Development of Environmental Life-Cycle Assessment Framework for Rehabilitation of Pavements Using Full-Depth Reclamation

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TRB 2015

Overview

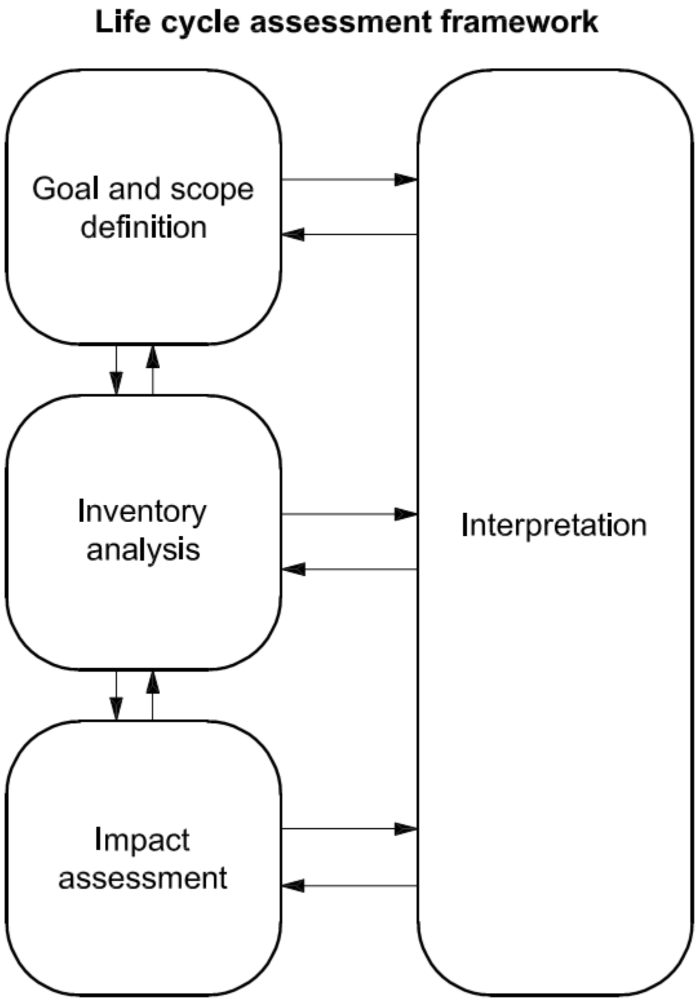
1. Life Cycle Assessment (LCA) Methodology
2. UCPRC Framework for Pavement LCA
3. End of Life (EOL) Phase of Pavements, Issues and Challenges
4. Conclusions and Future Steps

1. LCA Methodology

Sustainability and LCA

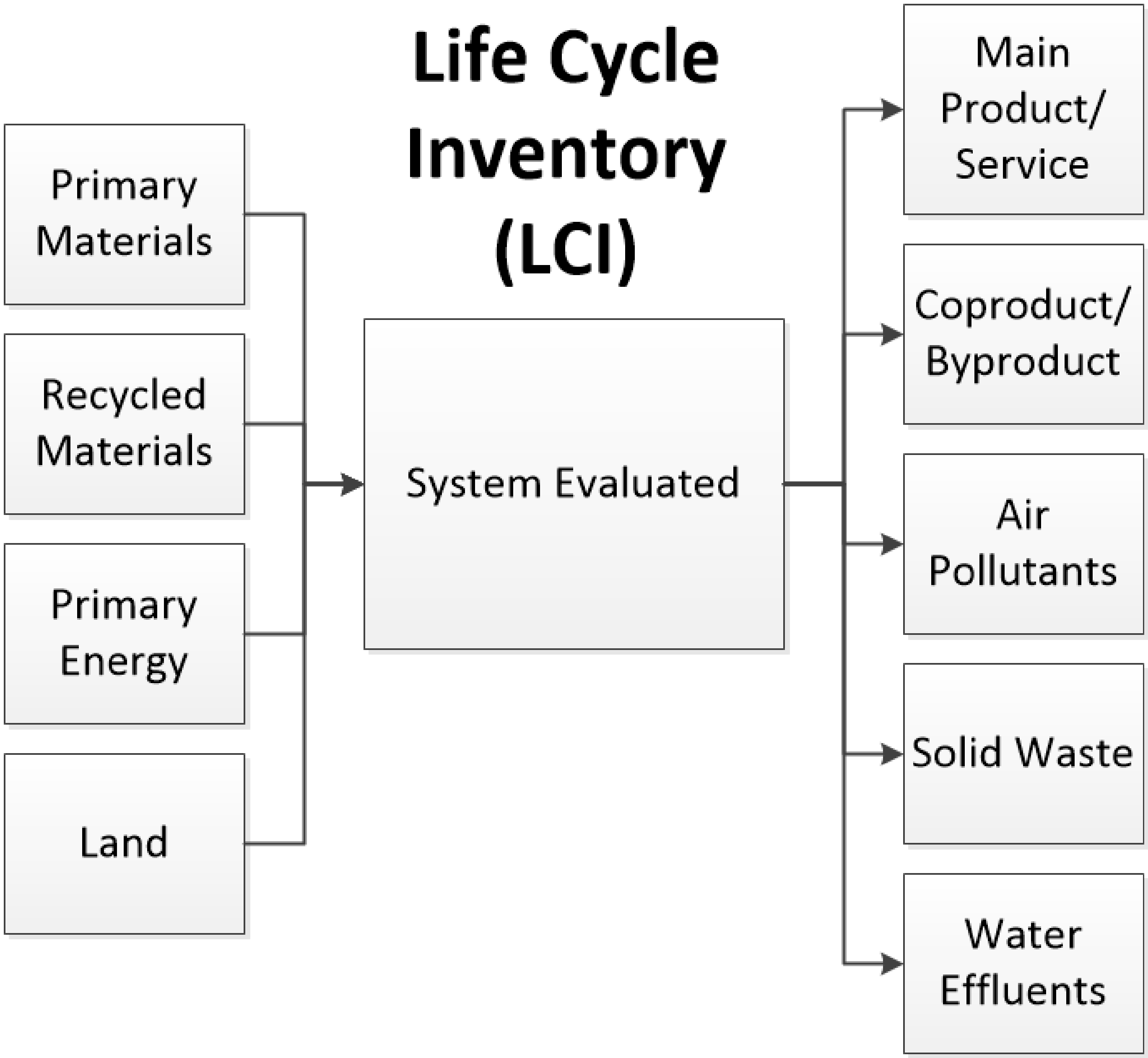
- "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland Com., 1987)
- LCA is a globally accepted methodology for evaluating environmental sustainability of any product or service
- ISO 14040 series provides general guidelines for conducting LCA

LCA Stages – ISO 14040



Source: ISO 14040

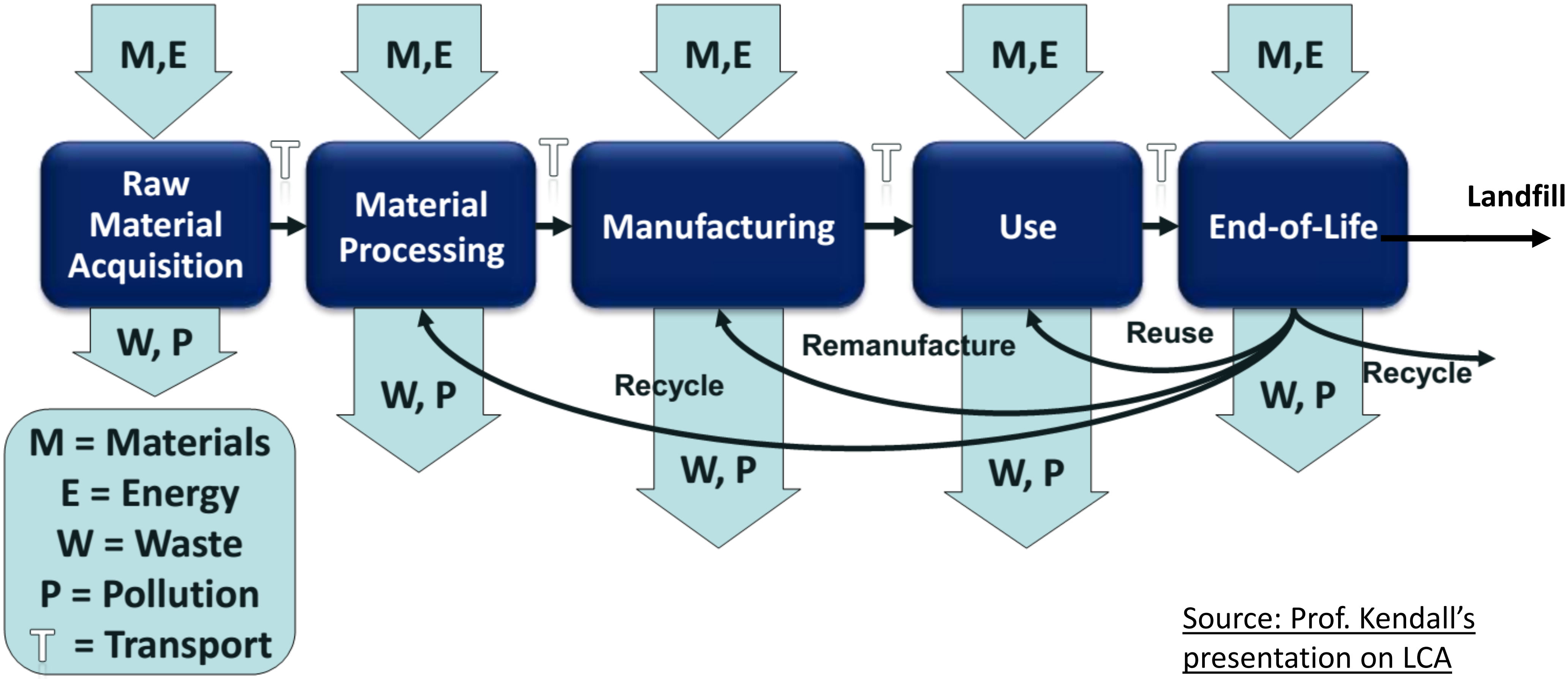
Life Cycle Inventory (LCI)



Impact Assessment

- LCIA is the step in which LCI outputs are translated into indicators, some categories are:
  - Global Warming Potential (GWP)
  - Acidification
  - Neutrification
  - Ecotoxicity
  - Human Toxicity
- Primary Energy Demand (PED), which is an LCI item, is reported with LCIA results

Cradle to Grave Approach

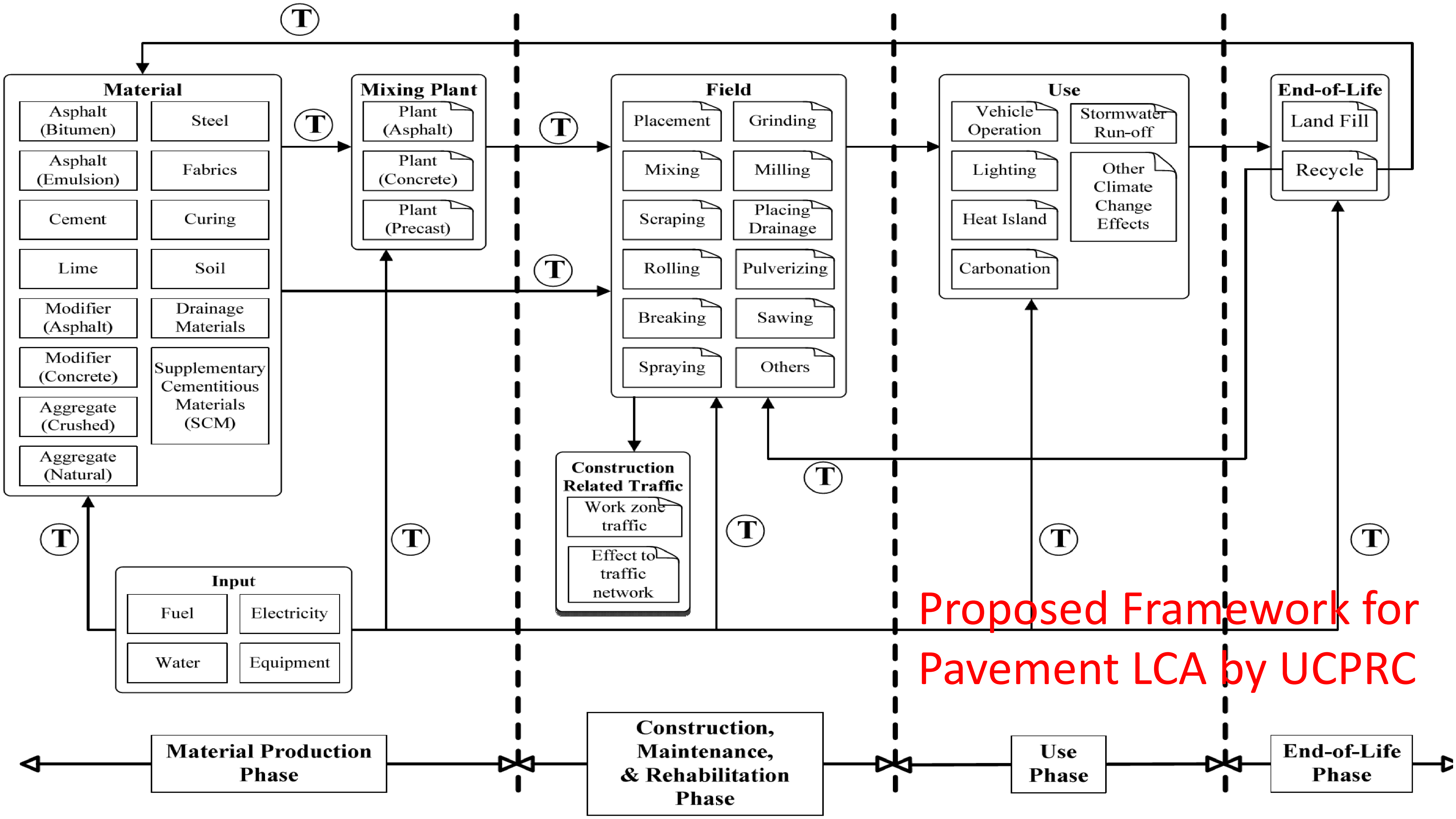


Source: Prof. Kendall's presentation on LCA

2. UCPRC Framework for Pavement LCA

Selected UCPRC LCA Efforts

- *UCPRC Pavement LCA Guideline,* the first framework for pavement LCA
- First Pavement LCA Workshop (May 2010)

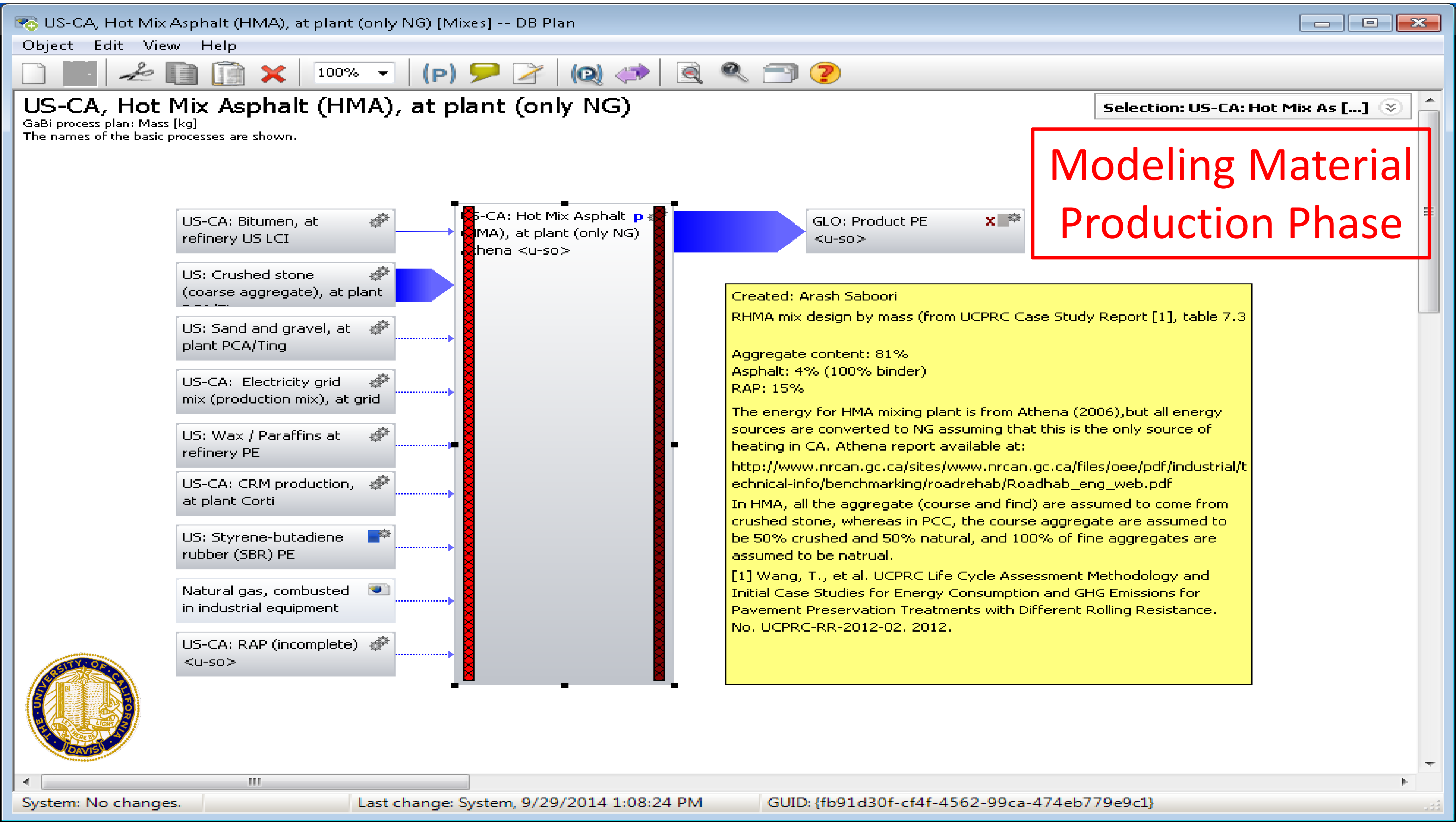


T
Material
Asphalt (Bitumen)
Steel
Asphalt (Emulsion)
Fabrics
Cement
Curing
Lime
Soil
Modifier (Asphalt)
Drainage Materials
Modifier (Concrete)
Supplementary Cementitious Materials (SCM)
Aggregate (Crushed)
Aggregate (Natural)
Mixing Plant
Plant (Asphalt)
Plant (Concrete)
Plant (Precast)
Field
Placement
Grinding
Mixing
Milling
Scraping
Placing Drainage
Rolling
Pulverizing
Breaking
Sawing
Spraying
Others
Construction Related Traffic
Work zone traffic
Effect to traffic network
Use
Vehicle Operation
Stormwater Run-off
Lighting
Other Climate Change Effects
Heat Island
Carbonation
End-of-Life
Land Fill
Recycle
Input
Fuel
Electricity
Water
Equipment
Proposed Framework for Pavement LCA by UCPRC
Material Production Phase
Construction, Maintenance, & Rehabilitation Phase
Use Phase
End-of-Life Phase

Selected UCPRC LCA Efforts

- LCI datasets for material production phase calibrated based on CA electricity grid mix and CA plant fuels
- Case studies on preservation treatments including material production, construction, and use phase
- 2014 Pavement LCA Symposium in Oct. 2014

Modeling Material Production Phase



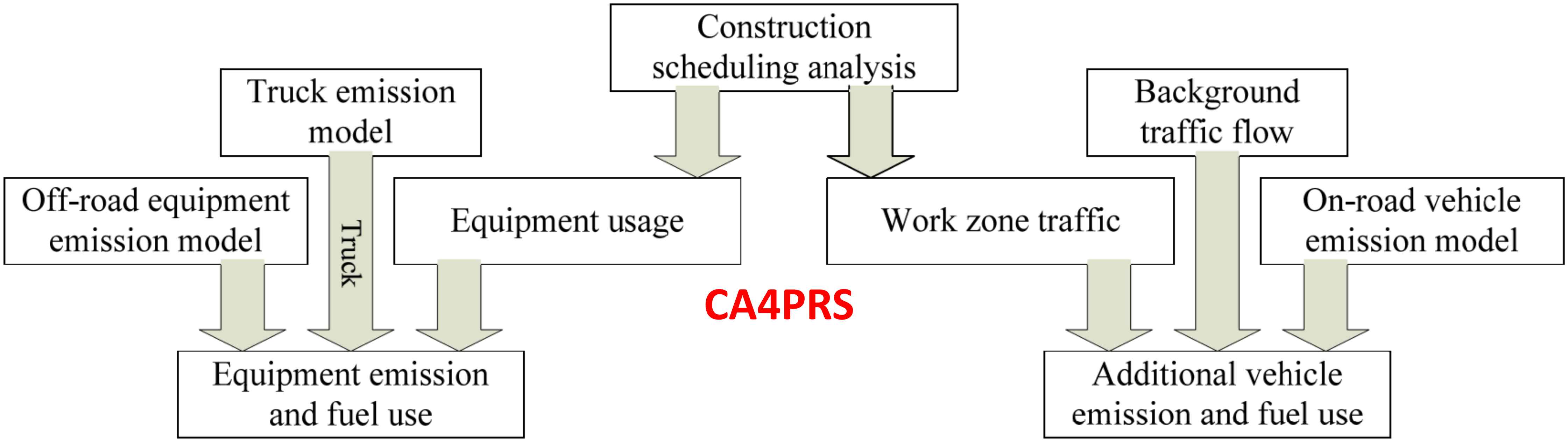
LCI datasets have been developed for these materials (cradle-to-gate)

	#	Item	
Material Production	1	Aggregate - Crushed	
	2	Aggregate - Natural	
	3	Bitumen	
	4	Bitumen Emulsion	
	5	Crumb Rubber Modifier (CRM)	
	6	Dowel & Tie Bar	
	7	Energy Sources	Diesel Burned
	8		Electricity
	9		Natural Gas Combusted
	10	Limestone	
	11	Paraffin (Wax)	
	12	Portland Cement	Regular
	13		Slag Cement (19% Slag)
	14		Slag Cement (50% Slag)
	15	Portland Cement Admixtures	Accelerator
	16		Air Enterainer
	17		Plasticiser
	18		Retarder
	19		Superplasticiser
	20		Waterproofing
	21	Styrene Butadiene Rubber (SBR)	

Sample LCIA Summary – Material Production

Item	Functional Unit	GWP kg CO2e	POCP kg O3e	PM10 kg	PED (total) MJ	PED (non-ren) MJ
Aggregate - Crushed	1 kg	3.43E-03	6.53E-04	5.08E-11	6.05E-02	5.24E-02

Modeling Construction Phase



Sample LCIA Summary – Construction

Case	Equipment/Activity	Engine power (hp)	Hourly Fuel Consumption (gal/hr)	Speed (ft/min)	Speed (km/h)	Time (hr) for 1 pass over Functional Unit (1 lane-km)	Number of Passes	Fuel Used (gal)	Total Fuel Consumption
	Sweep	80	2	100	1.829	0.55	2	2.19	
	Emulsion Application	350	7.2	25	0.457	2.19	1	15.75	
Chip Seal	Aggregate Application	350	7.2	25	0.457	2.19	1	15.75	68.0
	Rolling (pneumatic)	120	4.9	25	0.457	2.19	3	32.15	
	Sweep	80	2	100	1.829	0.55	2	2.19	

Surface Treatments with LCIs Developed

Surface Treatment					
1	Cape Seal	9	Reflective Coatings		BPA
2	Chip Seal	10			Polyester Styrene
3	Fog Seal	11			Polyurethane
4	Hot Mix Asphalt (HMA)	12			Styrene Acrylate
5	Pavers	13	Rubberized HMA (RHMA)		
6	Permeable HMA	14	Sand Seal		
7	Permeable PCC	15	Slurry Seal		
8	Portland Cement Concrete	16	White Topping		

Modeling Different Recycling Techniques

- Additives (LCIs already available)
- Site works and construction activities, which is basically estimating how much fuel is used, options are:
    - Collect from literature/contractors
    - Calculate based on equipment specs (hp) and the recycling process (speed of equip. and # of passes)
    - Collect field data (FHWA project with UIUC)

Modeling Different Recycling Techniques

Energy Demand (Btu/Yd^2)

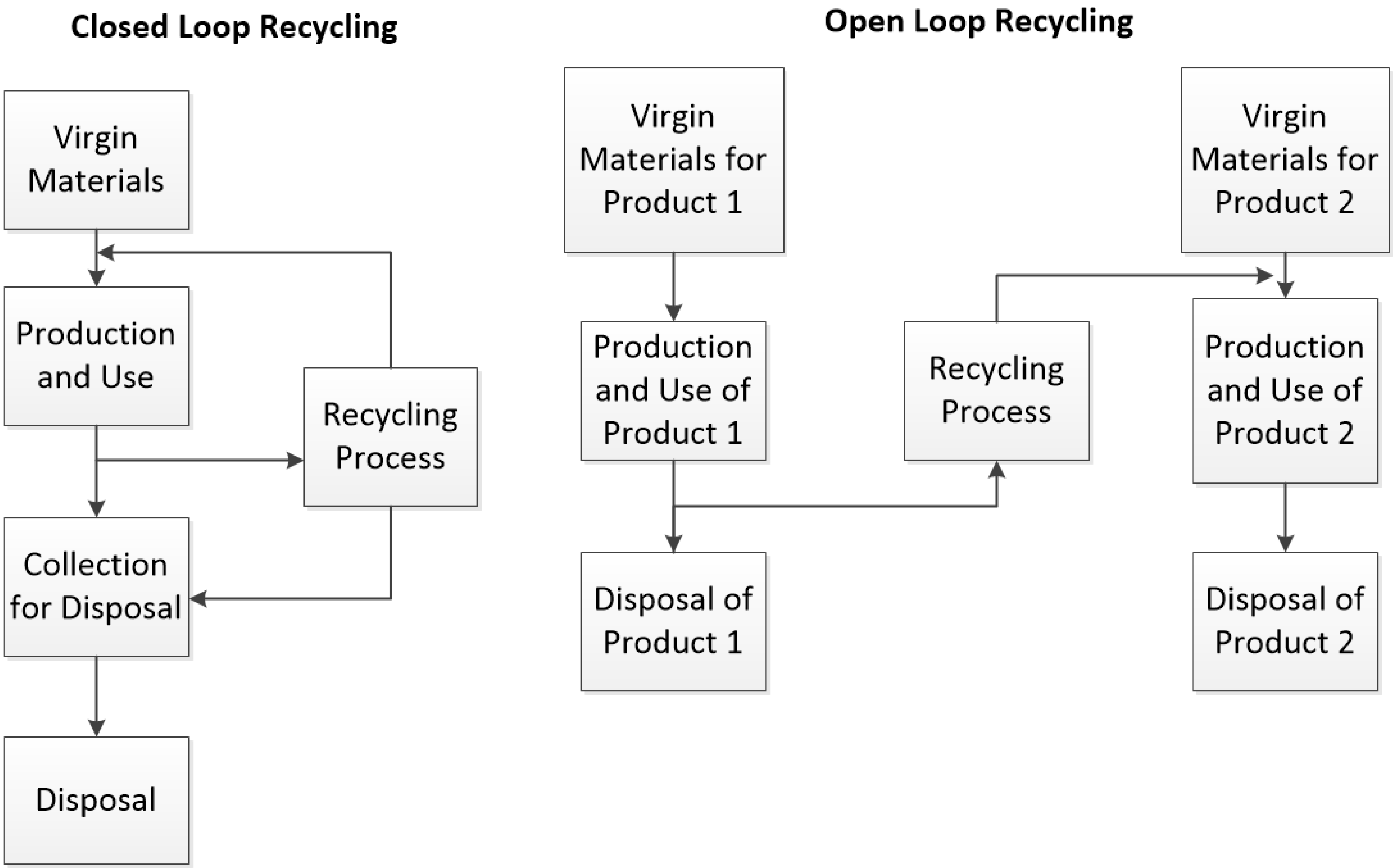
Operation	NCHRP 214	Colas Group	PaLATE	Granite Construction	Representative Range
CIPR—partial depth		6,400	24,600	3,100	3,000–24,000
CIPR—full depth	15,000–20,000	6,200	34,700	1,300–11,100	1,300–15,000
HIPR—scarifying	13,300–26,700	26,200	5,700	3,750	3,500–27,000
HIPR—remixing	13,300–26,700	26,200	21,100	9,260	9,000–27,000
HIPR—repaving	13,300–26,700	26,200	43,800	17,460	13,000–44,000

Source: Robinette and Epps, 2010

3. End of Life (EOL) Phase of Pavements, Issues and Challenges

End of Life Phase

- EOL options for both asphalt and concrete pavements:
  - Recycle
  - Allow to remain in place and reuse as part of the supporting structure for a new pavement
  - Remove and landfill
- Specific to asphalt pavements:
  - Central Plant Recycling (hot and cold)
  - Cold-in-Place Recycling (both partial and Full-Depth Reclamation)
  - Hot-in-Place Recycling
- Ideal goal is effectively achieving a zero-waste highway construction stream


Closed Loop Recycling
Virgin Materials
Production and Use
Recycling Process
Collection for Disposal
Disposal
Open Loop Recycling
Virgin Materials for Product 1
Production and Use of Product 1
Disposal of Product 1
Recycling Process
Virgin Materials for Product 2
Production and Use of Product 2
Disposal of Product 2

Main Challenge: Allocation

- Allocation: "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems." ISO 14044

- Areas of challenge:
  - Coproducts such as oil refinery products
  - Byproducts such blast furnace slag and fly ash
  - Recycling

Suggested Allocation Methods

- Based on value ($, mass, energy content, etc.)
- Based on subdivision (divide production processes into sub-processes and assign each to a co-product)
- System expansion
  - Broadens system boundary to introduce a new functional unit that includes both main and by/co-product
  - Subtracting the environmental burdens of an alternative way of producing the by/co-product

Allocation Methods for Recycling

- Cut-off Method

  Benefits and burdens of recycling are all allocated to downstream, no credit for the first pavement in using recyclable materials)

- 50/50 Method

  Half of the impacts allocated to the initial pavement and half to the new pavement using recycled materials

- Substitution Method

  The first pavement is given the full benefits

Breakout Session at 2014 LCA Symposium

Summary of break-out session on EOL:

- Transparency in execution of allocation is a must
- Cutoff method appears to potentially meet the goals
- 50-50 method might be plausible or attractive

Need to fill gaps:

- Suggest to conduct a study of a comprehensive set of pavement recycling scenarios with cutoff and 50/50 to check impacts and economic incentives (this is ongoing)

4. Conclusions and Future Steps

Conclusions

- Recycling pavements at the end of life is accepted as one of the most effective ways to improve sustainability, major (potential) benefits are:
  - Conservation of virgin materials
  - Reduction in the cost of pavement preservation
  - Reduced lane closures, reduced fuel consumption, and reduced emissions
- However, it is needed to conduct a comprehensive economic and environmental analysis for different alternatives at EOL to fully quantify the impacts

Future Steps

- Case studies for Caltrans on different recycling scenarios and allocation methods
- Comparison of pavement performance for sections made from recycled material vs virgin materials to understand the impact of using recycled materials on:
  - Future M&R frequencies
  - IRI vs time and therefore use phase fuel consumption
- Development of reliable pavement performance prediction models for sections made from different recycling techniques (ongoing, Caltrans PMS under revision by UCPRC)

Thank you for your attention!

Questions?

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