential (GWP)
- NO_x [kg] emissions
- PM_{10} [kg] emissions
- SO_2 [kg] emissions
- CO [kg] emissions
- Hg [g] emissions
- Pb [g] emissions
- RCRA Hazardous Waste Generated [kg]
- Human Toxicity Potential (Cancer)
- Human Toxicity Potential (Non-cancer)

In addition to the table, results are also depicted in bar graphs by life-cycle phase. Scroll to the right and down if you want to view more levels of detail.

3. Data Worksheets

Data worksheets contain a collection of data and sources for the information used throughout PaLATE. Data worksheets are placed to the right of the worksheets the user is expected to use. The data worksheets should only be modified if needed.

Data worksheets contain information from several references, and the major references for each one are listed in this document. In addition, a “Reference” sheet with all references is provided in a separate sheet of PaLATE for further information.

3.1. References

References used in the development of this tool are provided in this worksheet. Complete references resulting from a literature survey are below, organized by topic.

3.2. Data

This is an empty sheet that indicates the position of the remaining data sheets in PaLATE. The 10 worksheets found after the "Reference" worksheet contain intermediate calculations and data sources. The user need not consult these unless data updates are necessary.

3.3. Densities

This page contains density values for various materials used in road construction. The values are represented through ranges or single values accompanied by references and the characteristics of the materials.

3.3.1 References for "Density Worksheet"

1) Cement Association of Canada 2003 The Fly Ash Resource Center. "Fly Ash Quality Control" http://www.geocities.com/CapeCanaveral/Launchpad/2095/qualitycontrol.htm
2) Chesner, W.H., Collins, R. J., MacKay, M.H. (2001c) "Reclaimed Asphalt Pavement," Recycled Materials Resource Center, Publication FHWA-RO-97-148
3) Christory, J.P., Nissoux, J.L., Neussner, E., Rossberg, K., Walker, B.J., Borchgrevink, T., and Iwama, S. (1992), "Evaluation and Maintenance Of Concrete Pavements," Technical Committee on Concrete Roads, Permanent International Association of Road Congresses, 07.04.B
4) Das, B.M. (1998), Principles of Geotechnical Engineering, Fourth Edition, California State University, Sacramento, PWS Publishing Company, International Thomson Publishing
5) EduMine (2003), "Rock Types and Specific Gravity," http://www.edumine.com/Xtoolkit/tables/sgtables.htm, accessed 8/17/2003.
6) Forsberg, F., Lukanen, E., and Thomas, T. (2002) "Blue Earth County CSAH 20 – An Engineered Cold In-Place Recycling Project". 81st Annual Meeting of the Transportation Research Board. January 13-17, Washington, DC
7) Frank R. Walker Company (1986), Walker's Building Estimator's Reference Book, Frank R. Walker Company, edited by William H. Spradlin, Jr., 22nd edition, Chicago, Ill.
8) Kazmierowski, T. "In-Place Pavement Rehabilitation: The MTO Perspective" Ontario Ministry of Transportation, accessed from http://www.msoconstructionusa.com/library.html March 16, 2003.
9) Kelly, T.D., 1998, The substitution of crushed cement concrete for construction aggregates: U.S. Geological Survey Circular 1177, 15 p. Available online at URL http://greenwood.cr.usgs.gov/pub/circulars/c1177/
10) Majizadeh, K., Bokowski, G. and El-Mitiny, R. (1979), "Material Characteristics of Power Plant Bottom Ashes and Their Performance in Bituminous Mixtures: A Laboratory Investigation," Proceedings of the Fifth International Ash Utilization Symposium, U.S. Department of Energy, Report No. METC/SP-79/10, Part 2, Morgantown, West Virginia, 1979.
11) Murphy, D. and Emery, J., "Evaluation of Modified Cold In-Place Asphalt Recycling," accessed from http://www.msoconstructionusa.com/library.html March 16, 2003.
12) Naik, T.R. et. al. (2001) Performance and Leaching Assessment of Flowable Slurry. Journal of Environmental Engineering.
13) Stidger, R. (2002), "How to Manage Concrete Road Life Cycles," *Better Roads*, April 2002
14) Stidger, R.W. (2002) "New Practices for Managing Pavement Life," *Better Roads*, April 2002.
15) Stidger, R.W. (2002), "Road Works", *Better Roads,* June 2002.
16) Summers, C.J. (2002), "The Idiots' Guide to Highways Maintenance," http://www.highwaysmaintenance.com/visc.htm, accessed 8/13/2003.
17) TFHRC (2003a), "Blast Furnace Slag Material Description," Turner-Fairbank Highway Research Center, http://www.tfhrc.gov/hnr20/recycle/waste/bfs1.htm, accessed 8/13/2003
18) TFHRC (2003b), "Coal Bottom Ash/Boiler Slag Material Description," Turner-Fairbank Highway Research Center, http://www.tfhrc.gov/hnr20/recycle/waste/cbabs3.htm, accessed 8/13/2003
19) TFHRC (2003c), "Reclaimed Asphalt Pavement, Material Description," Turner-Fairbank Highway Research Center, http://www.tfhrc.gov/hnr20/recycle/waste/rap131.htm, accessed 8/13/2005
20) TFHRC (2003d), "Reclaimed Concrete Material, Material Description," Turner-Fairbank Highway Research Center, http://www.tfhrc.gov/hnr20/recycle/waste/rcc1.htm, accessed 8/13/2004

21) TFHRC (2003e), "Scrap Tires, Material Description," Turner-Fairbank Highway Research Center, http://www.tfhrc.gov////hnr20/recycle/waste/st1.htm, accessed 8/13/2004
22) TFHRC (2003f), "Waste Glass, Material Description," Turner-Fairbank Highway Research Center, http://www.tfhrc.gov/hnr20/recycle/waste/rcc1.htm, accessed 8/13/2005
23) Wilburn, D.R., and Goonan, T.G., 1998, Aggregates from natural and recycled sources: U.S. Geological Survey circular 1176, 36 p. Available only online at URL http://greenwood.cr.usgs.gov/pub/circulars/c1176/

3.4. Equipment (details)

This sheet contains information about construction and maintenance equipment such as productivity, engine capacity, fuel consumption, brand, source of information, etc.

The equipments are organized according to their use and for each type class there is a row named “Other” that should be used to customize values related to a given equipment class when the user decides to input his/her own information. In order to use the customized equipment, the user should go to the equipment sheet and select “Other” in the pull-down menu.

3.4.1. References for “Equipment (details)”

1) Air Resources Board (ARB) Notice Of Public Meeting To Consider Approval Of California’s Emissions Inventory For Off-Road Large Compression-Ignited Engines (≥25hp) Using The New Offroad Emissions Model Mail-Out #: MSC 99-32 January 27, 2000 http://www.arb.ca.gov/msei/on-road/downloads/pubs/mo9932.zip (accessed 5/12/2004)
2) Andela Co. Andela Pulverizer System http://www.andelaproducts.com/products/pulverizer4.html (accessed 5/12/2004)
3) Badger State Highway Equipment, Inc. 2004. MHB Badger Breaker http://www.badgerbreaker.com/mhb.html (accessed 5/12/2004)
4) Caterpillar 2004. Industrial Engine 3116 140-275 hp http://www.cat.com/products/engines_n_power_systems/spec_sheet_library/industrial/pdf/lehh7283.pdf (accessed 5/12/2004)
5) Caterpillar 2004. Industrial Engine 3412E 580-1050 hp http://www.cat.com/products/engines_n_power_systems/spec_sheet_library/industrial/pdf/lehh6677.pdf (accessed 5/12/2004)
6) Dynapac 2004. Soil, Asphalt and Concrete Equipment http://www.dynapac.com/index_main.asp (accessed 5/12/2004)
7) Gomaco 2004. T/C-400 Texture/Cure Machine http://www.gomaco.com/Resources/t_c400.html (accessed 5/12/2004)
8) Ingersol Rand 2004. Road Development. http://www.road-development.irco.com/index_read.html (accessed 5/12/2004)
9) John Deeere. Construction; 4WD Loaders http://www.deere.com/en_US/cfd/construction/deere_const/wheelloaders/deere_4wdloader_selection.html?sidenavstate=11 (accessed 5/12/2004)
10) Means (1995), “R. S. Means Building Construction Cost Data”, R. S. Means Co., Kingston, MA, 1995.
11) Sterling Trucks http://www.sterlingtrucks.com/PageServer.asp?Location=Sitemap (accessed 5/12/2004)
12) U.S. EPA (2000) Hot Mix Asphalt Plants - Emission Assessment Report (EPA 454/R-00-019). Final report dated December 2000. Report body. Posting date: 12-22-00
13) Wendt Co. Scrap Tire Processing http://www.wendtcorp.com/tires.asp (accessed 5/12/2004)
14) Wirtgen 2004. Wirtgen Products. http://www.wirtgen.com/eng/eprod/index.html
15) Factor Information Retrieval (FIRE) http://www.epa.gov/ttn/chief/software/fire/

3.5. EMF transport

This page contains the information used to calculate emission factors for transport, equipment, and materials used in PaLATE.

3.5.1. References for “EMF transport”

1) [OECD. 1997] Organisation for Economic Co-operation and Development (1997), "The environmental impacts of freight", Table 9. Truck Air Pollution Emission Factors, in grams/tonne-km http://www1.oecd.org/ech/pub/TRANSP4.PDF, accessed July 10, 2003.
2) Air Resources Board (ARB) Notice Of Public Meeting To Consider Approval Of California’s Emissions Inventory For Off-Road Large Compression-Ignited Engines (≥25hp) Using The New Offroad Emissions Model Mail-Out #: MSC 99-32 January 27, 2000 http://www.arb.ca.gov/msei/on-road/downloads/pubs/mo9932.zip (accessed 5/12/2004)
3) Carnegie Mellon University Green Design Initiative (2003), Economic Input-Output Life Cycle Assessment (EIO-LCA) model [Internet], Available from: <http://www.eiolca.net/> [Accessed 23 Jul, 2003]
4) Gasoline and Diesel Industrial Engines-Emission Factor Documentation for AP-42 Section 3.3, USEPA, October 1996; http://www.epa.gov/ttn/chief/ap42/ch03/bgdocs/b03s03.pdf; Accessed 03/20/02 at 12PM
5) Health Assessment Document for Diesel Engine Exhaust, US EPA, EPA/600/8-90/057F, May 2002.
6) Hertwich E G, Mateles S F, Pease W S, McKone T E, "Human Toxicity Potentials for Life Cycle Assessment and Toxics Release Inventory Risk Screening", Environmental Toxicology and Chemistry, 20(4), 2001.
7) TIET-4-10-03, transportation emissions factors.
8) USEPA AP-42 Section 3.3 Gasoline and Diesel Industrial Engines http://www.epa.gov/ttn/chief/ap42/ch03/

3.6. Fumes

This page contains the source of information for the fumes released during asphalt paving and the calculation of the human toxicity potential (HTP) associated with emissions.

3.6.1. References for “Fumes”

1) Hertwich E G, Mateles S F, Pease W S, McKone T E, "Human Toxicity Potentials for Life Cycle Assessment and Toxics Release Inventory Risk Screening", Environmental Toxicology and Chemistry, 20(4), 2001.
2) U.S. Department of Health and Human Services. Public Health Service. Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health. 2000. Hazard ReviewHealth Effects of Occupational Exposure to Asphalt. DHHS (NIOSH) Publication No. 2001–110.

3.7. Leachate

This worksheet contains leachate estimations for various construction materials, the information source, and the calculation of HTP based on leachates.

3.7.1. References for “Leachate”

1) Morse, A., Jackson, A., and Davio, R. (2003), "Environmental Characterization of Traditional Construction and Maintenance Materials," Texas Tech University, Texas DOT, Beneficial Use of Recycled Materials in Transportation Applications, November 13-15, 2001, sponsored by the Recycled Materials Resource Center, University of New Hampshire, Durham, New Hampshire, and the Air & Waste Management Association, published 2003.
2) Naik, T.R. et. al. (2001) Performance and Leaching Assessment of Flowable Slurry. Journal of Environmental Engineering.

3.8. Cost Data

This page contains a compilation of costs and their respective references for various materials and processes used in pavement construction and maintenance.

3.8. References for “Cost Data”

1) “Ferrous” (2002), Recycling Today, January 2002, p. 11.
2) Asphalt Pavement Alliance (2003b), “Rubblization-The Fast, Long-Lasting Solution” http://www.AsphaltAlliance.com, visited March 16, 2003.
3) Butalia, T.S. and Wolfe, W.E. (2003), “Utilization of Coal Combustion Products in Ohio for Construction and Repair of Highways,” Beneficial Use of Recycled Materials in Transportation Applications, November 13-15, 2001, sponsored by the Recycled Materials Resource Center, University of New Hampshire, Durham, New Hampshire, and the Air & Waste Management Association, published 2003.
4) Button, J.W., Estakhri, C.K., Little, D.N. (1995) “Performance and Cost of Selected Hot in Place Recycling Projects”. *Transportation Research Record.* 1507 – Seal Coats and Asphalt Recycling.
5) Button, J.W., Little, D.N., Estakhri, C.K. (1994) Synthesis of Highway Practice 193. Hot in Place Recycling of Asphalt Concrete. National Cooperative Highway Research Program. National Academy Press.
6) Christory, J.P., Nissoux, J.L., Neussner, E., Rossberg, K., Walker, B.J., Borchgrevink, T., and Iwama, S. (1992), “Evaluation and Maintenance Of Concrete Pavements,” Technical Committee on Concrete Roads, Permanent International Association of Road Congresses, 07.04.B
7) Federal Highway Administration, U.S. Department of Transportation, (1999a), “Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements, Manual of Practice,” FHWA Report No. FHWA-RD-99-152.
8) Federal Highway Administration, U.S. Department of Transportation, (1999b), “Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements, Manual of Practice,” FHWA Report No. FHWA-RD-99-147,
9) Forsberg, F., Lukanen, E., and Thomas, T. (2002) “Blue Earth County CSAH 20 – An Engineered Cold In-Place Recycling Project”. *81st Annual Meeting of the Transportation Research Board*. January 13-17, Washington, DC
10) Landers, K. (2001c), “North America’s Road Reclaimers Take a Power Trip,” *Better Roads*, July 2001.
11) Malhotra, V.M. (1993), “Fly ash, slag, silica fume, and rice-husk ash in concrete: a review”, *Concrete International*, April 1993, pp.23-28
12) Murphy 2003
13) Murphy, D. and Emery, J., “Evaluation of Modified Cold In-Place Asphalt Recycling,” accessed from http://www.msoconstructionusa.com/library.html March 16, 2003.
14) Nash, P.T., Senadheera, S., and Davio, R. (2003), “A Summary of Findings for Eight Nonhazardous Recycled Materials (NRMs) Applied to Roadway Construction in Texas”, Beneficial Use of Recycled Materials in Transportation Applications, November 13-15, 2001
15) Stidger, R.W. (2002) “New Practices for Managing Pavement Life,” Better Roads, April 2002.
16) USGS (2000), “USGS: Recycled Aggregates—Profitable Resource Conservation” USGS Fact Sheet FS-181-99, February 2000.

17) Wilburn, D.R., and Goonan, T.G., 1998, Aggregates from natural and recycled sources: U.S. Geological Survey circular 1176, 36 p. Available only online at URL http://greenwood.cr.usgs.gov/pub/circulars/c1176/
18) Zimmerman, K.A. (1997) Guidelines for Using Economic Factors and Maintenance Costs in Life-Cycle Cost Analysis. Study SD96-08. SDDOT – Applied Pavement Technology, Inc. Urbana, IL.

3.9. Conversions

This page contains conversion factors used in PaLATE.

3.9.1. References for "Conversions"

1) ORNL 2004. Transportation Energy Data Book: Edition 21 www-cta.ornl.gov/data/tedb21/Full_Doc_TEDB21.pdf
2) IPCC 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (3 Volumes) Approved in 1996, and published in 1997.Module 1: Energy. http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1wb1.pdf

3.10. Diagrams

This page contains a diagram representing the structure of PaLATE and its analytical linkages.