Introduction to LCA and application to pavement

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LCA Workshop 2015
Harbin, CHINA
7-8 August, 2015

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PAVEMENT RESEARCH CENTER

Outline

- Pavement facts
- Forces driving consideration of environmental impact in pavement
- Introduction to LCA and how it works
- Application of LCA to pavement

China and US road networks
Largest road networks in the world

- China: #1 expressway network; #3 road network
- USA: #1 road network; #2 expressway network

	China	United States
Expressway network (km)	111,950	77,017
Road network (km)	4,460,000	6,586,610

Why Care? US Pavement Facts

- Mobility & access: almost 5 x 10^{12} vehicle-km travelled annually
- Value: Roads carry about 67 percent of all freight in the US (tons and $)
- Employment: 300,000 people employed in roads and bridges
- Cost: $182.1 x 10^{9} spent on highways per year
- Owners: State and local governments, private and institutional owners, federal government

Image sources: Pixbay.com and Microsoft Clip Art

Source: FHWA Pavement Sustainability Reference Document

Why Care? US Pavement Facts

- Energy: vehicles moving on pavement burn 640 x 10^9 liters of fuel per year
- Natural resources used each year (million metric tons):
  - 1,200 crushed stone, 987 sand/gravel,
  - 21 asphalt binder,
  - 72 cement (incl. bridges),
  - all highly recycled
- Emissions from road system: Greenhouse gases (GHGs), air and water pollutants

Image sources: Pixbay.com and Microsoft Clip Art

Source: FHWA Pavement Sustainability Reference Document

Are pavements sustainable? My opinion of how the question was being answered in 2009

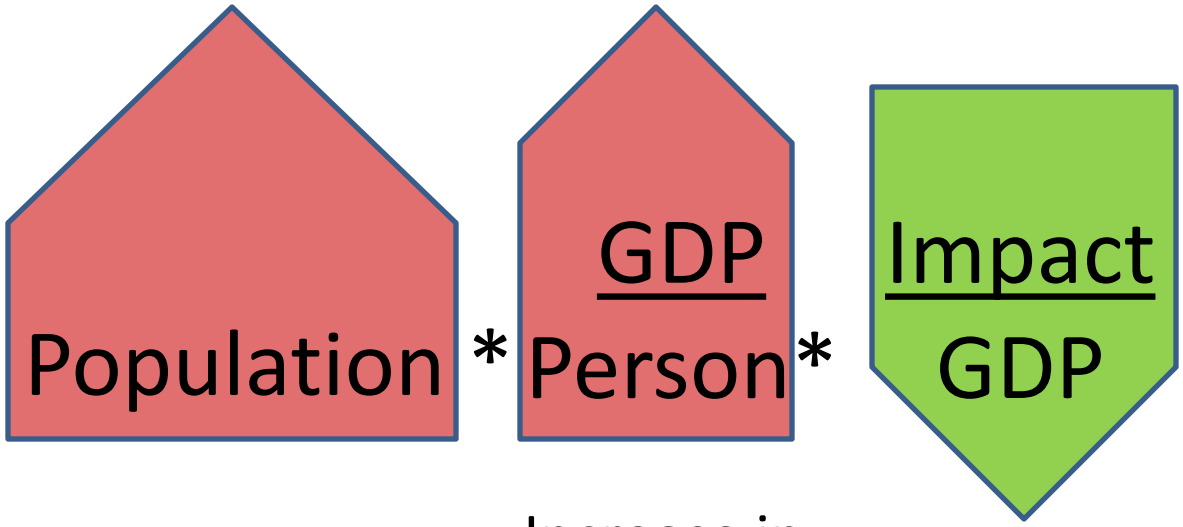
- Prior to LCA "sustainability" was primarily a marketing theme
- Previous approaches for looking at sustainability were often:
  - Confusing to engineers and decision-makers
    - Unscientific, biased, incomplete, no transparency, not peer-reviewed, no established principles
    - Focused on wrong question: concrete vs asphalt for new pavement (see first bullet above)
  - Irrelevant by not addressing how decisions are made (cost)
- Policies were often made without understanding unintended consequences.
- Use of "indices" that arbitrarily award "points" for decisions on pavement project that had small effect on environmental impact, or sometimes lead to negative consequences.

Are pavement sustainable? My overall opinion

- Sustainability means that we can keep doing the same thing for a long time (100 years?) without significant negative effects on human society and the environment on which it depends
- Pavements are not currently sustainable by that definition
- I think these should be our goals:
  - We must do everything we can to make them as sustainable as possible as fast as possible
  - We need move towards sustainability as cost efficiently as we can or we will not succeed
- To achieve these goals we must apply scientific principles and we broadly define the system we are analyzing and take a long-term (life cycle) view

Master equation for environmental impacts

Environmental impact as function of Gross Domestic Product (national economic output) =



Increase in wealth and economic activity

Technological efficiency (how to measure?)

Ehrlich and Holdren (1971) Impact of population growth. e.g. via LCA
Science 171, 1211-1217
Slide adapted from R. Rosenbaum, Pavement LCA 2014 keynote address

Assembly Bill 32 (2007)

Reaffirmed by direct vote in 2010 61% to 39%

Requires reduction to 2020 GHG emissions at 1990 levels

2050 GHG emissions at 0.2 x 1990 levels

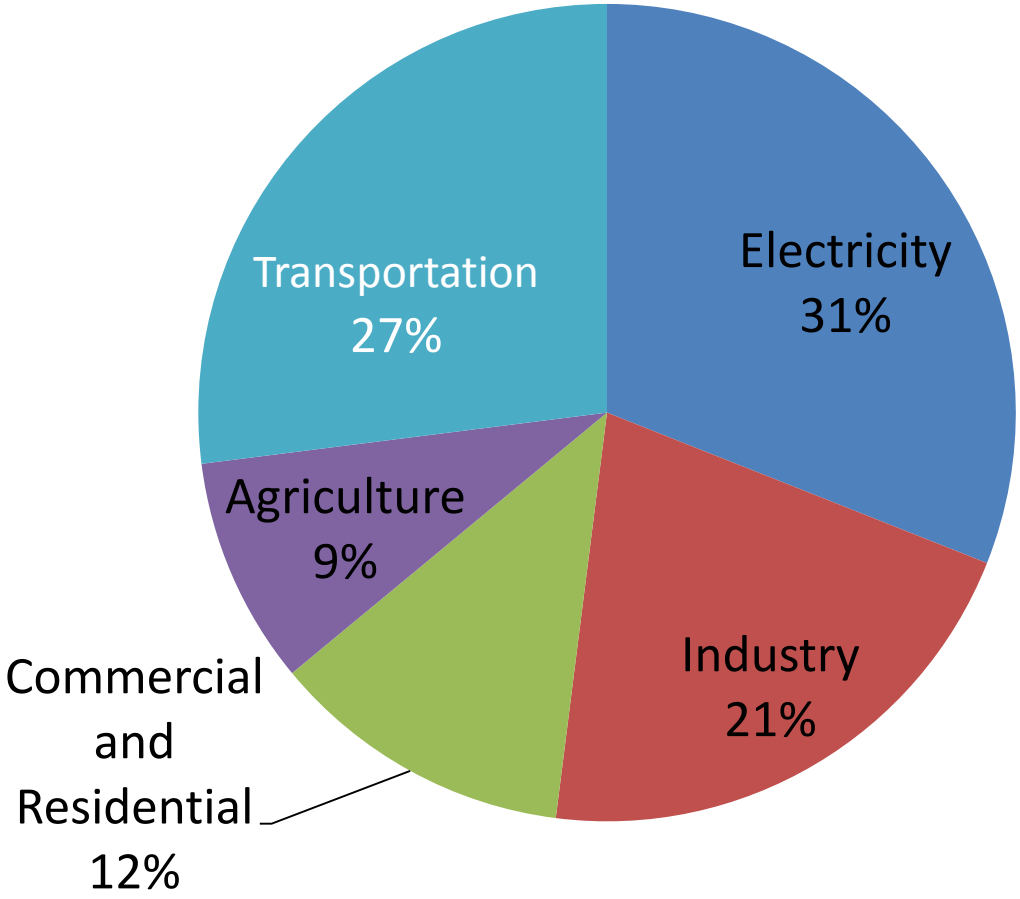
- Current state approaches for meeting AB32 goals for transportation sector
  - Change vehicle technology
  - Change carbon content of vehicle fuel
  - Reduce vehicle miles traveled (SB 375 land-use bill affects freeway widening)
- Can pavements make a contribution as well?
  - Is it cost-effective compared to other strategies?

Why Care? Greenhouse Gas Emissions

In US, road vehicles are largest contributor in Transportation – With Gasoline and Diesel accounting for 90% of all emissions

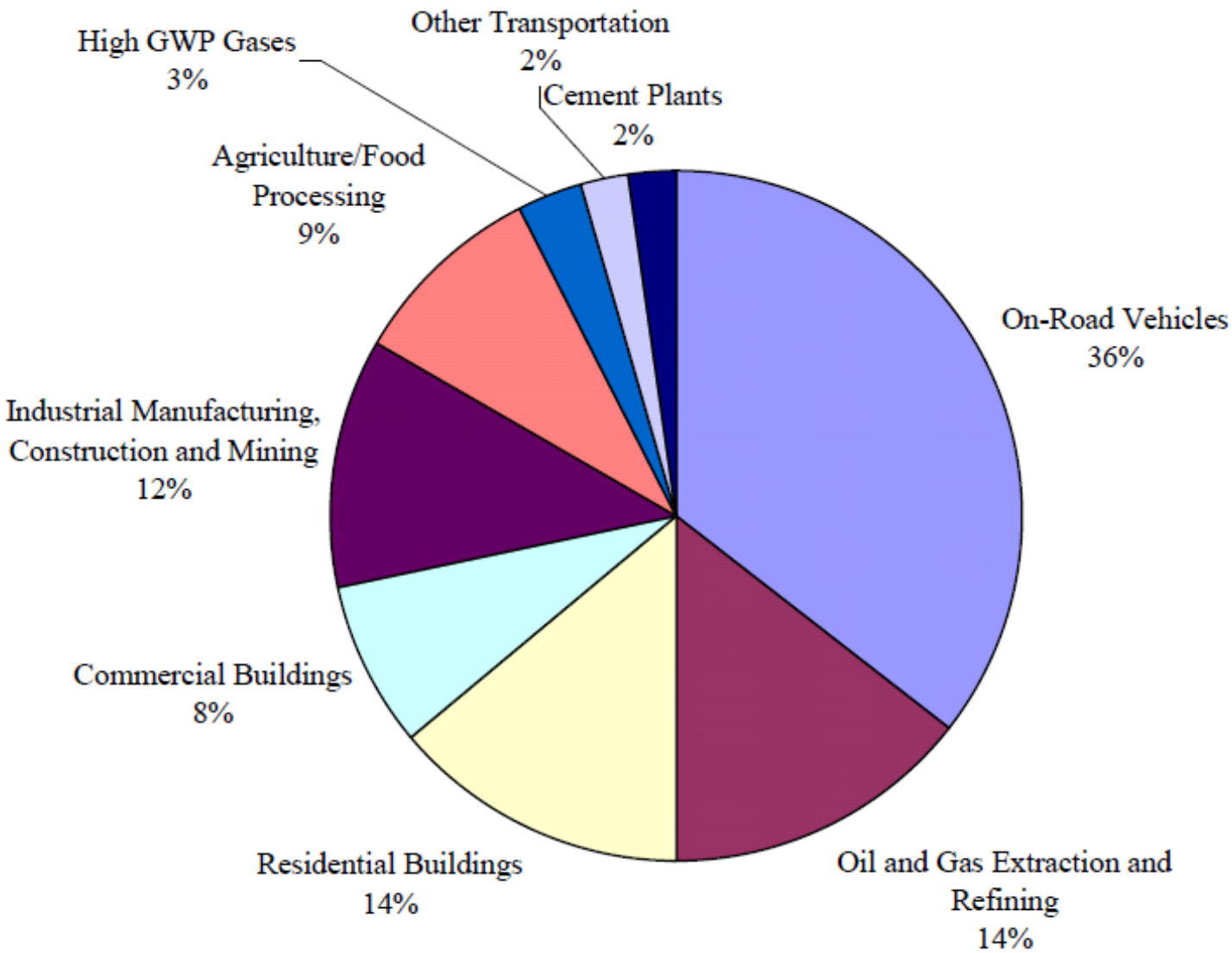
Pavements affect vehicle fuel use

US Greenhouse Gas (GHG) Inventory 2013, US EPA

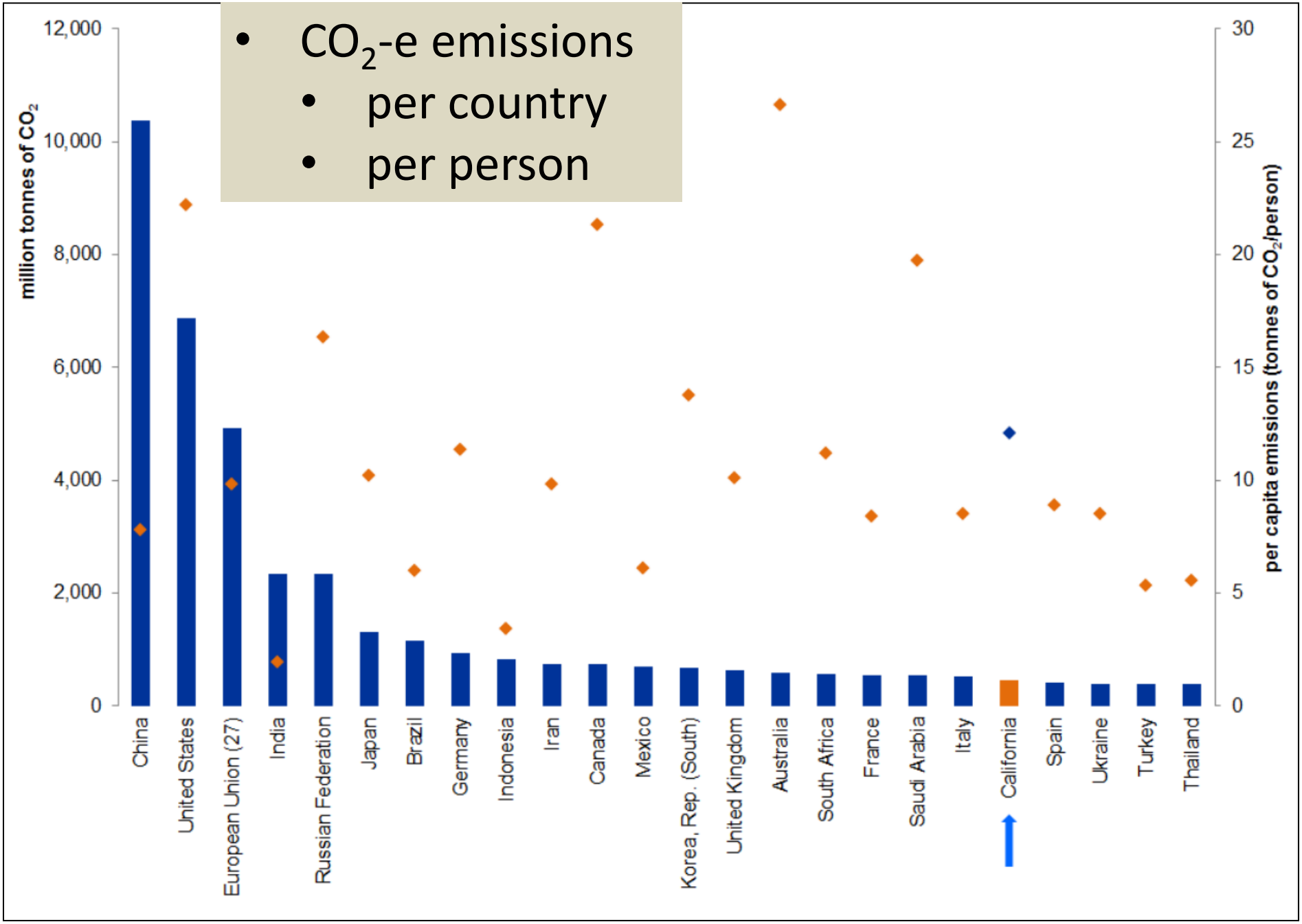


California sources of greenhouse gas emissions by end use

California Air Resources Board



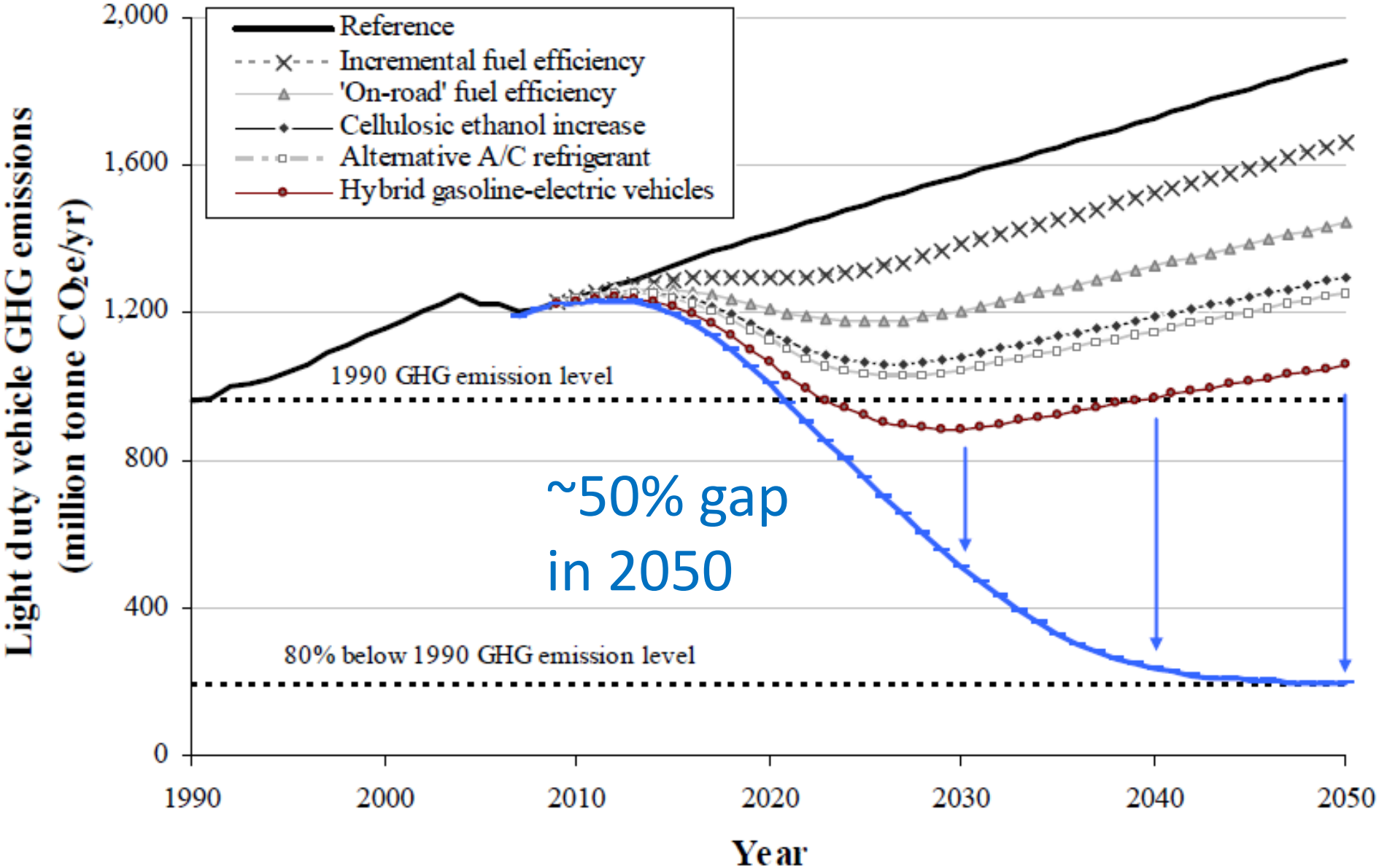
- CO_2-e emissions
  - per country
  - per person



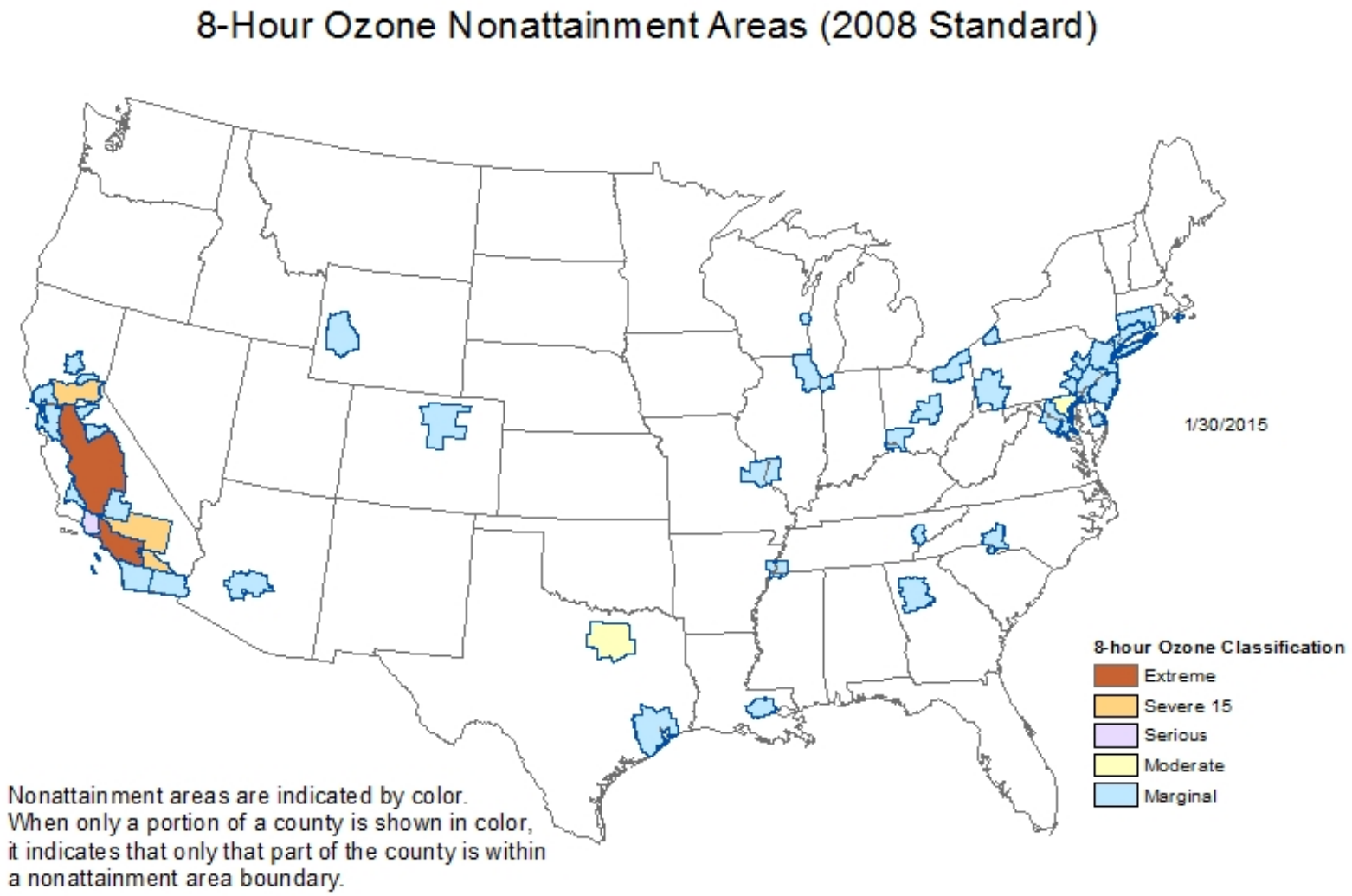
California Air Resources Board, 2014

The "Gap" for Transportation

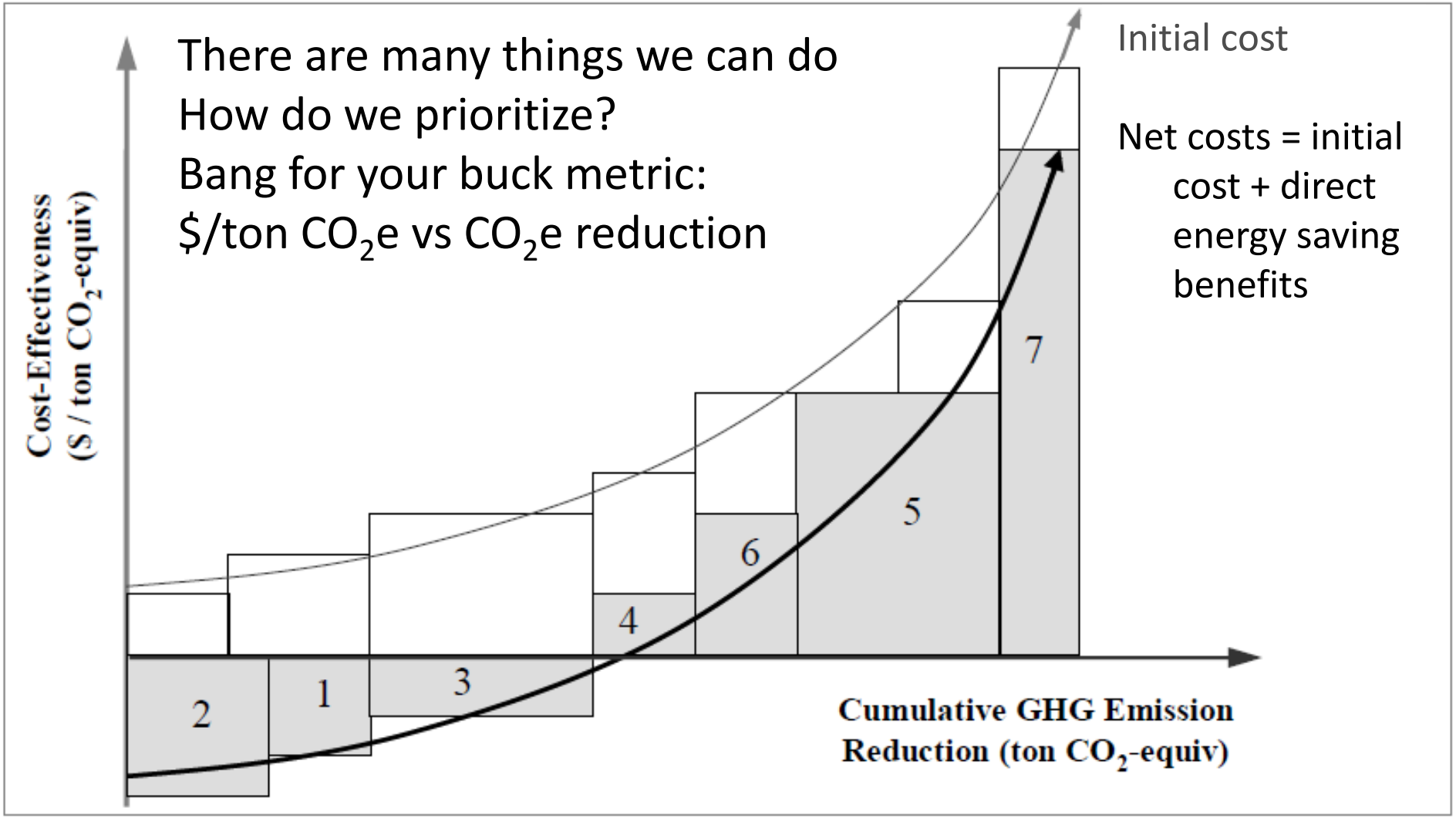
N. Lutsey, doctoral thesis, UC-Davis



Other types of environmental impact: 8 hour ozone non-attainment by county



http://www.epa.gov/oaqps001/greenbk/map8hr_2008.html



- **Prioritizing Climate Change Mitigation Alternatives: Comparing Transportation Technologies to Options in Other Sectors**
- **Lutsey, N. (2008)**
  Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-15

Motivations to improve environmental performance of pavement

- Political forces
  - Local: people do not want to live in high pollution environments
  - Global: awareness of global mechanisms affecting human society
- Market forces
  - Increasing pressure to compete in terms of environmental impact as well as cost
  - Environmental improvement often leads to reduced cost
- Pavement uses a lot of resources and produces a lot of pollution: we can make a significant contribution

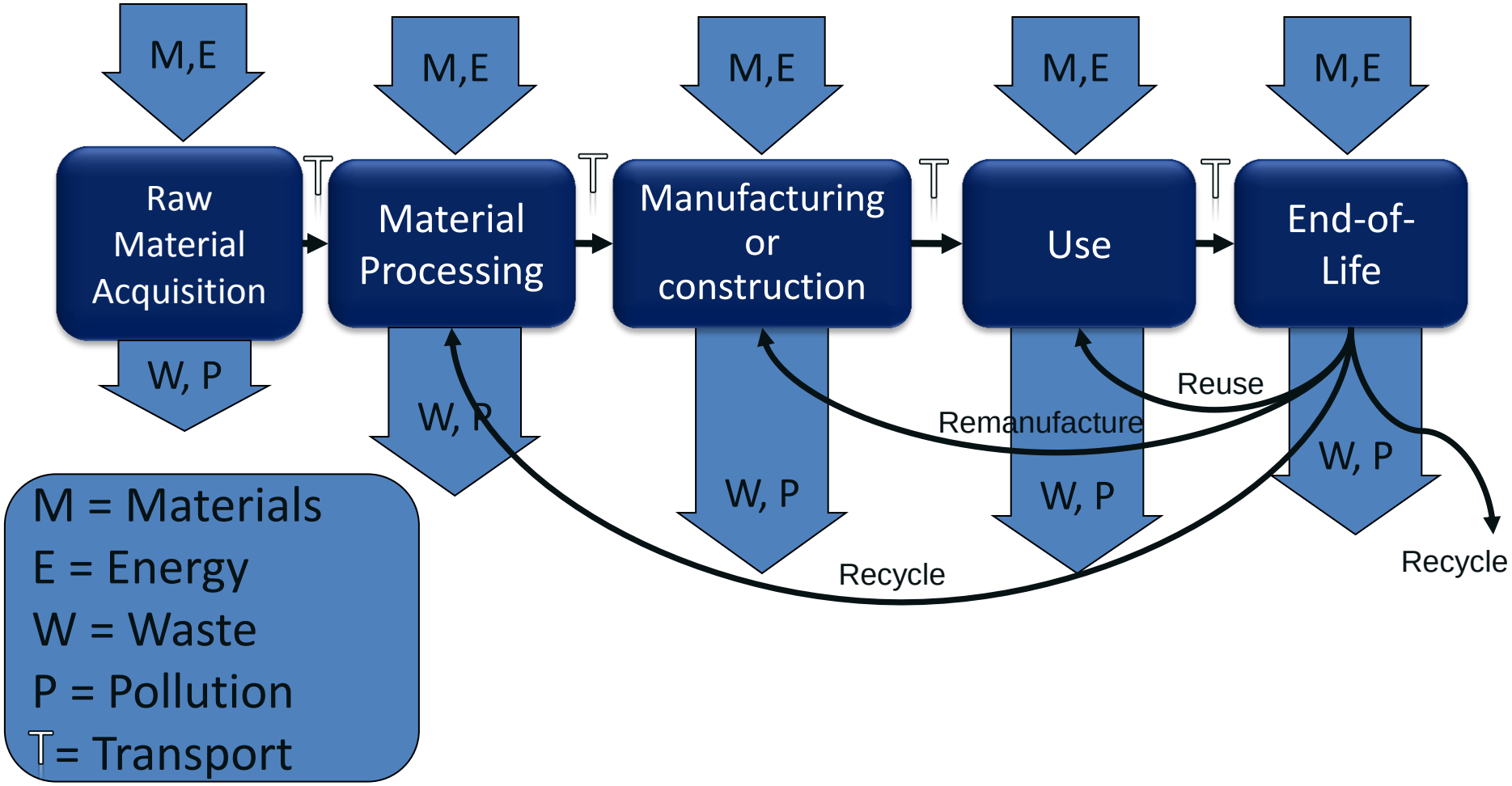
Life Cycle Assessment (LCA)

- If we are to improve sustainability of pavement must be able to measure impacts
- LCA provides a method for characterizing and quantifying environmental sustainability using a cradle-to-grave perspective, and considering system-wide impacts for a product, policy, or system.

History of LCA

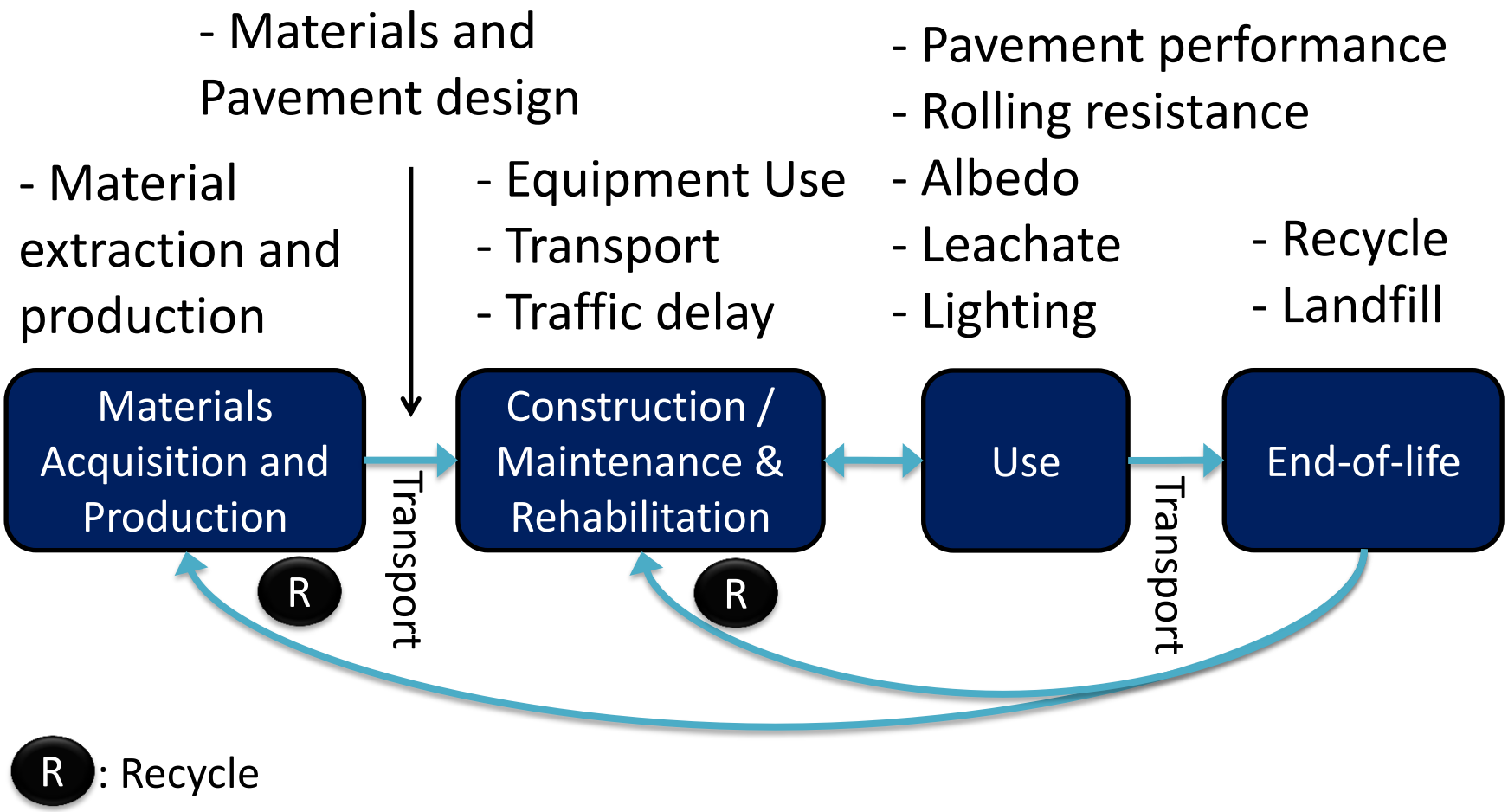
- Precursors to LCA developed in late 1960s to analyze air, land, and water emissions from solid wastes.
- Broadened to energy, resource use, and chemical emissions, with a focus on consumer products and product packaging rather than complex infrastructure systems.
  - Coca-cola containers and baby diapers
- 1960 to 1990, focus on generating *life cycle inventory (LCI)* methods.
- 1990 to 2000, creation of full-fledged impact assessment methods and the standardization of methods by the International Organization for Standardization (ISO).
- Since 2000, impact assessments broadened and methods enhanced; expansion to more complicated systems, like transportation infrastructure deployment and operation.

Generic Life Cycle

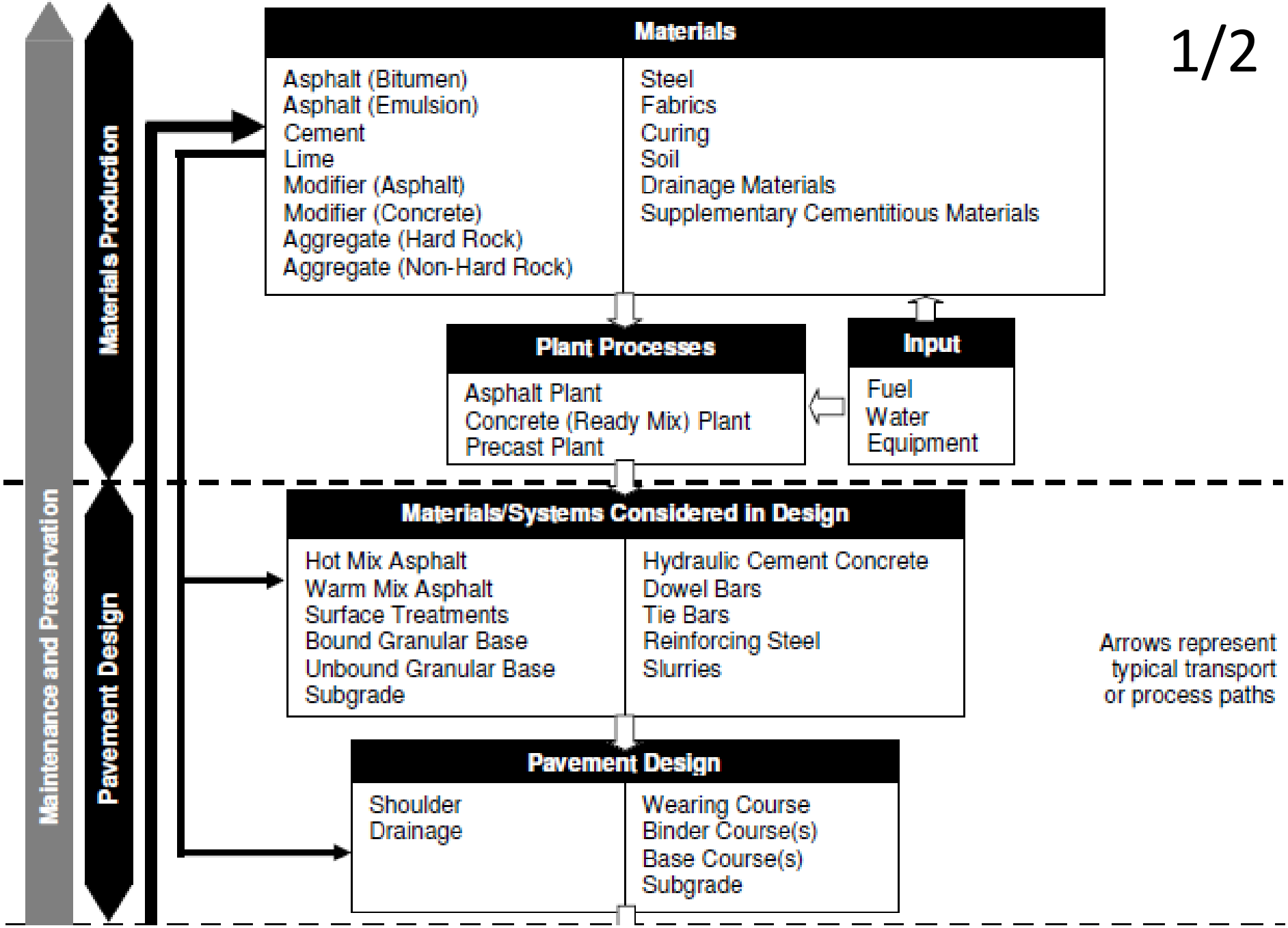


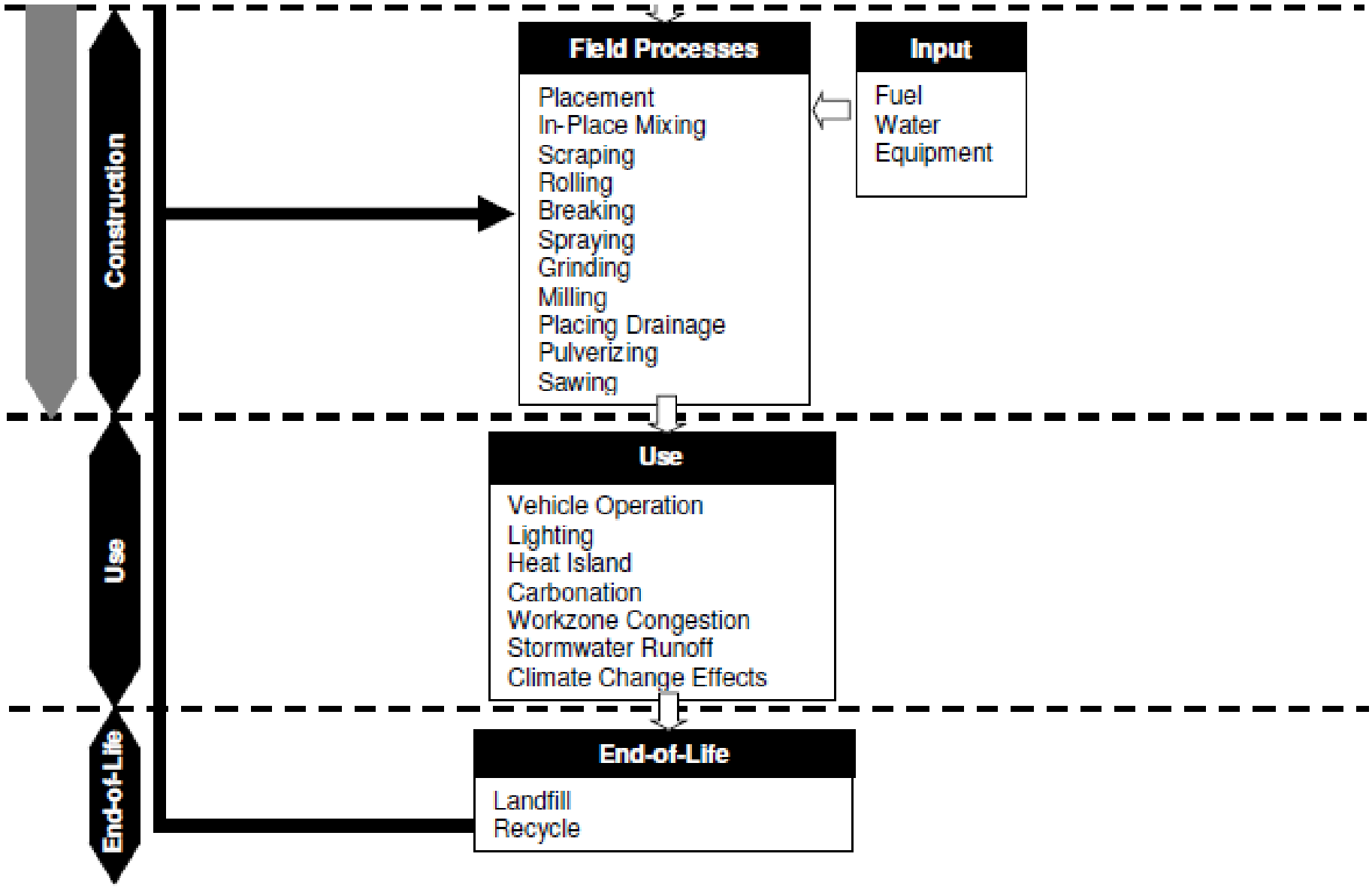
Kendall, A., Keoleian, G. A., 2009

Pavement Life Cycle



From: Kendall et al., *2010*

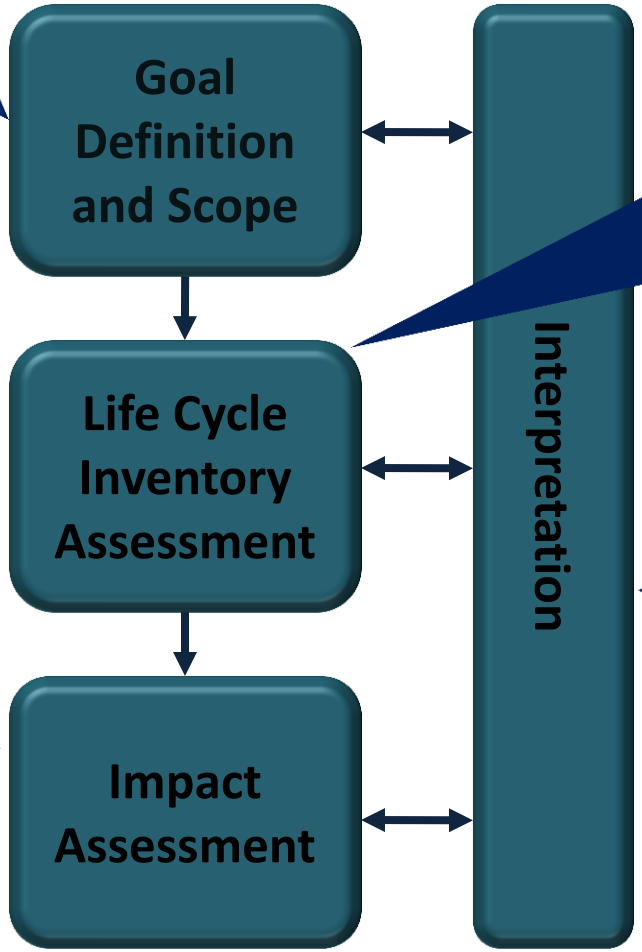

Materials Production
Pavement Design
Maintenance and Preservation
Materials
Asphalt (Bitumen)
Asphalt (Emulsion)
Cement
Lime
Modifier (Asphalt)
Modifier (Concrete)
Aggregate (Hard Rock)
Aggregate (Non-Hard Rock)
Steel
Fabrics
Curing
Soil
Drainage Materials
Supplementary Cementitious Materials
Plant Processes
Asphalt Plant
Concrete (Ready Mix) Plant
Precast Plant
Input
Fuel
Water
Equipment
Materials/Systems Considered in Design
Hot Mix Asphalt
Warm Mix Asphalt
Surface Treatments
Bound Granular Base
Unbound Granular Base
Subgrade
Hydraulic Cement Concrete
Dowel Bars
Tie Bars
Reinforcing Steel
Slurries
Pavement Design
Shoulder
Drainage
Wearing Course
Binder Course(s)
Base Course(s)
Subgrade
Arrows represent typical transport or process paths


Construction
Use
End-of-Life
Field Processes
Placement
In-Place Mixing
Scraping
Rolling
Breaking
Spraying
Grinding
Milling
Placing Drainage
Pulverizing
Sawing
Input
Fuel
Water
Equipment
Use
Vehicle Operation
Lighting
Heat Island
Carbonation
Workzone Congestion
Stormwater Runoff
Climate Change Effects
End-of-Life
Landfill
Recycle

Four Key Stages of Life Cycle Assessment

Key steps include definition of Goal (question)system boundary definition – essentially, what can be left out of the LCA?

The "accounting" stage. Where we track all the inputs and outputs from the system



Where we translate the inventory into meaningful environmental and health indicators

Where the results of the impact assessment are related back the questions asked in the Goal

Figure based on ISO 14040, adopted from Kendall

Goal and Scope

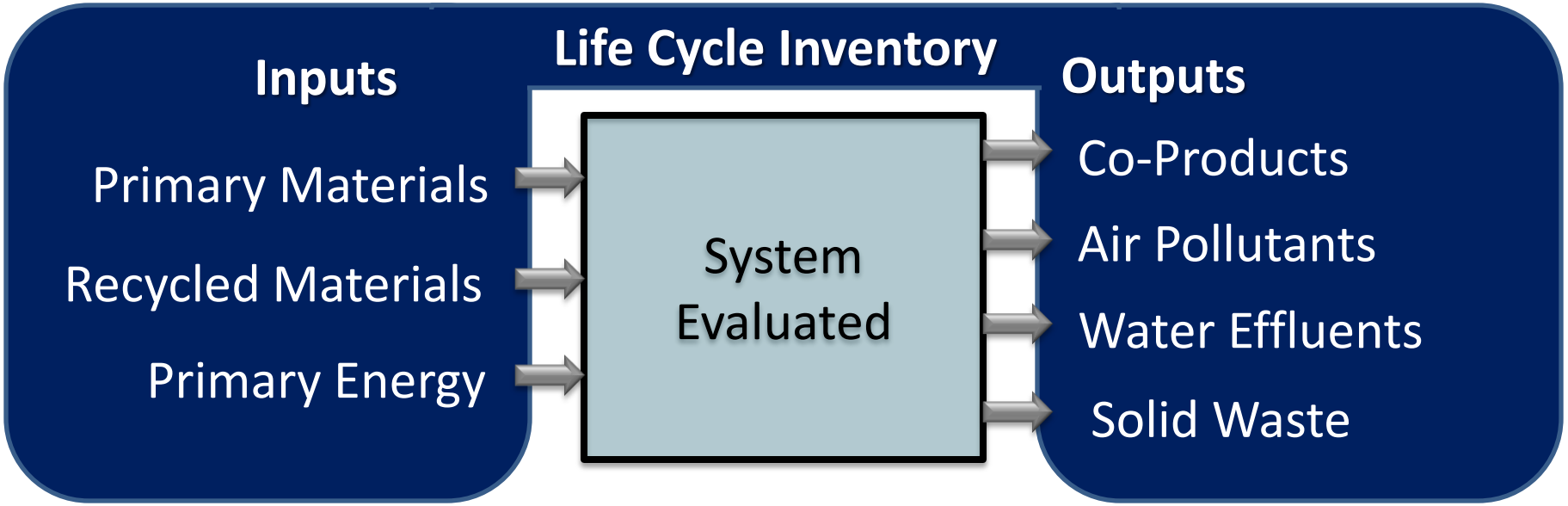
- The scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study
- The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA
- Goals will differ between agencies depending on their overall environmental goals, policies, laws, and regulations, all of which should be based on the environmental values of the agency that produces them

Goal Definition

- The goal can be stated as a question, for example:
  - What are the impacts of my product from cradle to gate and how can I reduce them?
  - Which of two alternative materials has lowest impact?
  - Which of two pavement design alternatives has the lowest environmental impacts?
  - How should I manage maintenance and rehabilitation of my network?
  - If I change something in my system what will be the impact on the environment?
  - How does this policy or specification affect the environmental impact of my network?

Life Cycle Inventory (LCI)

- The quantification of relevant inputs and outputs for a given product system throughout its life cycle

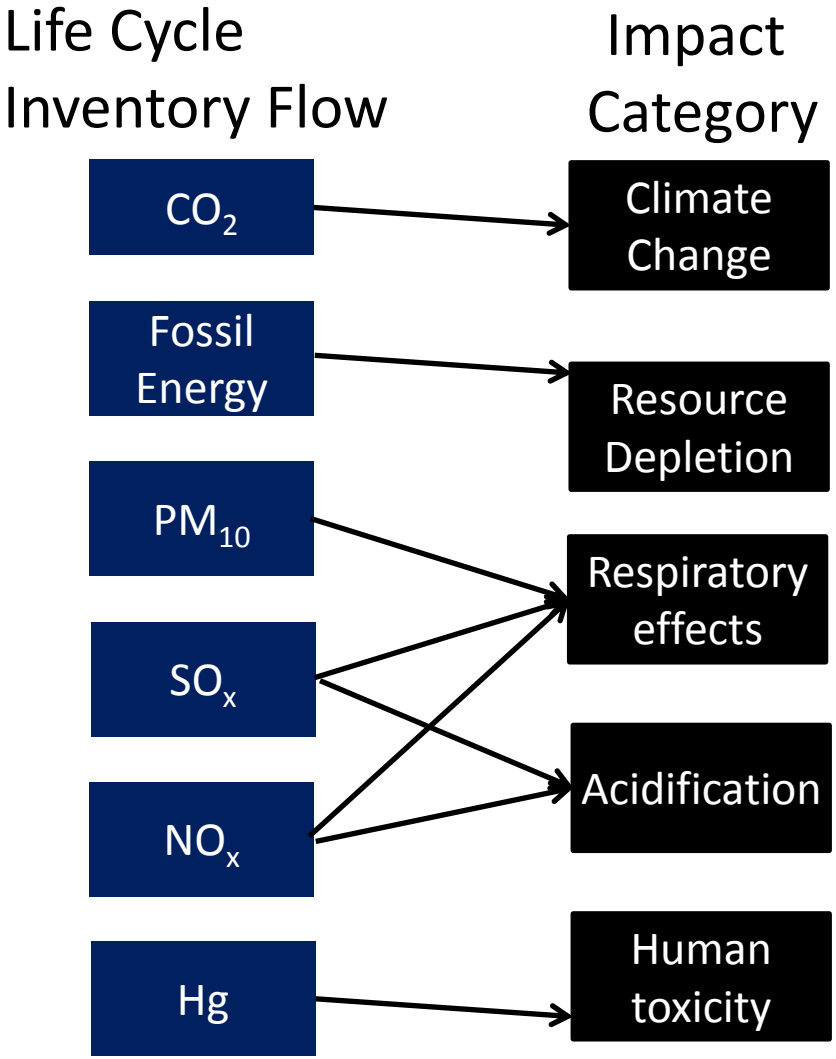


Life cycle impact assessment

- The flows of pollutants and resources are used to calculate the impacts in terms of impact indicators
- Models are used to calculate impact indicators
- The purpose of LCIA is to provide additional information to help assess a product system's LCI results to better understand environmental significance.
- The impact categories being assessed are selected to answer the questions of the goal of the study
- Example, most commonly calculated:
  - global warming potential (GWP), which is calculated as a function of all of the gases than affect global warming (carbon dioxide, methane, etc)

Life cycle impact assessment

- Translate resources consumed or pollutants emitted into effects on humans or the environment



US EPA Impact Assessment Categories

(TRACI – Tool for the Reduction and Assessment of Chemical and other environmental Impacts)

- Global warming
- Stratospheric ozone depletion
- Acidification
- Eutrophication
- Photochemical smog
- Terrestrial toxicity
- Aquatic toxicity
- Human health
- Abiotic resource depletion
- Land use
- Water use

Impacts to people

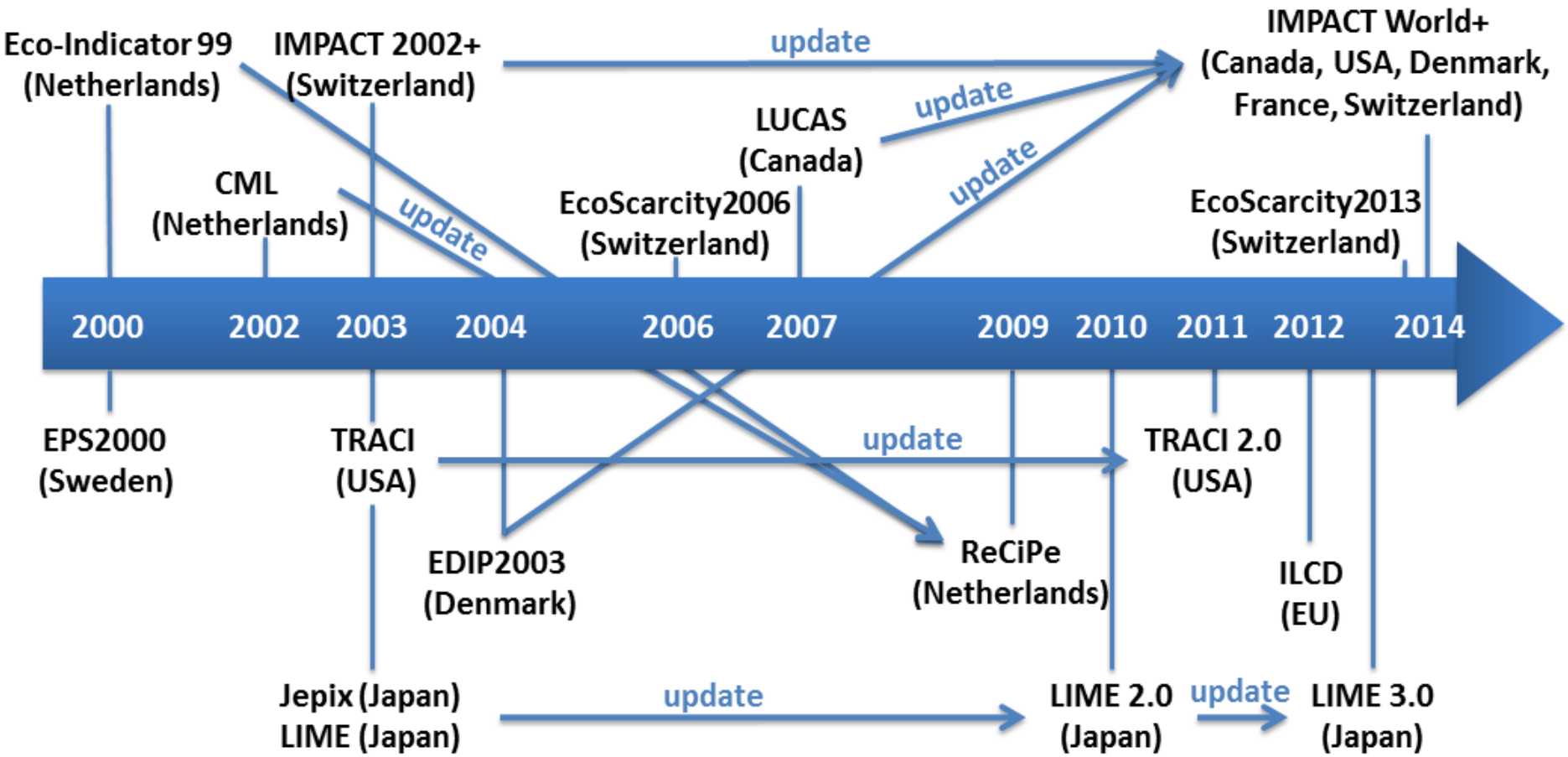
Impacts to ecosystems

Depletion of resources

Note: Most Pavement LCA to date focused only on global warming (greenhouse gases) and energy use

From Saboori *Image sources: Google*

LCIA (modern) History



From R. Rosenbaum, Pavement LCA 2014

Life cycle interpretation

- Answer the questions posed by the goal to produce conclusions, recommendations and decision-making support, with these elements:
  - Identification of major issues based on findings of LCI and LCIA stages
  - Check completeness, sensitivity and consistency
  - Write conclusions, discussion on limitations, and further recommendations
- Recommended to do sensitivity and uncertainty analysis and discuss limitations when answering goal questions

LCA Standards

- International standards exist (ISO LCA Standards):
  - 14040 Principles and Framework
  - 14044 Requirements and Guidelines
  - 14047 Impact Assessment
- Most all pavement LCA guidelines should follow these globally accepted guidelines
- But they provide general guidance, not detailed information necessary for individual products or systems

Note: Carbon (or energy) footprints are a narrow and incomplete form of LCA, where only one kind of environmental impact is tracked and quantified

LCA Standards

- UCPRC Pavement LCA Guidelines (2010)
  - Comprehensive summary of pavement related requirements, but lacks detail
  - Transparency checklist so that readers of LCA can understand what was included, what was not included, and assumptions
  - http://www.ucprc.ucdavis.edu/P-LCA/pdf/ucprc_plca_guideline_v1.pdf
- EN 15804:2012+A1 (2012 and update)
  - Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products
- US Federal Highway Administration (FHWA) Guidelines for Pavement LCA (expected 2016)

Uses for LCA

- Identifying opportunities to improve the environmental performance of products at various points in their life cycle.
- Informing and guiding decision makers as part of strategic planning, priority setting, product or process design selection, and redesign.
- Selecting appropriate indicators of environmental performance.
- Quantifying information on the environmental performance of a product or system to produce an environmental product declaration (EPD) or other statement of environmental impact
- Identifying trade-offs in decision making as it allows for the evaluation of all life cycle stages and multiple environmental indicators.

Interaction of LCA and Life Cycle Cost Analysis (LCCA)

- All environmental decisions based on LCA need to be considered along with cost and social impacts
- LCA (environment) and LCCA (cost) results can be explicitly considered together and tradeoffs calculated between them
- In many cases, LCA and LCCA show that reduced environmental impacts also results in reduced direct costs!!
  - Even more so when long-term costs of pollution and climate change are considered in cost analysis

Summary: why use LCA for evaluating environmental performance?

- Quantifies outcomes:
  - GHG, energy, pollutants, finite resources
- Uses project-specific inputs:
  - materials, transport, construction, traffic levels, re-use
- Requires explicit prioritization of outcomes for decision-making
- Can account for regional and time variability, and other uncertainties in data sets and analysis
- Applies scientific principles and systems analysis to support decision-making
- Can be combined with cost analysis

Questions?

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