American Concrete Institute

Demonstration of Environmental Impact of Concrete Pavement Full Life Cycle Using Caltrans eLCAP Software

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How do we work towards sustainability?

- Is it just reducing greenhouse gases (GHG) and making sure we are recycling?

  These relate back to environmental impacts, economics and social well being, but there is a lot more

  GHGs and recycling do not address all the environmental impacts

- Need to set sustainability goals and routinely use quantitative approaches in our work to address and work towards those goals

  Approaches should also help avoid negative unintended consequences of well-intentioned partially informed actions

Good answers will come from full system and complete life cycle-based decision making

- Full System for pavement considers:
  - Resources
  - Processes
  - Structure/traffic/climate/soil application
  - All environmental and resource use impacts of interest
  - Interactions and effects on other systems

- Complete Life Cycle for pavement:
  - Looks at consequences of current decisions as far into the future as can be calculated with some certainty
  - Looks at effects of current decisions on ability to make future decisions

Pavement LCA Framework (Adapted from A.A.Butt 2014)

Electricity

Raw Materials

Recycled Materials

Pavement Design & Lifetime Prediction

Input

Material	Construction	Maintenance	Use	End Of Life
• Extraction • Processing • Transportation	• Laying • Compaction • Transport	• Mill • Lay • Compact • Transport	• Albedo • Lighting • Pavement-Vehicle Interaction	• Recycle • Dispose • Incinerate • Transport

Output

Airborne Emissions

Waterborne Emissions

Waste

Recyclable Materials

Energy

environmental Life Cycle Assessment for Pavements Tool (eLCAP)

- eLCAP is a web-based transport infrastructure LCA tool
- Capable to model the life cycle of any pavement project
- Database library is developed based on the California specific inventories of
  materials and mixes,
  construction equipment and activities,
  transportation modes,
  use stage impacts (based on IRI and vehicle fuel use),
  end of life scenarios
- eLCAP computes 18 different impact category for any user defined case

Overview of eLCAP

- eLCAP data and models have been reviewed by three external reviewers who:
  - are road transport infrastructure experts, and
  - have extensive knowledge of LCA
- Current version of eLCAP uses proprietary data, therefore per licensing agreement can only be used by:
  - Caltrans
  - UC Davis
- Working to develop models in OpenLCA and use in eLCAP to replace models developed in a software that uses proprietary data
- Plan to make eLCAP available for all by early 2024*

eLCAP™: environmental Life Cycle Assessment for Pavements Tool

Home | Projects | Input | Analyze & Results | Data Quality | ? | About | Save To DB | Save To File

Useful Links

- Caltrans
- UCPRC

Login to Site

User Name

Password

Log in or Register

Forgot your Password?

Please login to use eLCAP

0

Welcome

eLCAP is a web-based transport infrastructure life cycle assessment tool that has the capability to model the life cycle history of a pavement project by allowing a user to specify any number of construction events, occurring at a user-specified date, followed by an automatically generated Use Stage event that begins immediately afterward and lasts until the next construction event or the End-of-Life date.

eLCAP database library is developed based on the California specific extensive inventories of materials and mixes, construction equipment and activities, transportation modes, use stage impacts with consideration of pavement vehicle interaction and traffic congestion. The database is built in-house (UCPRC) to represent local conditions to the extent possible, by using California's electricity grid mix and fuels and following local practices in production, mix design, and construction.

eLCAP computes 18 different impact category values which include Primary Energy Demand used as Raw Materials (feedstock energy), Primary Energy Demand from Renewable and Non-renewable Resources (gross and net caloric value, separately), Primary Energy from Nonrenewable Resources (gross and net caloric value, separately), Primary Energy from Renewable Resources (gross and net caloric value, separately) and United States Environmental Protection Agency's Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI); Acidification, Ecotoxicity, Eutrophication, Global Warming Air (excluding and including biogenic carbon, separately), Human Health Particulate Air, Human toxicity (cancerous and non-cancerous, separately), Ozone Depletion Resources, Fossil fuels, and Smog Air.

eLCAP has two main built features:

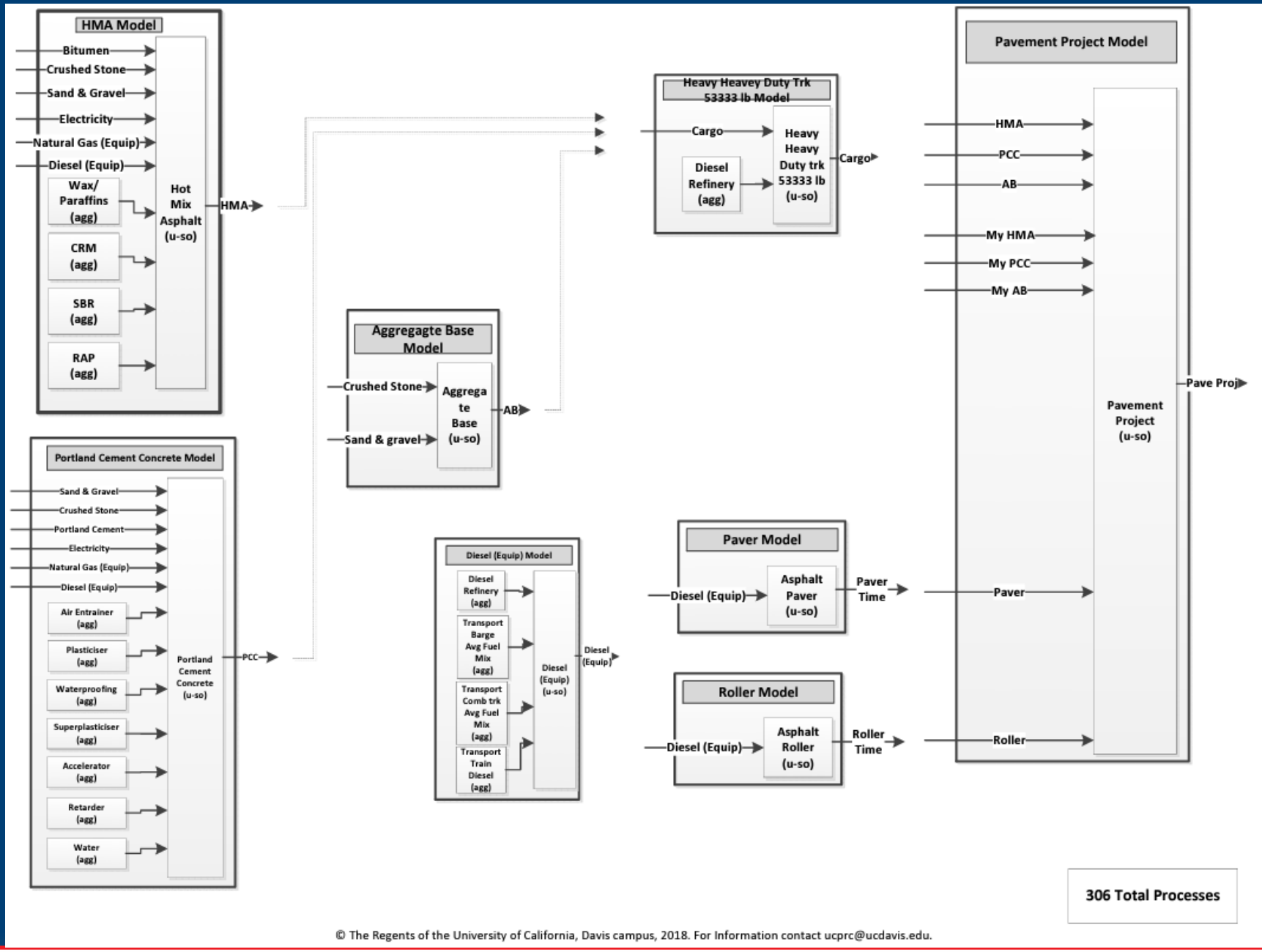
- Specifically for Caltrans with built-in Caltrans databases (location, cross-section and traffic)
- For local agencies, researchers and academics

LCA models for various processes in ***eLCAP*** are available using the following button links.

Pavement Model	HMA Model	Bitumen Model	PCC Model	Portland Cement
Crushed Stone Model	Sand & Gravel Model	Electricity Model	Natural Gas (Equip) Model	Diesel (Equip) Model

A list of acronyms used throughout *eLCAP* is located in the online help system.

An Example Pavement Model in eLCAP



eLCAP Summarized

eLCAP→ Instructions

View eLCAP documentation, user manual and data (materials, equipment and transports) library documents.

eLCAP→ Data Quality

View meta data and data quality assessment for eLCAP's materials, equipment and transports library.

eLCAP→Projects

- Add a project (Caltrans)
- Describe what's the project about
- Add one or more trial/s
- Describe what's the goal of the trial/s

eLCAP→ Input→ Manage User Processes

- User has capability to add user defined input material, equipment and transport data
- User can work with SI and/or Imperial Units in eLCAP

eLCAP→ Input→ Project Information

- Select District, County, Route, Direction, and start and end post miles (PM) in *Project Location Table*
- Edit cross-section of the project if needed
- Traffic is preloaded for the section selected and cannot be edited.

eLCAP→ Analyze & Results

- Click Balance and generate interactive graphs
- Reports can also be downloaded which includes detailed user defined problem statement (in pdf) and detailed LCIA results (in excel with graphs)

eLCAP→ Input→ Life Cycle

- Input analysis period based on the functional unit
- Input traffic growth
- Add and describe an event, input event date and service life of the event, select if use stage should be included or not in the *Life Cycle Events Table*.

eLCAP→ Input→ Life Cycle

Add or remove equipment (for the selected activity), edit number of hours of operation in the *Equipment used at the Site Table*.

eLCAP→ Input→ Life Cycle

- Add or remove pavement layers (for the selected event), select the layer types and input layer thicknesses in the *Life Cycle Activities Table*.

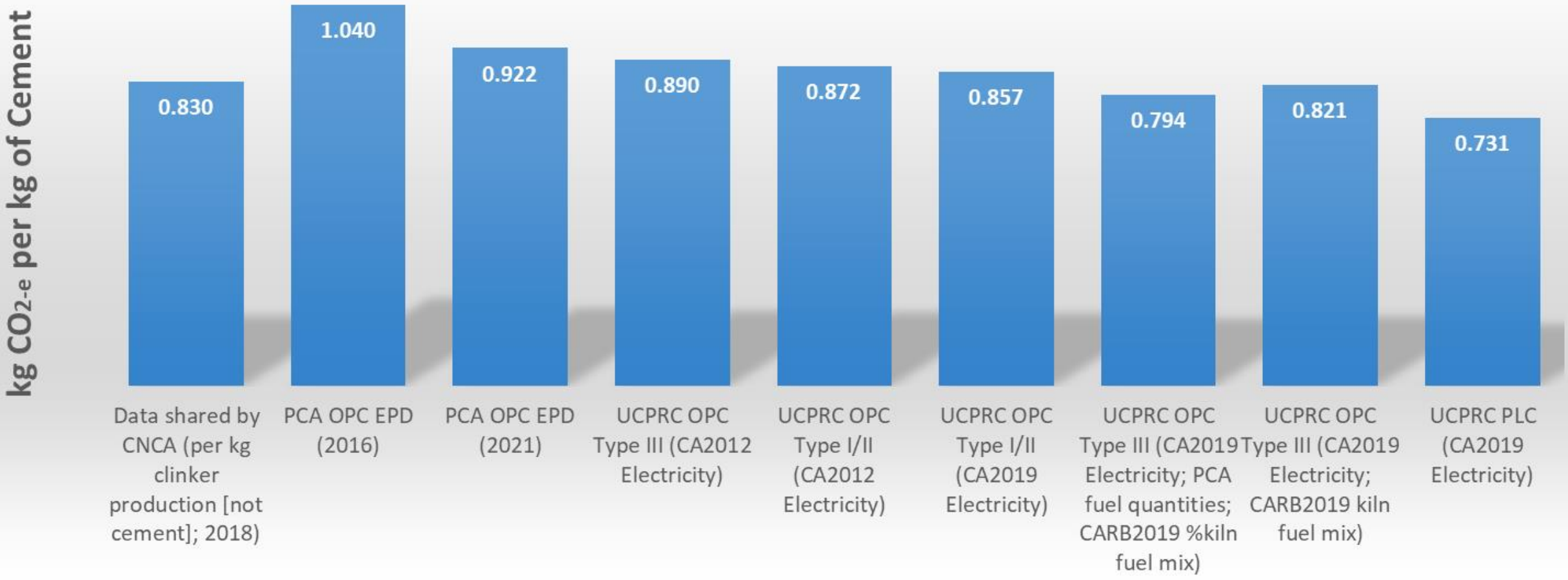
eLCAP→ Input→ Life Cycle

Add or remove materials (for the selected activity), edit material density, quantity, transportation type and transport distances in the *Materials and Transports Table*.

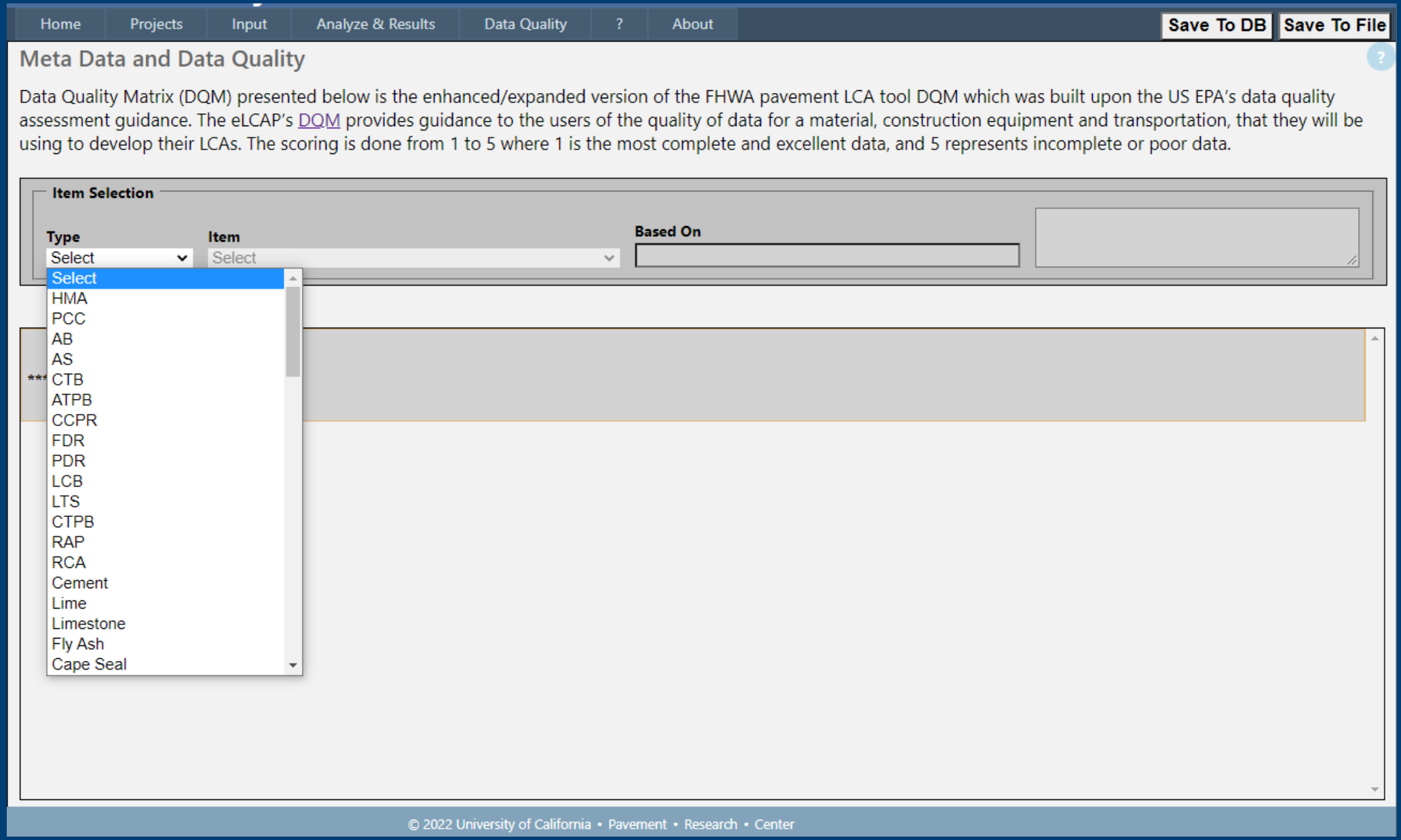
eLCAP Database: Material Stage using 2019 California Electricity Mix

Item	Functional Unit	GWP [kg CO2-e]	POCP [kg O3-e]	PM2.5 [kg]	PED (Total)[a] [MJ]	PED (Non-Renewable)[b] [MJ]	Feedstock Energy [MJ]
Aggregate (Crushed)	1 kg	2.85E-03	6.32E-04	1.46E-06	6.63E-02	4.47E-02	0.00E+00
Aggregate (Natural)	1 kg	1.86E-03	3.86E-04	8.42E-07	4.68E-02	2.98E-02	0.00E+00
Virgin Asphalt Binder	1 kg	4.49E-01	7.99E-02	4.04E-04	4.98E+01	4.90E+01	4.02E+01
Asphalt Emulsion	1 kg of Residual Asphalt Binder	4.71E-01	8.10E-02	4.09E-04	5.12E+01	4.99E+01	4.02E+01
OPC Type I/II (PCA kiln fuel mix)	1 kg	8.57E-01	7.21E-02	4.94E-04	6.50E+00	5.39E+00	0.00E+00
OPC Type III (PCA fuel quantities; CARB2019 kiln %fuel mix)	1 kg	7.94E-01	6.96E-02	2.58E-04	5.47E+00	4.65E+00	0.00E+00
OPC Type III (CARB2019 kiln fuel mix)	1 kg	8.21E-01	7.55E-02	1.69E-04	5.75E+00	4.61E+00	0.00E+00
CSA-HS	1 kg	5.24E-01	7.25E-02	1.57E-04	4.94E+00	3.86E+00	0.00E+00
CSA-LS	1 kg	6.93E-01	7.03E-02	1.55E-04	5.19E+00	4.09E+00	0.00E+00
Limestone, at mine	1 kg	3.66E-03	1.83E-04	1.23E-05	8.14E-02	5.74E-02	0.00E+00
Limestone, grinded	1 kg	1.39E-02	5.01E-04	1.37E-05	4.49E-01	2.51E-01	0.00E+00
Portland-Limestone Cement (PLC)[c]	1 kg	7.31E-01	6.14E-02	4.22E-04	5.59E+00	4.62E+00	0.00E+00
Crumb Rubber Modifier (CRM)	1 kg	2.03E-01	6.70E-03	1.05E-04	4.70E+00	3.59E+00	0.00E+00

GWP of Cement - "Cradle-to-Gate"



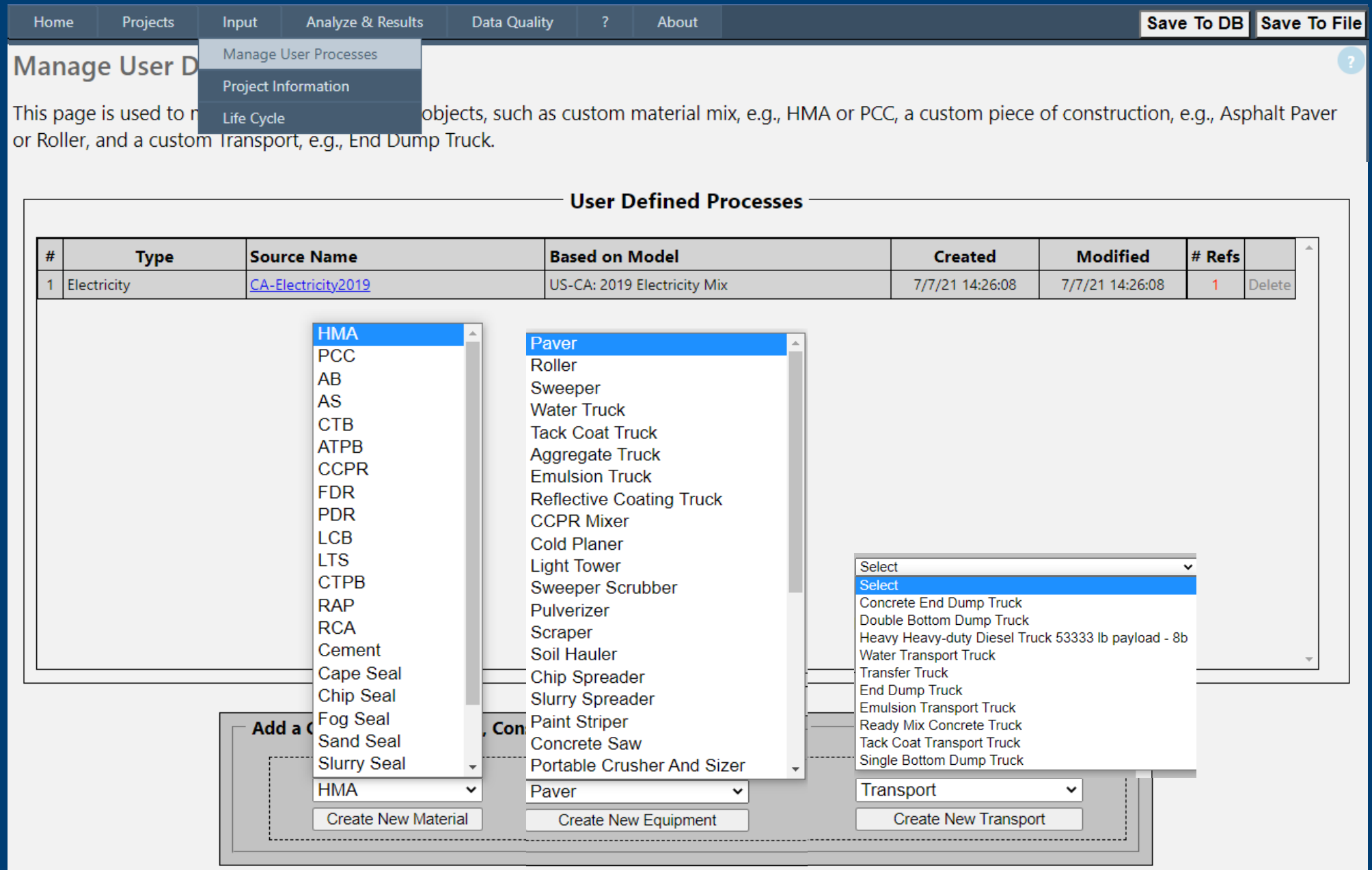
Data Quality Assessment



			High score				Low Score
Quality Indicators	**Indicator Sub-categories**	**Indicator Description**	**1 (Excellent)**	**2 (Very Good)**	**3 (Good)**	**4 (Poor)**	**5 (Unsatisfactory)**
Reliability	**Data Checks**	Is the inventory data checked for mass/ energy balance, recalculation etc.?	Verified data based on measurements	Verified data based on a calculation or non-verified data based on measurements	Non-verified data based on a calculation	Documented estimate	Undocumented estimate
	Data Support	What is the status quo for the ownership and continuous support of data?	Hosts and Owns	Owns but does not host	Hosts but does not owns	Hosts and owns partially	Does not host or own
	Data Updates	Is the data regularly updated?	Regular Updates	Less frequent updates	No Updates	-	-
Data Collection Methods	**Representativeness**	How representative is the data of the market?	Representative data from >80% of the relevant market, over an adequate period	Representative data from 60-79% of the relevant market , over an adequate period **OR** representative data from >80% of the relevant market, over a shorter period of time	Representative data from 40-59% of the relevant market, over an adequate period **OR** representative data from 60-79% of the relevant market, over a shorter period of time	Representative data from <40% of the relevant market, over an adequate period of time **OR** representative data from 40-59% of the relevant market, over a shorter period of time	Unknown **OR** data from a small number of sites **and** from shorter periods
	Seasonal Variations	Does the data capture seasonal variations?	Seasonal variations captured	Seasonal variation not captured	-	-	-
	TRACI Compatibility	How compatible is the life-cycle inventory data with TRACI 2.1 impact assessment method?	100% TRACI compatible	75% TRACI compatible	50% TRACI compatible	25% TRACI compatible	TRACI uncompatible

Time Period	**Data Quality Objective**	How well is the time period the data correlated with the data quality objective?	Less than 3 years of difference	Less than 6 years of difference	Less than 10 years of difference	Less than 15 years of difference	Age of data unknownor more than 15 years
	Correlated to Relevant Periods	Has the data been adjusted for the relevant time period?	Data **fully** adjusted for relevant time periods of analysis	Data fully adjusted for relevant time periods but with **medium** level of uncertainity	Data fully adjusted for relevant time periods but with **high** level of uncertainity	**Some** data adjusted for relevant time periods but with **high** level of uncertainity	Data **unadjusted** for relevant time periods
Geography	**Data Origin**	How well is the geography of the data correlated with the data quality objective?	Data from same resolution **AND** same area of study	Within one level of resolution **AND** a related area of study	Within two levels of resolution **AND** a related area of study	Outside of two levels of resolution **BUT** a related area of study	From a different or unknwn area of study
Technology	**Categories Equivalent**	How well is the technology of the data correlated with the data quality objective?	All technology categories are equivalent	Three of the technology categories are equivalent	Two of the technology categories are equivalent	One of the technology categories are equivalent	None of the technology categories are equivalent
	Relevant Coverage	Is the relevant technology covered?	Yes	No			
Process Review	**Review Check**	How well is the process reviewed?	Documented reviews by a minimum of two types of third party reviewers	Documented reviews by a minimum of two types of reviewers, with one being a third party	Documented review by a third party reviewer	Documented review by an internal reviewer	No documented review
Process Completeness	**Completeness Check**	How complete is the process?	>80% of determined flows have been evaluated and given a value	60-79% of determined flows have been evaluated and given a value	40-59% of determined flows have been evaluated and given a value	<40% of determined flows have been evaluated and given a value	Process completeness not scored

User Defined Processes: Materials, Construction Equipment, Energy and Transport Vehicles



User Defined: Concrete Mix Design

eLCAP: UCPRC Environment Life Cycle Assessment for Pavements Tool

This form allows you to add a User Defined PCC Process by changing the input flow quantities into the PCC Process. The initial flow quantities come from the built-in Library PCC. Select the Edit link to edit one or more input flow quantity, specify a unique name for the User Defined PCC and select Save. Once saved, the User Defined PCC will be available to use wherever a PCC is appropriate.

Input Flows for: ACI 2023 Concrete Mix Example **Based On:** Caltrans Type II PCC

Define Quantities for a New PCC

PCC Reference Flow Amount: *1.000* kg of PCC with Bulk Density: 150.0 lb/ft3 Data Documentation

#	Type	Source Name	Quantity	Unit	
1	Parameter	Agg_Natural	0.000	%	Edit
2	Parameter	Agg_Crushed	79.602	%	Edit
3	Parameter	Cement_Content	11.961	%	Edit
4	Parameter	Water	6.276	%	Edit
5	Parameter	Accelerator	0.000	%	Edit
6	Parameter	Retarder	0.000	%	Edit
7	Parameter	Plasticiser	0.000	%	Edit
8	Parameter	Superplasticiser	0.000	%	Edit
9	Parameter	Air_Entrainer	0.004	%	Edit
10	Parameter	Waterproofing	0.051	%	Edit
11	Parameter	Blast_Furnace_Slag	0.000	%	Edit
12	Parameter	Fly_Ash	2.106	%	Edit
13	Parameter	Fiber	0.000	%	Edit
14	Cement	CA Portland Cement at Plant	0.120	kg	Edit

Source Transports Save Cancel/Back

Reclaimed Asphalt Pavement and Recycled Concrete Aggregate

- In-Place Recycling or Cold Central Plant Recycling
- In-Plant Recycling (Fractionated and Unfractionated)

  Existing RAP/RCA stockpiles at the plant

  RAP/RCA stockpiled at a different site and transported to the plant

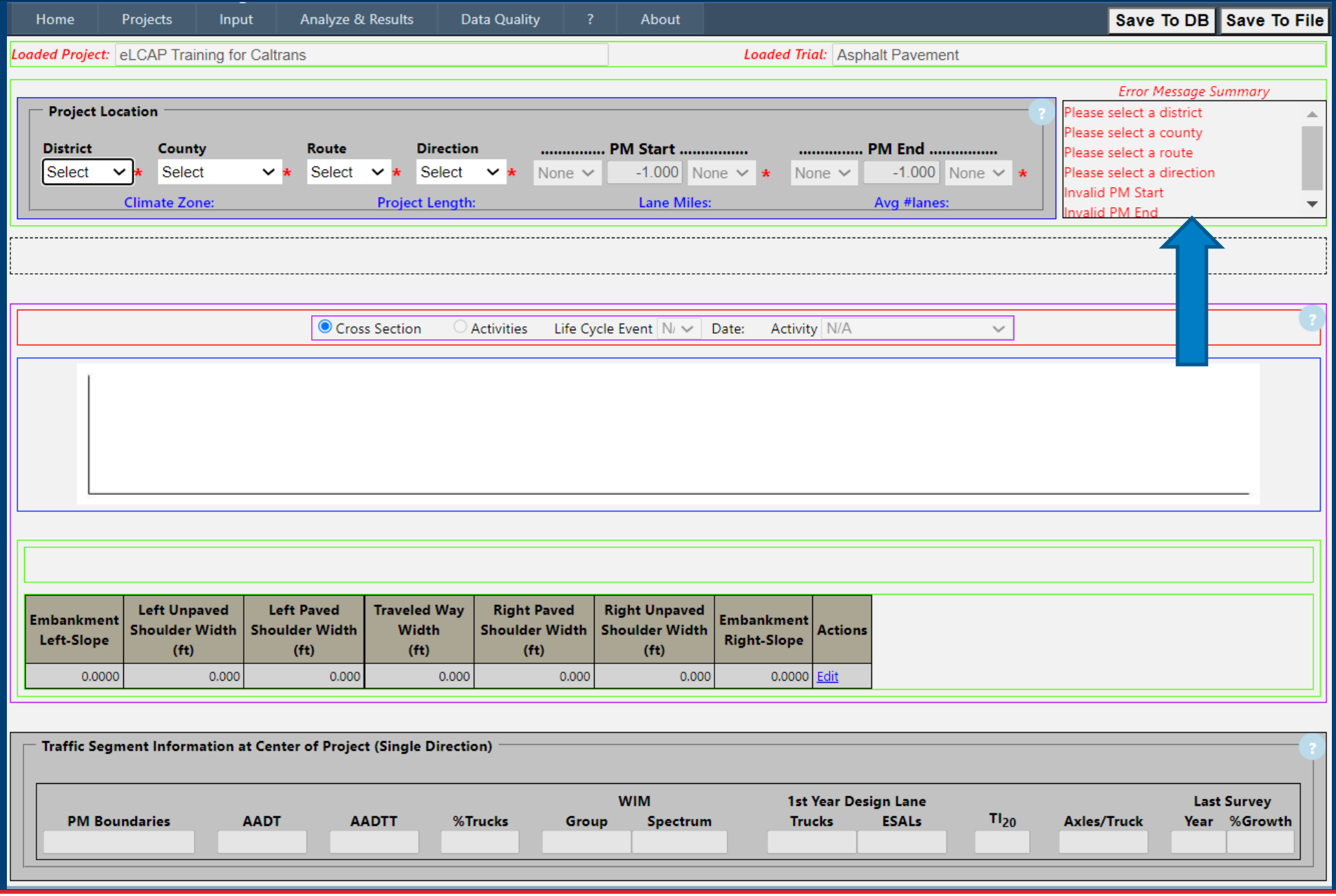
  RAP/RCA produced and used in the same project

  RAP/RCA produced but not being used in the current project

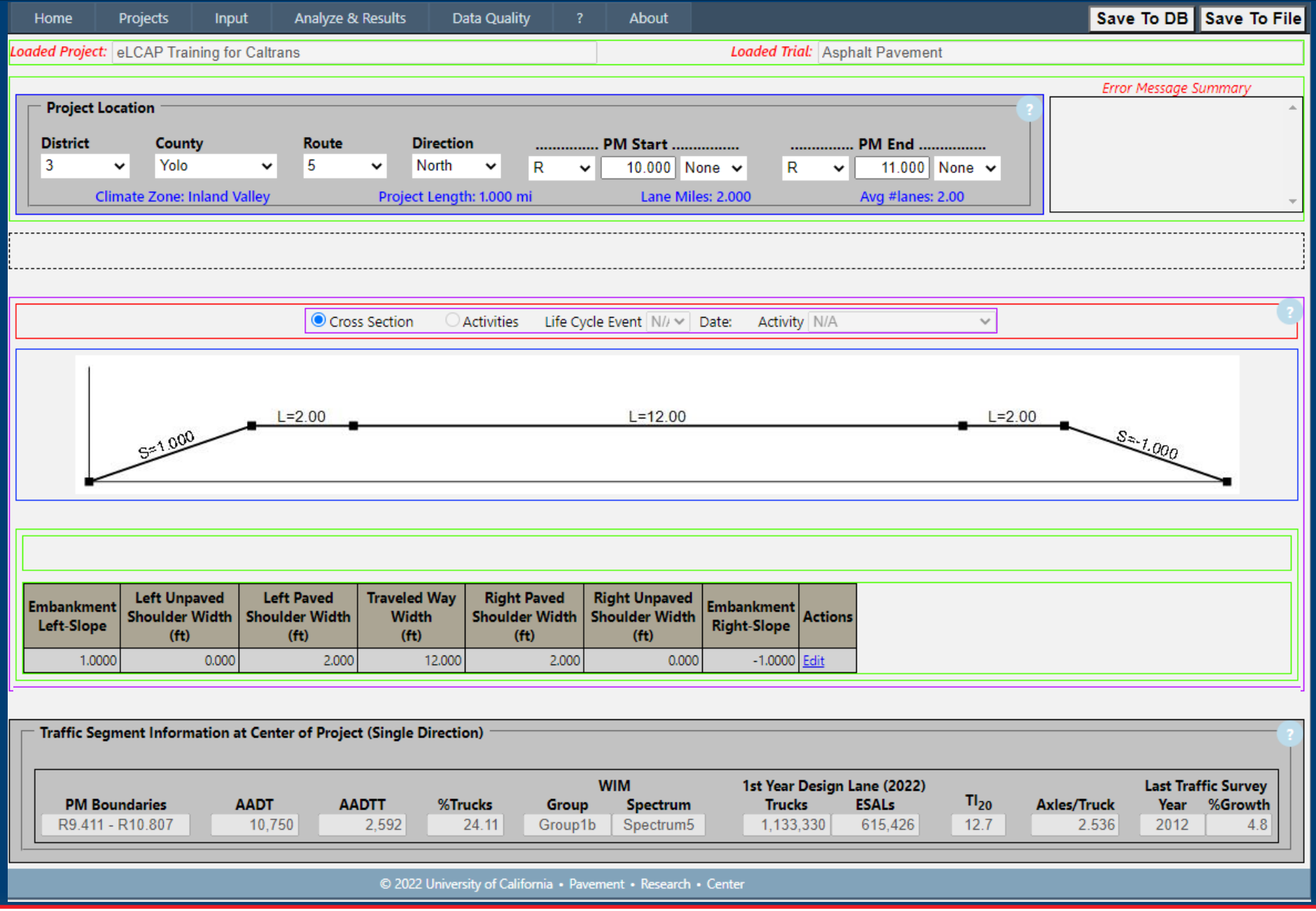
Construction Activities for Pavement Layers

- List of Major Activities in eLCAP
  - HMA pavement
  - Joint Plain Concrete Pavement
  - Continuously Reinforced Concrete Pavement
  - Aggregate Base
  - Lean Aggregate Base
  - Cement/Lime Treated Base
  - Asphalt/Cement Treated Permeable Base
  - Concrete Lane Removal
  - Milling Asphalt Pavement
  - Groove and Grind

Location and Cross Section Input



Example: Location and Cross Section Input

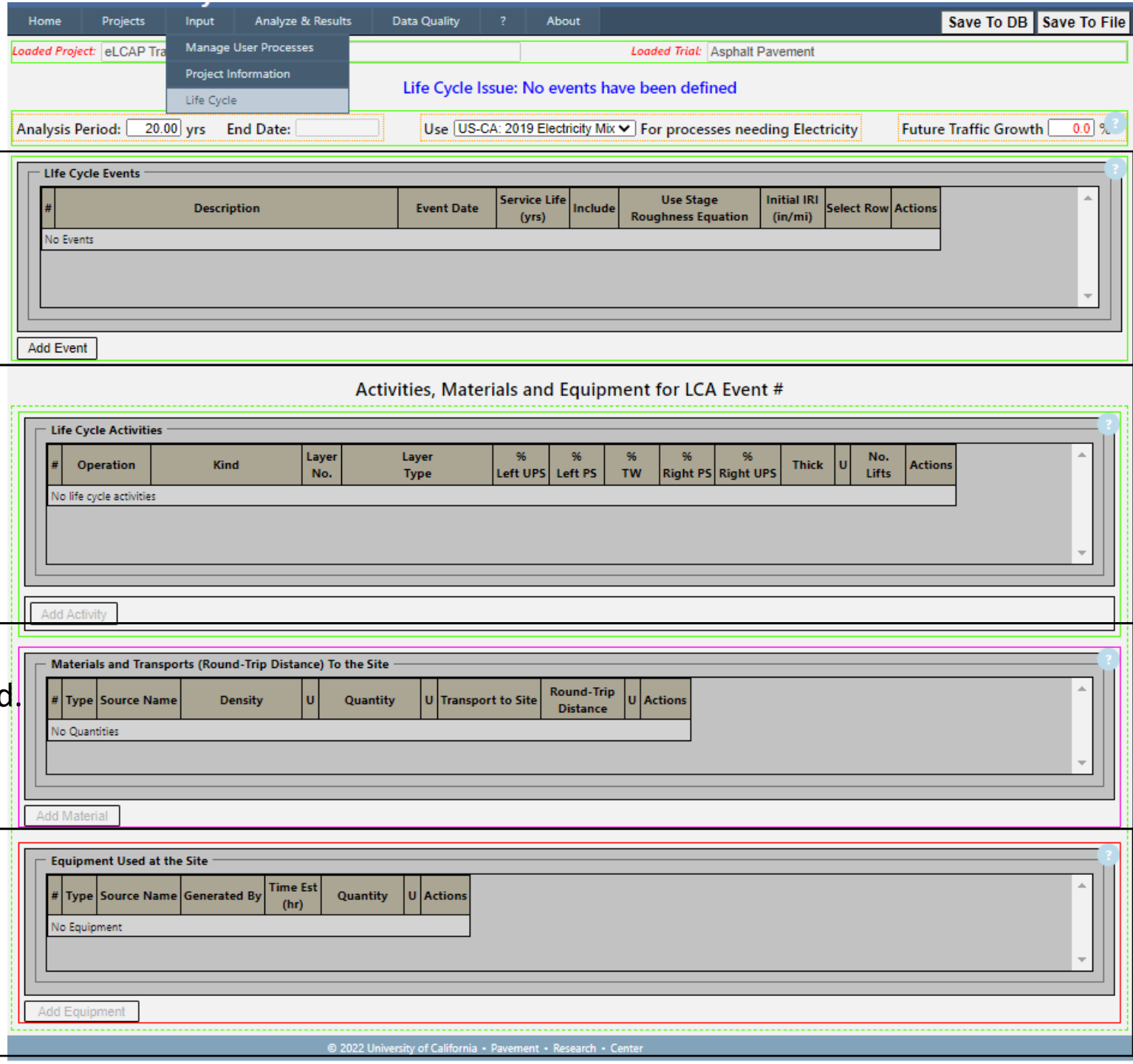


Life Cycle Events: User can define what event or Construction activity will be taking place at the User defined event date, service life of the event, and initial IRI for the selected roughness equation.

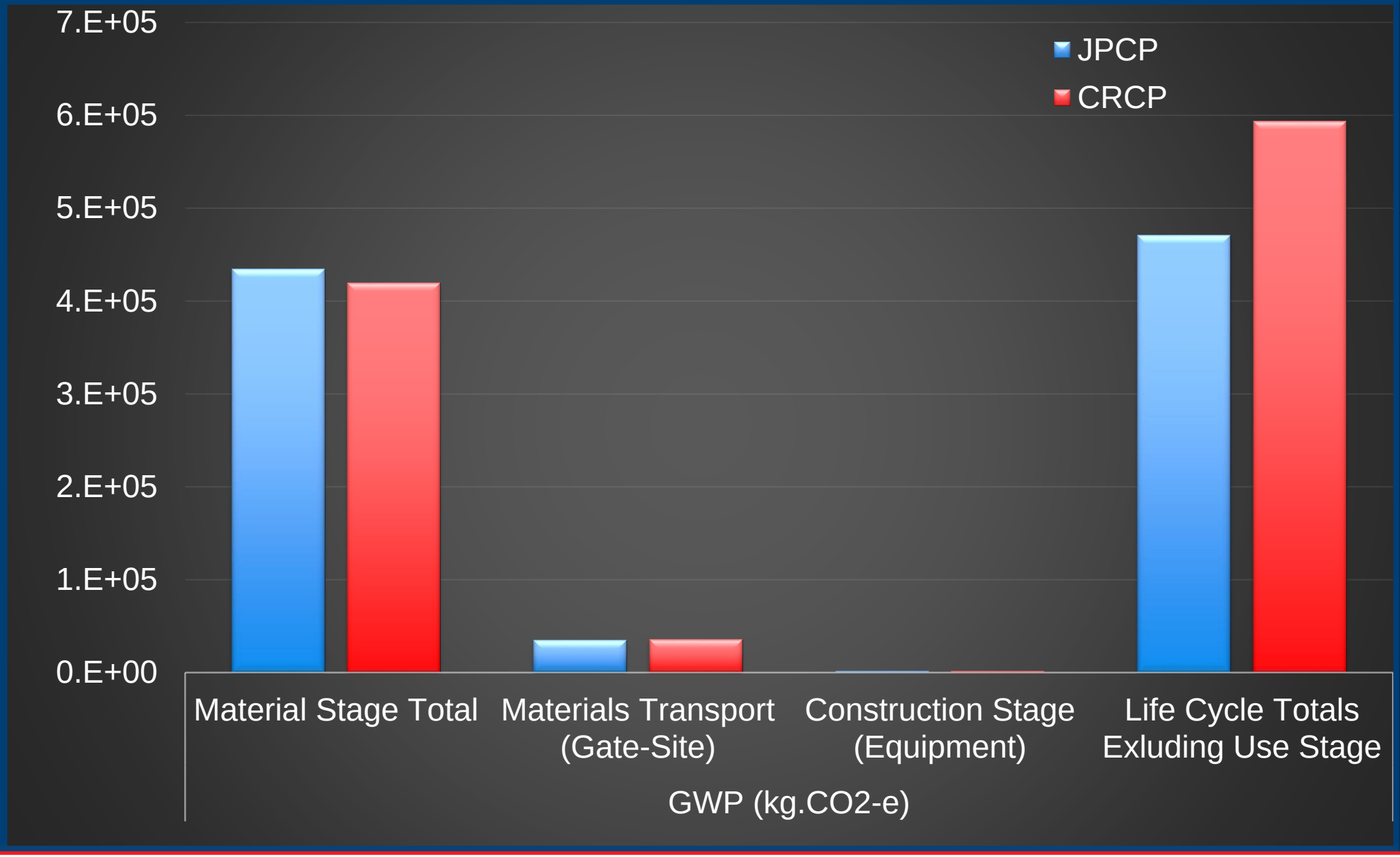
Life Cycle Activities: For the defined event, User will be asked to add or remove pavement layers. User will have to input the layer thickness.

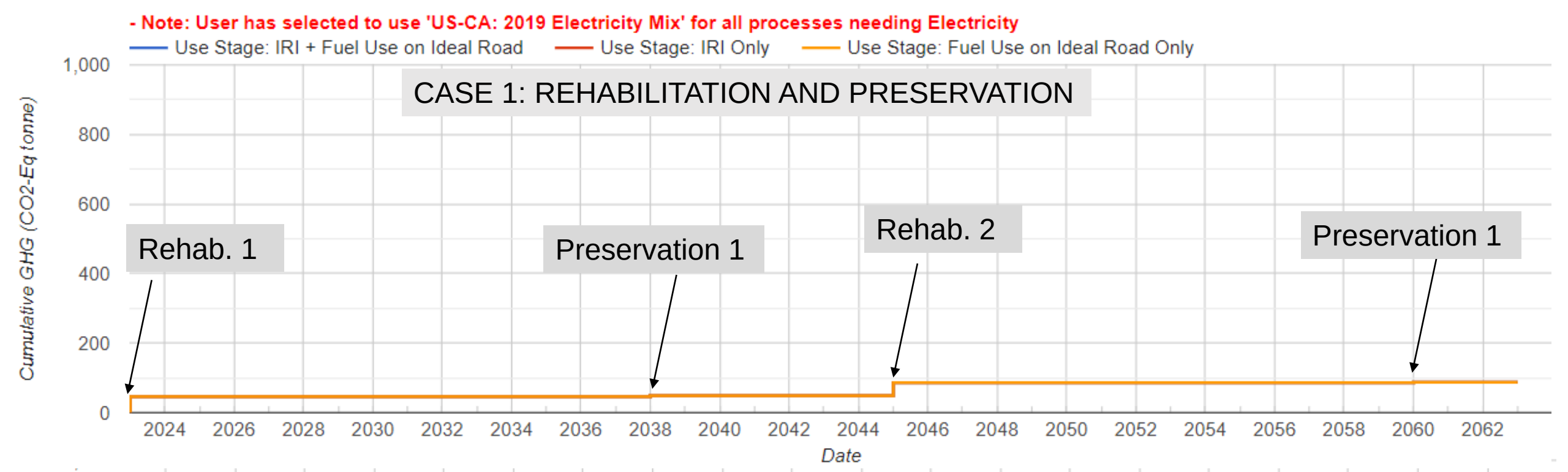
Materials and Transport: For the added/removed layer, default material & transport will be generated. User can change material type, densities, quantity, units, transport type & distance for each layer.

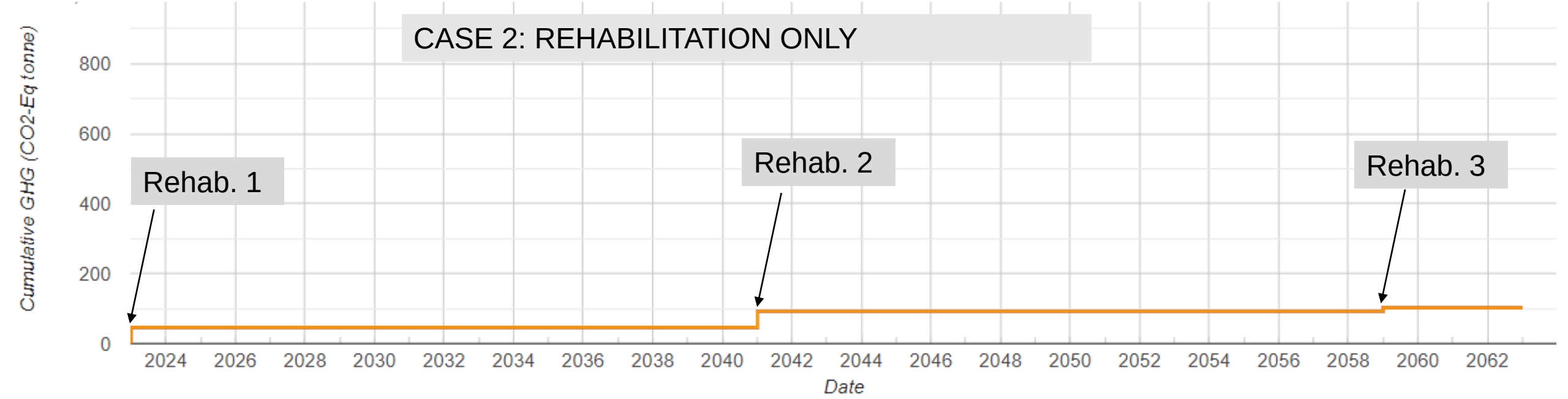
Equipment: For the added/removed layer, default equipment associated to the construction activity will be generated. User can change equipment type, number of hours of operation.



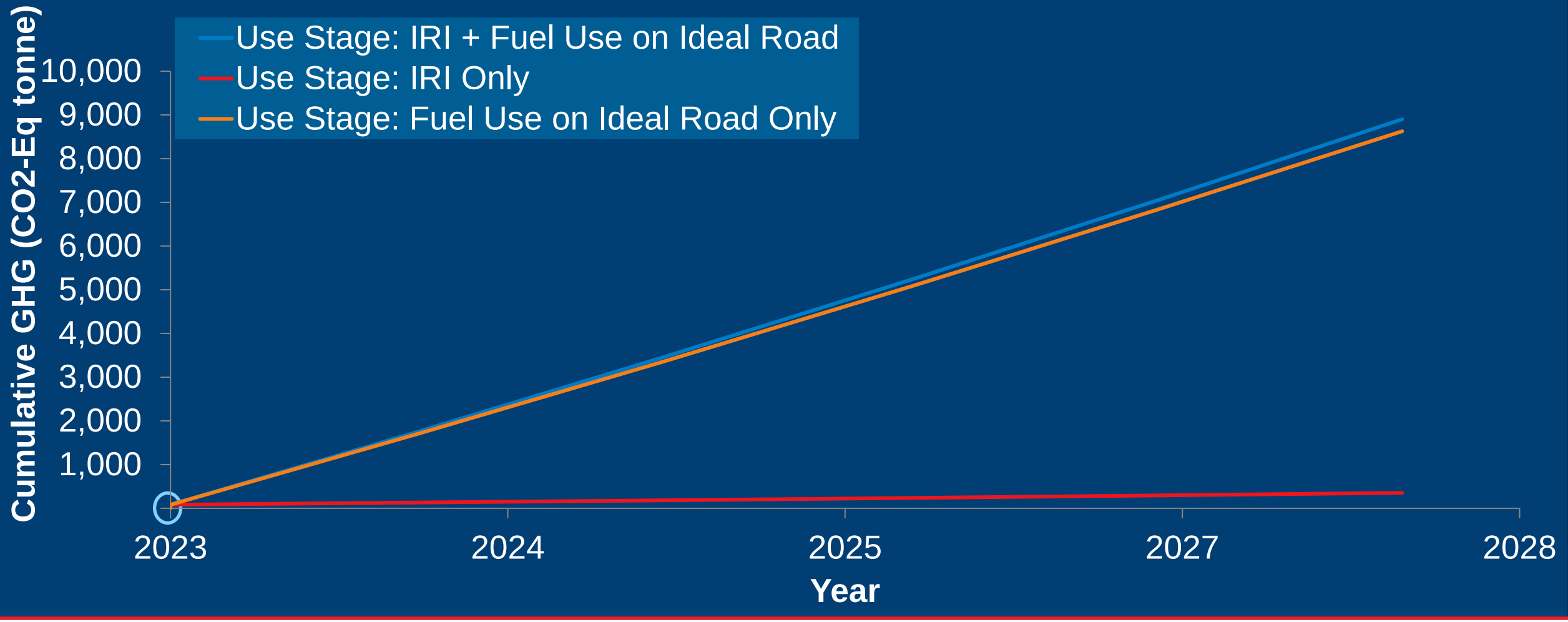
Example: Cradle-to-Laid (Lane-mile; analysis period 30 years)




- Note: User has selected to use 'US-CA: 2019 Electricity Mix' for all processes needing Electricity
Use Stage: IRI + Fuel Use on Ideal Road
Use Stage: IRI Only
Use Stage: Fuel Use on Ideal Road Only
CASE 1: REHABILITATION AND PRESERVATION
Rehab. 1
Preservation 1
Rehab. 2
Preservation 1
Cumulative GHG (CO2-Eq tonne)
1,000
800
600
400
200
0
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050
2052
2054
2056
2058
2060
2062
Date


CASE 2: REHABILITATION ONLY
Rehab. 1
Rehab. 2
Rehab. 3
Cumulative GHG (CO2-Eq tonne)
800
600
400
200
0
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050
2052
2054
2056
2058
2060
2062
Date

Use Stage with Low Traffic: BUT-70-E



Summary

- Life cycle assessment (LCA) can be used to quantify environmental impacts
- Guidance for applying LCA to pavements is available
- Tools for applying LCA to pavement sustainability problems are becoming available

  eLCAP is one of such tools (working to make it available for others to use)
- Primary data from industry can make LCAs meaningful and impactful

Disclaimer

This document is disseminated in the interest of information exchange. The contents of this presentation reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This publication does not constitute a standard, specification, or regulation. This presentation does not constitute an endorsement by the Department of any product described herein.

References

- Pavement Life Cycle Inventories for California: Models and Data Development in the Last Decade for Caltrans: https://doi.org/10.7922/G2RX99FD
- eLCAP: A Web Application for Environmental Life Cycle Assessment for Pavements: https://doi.org/10.7922/G2ST7N5G
- Multicriteria Decision Analysis

  State

    Life Cycle Assessment and Life Cycle Cost Analysis for Six Strategies for GHG Reduction in Caltrans Operations: https://doi.org/10.7922/G22R3PZG

    Alternative Strategies for Reducing Greenhouse Gas Emissions: A Life Cycle Approach using a Supply Curve: https://doi.org/10.7922/G2Z036FF

  Local Government

    Greenhouse Gas Reduction Opportunities for Local Governments: A Quantification and Prioritization Framework: https://doi.org/10.7922/G2SJ1HVR

Thanks to many colleagues and Caltrans!

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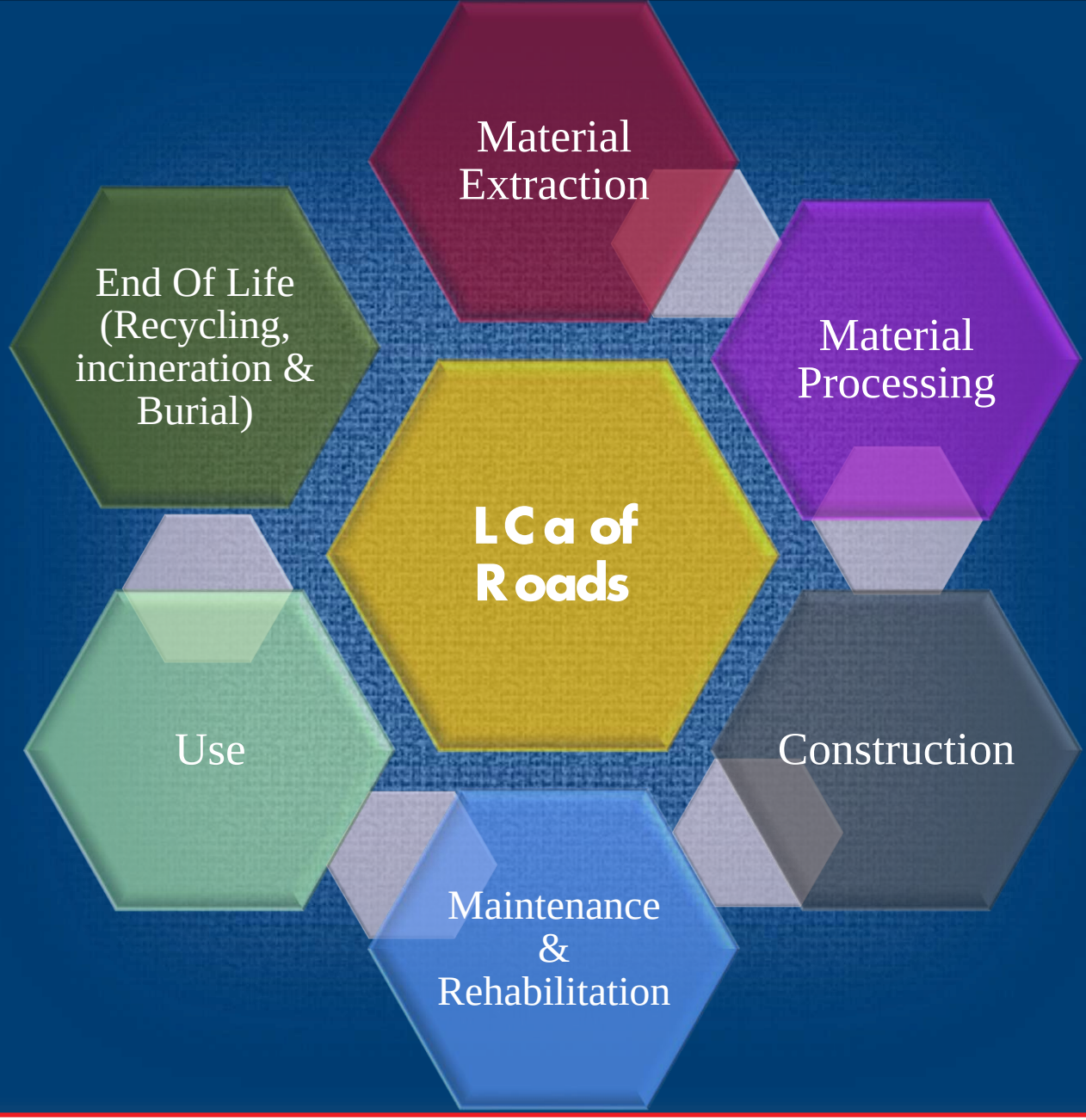
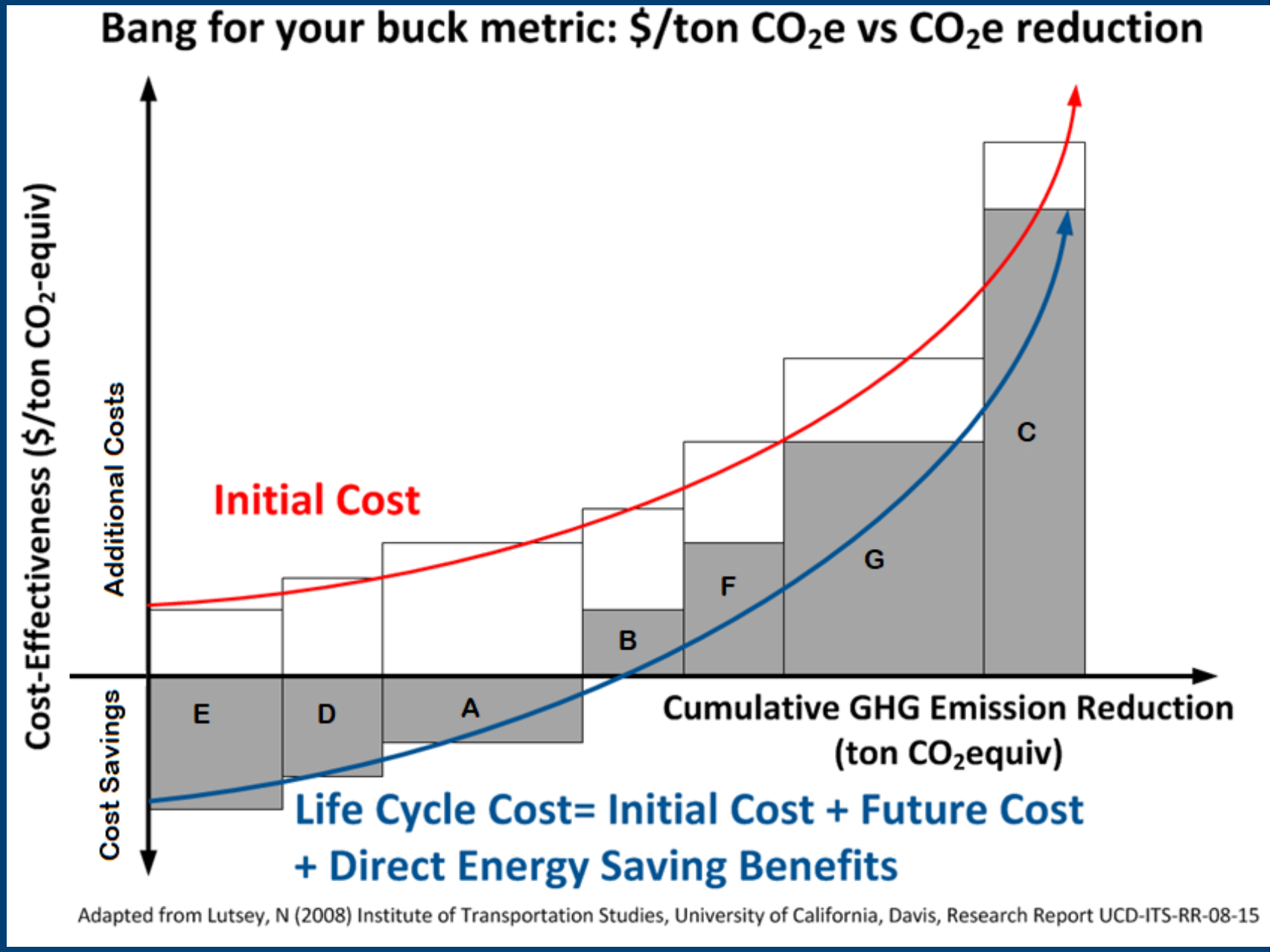
Prioritization of Strategies using LCa (LCA and LCC)



- "Supply curve", "Marginal abatement curve", "McKinsey Curve"
- Provides first-order analysis prioritization of which ideas to further investigate
- UCPRC pilot projects
  - Caltrans changes to internal operations
  - Local government review of climate action plans



Adapted from Lutsey, N (2008) Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-15

Example: Supply Curve Output for Caltrans alternatives