Sustainability and Life Cycle Analysis of Recycled Materials in Geotechnical Applications

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Why is Sustainability Important?

- Nexus of major issues caused by rapidly growing global economy:
  - Global warming
  - Energy constraints
  - Resource availability (metals, cement, water etc.)
- World population is 6 billion (B) → 12 B projected by 2100. US at 0.5B by 2050.
- US and EU (combined population = 0.75 B) consume most of world resources. China catching up fast.
- Remaining 5.25 B want everything we have. Not enough to go around if we do business as usual.

How Can We Make Infrastructure Construction More Sustainable?

1. Reduce energy consumed in construction and rehabilitation.

2. Reduce emissions emitted in construction and rehabilitation.

3. Reduce consumption of natural resources.

4. Increase service life.

How Do Recycled Materials Fit In?

1. Avoid energy and emissions associated with mining and processing construction materials. Energy has already been expended in first life of recycled material.

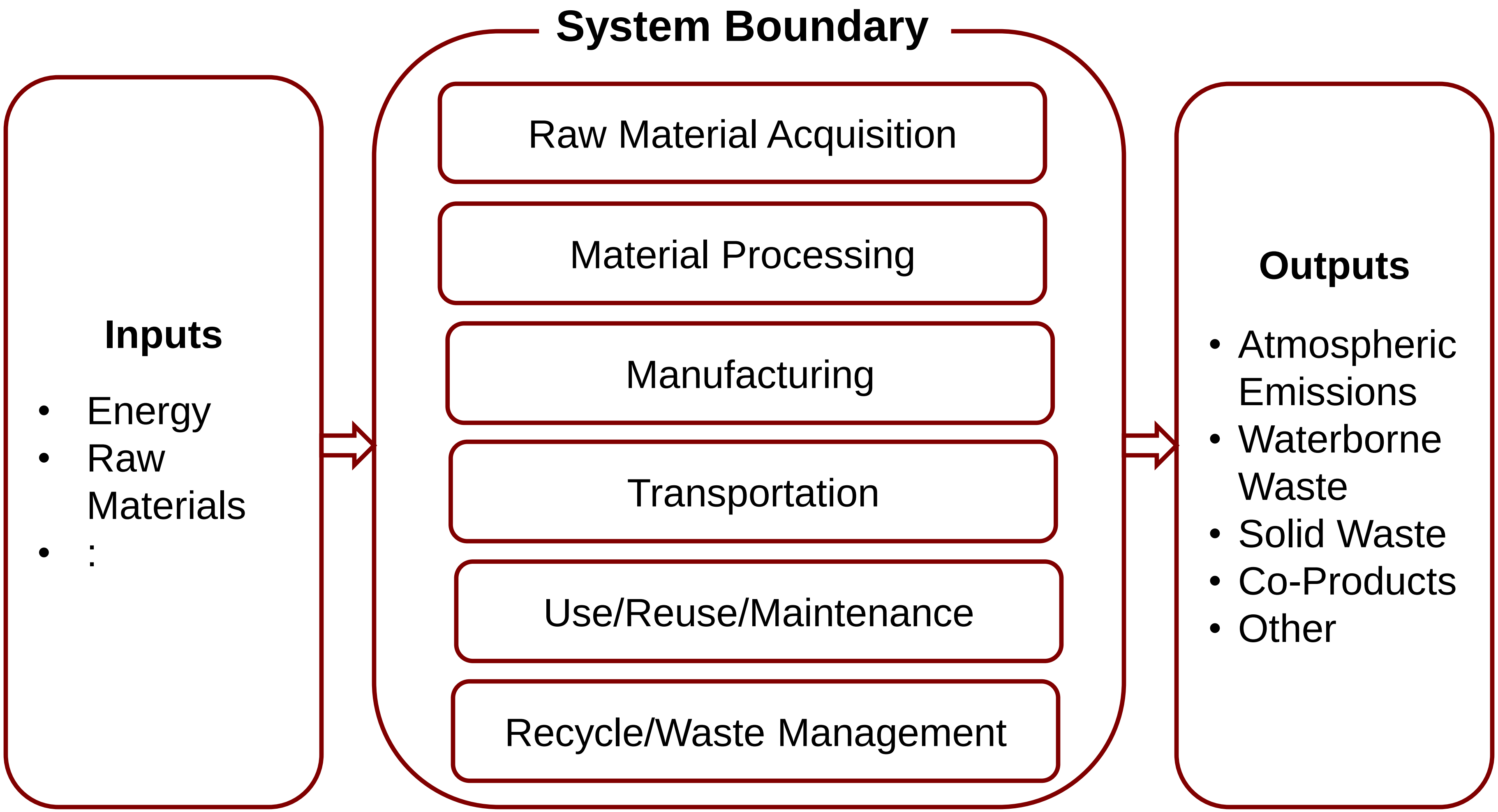
2. Avoid use of a natural resource (sand and gravel, limestone, oil).

3. Increase service life. Not a "linear landfill," but better and longer lasting infrastructure.

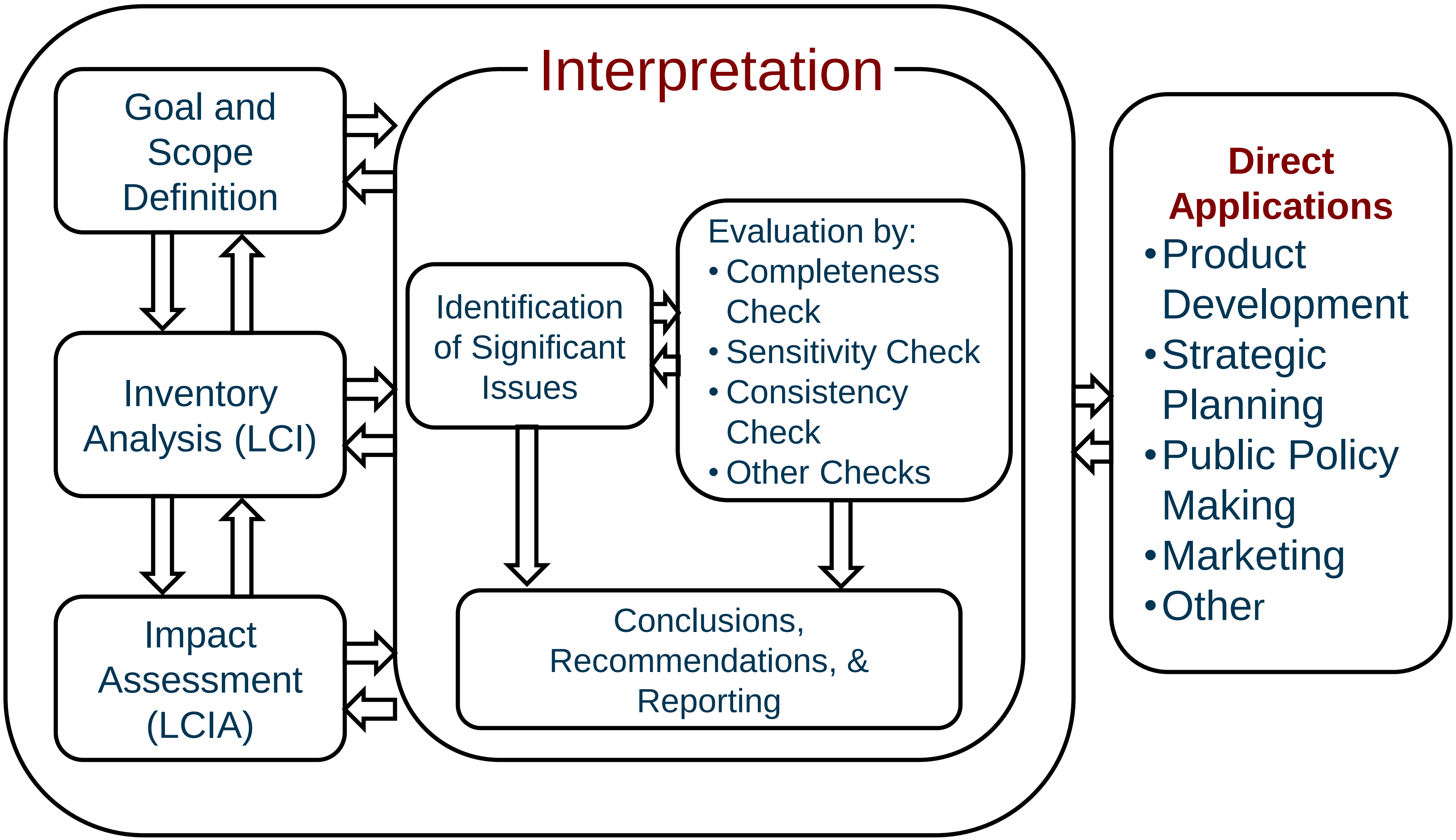
How do we demonstrate that we are contributing to sustainability? Using life cycle analysis, or LCA

LCA Definition - ISO 14040

Compilation & evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.



LCA Framework



Goal and Scope Definition

- Intended application & audience
- Identify product system
- Identify functional units
- Define system boundaries
- Identify assumptions, limitations, & allocations
- Data requirements

Life Cycle Inventory Analysis (LCIA)

Data Collection

- Inputs (energy, raw material, ancillary, etc.)
- Products, co-products, and waste
- Air emissions, water and soil discharges, etc.

Data Calculation

Connect data to unit processes & reference flows

Examples of LCI Databases

- Ecoinvent (http://www.ecoinvent.org/database/)
- US Life Cycle Inventory Database (http://www.nrel.gov/lci/)
- More LCI database info at:

http://www.epa.gov/nrmrl/lcaccess/pdfs/summary_of_global_lci_data_resources.pdf org/database/

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ecoinvent Centre

Swiss Centre for Life Cycle Inventories

a Competence Centre of ART PSI EPFL ETH EMPA

Direct access to database

Username:

Password:

Login Forgot your password?

Organisation | Database | Documentation | News | ecoinvent v3

Database

- Registration
- Price List
- Resellers
- EcoSpold Data Format
- How to use
- Terms of Use

Database

Our core product is the database ecoinvent data in its current version v2.2 – the world's leading database with consistent and transparent, up-to-date Life Cycle Inventory (LCI) data. With more than 4'000 LCI datasets in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics as well as waste treatment, we offer one of the most comprehensive international LCI databases. Our high-quality generic LCI datasets are based on industrial data and have been compiled by internationally renowned research institutes and LCA consultants. The data are available in the EcoSpold data format, and they are compatible with all major LCA and eco-design software tools.

A registration as a **Guest** (online here; free of charge) is a possibility to allow you to get a detailed overview of the content of the ecoinvent database, as well as an access to an electronic version of the background reports. Like this, you get an impression how to use the ecoinvent database and an overview of the numerous datasets contained in it, before you register as a **User** to make full use of all functions and download all the datasets you need, by ordering your ecoinvent licence …

… directly via registration here (price EUR 1'800, excl. VAT):
Enjoy an on-line access to our fully transparent life cycle inventory data, to life cycle inventory results and to impact assessment results. Read all details on the inventories in high-standard background reports shipped to you on a CD-ROM.

… via one of our resellers (price according to reseller):
Your LCA software supplier offers you software together with embedded ecoinvent data and

Cycle Invento

nrel.gov/lci/

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U.S. Life Cycle Inventory Database

More Search Options SEARCH
Site Map

About the Project

Database

Publications

Life Cycle Assessments

Related Links

NREL's Buildings research supports the U.S. Department of Energy's Building Technologies Program.

NREL and its partners created the U.S. Life Cycle Inventory (LCI) Database to help life cycle assessment (LCA) practitioners answer questions about environmental impact. This database provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S.

The goals of the U.S. LCI Database project are:

- Maintain data quality and transparency
- Cover commonly used materials, products, and processes in the United States with up-to-date, critically reviewed LCI data
- Support the expanded use of LCA as an environmental decision-making tool
- Maintain compatibility with international LCI databases
- Provide exceptional data accessibility
- Be fully and sustainably supported
- Support U.S. industry competitiveness.

Read the plan to achieve the goals of the LCI Database Project in the *U.S. Life Cycle Inventory Database Roadmap*.

LCA in the News and Related Research

Life cycle environmental impacts of selected U.S. ethanol production and use pathways in 2022

EVENTS

SolWest Renewable Energy Fair
July 29 - 31, 2011
John Day, OR

Renewable Energy Technology Conference & Exhibition (RETECH 2011)
September 20 - 22, 2011
Washington, DC

More Events

U.S. Life Cycle Inventory Database Roadmap

U.S. Life Cycle Inventory Database Dataset Additions

Recap Poll # 1 – True or False

- Life cycle analysis (LCA) can be used to assess a contribution to sustainability quantitatively: T/F

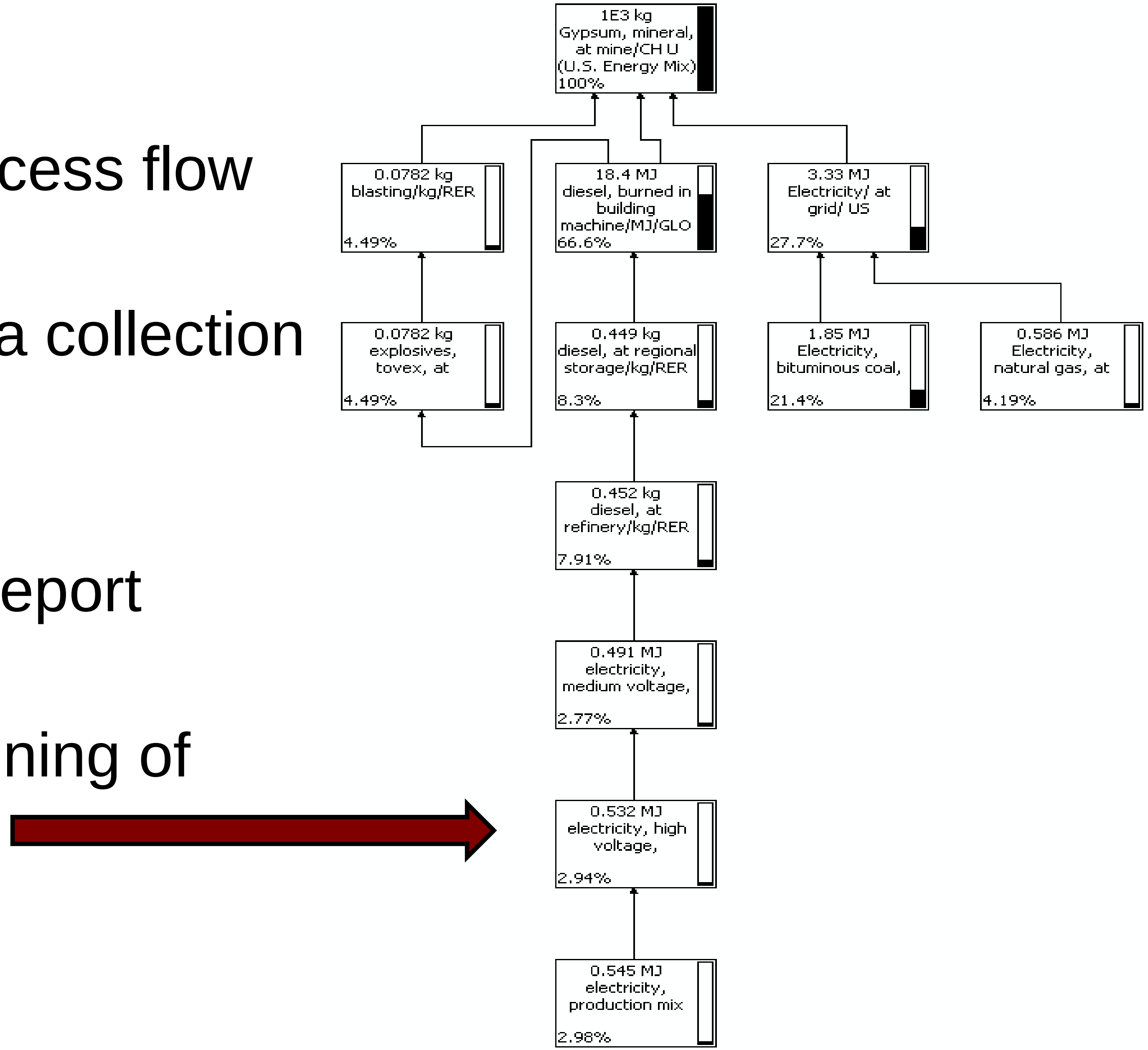
- LCAs will produce the same result regardless of the system boundary that is selected: T/F

- All LCAs are based on the same life cycle inventory (LCI): T/F

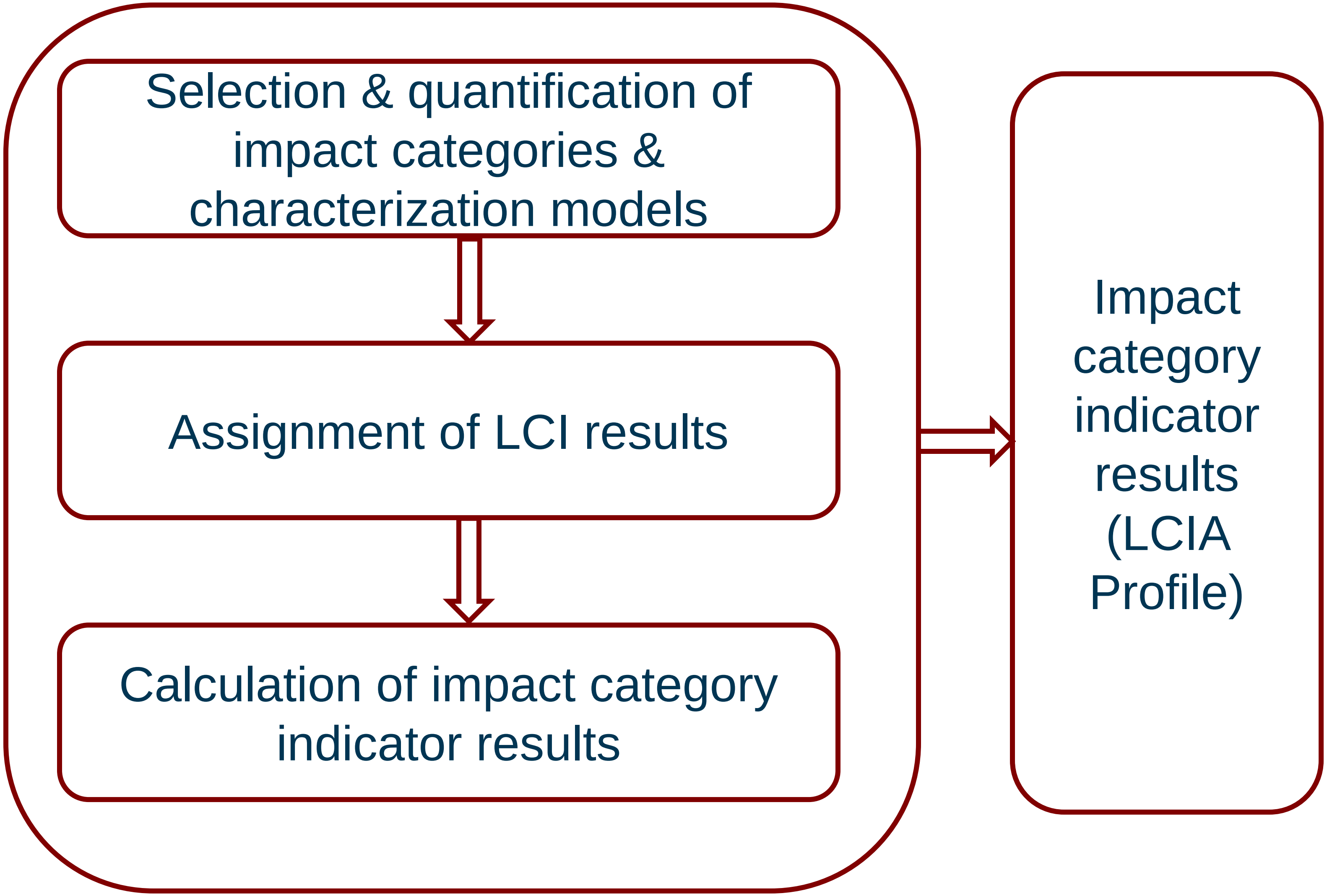
- Currently there are no standard methods for conducting LCAs: T/F

Steps to Conduct an LCI

- Develop process flow diagram
- Develop data collection plan
- Collect data
- Evaluate & report results
- Example: Mining of Gypsum



Life Cycle Impact Assessment (LCIA)



Common LCIA Impact Categories

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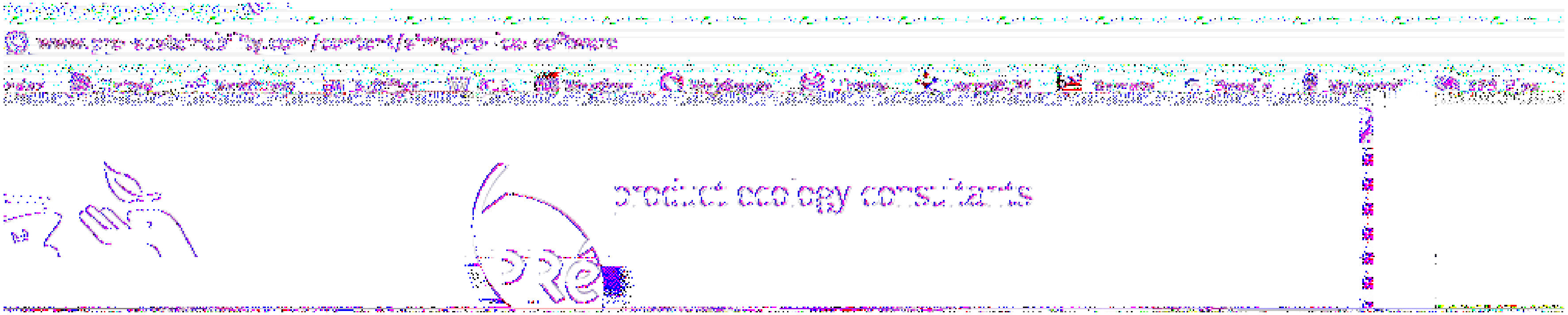
Interpretation

- Identify significant issues
- Evaluate completeness, sensitivity, and consistency of data
- Draw conclusions & recommendations
- Report results
- Critical review

LCA Modeling Software Tools

- PaLATE – pavement LCA
- SimaPro – general LCA software
- Umberto – general LCA software
- GaBi – general LCA software
- BEES (Building for Environmental and Economic Sustainability) – building material and product construction
- CMLCA – chain management by LCA
- GEMIS (Global Emission Model for Integrated Systems) – energy, material and transport system LCA


product ecology consultants

w.gabi-software.com/america/software/gabi-4/

United MapQuest E-Office GLE Weather WebSpace Library Learn@UW Remote Doodle Voicemail EPD Files EES at NSF

GaBi Software

Your Country:

Recap Poll # 2 – True or False

- The US Life Cycle Inventory from NREL must be used for US life cycle analyses: T/F

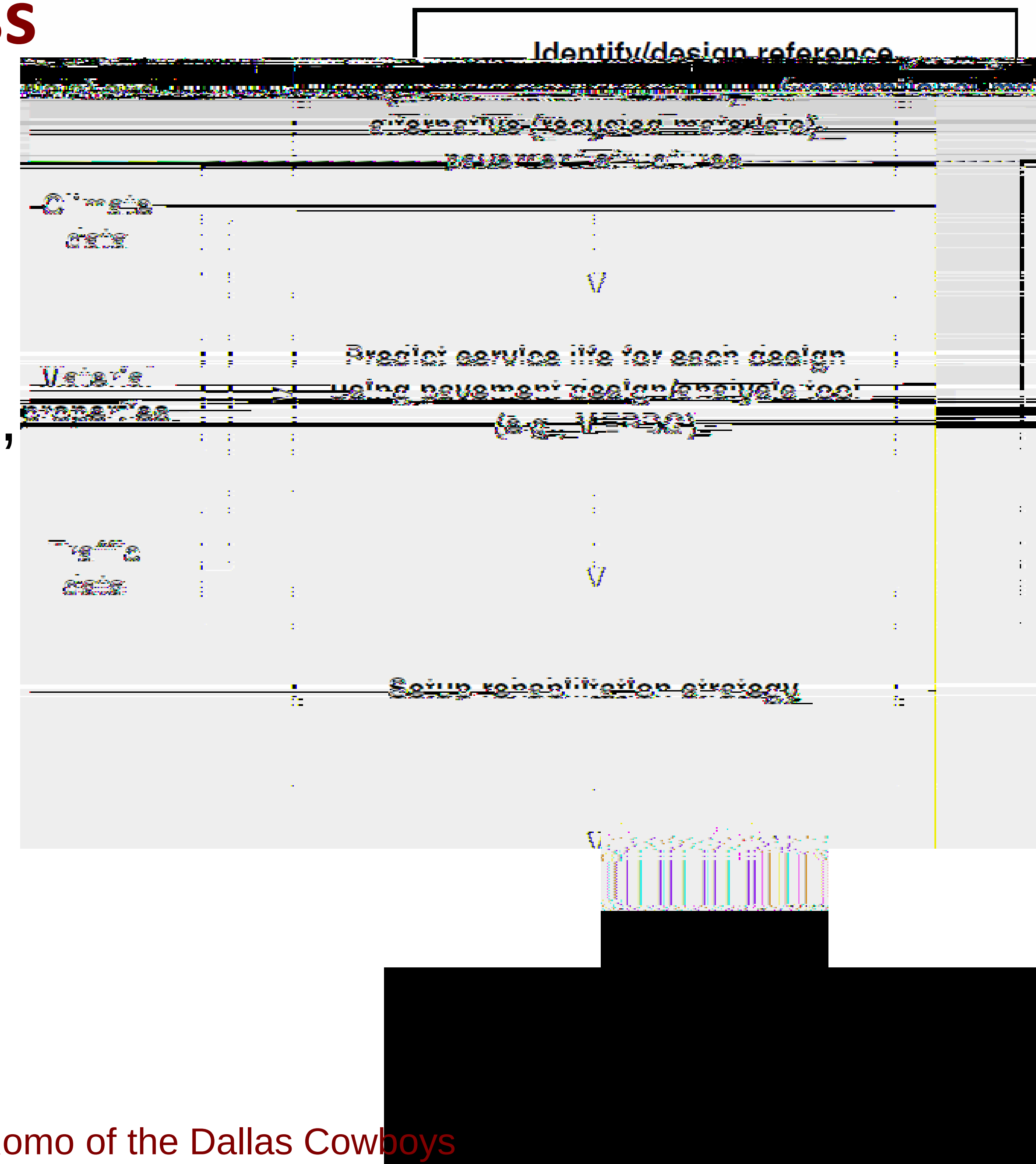
- Users can input their own energy and emissions data into a LCA: T/F

- The three life cycle impacts are energy, GHG emissions, and water usage: T/F

Burlington Bypass Case History Burlington, WI

Define:

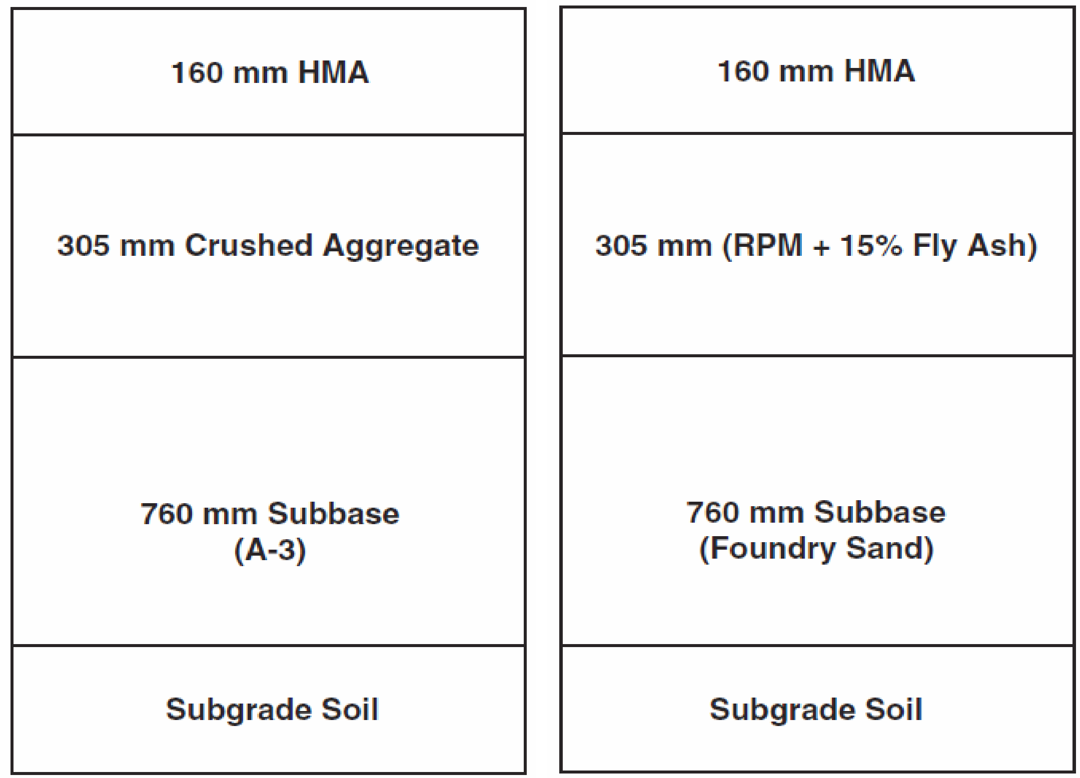
energy consumption, greenhouse gas emissions, water consumption, and hazardous waste generation for conventional pavement versus pavement with recycled materials



Burlington is the hometown of Tony Romo of the Dallas Cowboys

Highway Pavement Design Assumptions

- Recycled materials used in base & subbase layers.
- Same layer thickness.
- Structural capacity for both designs calculated with same procedure.
- Engineering properties of recycled vs. conventional materials change service life over a 50-yr design period.



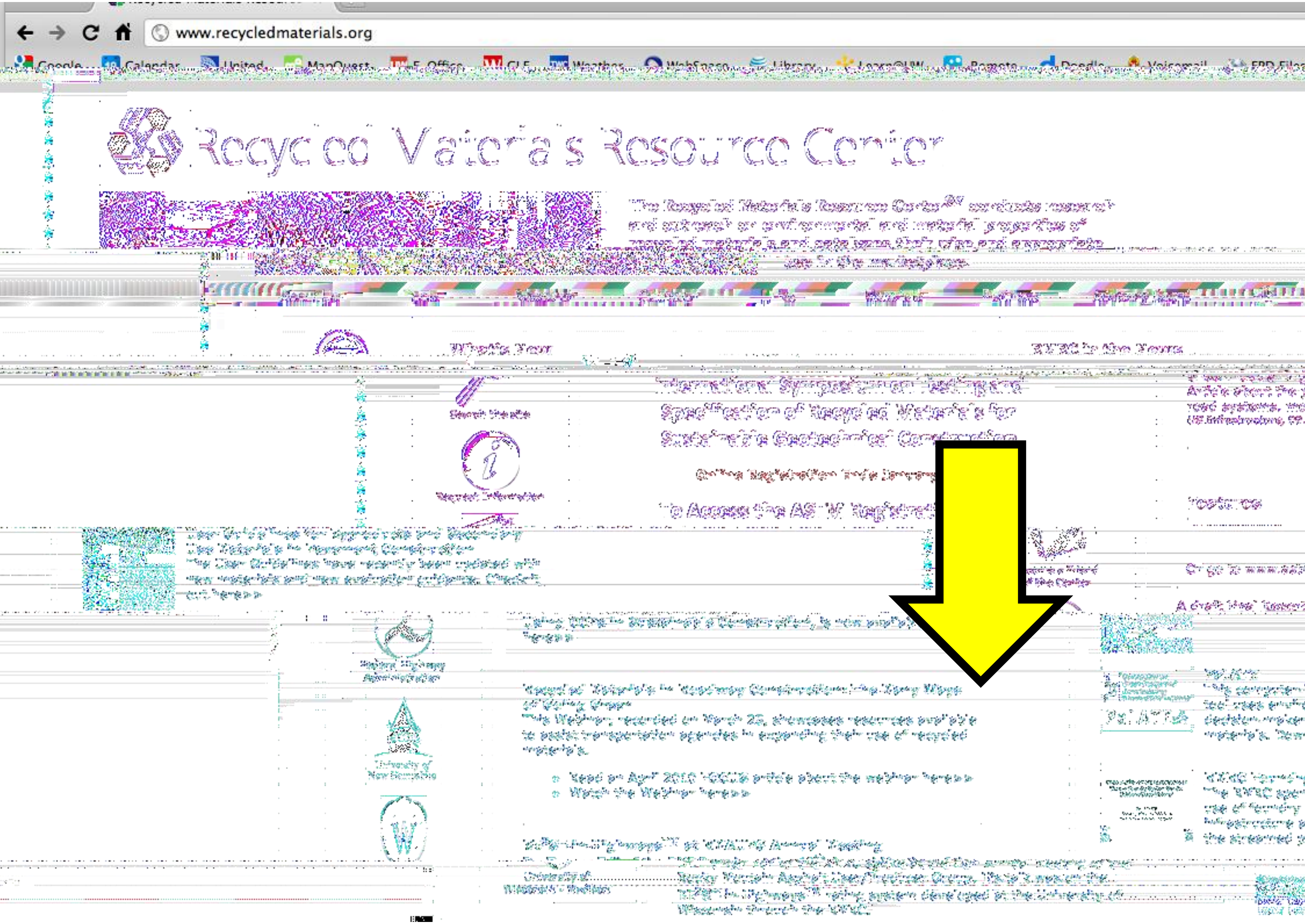
PaLATE Used for LCA

- Contains LCI information for common recycled materials in geo-construction (e.g., fly ash).
- Built in LCI for common construction equipment based on anticipated equipment activity.
- Economic input-output LCA methodology allows assessment of entire supply chain associated with conventional & recycled construction materials.
- **FREE** from RMRC website (www.recycledmaterials.org).

Consortium on Green Design and Manufacturing
University of California, Berkeley

PaLATE

Pavement Life-cycle Assessment Tool for Environmental and Economic Effects


www.recycledmaterials.org
Recycled Materials Resource Center

PaLATE Inputs – Roadway Example

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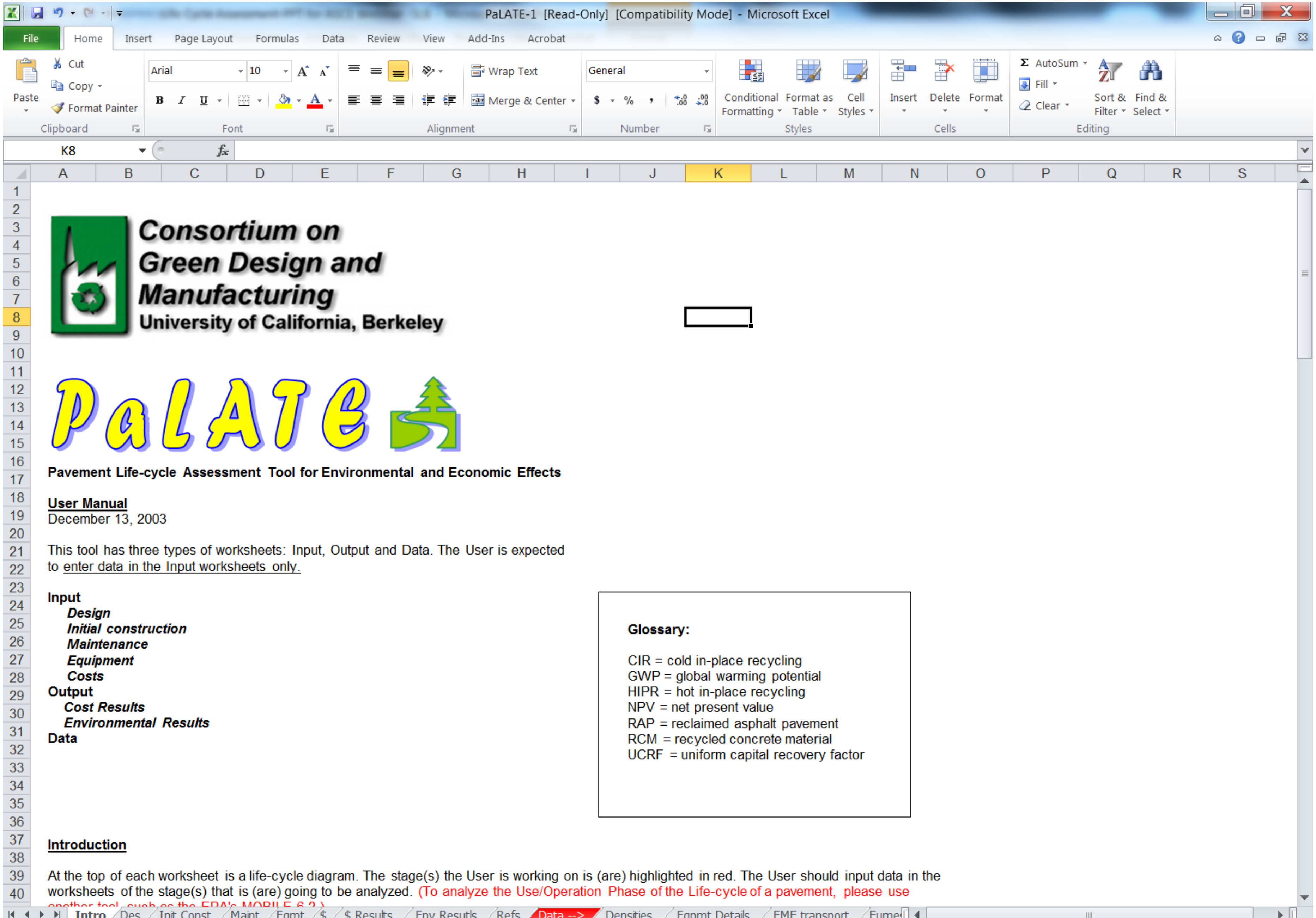
A Walk Through PaLATE



Consortium on Green Design and Manufacturing
University of California, Berkeley

PaLATE

Pavement Life-cycle Assessment Tool for Environmental and Economic Effects

User Manual
December 13, 2003

This tool has three types of worksheets: Input, Output and Data. The User is expected to enter data in the Input worksheets only.

Input
- ***Design***
- ***Initial construction***
- ***Maintenance***
- ***Equipment***
- ***Costs***

Output
- ***Cost Results***
- ***Environmental Results***

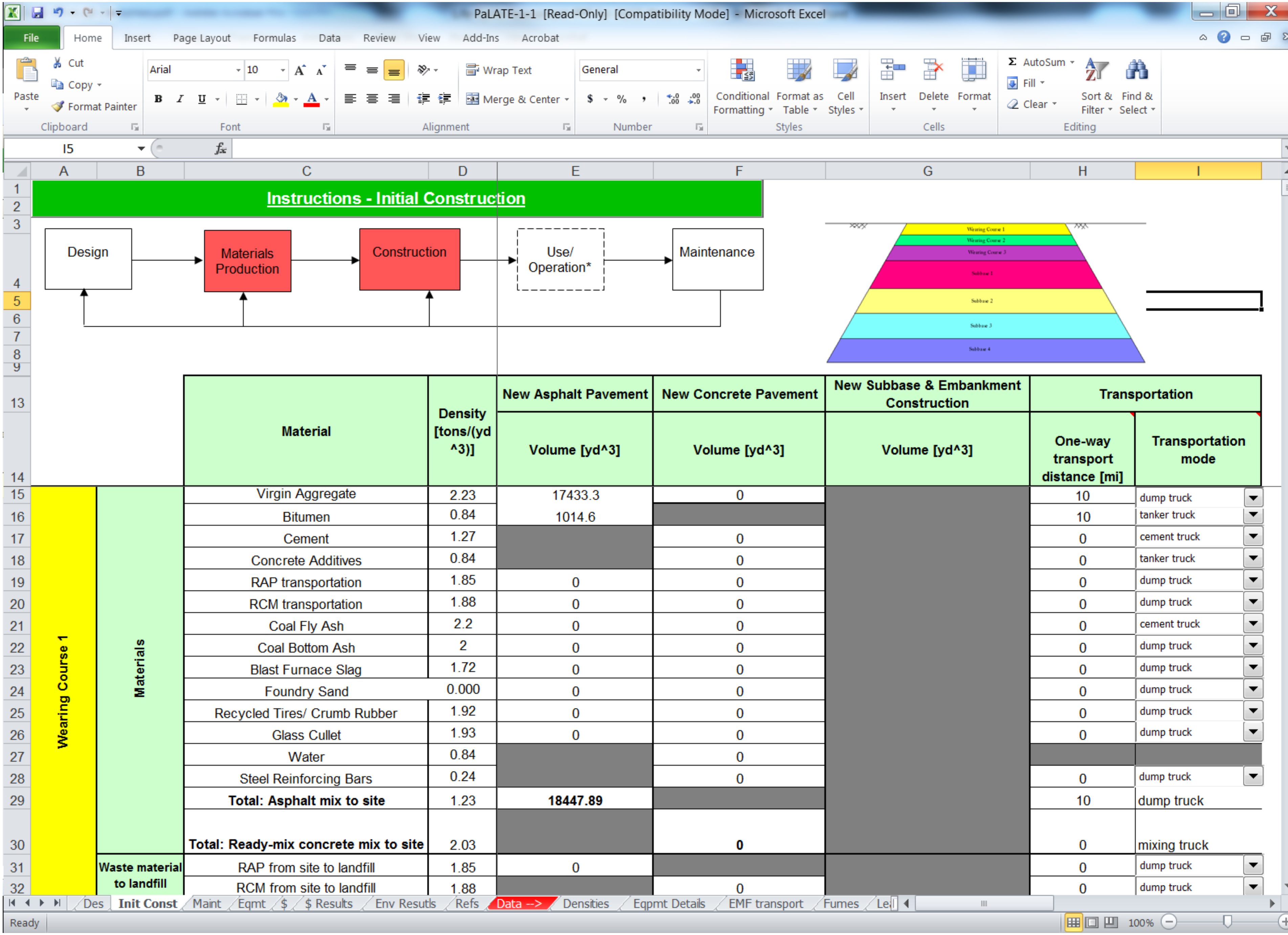
Data

Glossary:

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

Introduction

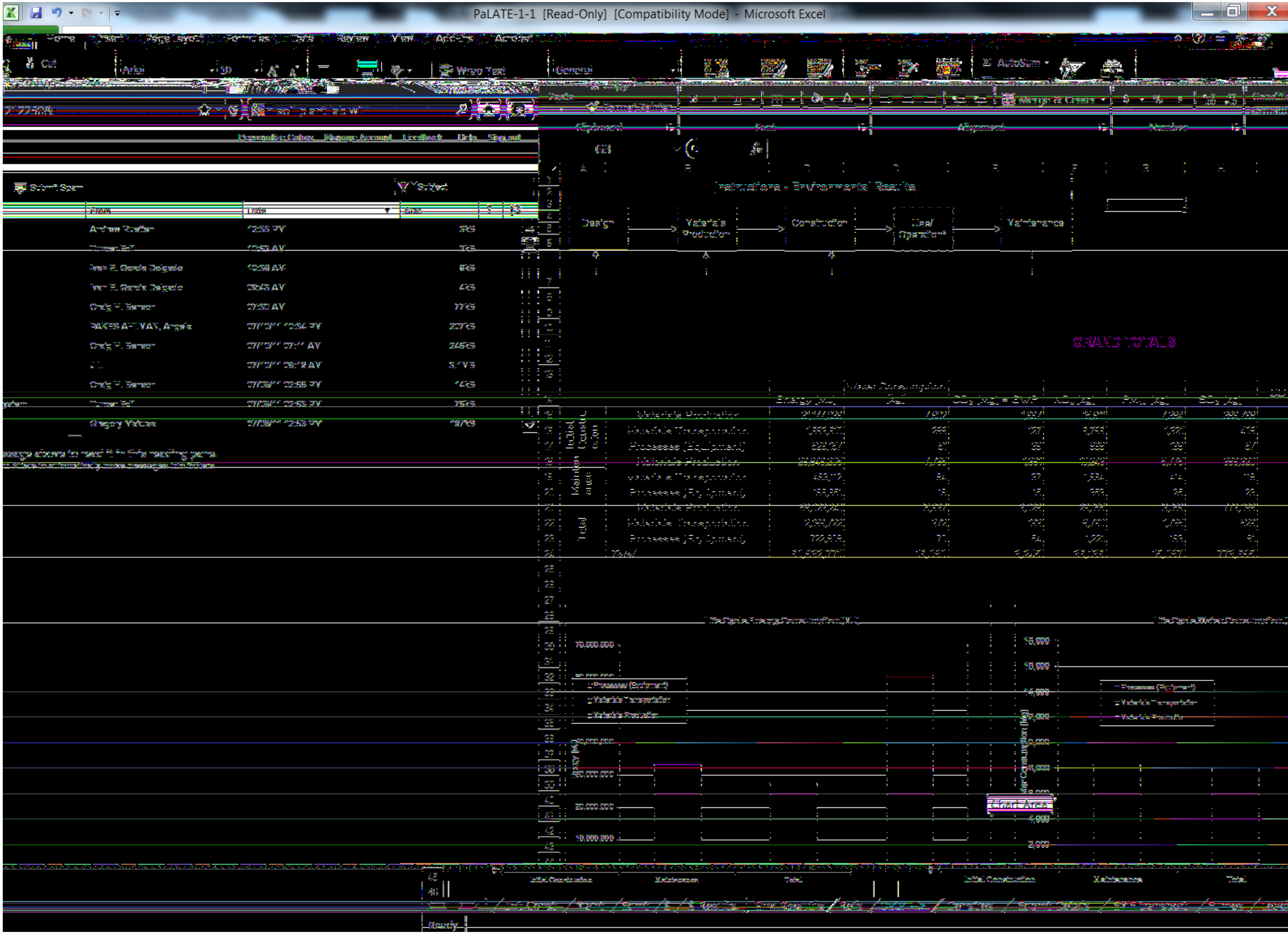
At the top of each worksheet is a life-cycle diagram. The stage(s) the User is working on is (are) highlighted in red. The User should input data in the worksheets of the stage(s) that is (are) going to be analyzed. (To analyze the Use/Operation Phase of the Life-cycle of a pavement, please use



		Material	Density [tons/(yd^3)]	New Asphalt Pavement: Volume [yd^3]	New Concrete Pavement: Volume [yd^3]	New Subbase & Embankment Construction: Volume [yd^3]	Transportation: One-way transport distance [mi]	Transportation: Transportation mode
Wearing Course 1	Materials	Virgin Aggregate	2.23	17433.3	0		10	dump truck
		Bitumen	0.84	1014.6			10	tanker truck
		Cement	1.27		0		0	cement truck
		Concrete Additives	0.84		0		0	tanker truck
		RAP transportation	1.85	0	0		0	dump truck
		RCM transportation	1.88	0	0		0	dump truck
		Coal Fly Ash	2.2	0	0		0	cement truck
		Coal Bottom Ash	2	0	0		0	dump truck
		Blast Furnace Slag	1.72	0	0		0	dump truck
		Foundry Sand	0.000	0	0		0	dump truck
		Recycled Tires/ Crumb Rubber	1.92	0	0		0	dump truck
		Glass Cullet	1.93	0	0		0	dump truck
		Water	0.84		0			
		Steel Reinforcing Bars	0.24		0		0	dump truck
		Total: Asphalt mix to site	1.23	**18447.89**			10	dump truck
		Total: Ready-mix concrete mix to site	2.03		**0**		0	mixing truck
	Waste material to landfill	RAP from site to landfill	1.85	0			0	dump truck
		RCM from site to landfill	1.88		0		0	dump truck

Volume (yd^3)	Volume (yd^3)	One way transport distance (mi)	Transportation mode
		0	dump truck
		0	tanker truck
		0	dump truck
		0	dump truck

Glass Cullet	1.83	0	0	0	dump truck
Water	0.84		0		
Reinforcing Bars	0.24		0	0	dump truck
…mix Asphalt to site	1.23	10447.868		0	dump truck
…mix Concrete mix to site	2.03		0	0	mixing truck
[illegible]	1.83	0			
CIR	1.83	0			
Patching	1.23	0	0		
Microsurfacing	1.23	0	0		
Crack Sealing	0.84	0	0		
Whitetopping	2.03		0		
Rubblization	1.85		0		


PaLATE-1-1 [Read-Only] [Compatibility Mode] - Microsoft Excel
Wrap Text
General
AutoSum
Merge & Center
Submit Spam
Subject
From
Date
Size
Andrew Shaffer
Ivan E. Garcia Delgado
Craig H. Benson
Gregory Valcarcel
Instructions - Environmental Results
Design
Materials Production
Construction
Use/ Operation
Maintenance
GRAND TOTALS
Water Consumption
Energy (MJ)
Initial Construction
Maintenance
Total
Materials Production
Materials Transportation
Processes (Equipment)
Life-Cycle Energy Consumption (MJ)
Life-Cycle Water Consumption (kg)
Chart Area
Ready

PaLATE LCA Results

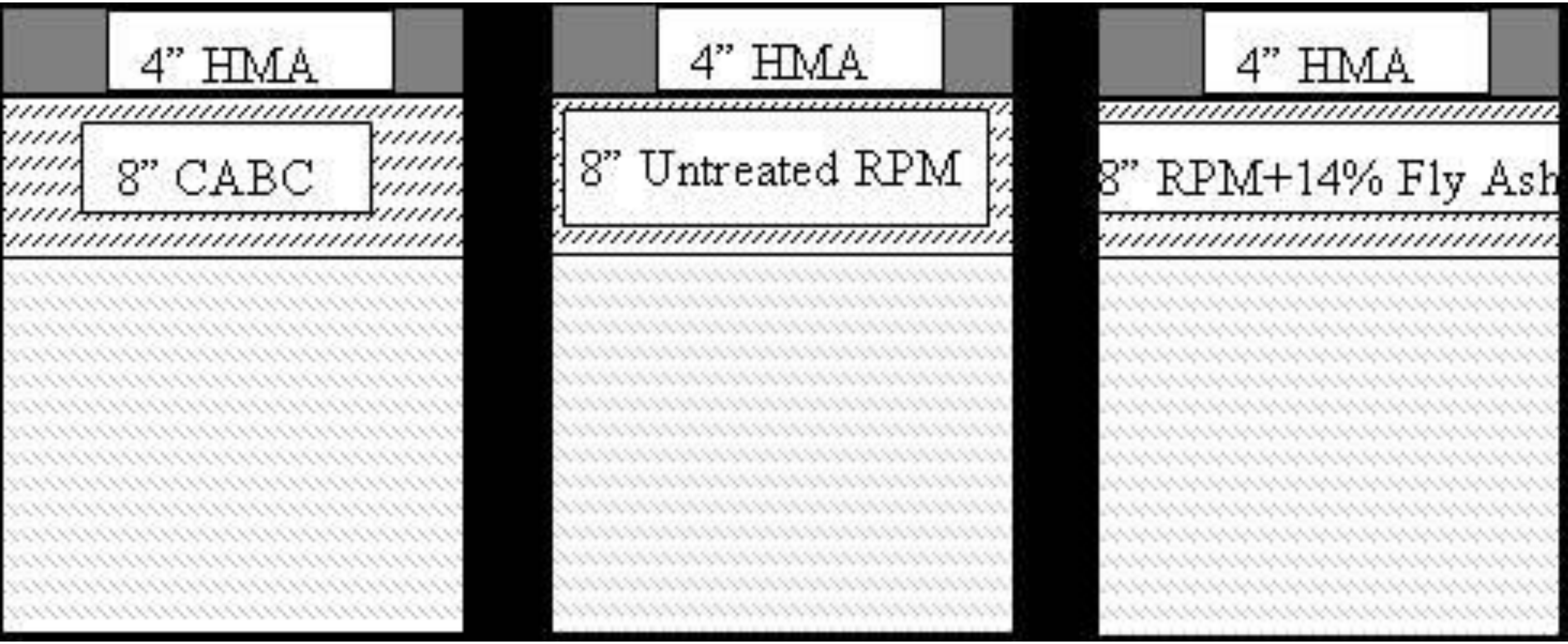
Environmental Metric	Conventional Materials			Recycled Materials			
	Material Production	Transportation	Construction	Material Production	Transportation	Construction	Difference (%)
CO_2 (Mg)	3,630	323	111	3,028	163	54	−20
Energy (GJ)	66,680	4,318	1,476	58,023	2,187	723	−16
RCRA hazardous waste (Mg)	629	31	9	611	16	4	−6
Water (L)	17,185	735	144	15,637	372	70	−11

NOTE: GJ = gigajoules = 0.001 terajoules (TJ); Mg = megagrams.

Using recycled materials reduces:

- GHG emissions by 20%
- Energy consumption by 16%
- Hazardous waste generation by 6%
- Water consumption by 11%

Life Cycle Analysis of Three Pavements with Alternative Base Course Materials



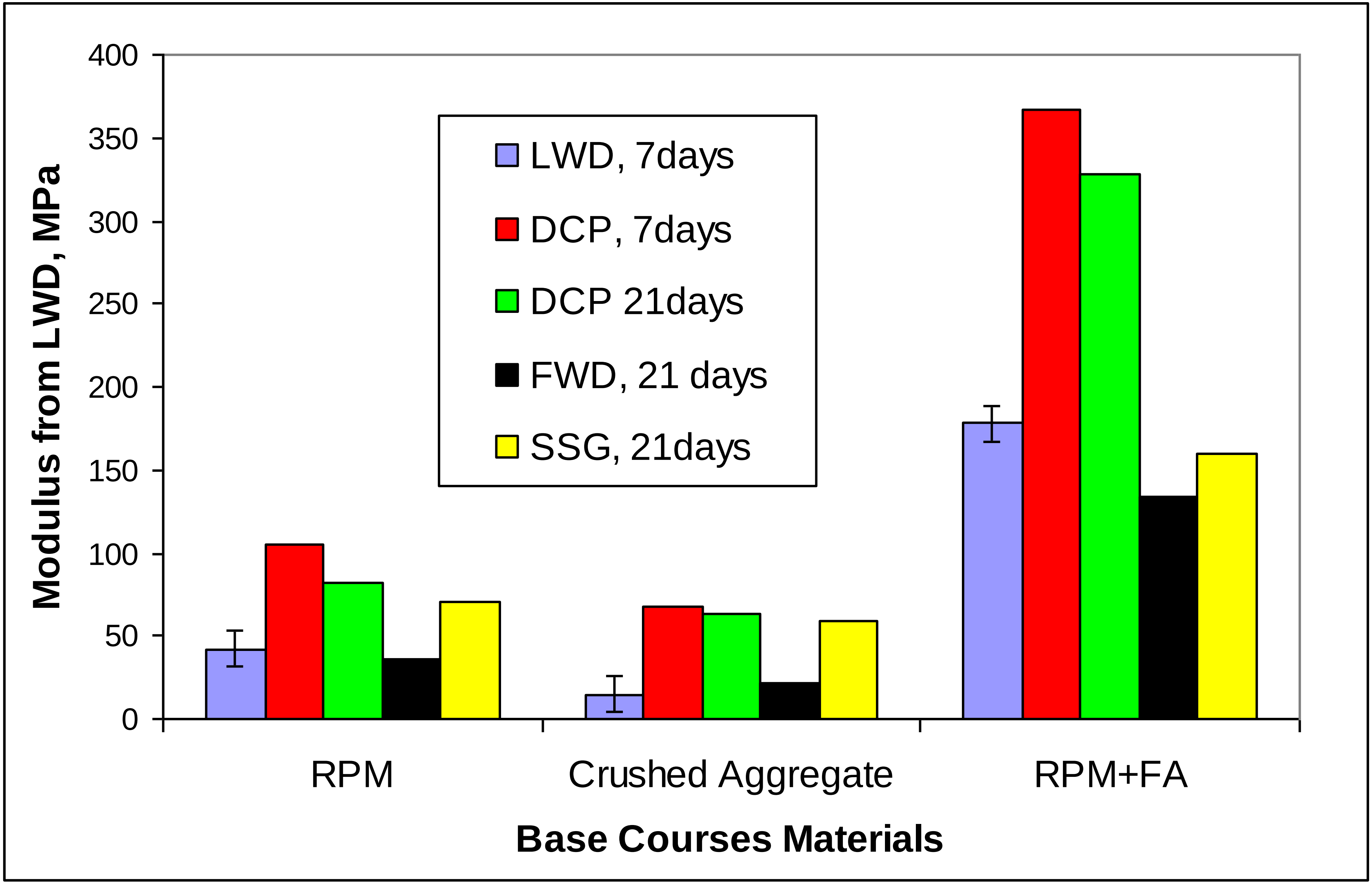
Conventional Aggregate Base

RPM Base

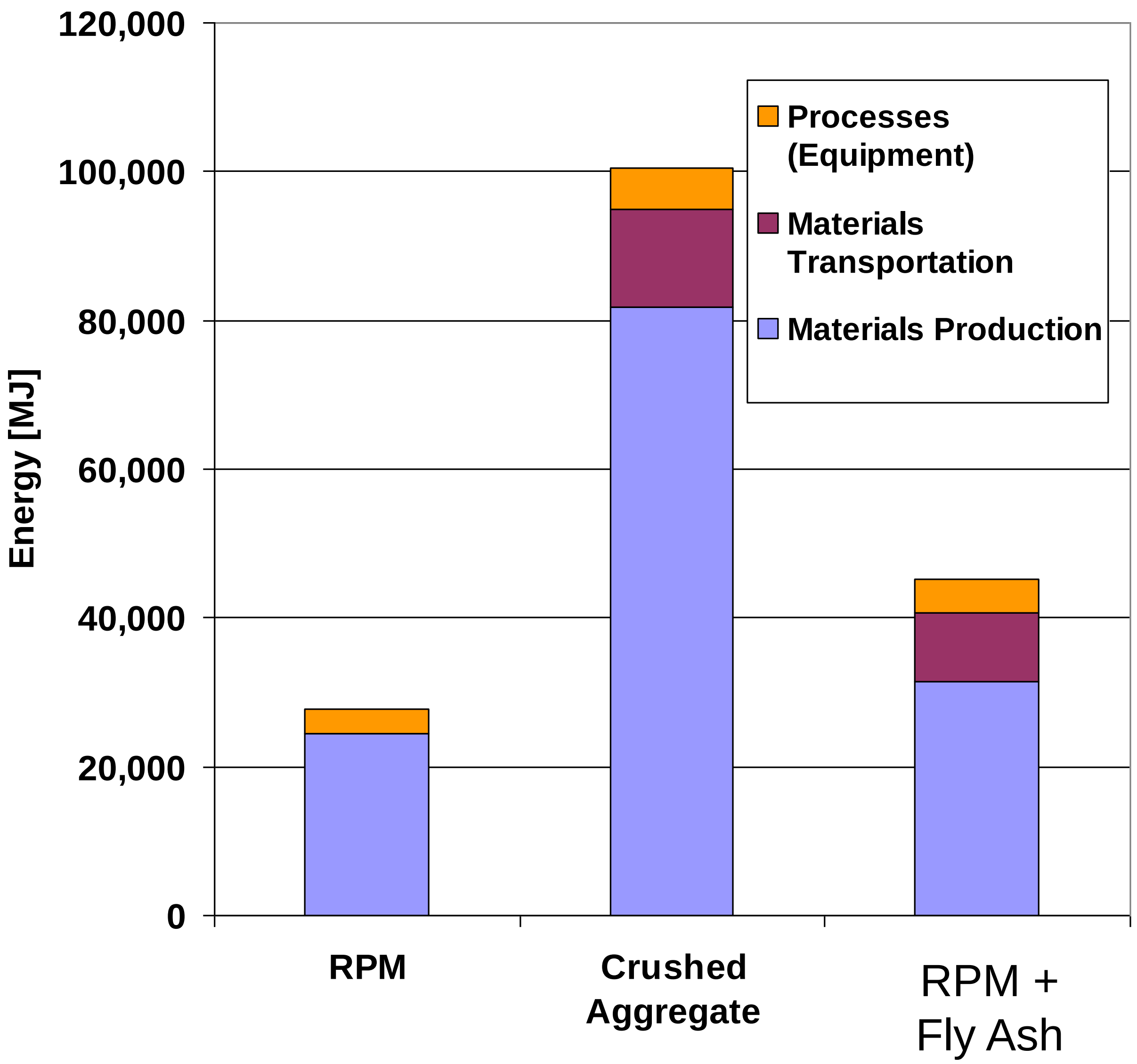
RPM + Fly Ash Base

Alternatives designed to have equal or better structural number.

Pavement Performance - Modulus



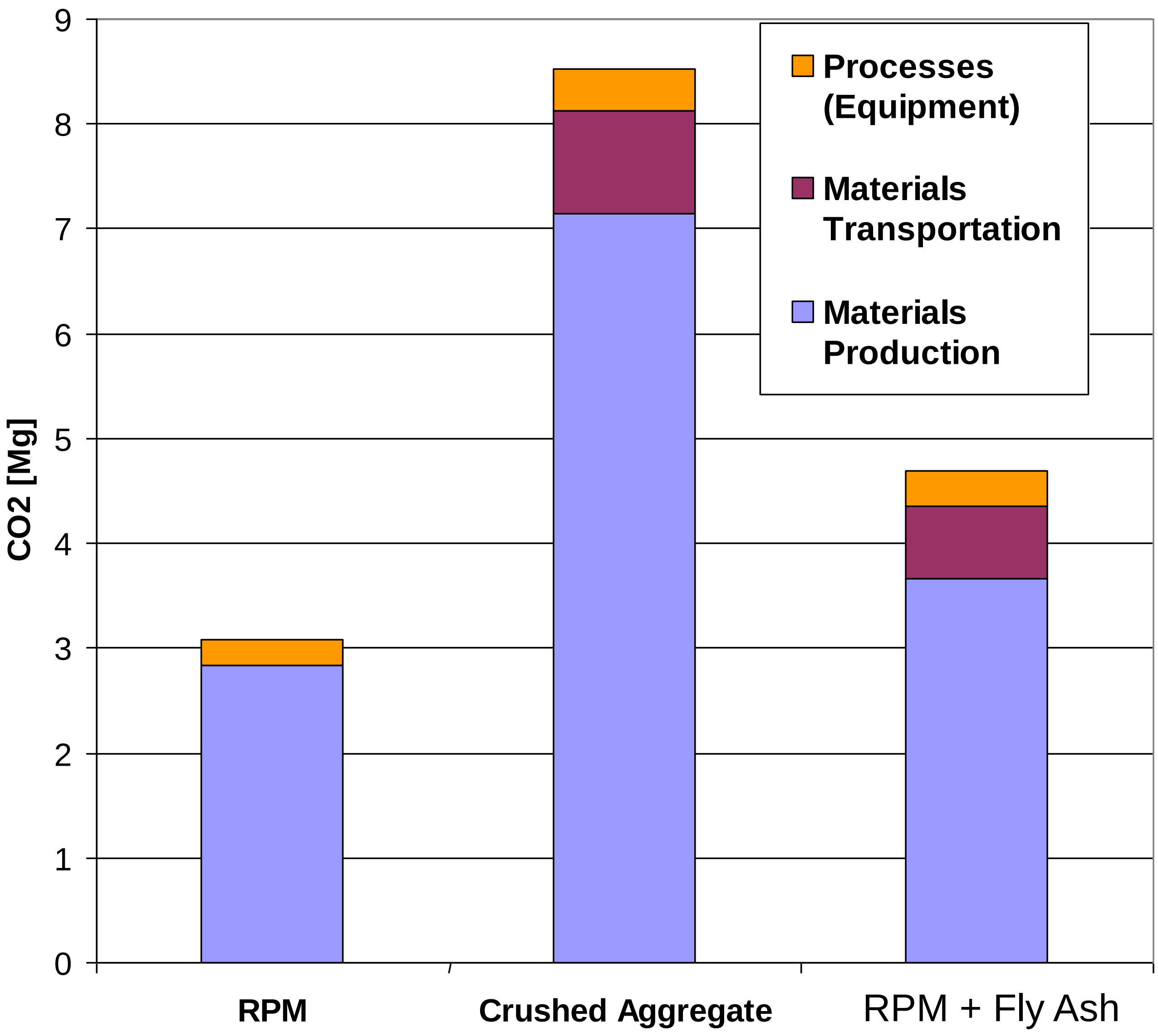
Construction Life Cycle Analysis – Energy Usage



Most energy: Conventional construction material.

Least energy: recycled pavement in place of crushed aggregate.

Construction Life Cycle Analysis – GHGs



Most emissions: Conventional construction material.

Least emissions: recycled pavement in place of crushed aggregate.

Evaluating Two Applications of Recycled Asphalt in Construction

Which use is more sustainable:

- Reintroduction into hot mix asphalt?
- Use as granular base?

Comparison of Alternatives using PaLATE

- HMA = hot mix asphalt

- RAP – reintroducing reclaimed asphalt into new hot mix asphalt

- RPM – using reclaimed asphalt as granular base

- SPRM – using reclaimed asphalt + fly ash binder as granular base.

Alternative Pavement Profiles

HMA
- HMA 5 ½”
- Base Aggregate 6"
- Subgrade

HMA-RAP
- HMA 5 ½” (RAP 15%)
- Base Aggregate 6"
- Subgrade

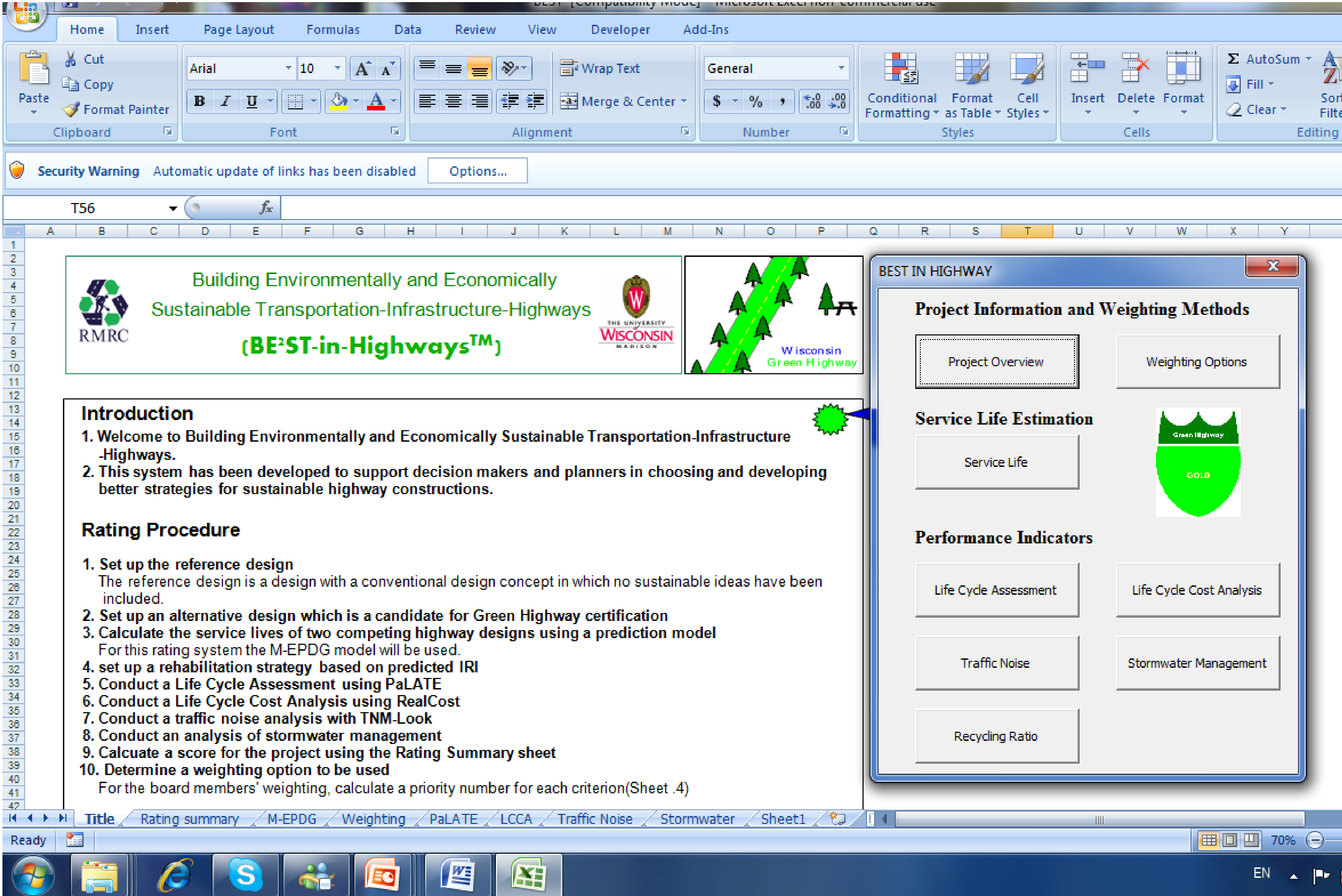
HMA-RPM
- HMA 5 ½”
- RPM 6"
- Subgrade

HMA-RAP-RPM
- HMA 5 ½” (RAP 15%)
- RPM 6"
- Subgrade

HMA-SRPM
- HMA 5 ½”
- RPM with 10% FA 2.8"
- Subgrade

HMA-RAP-SRPM
- HMA 5 ½” (RAP 15%)
- RPM with 10% FA 2.8"
- Subgrade

BE²ST Highway Sustainability Rating System



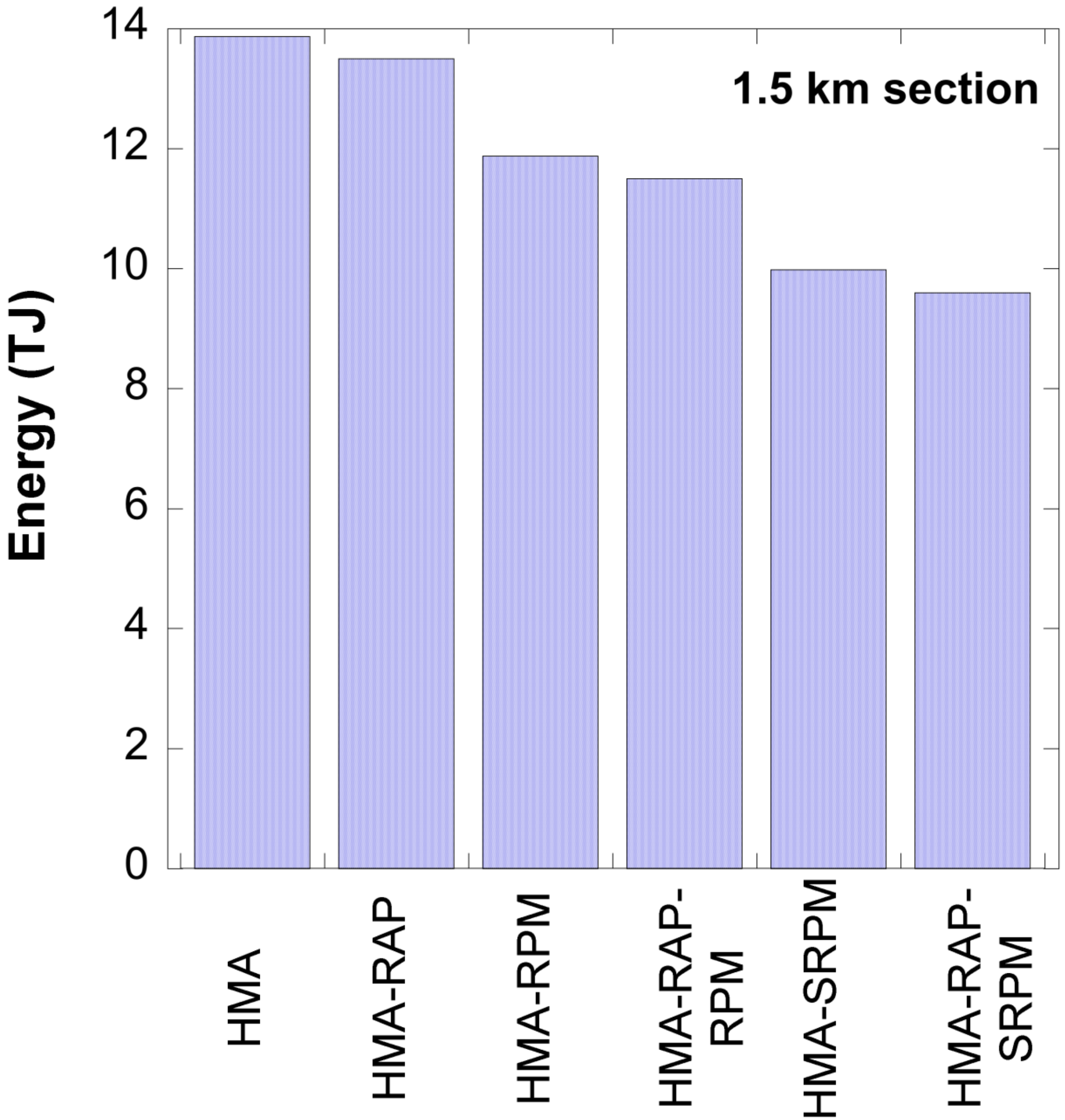
BE^{2}ST Highway Sustainability Rating System

- Life cycle analysis (LCA) to assess variety of sustainability metrics (energy, GHG emissions, water use, hazardous waste generation, etc.) – PALATE model.
- Life cycle cost analysis (LCCA) – evaluate life cycle cost of design alternatives.
- Quantitative and auditable metrics – provide perception & financial incentives for owners and contractors to incorporate sustainability principles in designs.

Engineering Characteristics of Alternatives

Design	Mr of Base Layer (MPa)	Base Layer Coefficient	**Service Life (yr)**	**No. of Rehabilitations for 50-yr Period**
HMA HMA-RAP	206	0.14	**13**	**3**
HMA-RPM HMA-RAP-RPM	249	0.14	**14**	**3**
HMA-SRPM HMA-RAP-SPRM	846	0.30	**18**	**2**

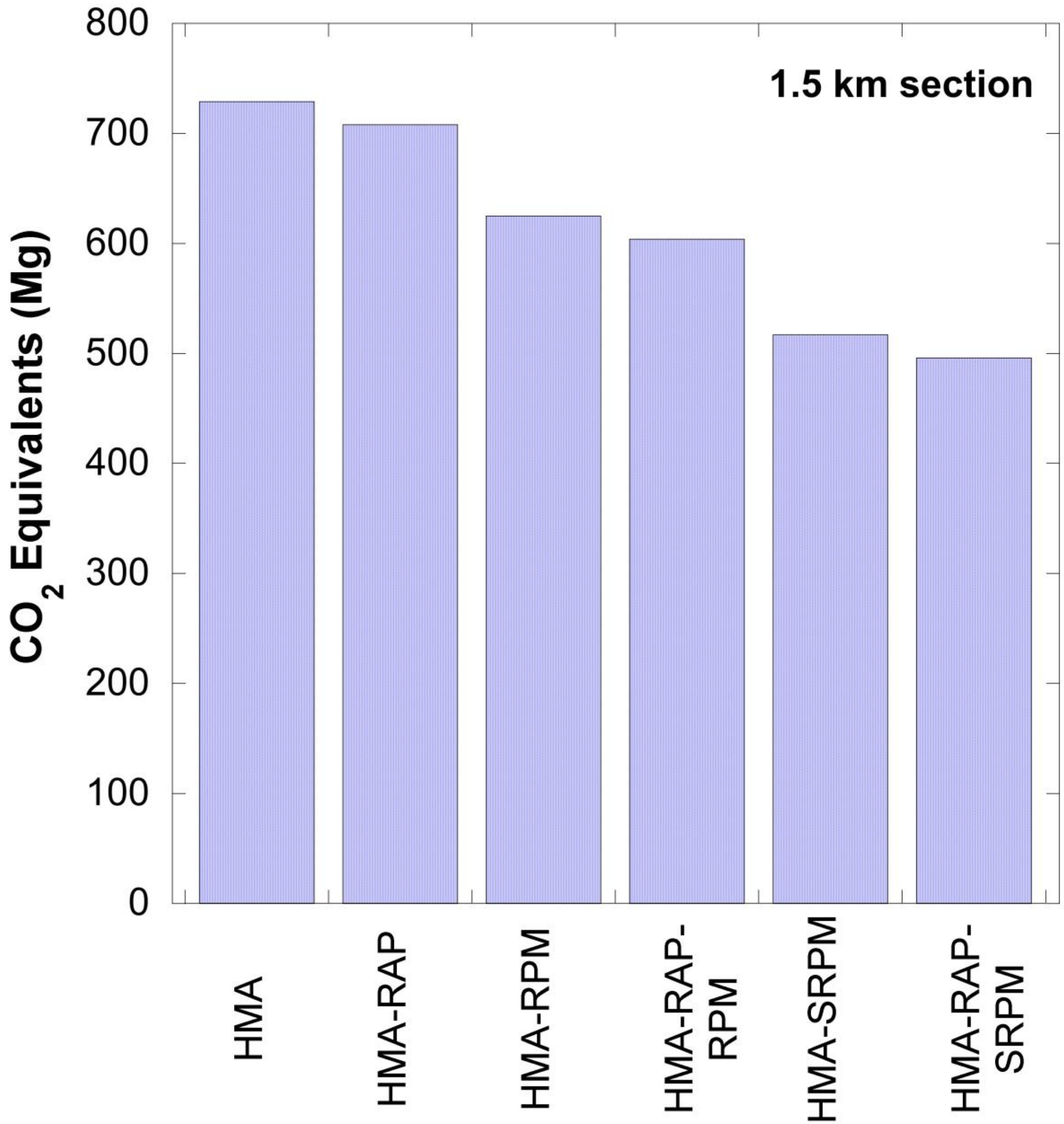
Life Cycle Energy Consumption



Most energy: reintroducing reclaimed asphalt into HMA (federal policy).

Least energy: using stabilize reclaimed asphalt in base.

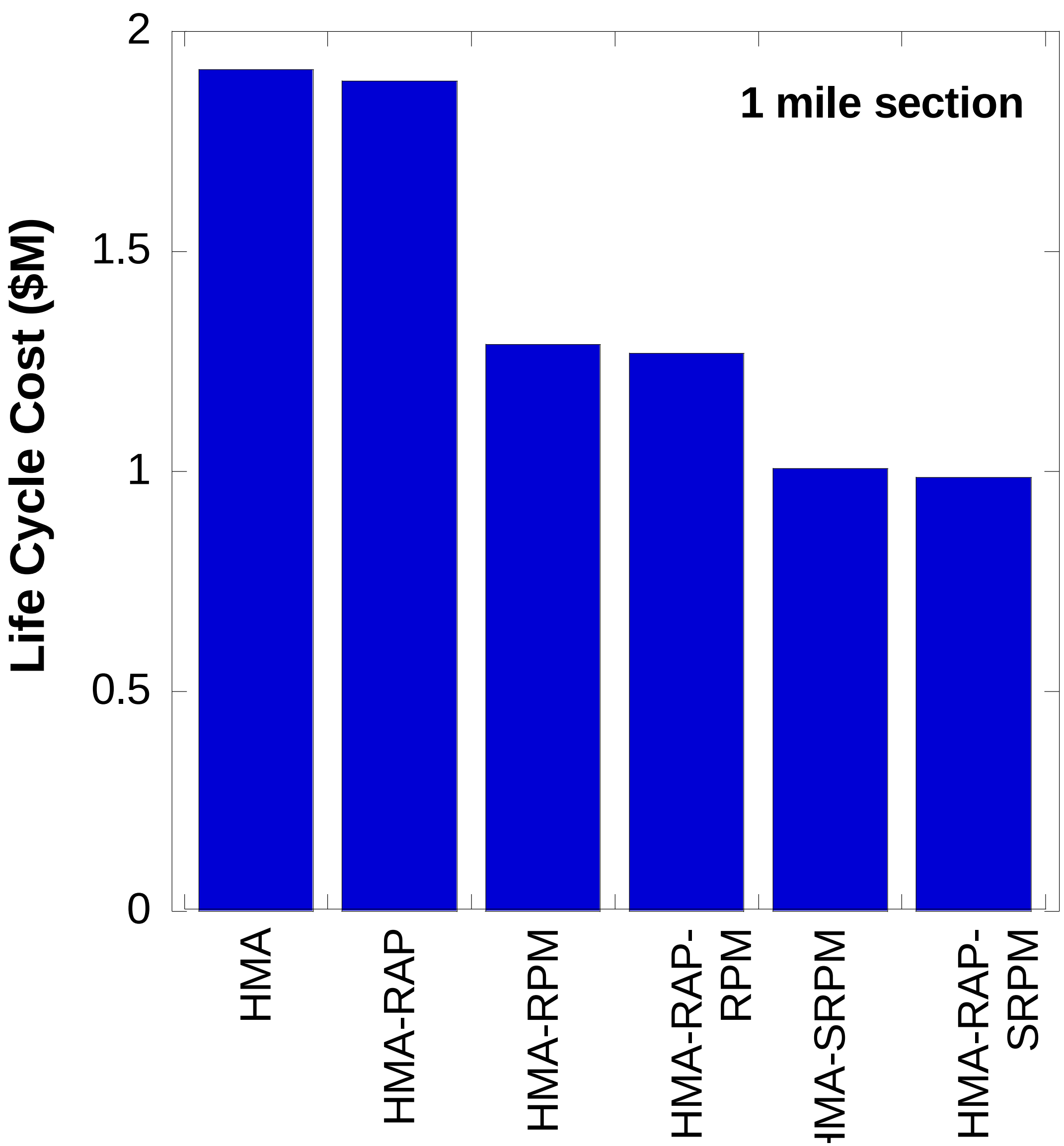
GHG Emissions



Most emissions: reintroducing reclaimed asphalt into HMA (opposite conventional "wisdom").

Least emissions: using stabilized reclaimed asphalt in base & HMA.

Life Cycle Cost



Least expensive: using stabilized reclaimed asphalt (SRPM) in base.

Most expensive: reclaimed asphalt in hot mix asphalt (HMA).

Industry Wide Analysis: Coal Combustion Products as Construction Materials

- Coal combustion products: fly ash, bottom ash, flue gas desulphurization (FGD) gypsum

- Construction applications: concrete (fly ash), geotechnical (fly ash, bottom ash), wall board (FGD).

- Considered benefits by offsetting conventional materials and eliminating disposal.

Industry Wide Analysis: Coal Combustion Products as Construction Materials

Metric	**Annual Savings**	**Equivalent to**
Energy (trillion Btu)	159	• Annual energy use for 1.7 million households
Water (billion gal)	32	• 31% of domestic water withdrawals of CA
CO_2e (million ton)	11	• Removal of 1.9 million passenger cars per year from roadways
Financial (US $B)	5.1-9.7	• Annual full-time salary ($39.5k/yr) of 130,000–240,000 average Americans

Recap Poll # 3 – True or False

- LCAs should consider the service life of each alternative: T/F
- The outputs of LCAs generally are consistent with “conventional wisdom” about when and where to use recycled materials: T/F
- LCAs can be used to shape policy regarding use of industrial byproducts and recycled materials: T/F

Wrap Up

- LCA can be used to demonstrate whether "green" activities truly contribute to sustainability. Avoid "eco-decoration" and "green-bling."
- LCAs are not perfect – sensitive to assumptions (e.g., system boundary) and inputs (e.g., energy or emission inventories).
- Use to evaluate whether a "green" alternative is more sustainable than conventional approach, assess alternatives (e.g., which is more sustainable?), or evaluate whether a policy makes sense.
- Most important – provides a quantitative assessment that reduces or eliminates subjectivity.