Pavement Sustainability, Resiliency and Life Cycle Assessment

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ISAP LCA Workshop
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11TH CONFERENCE ON ASPHALT PAVEMENTS FOR SOUTHERN AFRICA
CAPSA'15

TC APE
Asphalt Pavements & Environment
International Society for Asphalt Pavements

UCPRC
UNIVERSITY of CALIFORNIA Davis • Berkeley | PAVEMENT RESEARCH CENTER

Outline

- A perspective on sustainability
- Environmental impact quantification with emphasis on Southern Africa
- Resiliency and stationarity
- Life Cycle Assessment (LCA) for pavement
- Product Category Rules and Environmental Product Declarations
- Recent developments and implementation of LCA
- LCA examples: network and project level
- Gaps, expected future developments, recommendations

Are pavement sustainable?
My opinion

- Sustainability means that we can keep doing the same thing for a long time (let’s say 100 years) without significant negative effects on human society and the environment on which it depends
- Pavements are probably 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 to improve sustainability as cost efficiently as we can or we will not succeed

How to improve the sustainability of pavements? My opinion

- To achieve these goals and avoid unintended consequences we must:
  - Apply scientific principles
  - Broadly define the system we are analyzing
  - Take a long-term (life cycle) view
  - Have the trust of decision-makers that our information is unbiased, critically reviewed and transparent
- We must avoid:
  - Focusing on the wrong questions (example)
  - Not having a sense of scale (where we can make the biggest and most important changes)
  - Use of “indices” that arbitrarily award “points” for decisions without a scientific, regionally applicable, long-term system analysis

Master equation for environmental impacts

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

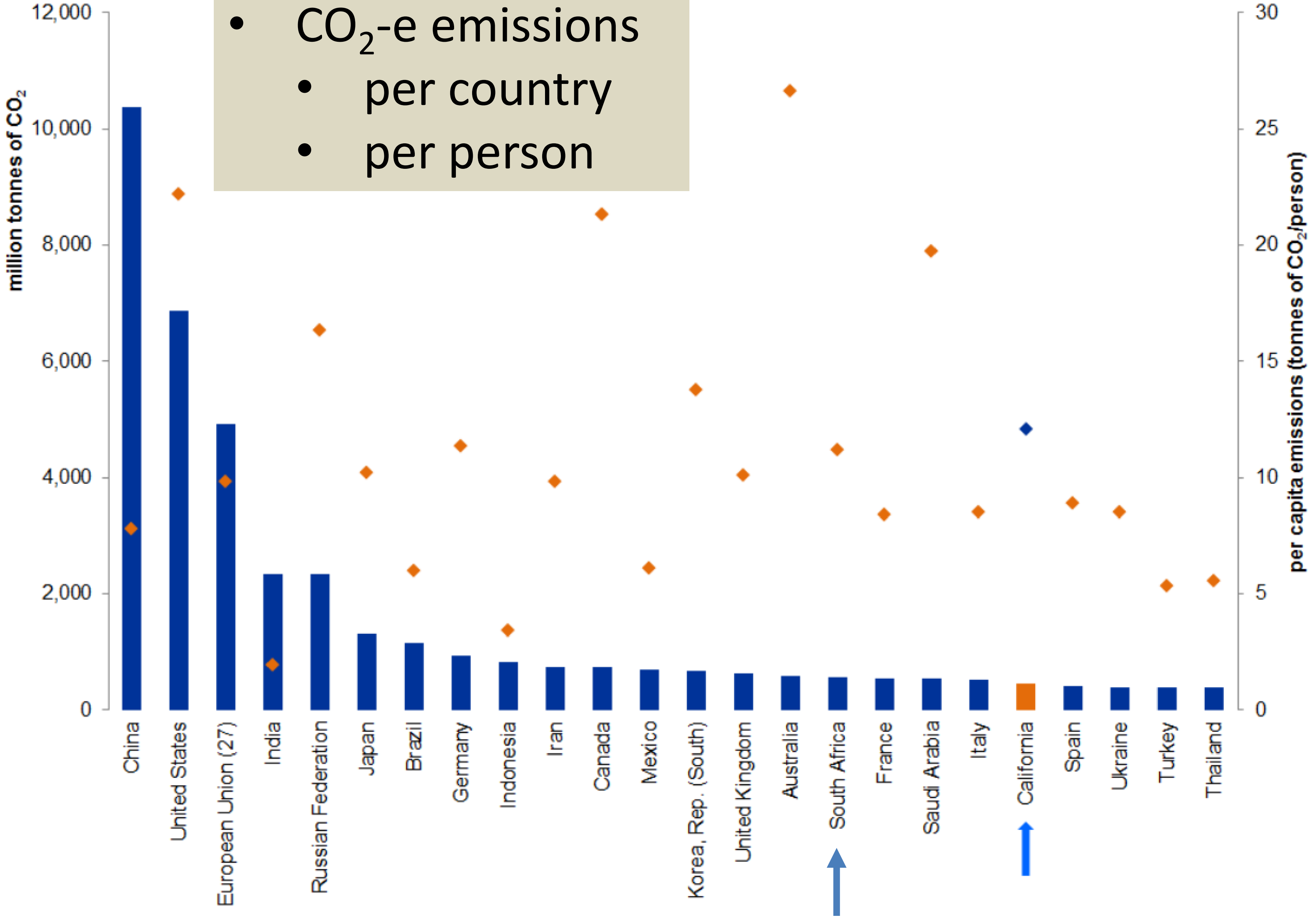
$$\text{Population} * \frac{\text{GDP}}{\text{Person}} * \frac{\text{Impact}}{\text{GDP}}$$

Increase in wealth and economic activity

Technological efficiency (how to measure?)

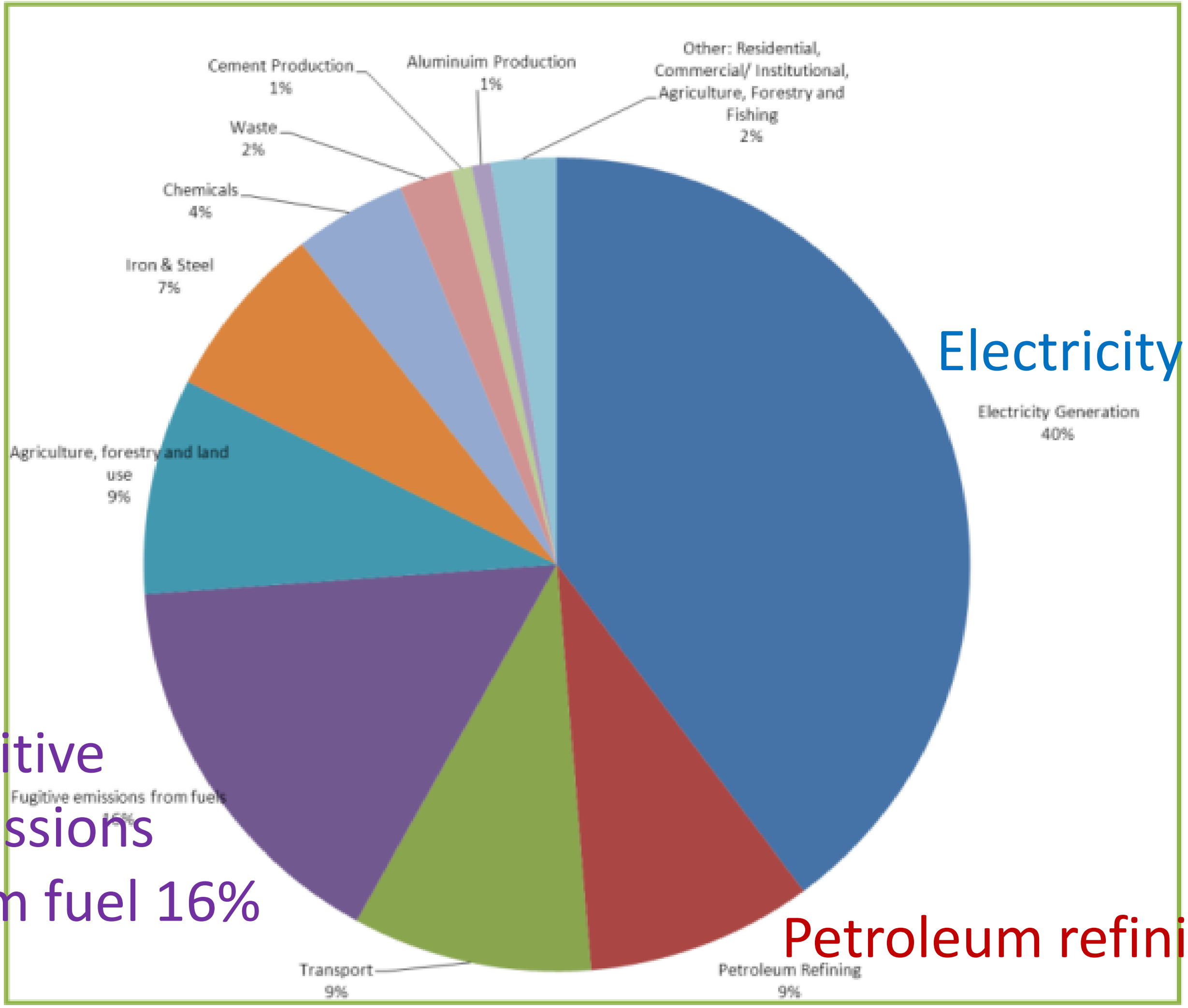
Ehrlich and Holdren (1971) Impact of population growth. e.g. via LCA *Science* 171, 1211-1217
Slide adapted from R. Rosenbaum, Pavement LCA 2014 keynote address

- CO_2-e emissions
  - per country
  - per person



California Air Resources Board, 2014

Cement production 1%



Electricity generation 40%

Fugitive emissions from fuel 16%

Petroleum refining 9%

Transport 9%

South Africa Emissions by sector, 2000 GHG Inventory (Source: South Africa Treasury)

http://www.ieta.org/assets/EDFCaseStudyMarch2014/south%20africa%20case%20study%20march%202014.pdf

Climate Change: Fight or flee?

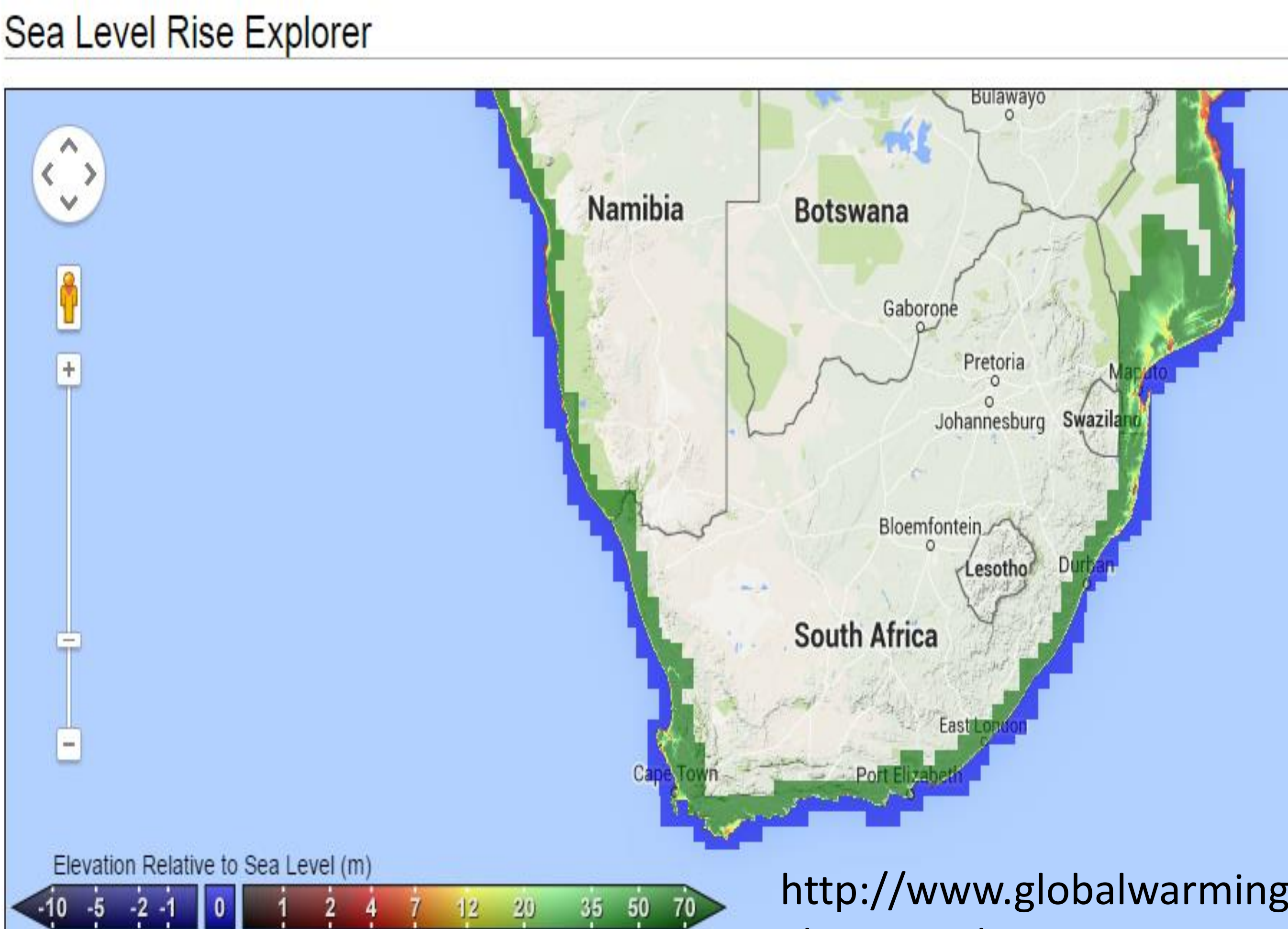
- Fight: Reduce global warming potential as quickly as possible
  - Considered in this lecture
  - Is it too late?
  - It can get much worse
  - GWP is not the only impact we need to deal with

- Flee: move and adapt people and infrastructure
  - Sea rise (move)
  - Extreme events (embankments, drainage, move)
  - Change in temperatures and rainfall (pavement design)

Photo: D. Jones

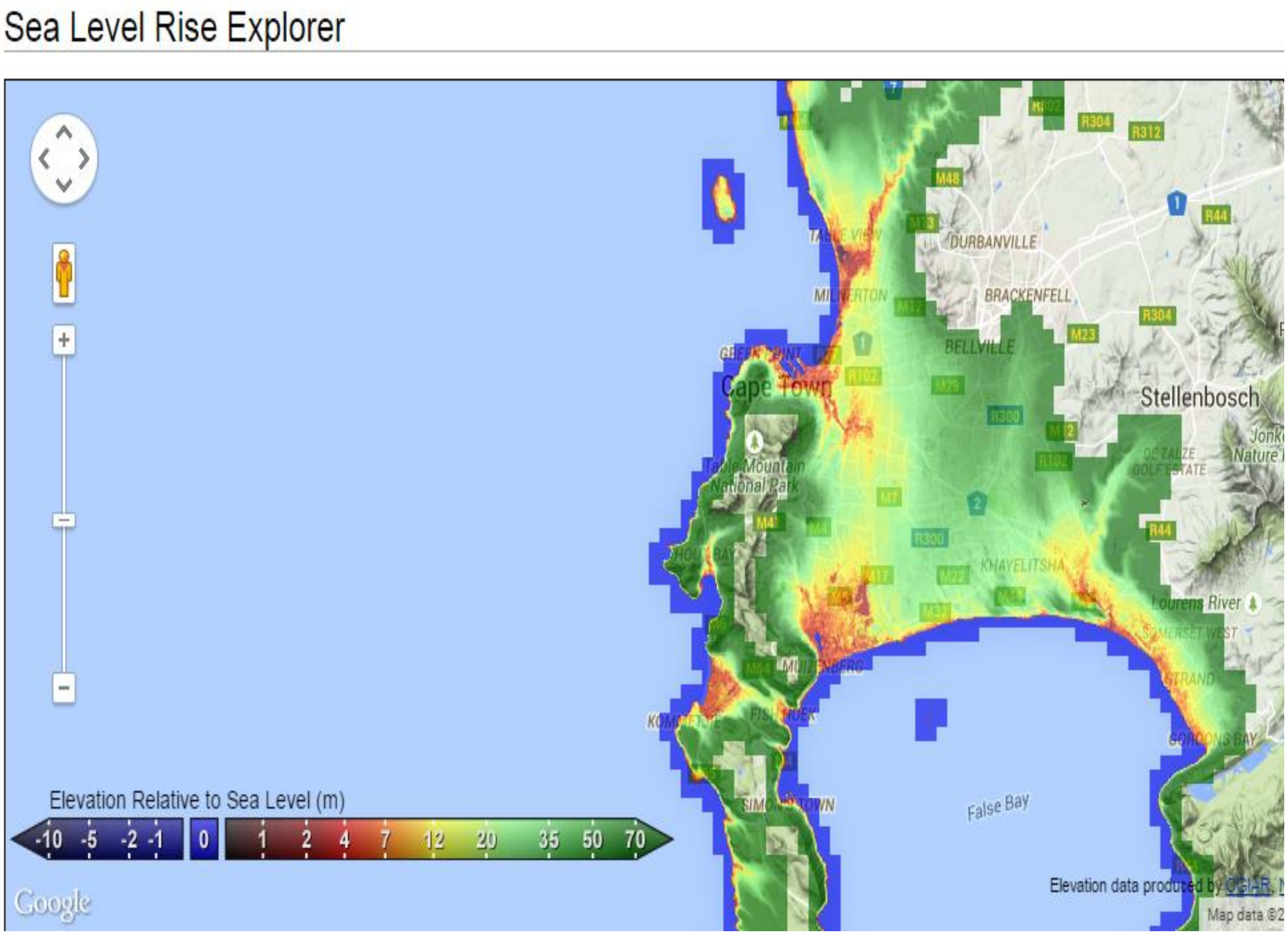
Global Warming: Overall Sea Level Effects

Effect on most of the country will be erosion of sandy beaches along coastline, except port cities



http://www.globalwarmingart.com/wiki/Special:SeaLevel#cite_note-5

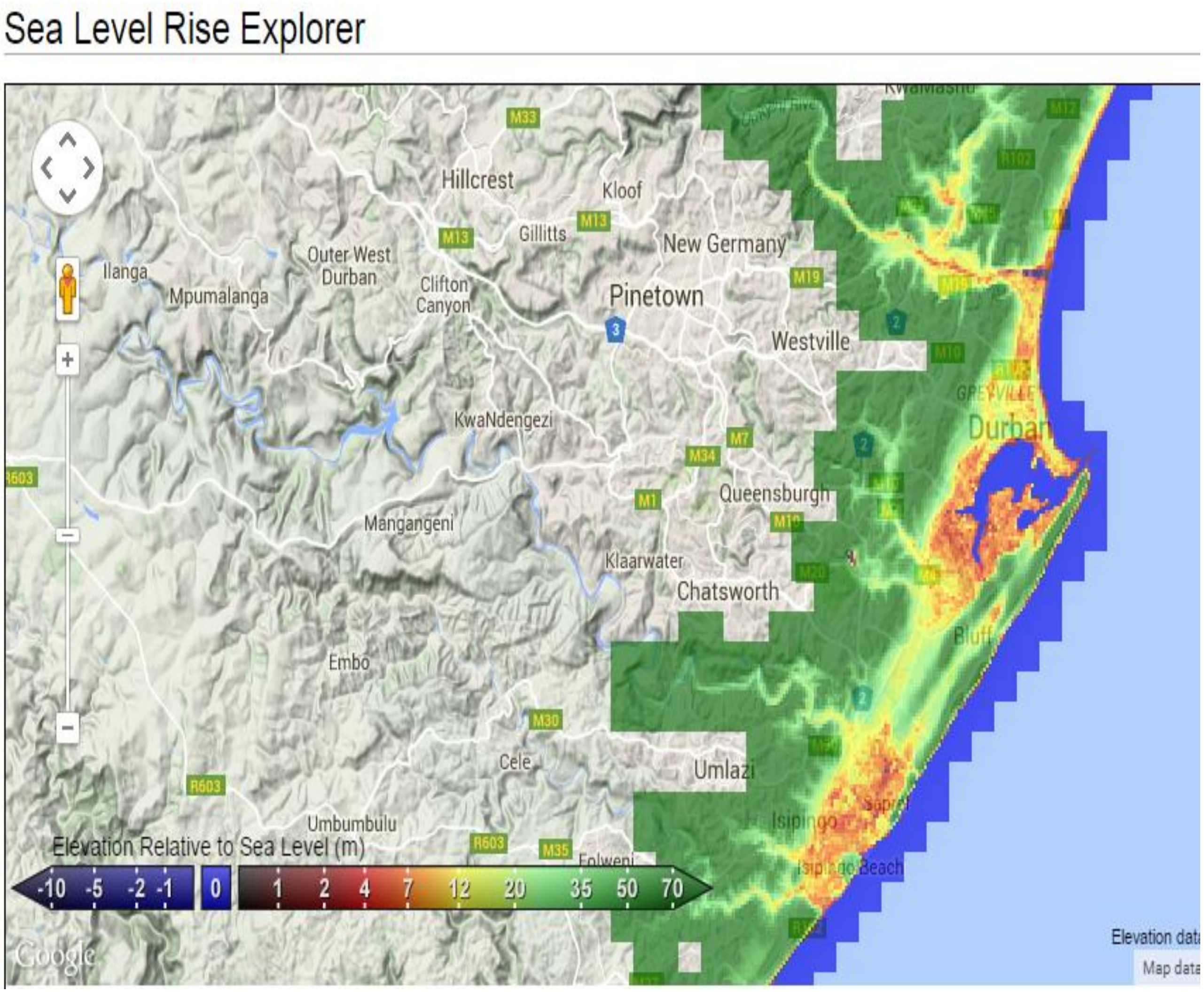
Cape Town



Estimate of R5 to 25 billion in damage over next 25 years

Cartwright, A., Brundrit, G. B. and Fairhurst, L. (2008). Global climate change and adaptation – A sea-level rise risk assessment. Phase four: Adaptation and risk mitigation measures for the City of Cape Town. Prepared for the City of Cape Town by LaquaR Consultants CC, 42 pp.

Durban



Loss of development and infrastructure including R750 million Ushaka Marine World without adaptive intervention

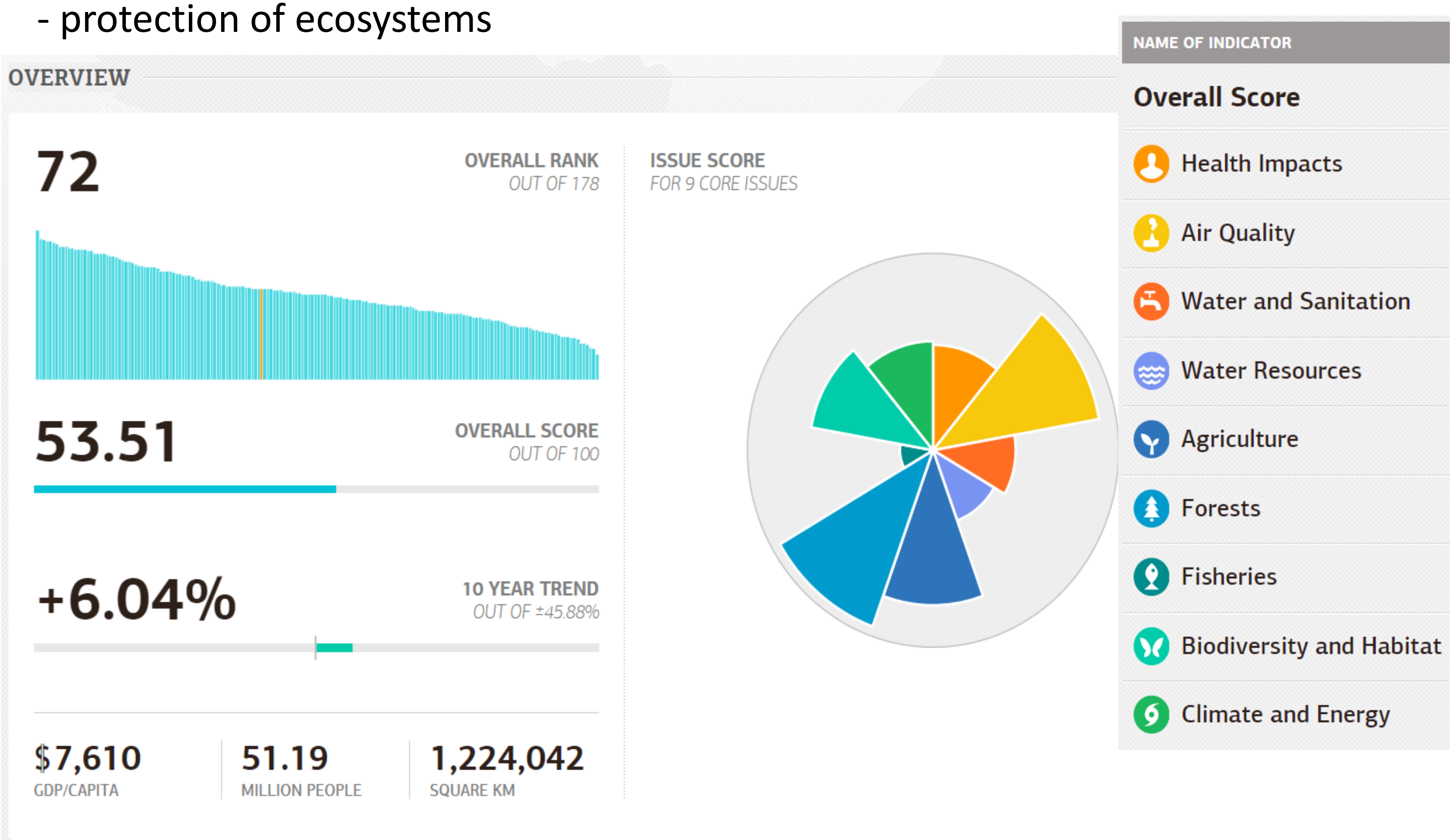
Mather, A. A., & Stretch, D. D. (2012). A perspective on sea level rise and coastal storm surge from Southern and Eastern Africa: A case study near Durban, South Africa. *Water*, *4*(1), 237-259.

Climate Change: Adapting to it for pavement

- Stationarity: assumption that can use past design inputs for future design
  - Pavement design temperatures
  - Rainfall intensities and lack of rain
  - Traffic characteristics
- For pavement we probably don't have stationarity
  - ASCE initiative to address the issue across all civil engineering design
  - Use climate change projections to change assumptions for pavement design and drainage
  - Consider changes in traffic patterns and vehicles in response to climate change (temperature, rain) as well as mitigation measures (less coal hauling, different vehicles, tire technology changes)

2014 EPI for South Africa (Sub-Saharan Africa)

- protection of human health from environmental harm
- protection of ecosystems



Hsu et al. (2014). The 2014 Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law and Policy. Available: http://www.epi.yale.edu.

Assembly Bill 32 (2007)

Reaffirmed by direct vote in 2010 61% to 39%

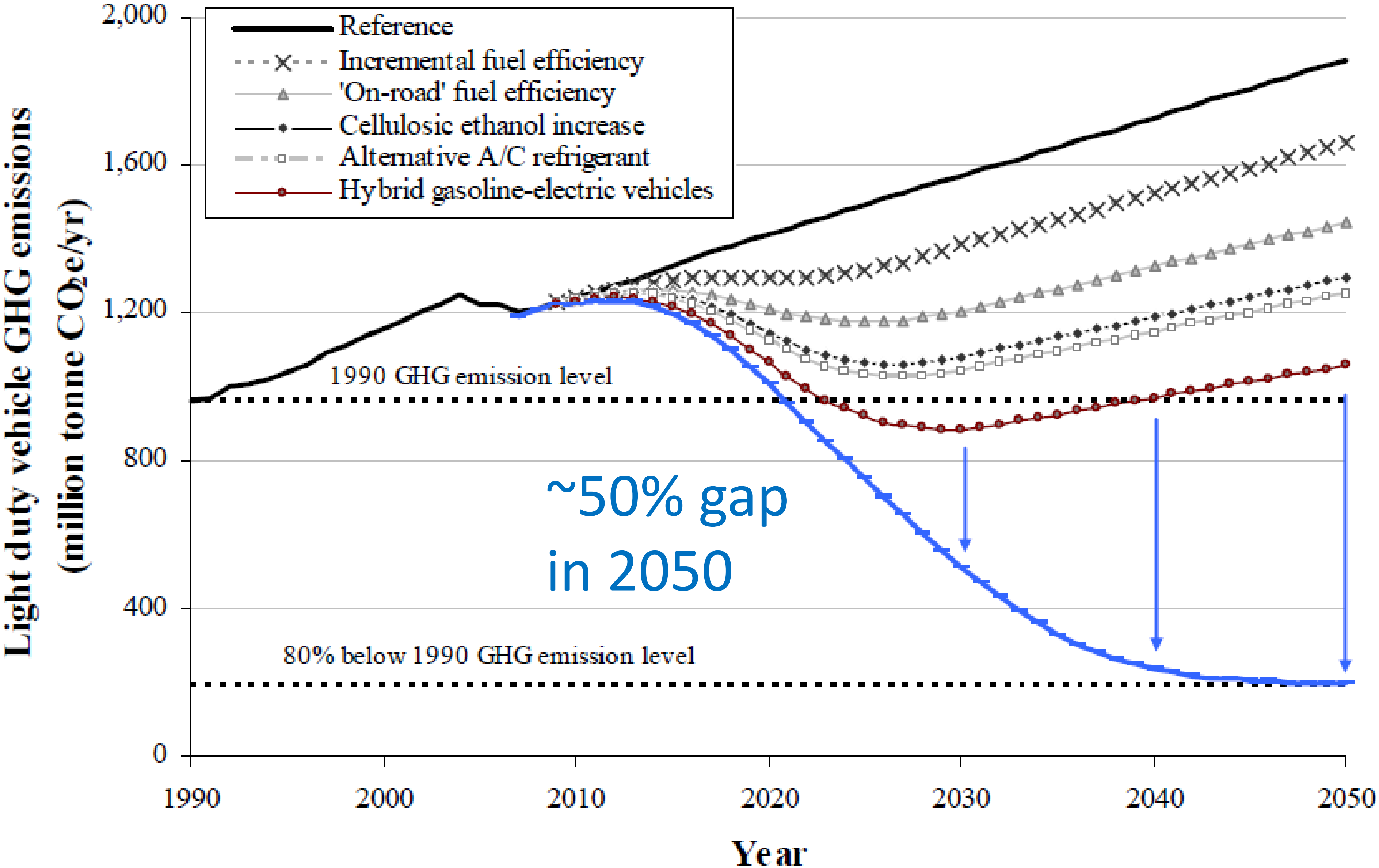
Requires reduction to 2020 GHG emissions at 1990 levels

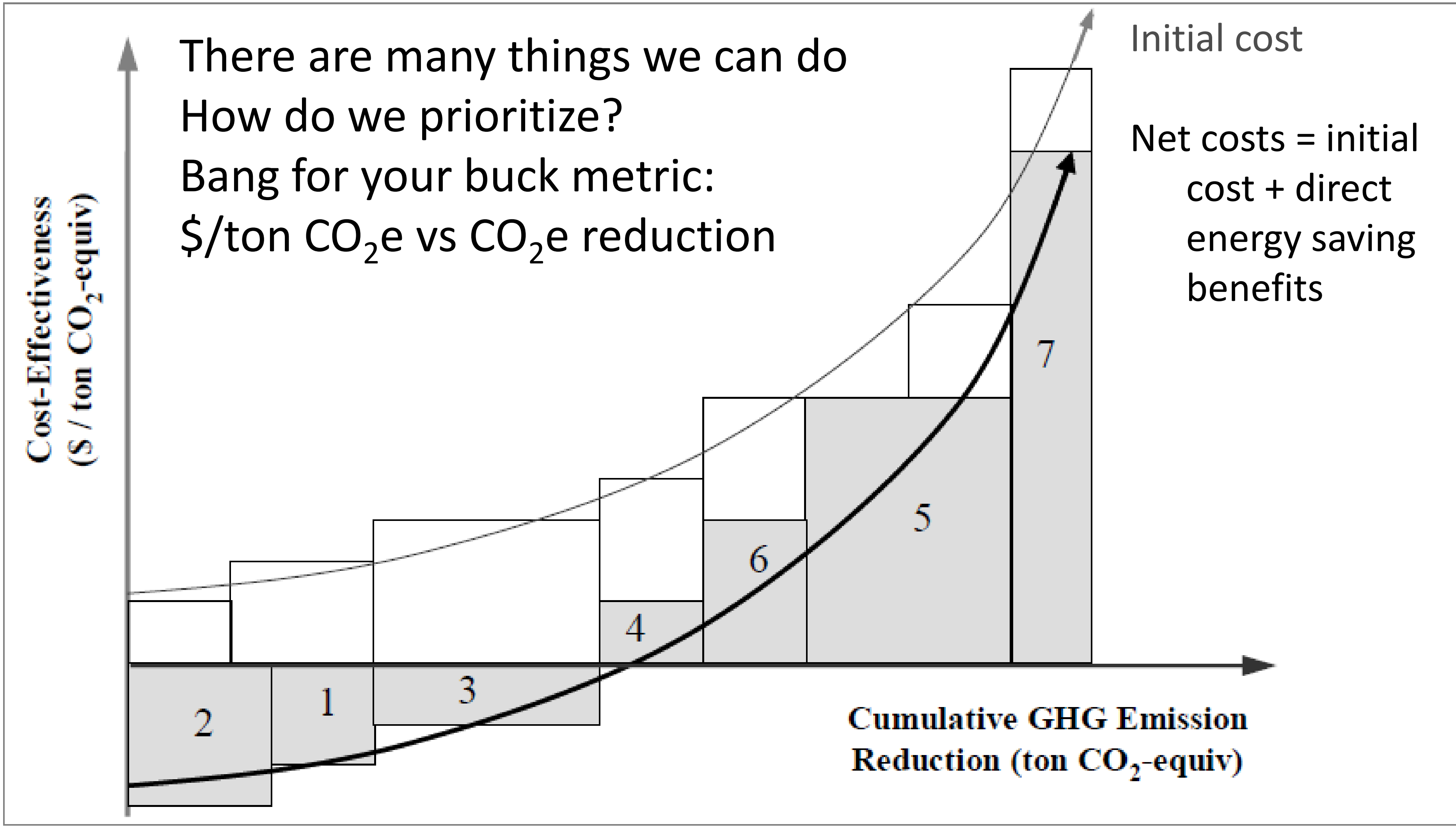
2050 GHG emissions at 0.2 x 1990 levels

- On-road vehicles 36% of emissions, current sector approaches for meeting AB32 goals
  - 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?

The "Gap" for Transportation

N. Lutsey, doctoral thesis, UC-Davis





- **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

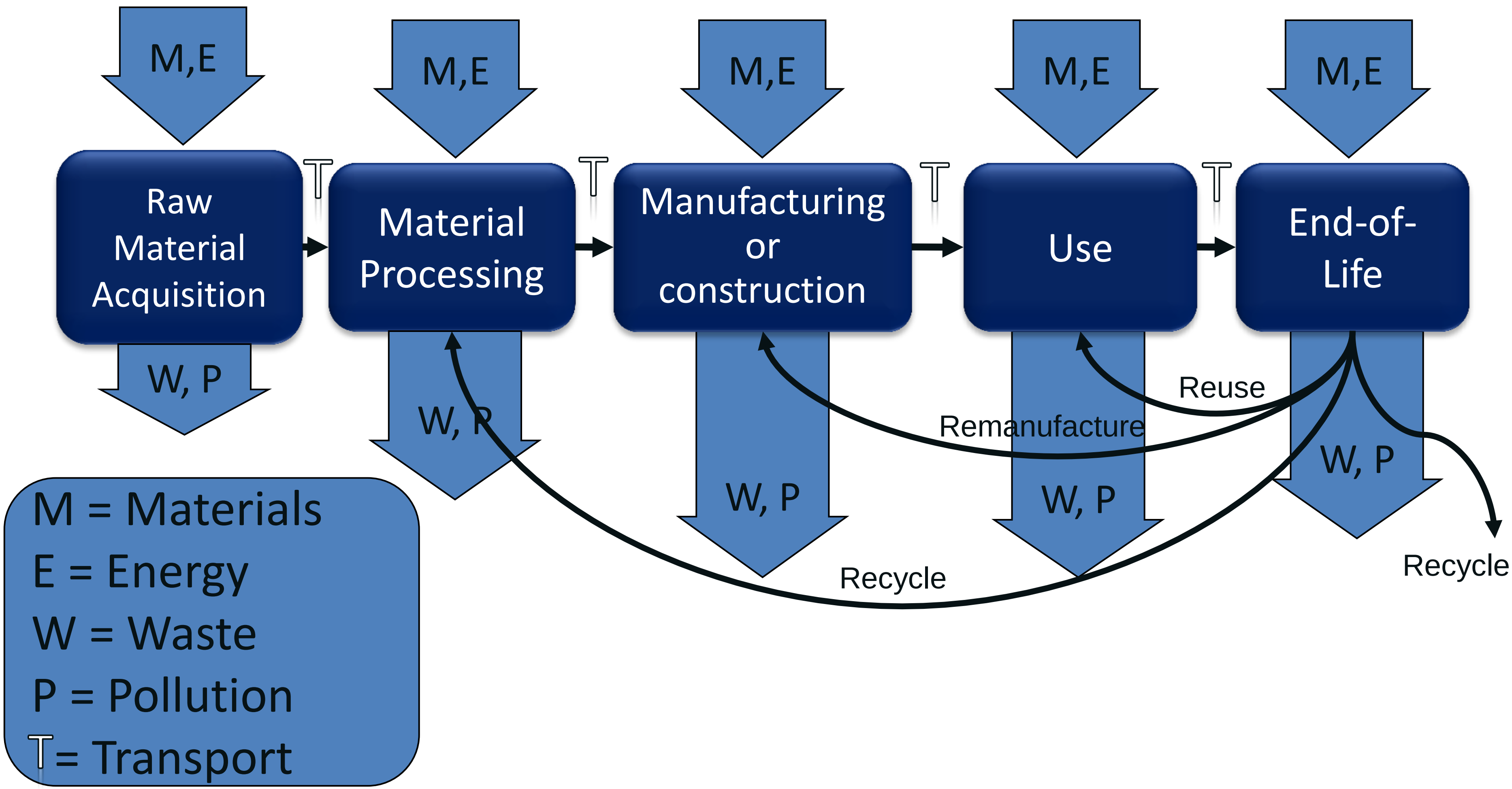
Motivations to improve environmental performance of pavement

- 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)

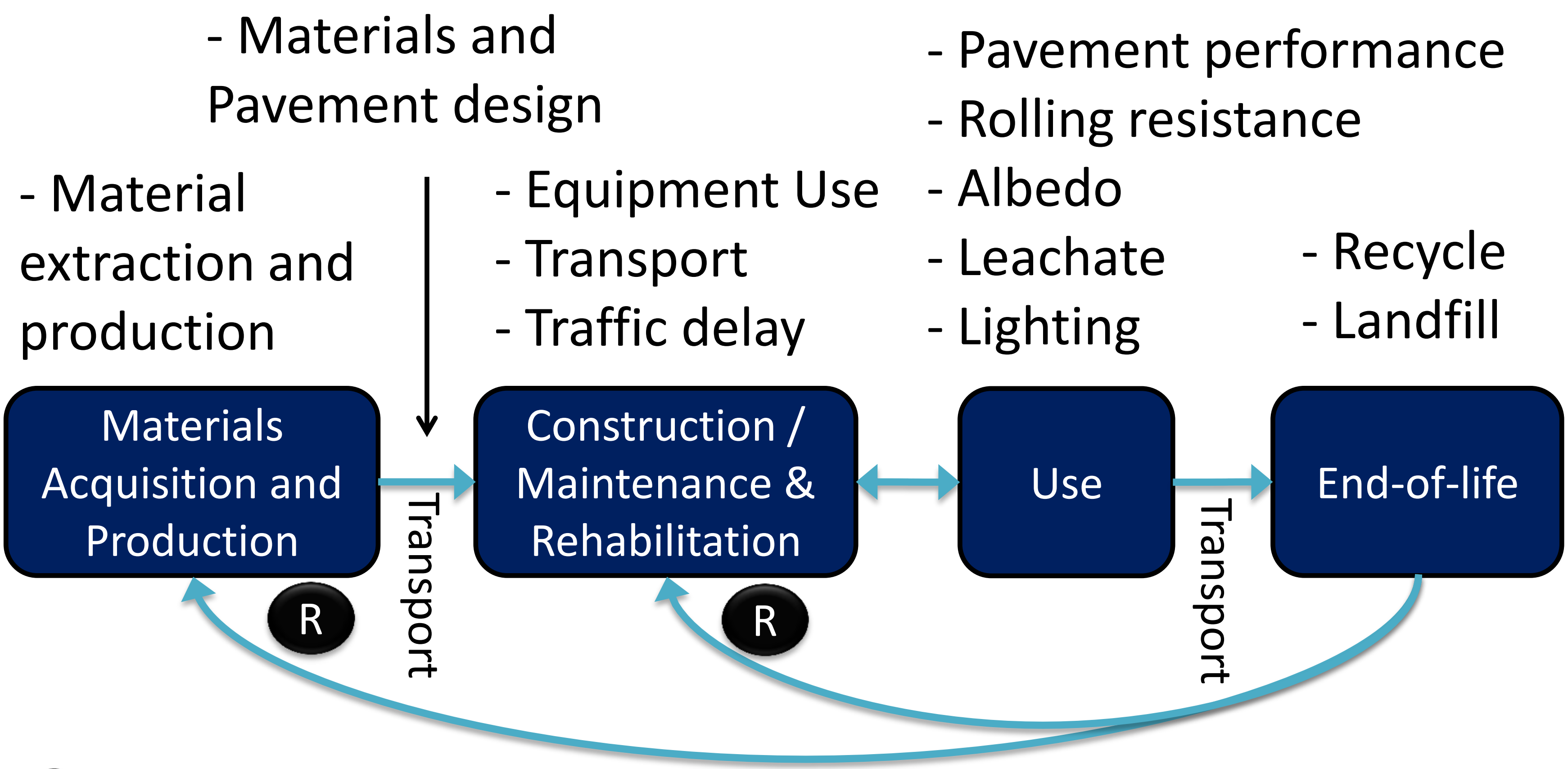
- If we are to improve sustainability of pavement must be able to measure impacts
- LCA provides a method for characterizing and quantifying environmental sustainability using a cradle-to-grave perspective, and considering system-wide impacts for a product, policy, or system
- Improves transparency and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

Generic Life Cycle



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

Pavement Life Cycle



R: Recycle

From: Kendall et al., *2010*

Four Key Stages of Life Cycle Assessment

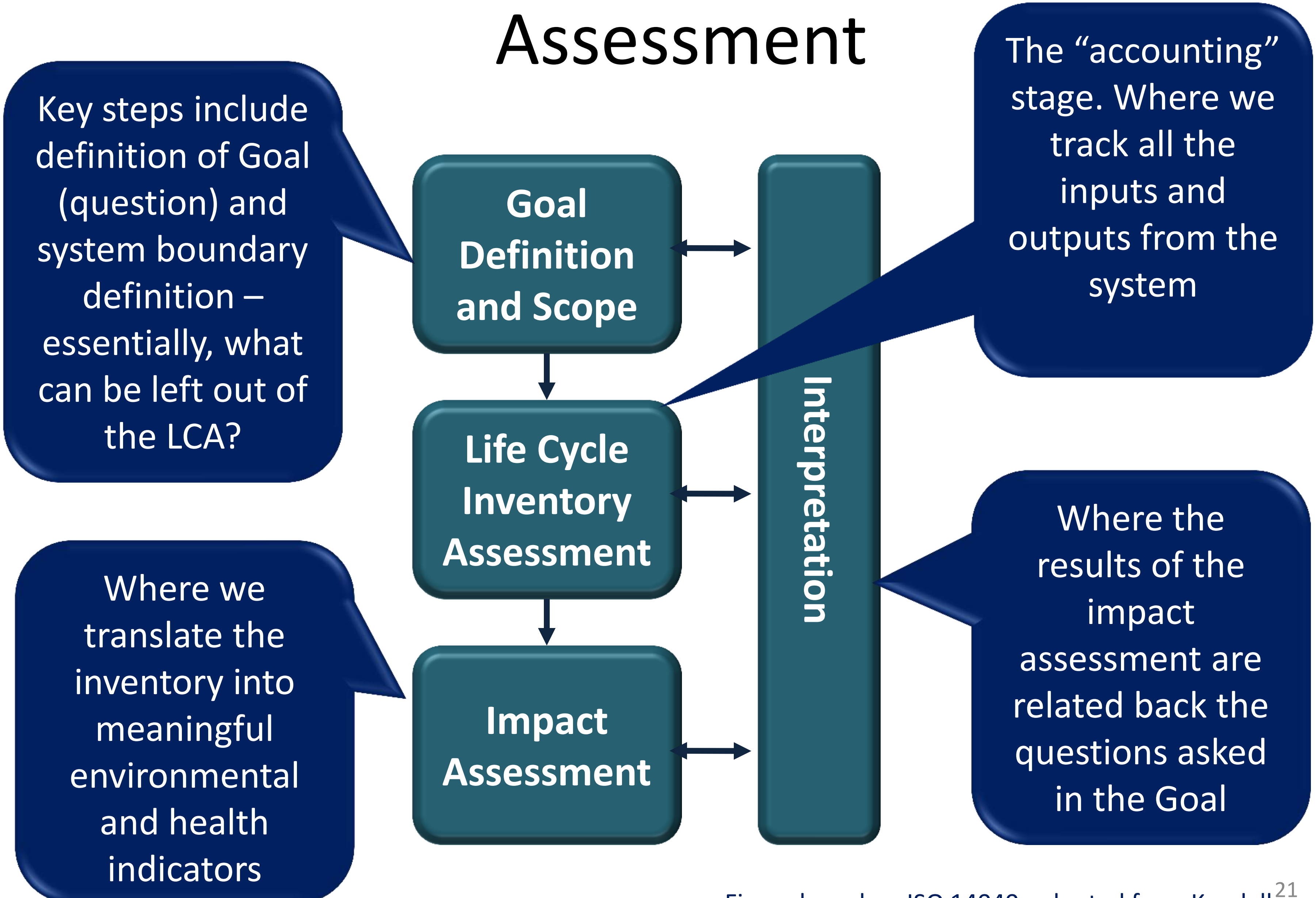


Figure based on ISO 14040, adopted from Kendall

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

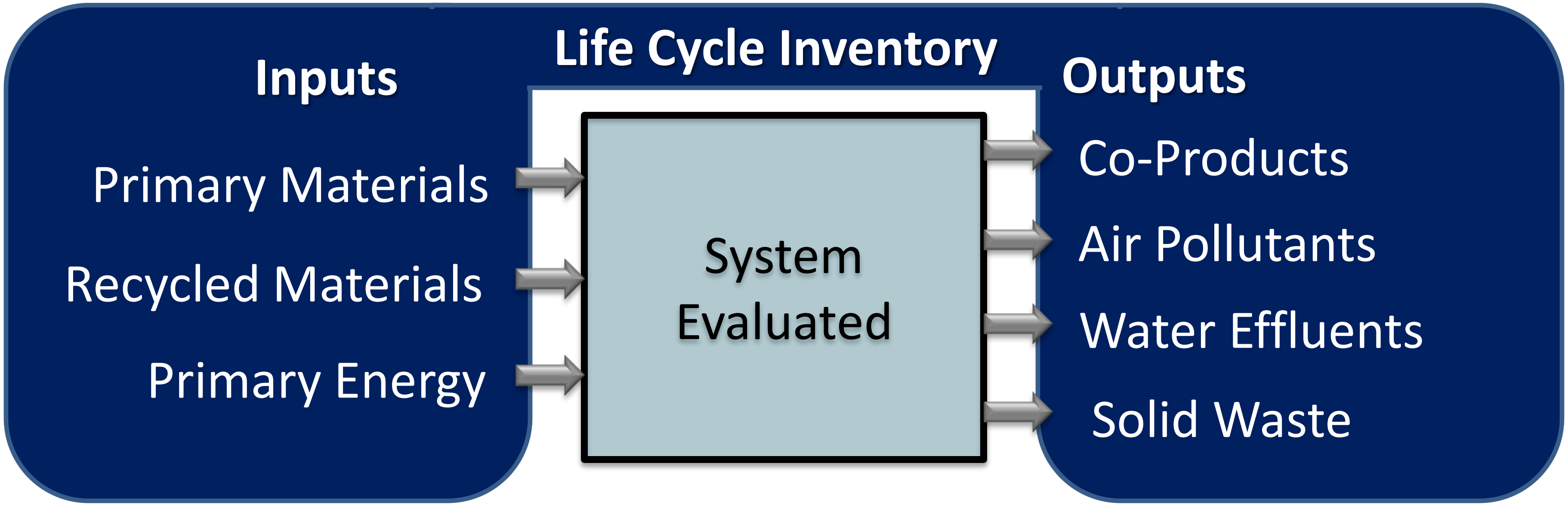
- The goal can be stated as a question, for example:
  - Project-level:
    - What are the impacts of my product from cradle to gate and how can I reduce them?
    - Which of two alternative materials has lowest impact?
    - Which of two pavement design alternatives has the lowest environmental impacts?
  - Network-level:
    - How should I manage maintenance and rehabilitation of my network?
  - Policy-level:
    - How does this policy or specification affect the environmental impact of my network?
  - Environmental Product Declaration:
    - Certified statement of environmental impact of my product for use by my customers

Scope Definition

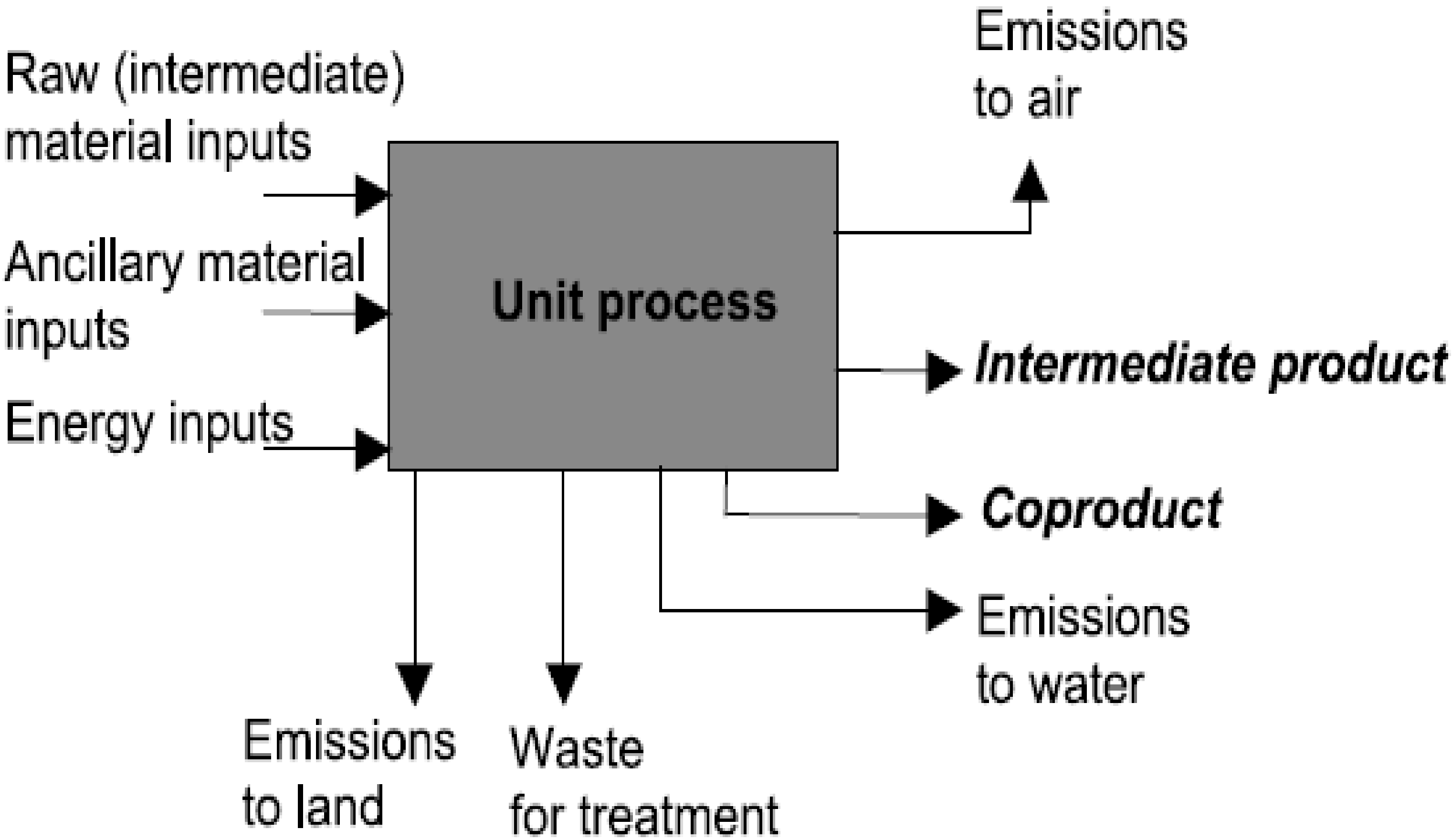
- Scope of an LCA defines
  - Functional unit of analysis: the required performance of the product or system and its dimensions
  - System boundary of analysis: life-cycle stages and processes to be included in the LCA
  - Analysis period: what is the time period over which the system will be analyzed
  - Impact indicators and how to calculate them
  - How results will be interpreted, including sensitivity analyses to be sure if results are robust
  - Inventory and data quality needs
  - Critical review process
  - How to report the results

Life Cycle Inventory (LCI)

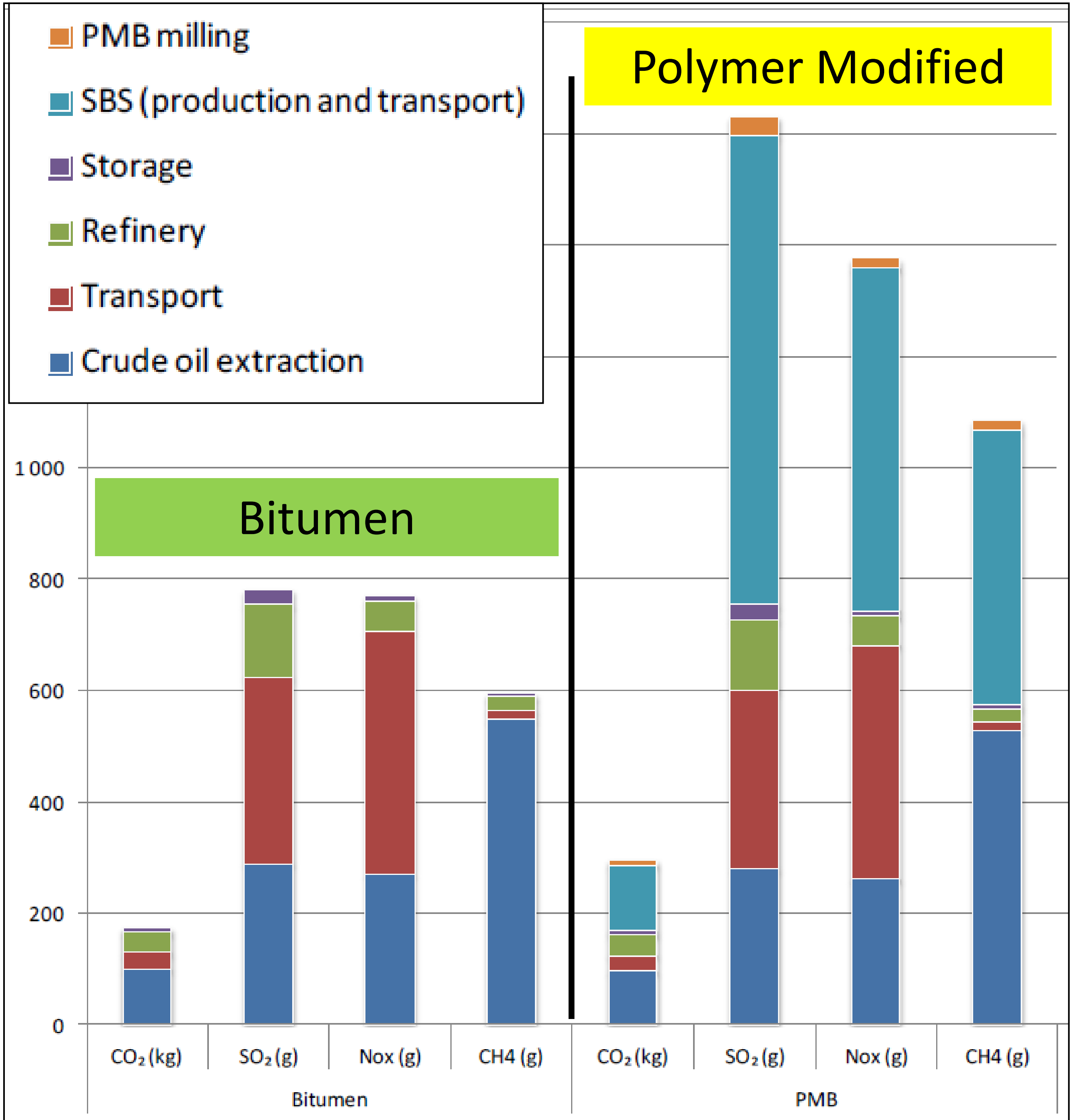
- The quantification of relevant inputs and outputs for a given product system throughout its life cycle



Develop Unit Process Models



ISO



Example Eurobitume LCI results:
PMB has about 60% more CO2 and other GHG emissions than bitumen from cradle to gate

Eurobitume LCI
Bernard et al. Nantes LCA 2012

Where to get data
Cost and availability?

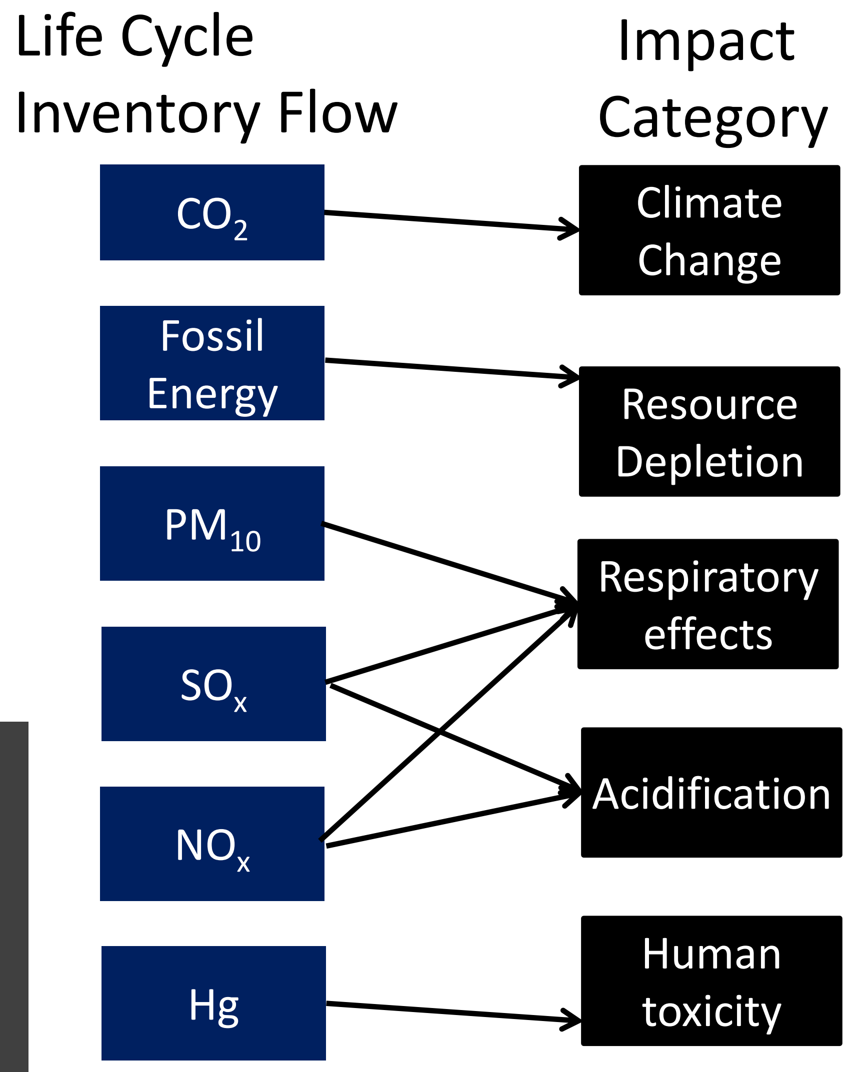
- Primary data (specific to process):
  - From direct measurements of input and output
  - Calculated from process flow data
    - Example: liters of fuel consumed translates into known amounts of pollution, etc
  - From questionnaires to producers
  - From product specific Environmental Product Declarations (EPD)
- Secondary data (averaged or calculated from averages):
  - From commercial databases
  - Calculated from process flow data and secondary data
  - From industry average EPDs

Life cycle impact assessment (LCIA)

- The flows of pollutants and resources are used to calculate the impacts in terms of impact indicators
- Impact indicators provide additional information regarding a product system's environmental significance
- Models are used to calculate impact indicators
- The impact categories to be used in a study are selected to answer the questions of the goal of the study
- Example: Global warming potential (GWP), calculated as a function of the gases that affect global warming over a 100 year period (carbon dioxide, methane, etc)

Life cycle impact assessment

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



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

Group	Impact Category (CML and TRACI)	Comment
Energy use	Fuel, non-renewable[1] Resources, non-renewable Resources, nonrenewable, secondary Fuel, renewable Resource, renewable Resource, renewable, secondary	Small uncertainty, both energy use and energy sources used as materials should be addressed
Resource use	Resource, renewable Resources, non-renewable[2]	Small uncertainty
Emissions	Climate Change[1, 2] Ozone layer depletion[1, 2] Acidification[1, 2] Tropospheric Ozone[1, 2] Eutrophication[1, 2]	Small uncertainty, global, biogenic CO_2 requires special attention Small uncertainty, global Small uncertainty, regional Medium uncertainty, local Small uncertainty, local
Toxicity	Human toxicity[2], respiratory[1] Human toxicity, carcinogenic[1] Human toxicity, non-carcinogenic[1] Ecotoxicity[1], fresh water[2] Ecotoxicity, marine water[2] Ecotoxicity, soil[2]	High uncertainty, incomplete
Water	Fresh water use	Small uncertainty
Waste	Hazardous Non-hazardous	Small uncertainty

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 can be complicated
How to get started 1/2

1. Define question to be answered and specific environmental goals or decision to be made
   – Calculate total impact
   – What if analysis, comparisons
2. Define system boundaries
   – Identify items that are the same and do not need to be considered
3. Define the functional unit and approach
   – specific project variables, cases for impact calculation of comparison, analysis period
4. Model the system
   – specific project variables, cases for impact calculation of comparison, analysis period
   – Identify operations, materials, thicknesses, functional lives, materials production and construction processes, etc.

LCA can be complicated
How to get started 2/2

5. Quantify differences between alternatives over the life cycle

First five steps may be enough to determine whether full LCA needed

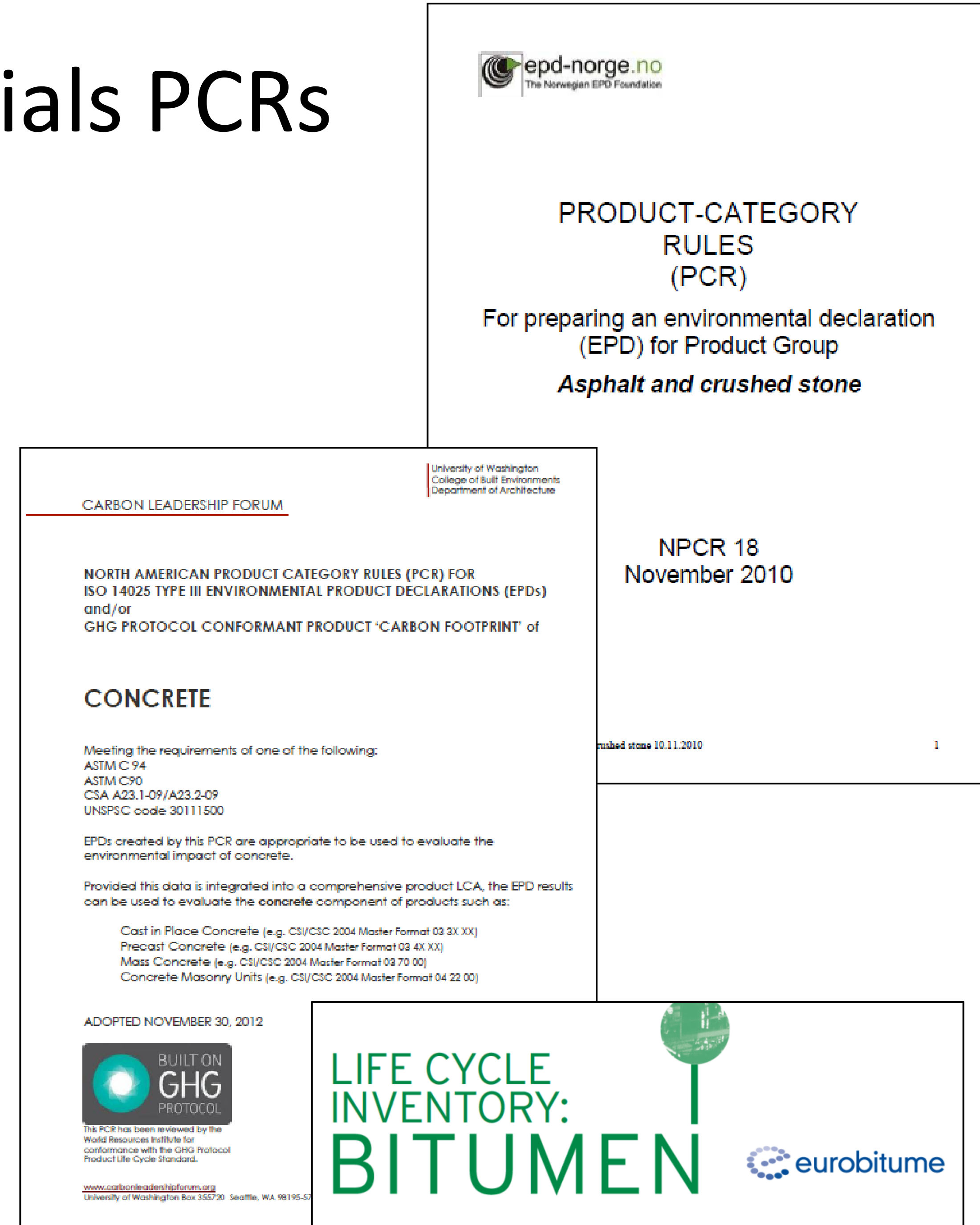
6. Identify appropriate environmental data sets (life cycle inventory data) needed and quantify the environmental impacts of differences, complete LCA

Interaction of LCA and Life Cycle Cost Analysis (LCCA) and Social Impacts

- 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

Pavement Materials PCRs

- Specific to a material
- Typically cradle-to-gate (i.e., excludes use and/or end-of-life)
- PCRs (and EPDs) are available for many basic materials
- Becoming more prevalent
- Pavement PCRs
  - Cement, concrete, lime aggregate in place
  - Asphalt, asphalt mixes under development



Example of LCA for Pavment:
Environmental Product Declaration:
Concise, quantitative information
Increasingly important in pavement product competition

Environmental Facts

Functional unit: 1 metric ton of asphalt concrete

Primary Energy Demand [MJ]	$4.0x10^3$
Non-renewable [MJ]	*$3.9x10^3$*
Renewable [MJ]	*$3.5x10^2$*
Global Warming Potential [kg CO_2-eq]	79
Acidification Potential [kg SO_2-eq]	0.23
Eutrophication Potential [kg N-eq]	0.012
Ozone Depletion Potential [kg CFC-11-eq]	$7.3x10^{-9}$
Smog Potential [kg O_3-eq]	4.4

Boundaries: Cradle-to-Gate
Company: XYZ Asphalt
RAP: 10%

Example LCA results

Adapted from N. Santero

Definitions and Relationships

PCRs, LCAs, and EPDs

PCR: the framework

Product Category Rule (PCR)

"Set of specific rules, requirements, and guidelines for developing Type III environmental product declarations for one or more product categories" (ISO 14025)

LCA: the analysis

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040)

EPD: the declaration

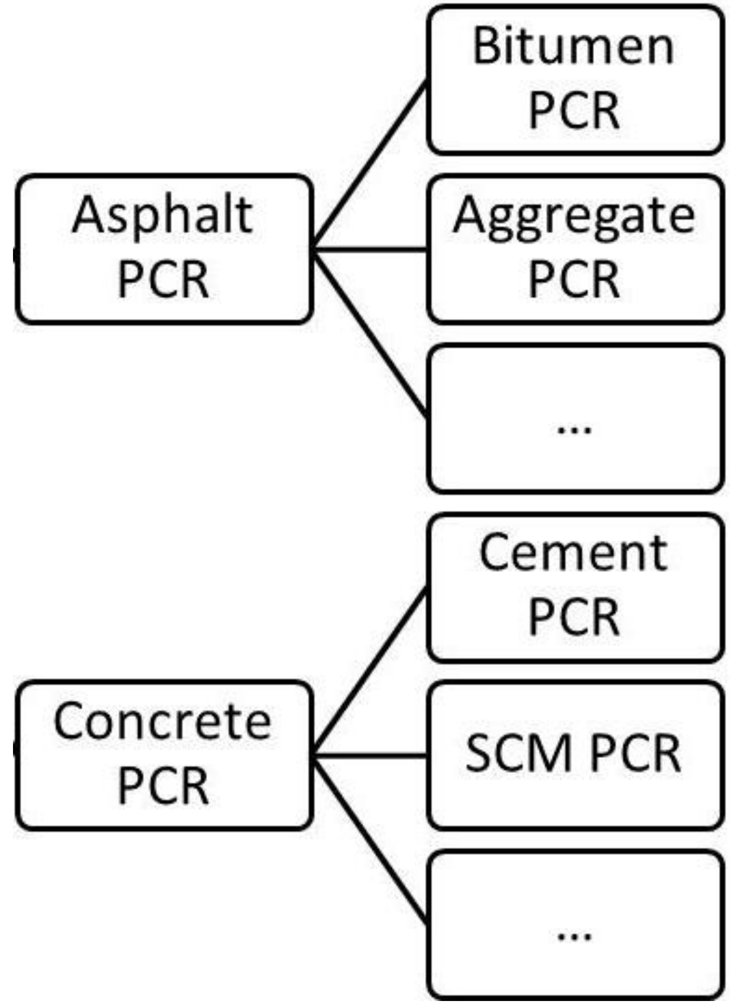
Environmental Product Declaration (EPD)

"Providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information" (ISO 14025)

Types of PCRs

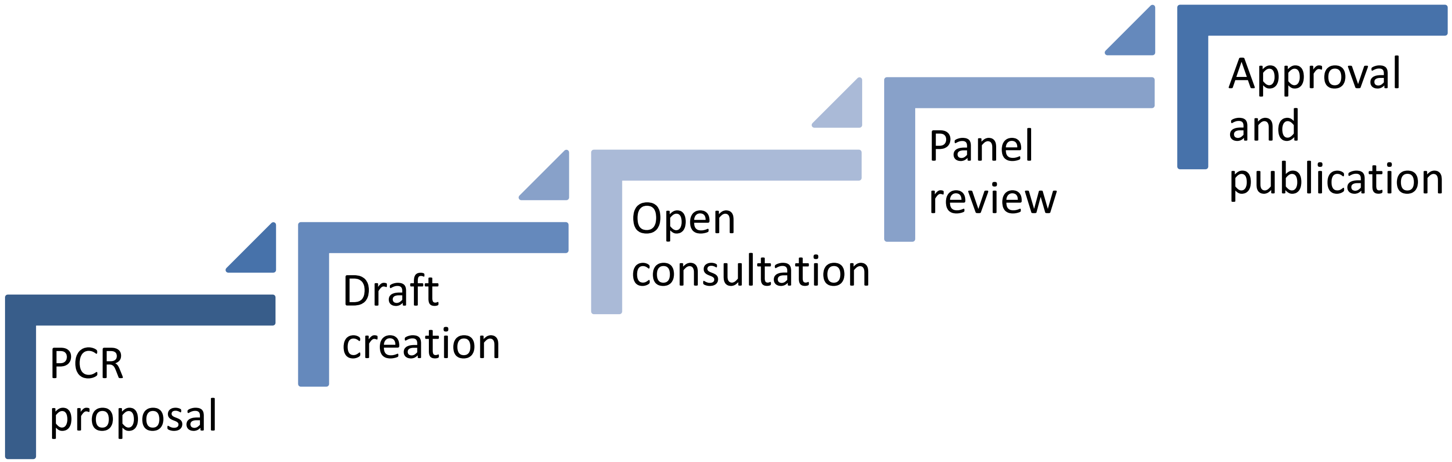
Systems

- **Component Product PCRs**
  - Cement
  - Bitumen
  - Additives
  - Aggregate
  - Polymer
- **Composite Materials PCRs**
  - More complicated than product-focused
  - Build on PCRs of component materials



Adapted from N. Santero, ThinkStep

PCR Development Steps



- Stakeholder engagement
  - Industry associations (e.g., ACPA, NAPA, IGGA, ISSA)
  - Manufacturers (e.g., companies)
  - LCA practitioners (e.g., LCA consultants)
  - Government agencies (e.g., FHWA, state DOTs)
  - NGOs
- Subject to critical review, relative to ISO and other standards of importance to customers

Adapted from N. Santero, ThinkStep

Who is Moving to PCR or LCIs in Europe/N. America Pavement Industry

asphalt institute

eurobitume

NRMCA

CSHub
MIT
CONCRETE SUSTAINABILITY HUB

concawe
ENVIRONMENTAL SCIENCE FOR THE EUROPEAN REFINING INDUSTRY

PCA
Portland Cement Association

NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

Asphalt Roofing Manufacturers Association

Adapted from N. Santero, ThinkStep

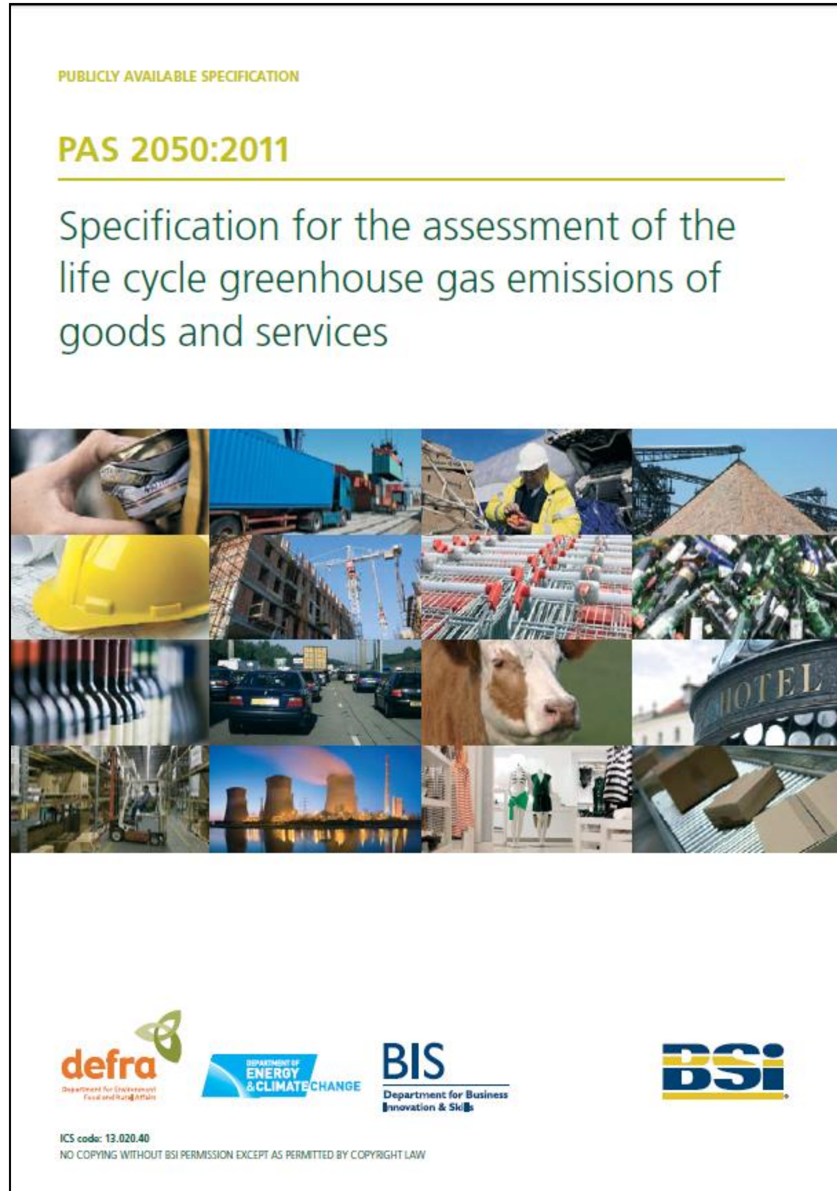
LCA Standards

- 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

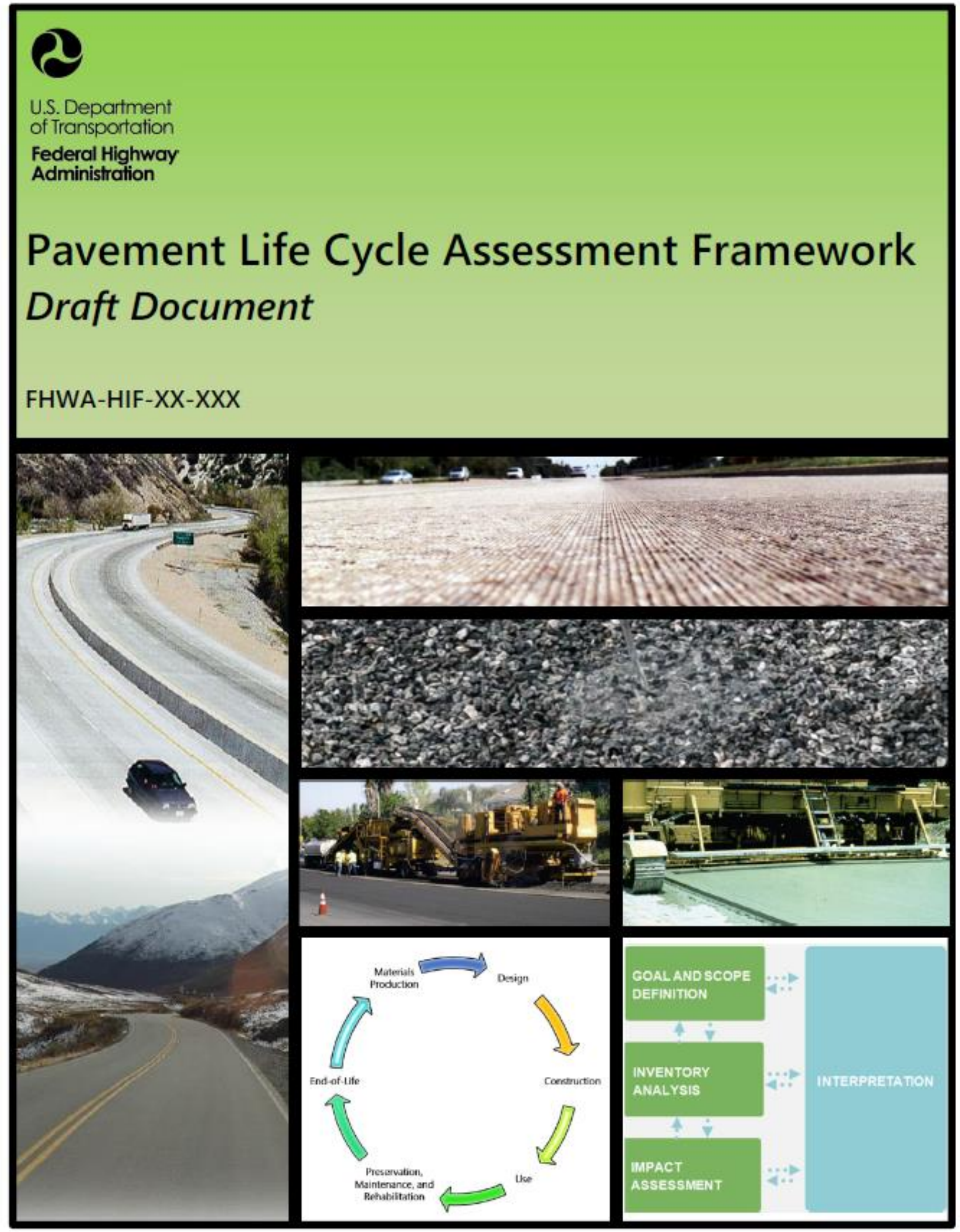
LCA Standards for Europe for Building Materials (elaboration on ISO)

- EN 15804:2012+A1 (2012 and update)
  - Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products
- National standards in France for building materials
- UK has new LCA standards for all products



- UCPRC Pavement LCA Guidelines (2010) http://www.ucprc.ucdavis.edu/P-LCA/pdf/ucprc_plca_guideline_v1.pdf
- 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

FHWA LCA Guidelines Specific to Pavement Should be available in early 2016



Dutch LCA experience: monetizing of impacts

Two criteria for the environmental quality of offers will be assessed and monetized:

Performance	**of**	**assessed with**
CO_2 emissions ------------→	working <u>processes</u>	CO_2 performance ladder
Environmental impact----→	the <u>product</u>	DuboCalc

The CO_2 performance ladder is a tool to assess the efforts of a company to reduce CO_2 emissions caused by the company's activities and processes and grants a rung in ascending order as the efforts are larger.

Adapted from Joep Meijer, The Right Environment

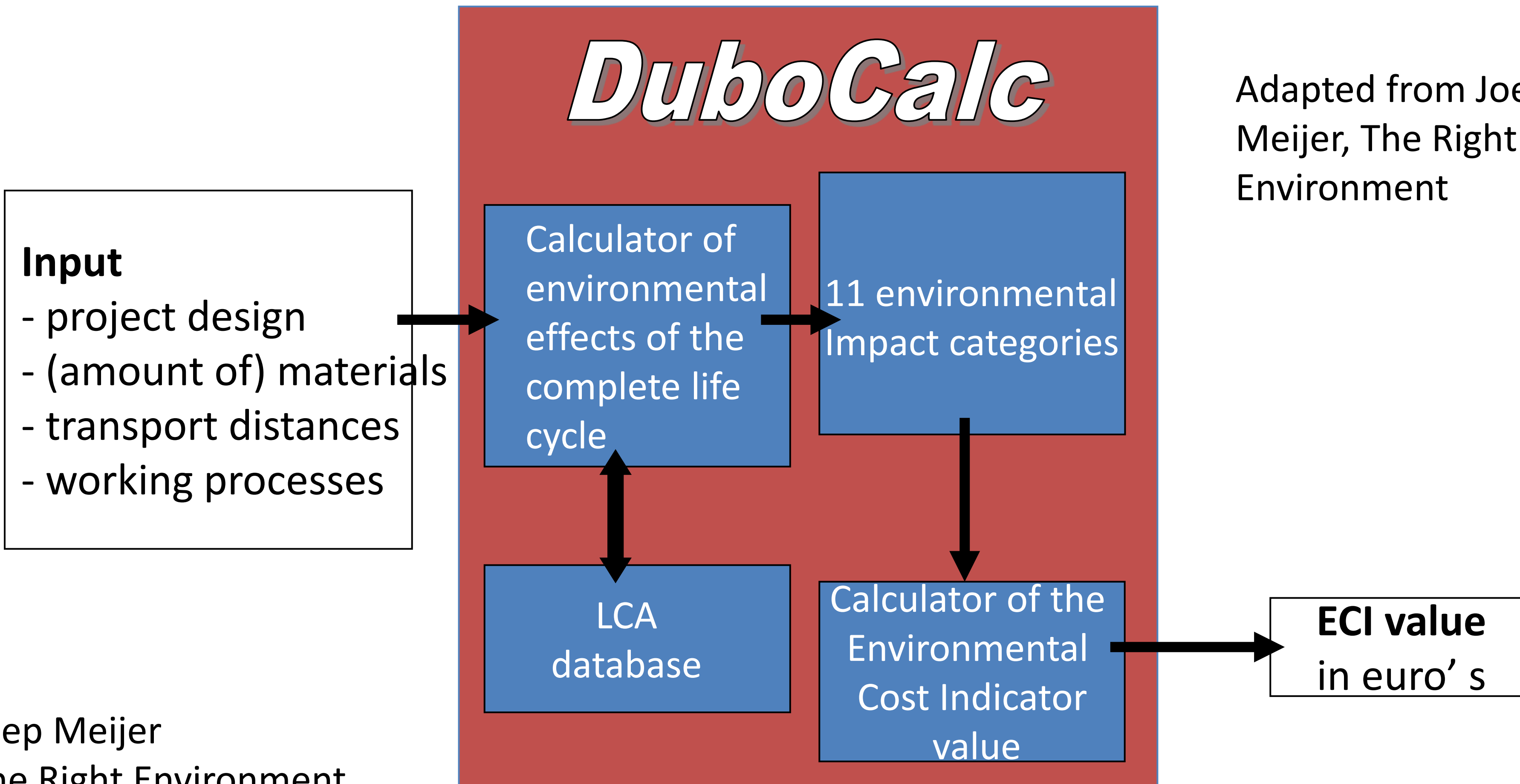
Damage (€) per parameter

Environmental parameter	Equivalent unit	Amount [€/unit]	Price [€]	Costs
• Climate change	CO_2 eq	5,8 eq	€ 0,05	€ 0,29
• Ozonlaagaantasting	CFK-11 eq	etc	€ 30,--	etc
• Humane toxiciteit	1,4-DCB eq		€ 0,09	
• Ecotoxiciteit, aquatisch (zoetwater)	1,4-DCB eq		€ 0,03	
• Ecotoxiciteit, aquatisch (zoutwater)	1,4-DCB eq		€ 0,0001	
• Ecotoxiciteit, terrestrisch	1,4-DCB eq		€ 0,06	
• Fotochemische oxidantvorming (smog)	C_2H_2 eq		€ 2,--	
• Verzuring	SO_2 eq	€ 4,--		
• Vermesting	PO_4 eq	€ 9,--		
• Uitputting van abiotische grondstoffen	Sb eq		€ 0,16	
• Uitputting van fossiele energiedragers	Sb eq		€ 0,16	
Total ECI value			sum	

Adapted from Joep Meijer, The Right Environment

DuboCalc: what is it?

DuboCalc is a tool to assess and monetize environmental impacts of a product/design based on life cycle analysis



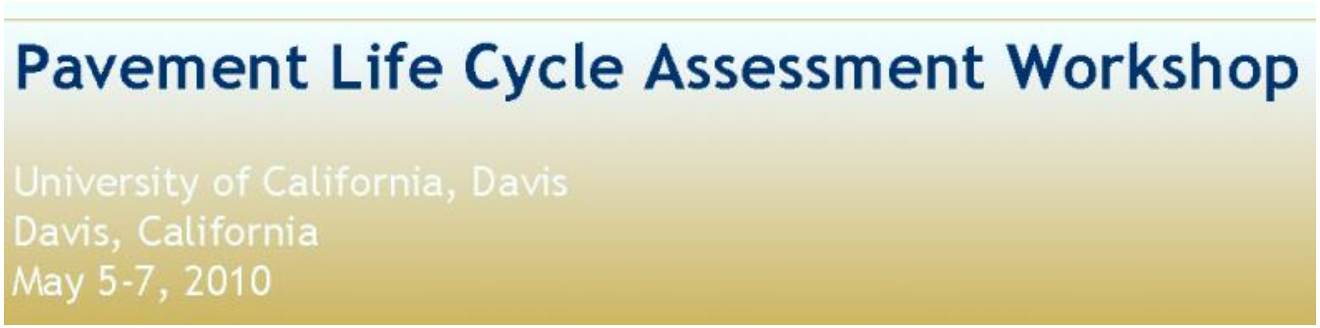
Adapted from Joep Meijer, The Right Environment

Joep Meijer
The Right Environment

Other Countries in Europe and USA

- France
  - National LCA software developed for proposal preparation for Design-Build-Maintain projects
  - Contractor selected based on LCCA + LCA
  - Software: Ecorce (government), Seve (industry)
- Sweden and UK currently developing similar system for likely implementation within two years
- Various EU projects to share LCA tools, data and knowledge
- USA:
  - FHWA has Sustainable Pavements Working group with industry and state DOT, preparing LCA Guidelines
  - Illinois Tollway preparing LCA system, soon requiring EPDs

Development of consensus on practice of Pavement LCA



Next:

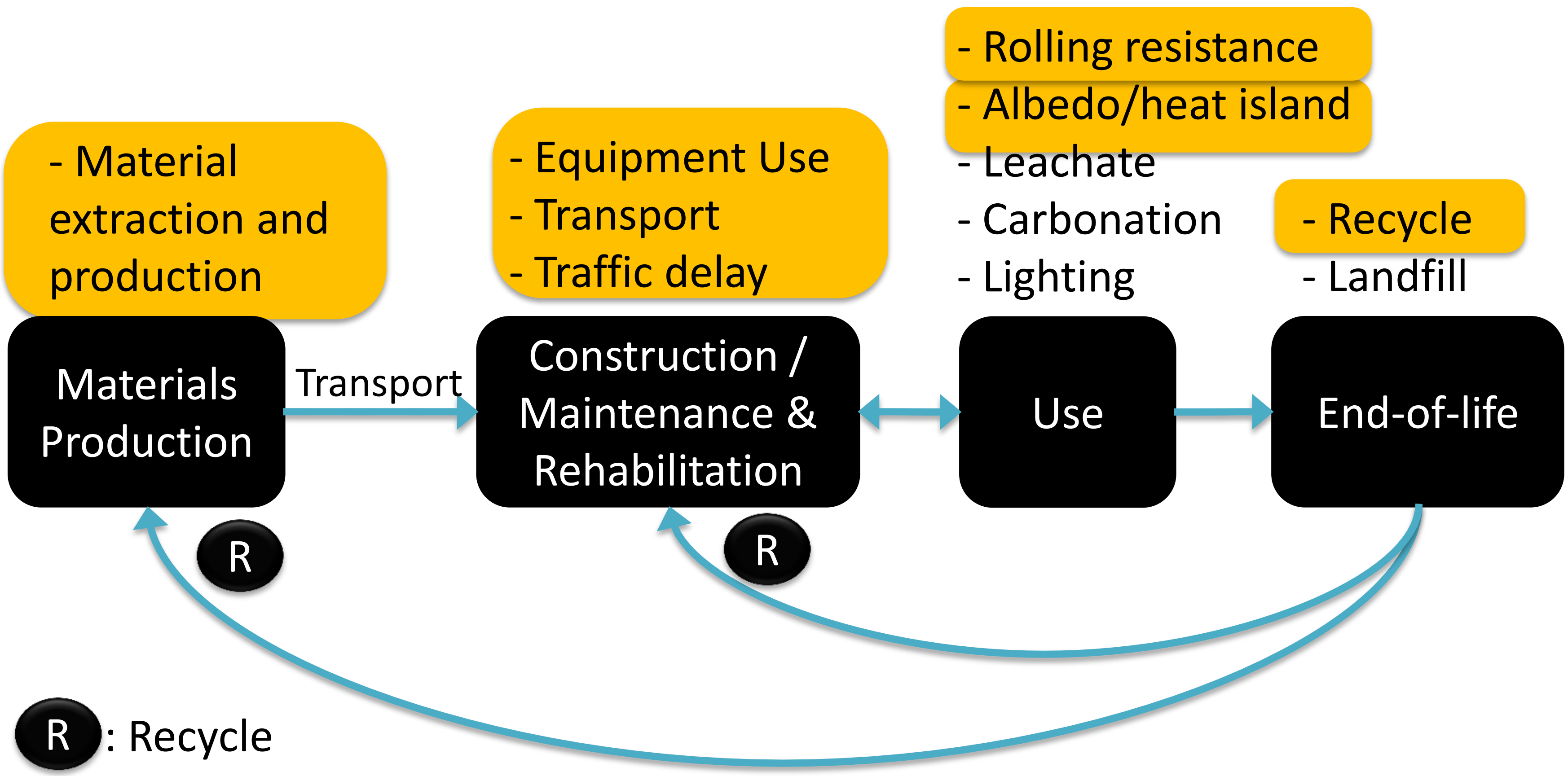
- Workshops in Aug 2015
  - China (8/8)
  - South Africa
- 4th Symposium in 2016 in Chicago

Topics

http://www.ucprc.ucdavis.edu/p-lca2014

- Application of Pavement LCA in Northern Europe
- Current status and future of standardizing LCA in US
- Approach for developing regional LCI dataset
- Integration of LCA into pavement management systems
- Integration into new design methods
- Use of LCA in different infrastructure delivery methods
- Panel discussion: Implementation of LCA by different organizations: state DOT, FHWA, industry perspectives
- Sponsors: TRB, FHWA, Caltrans, Int. Soc. for Asphalt Pavements, Int. Soc. For Concrete Pavements

Pavement Life Cycle Assessment
UCPRC focus area examples



From: Kendall et al*, 2010*

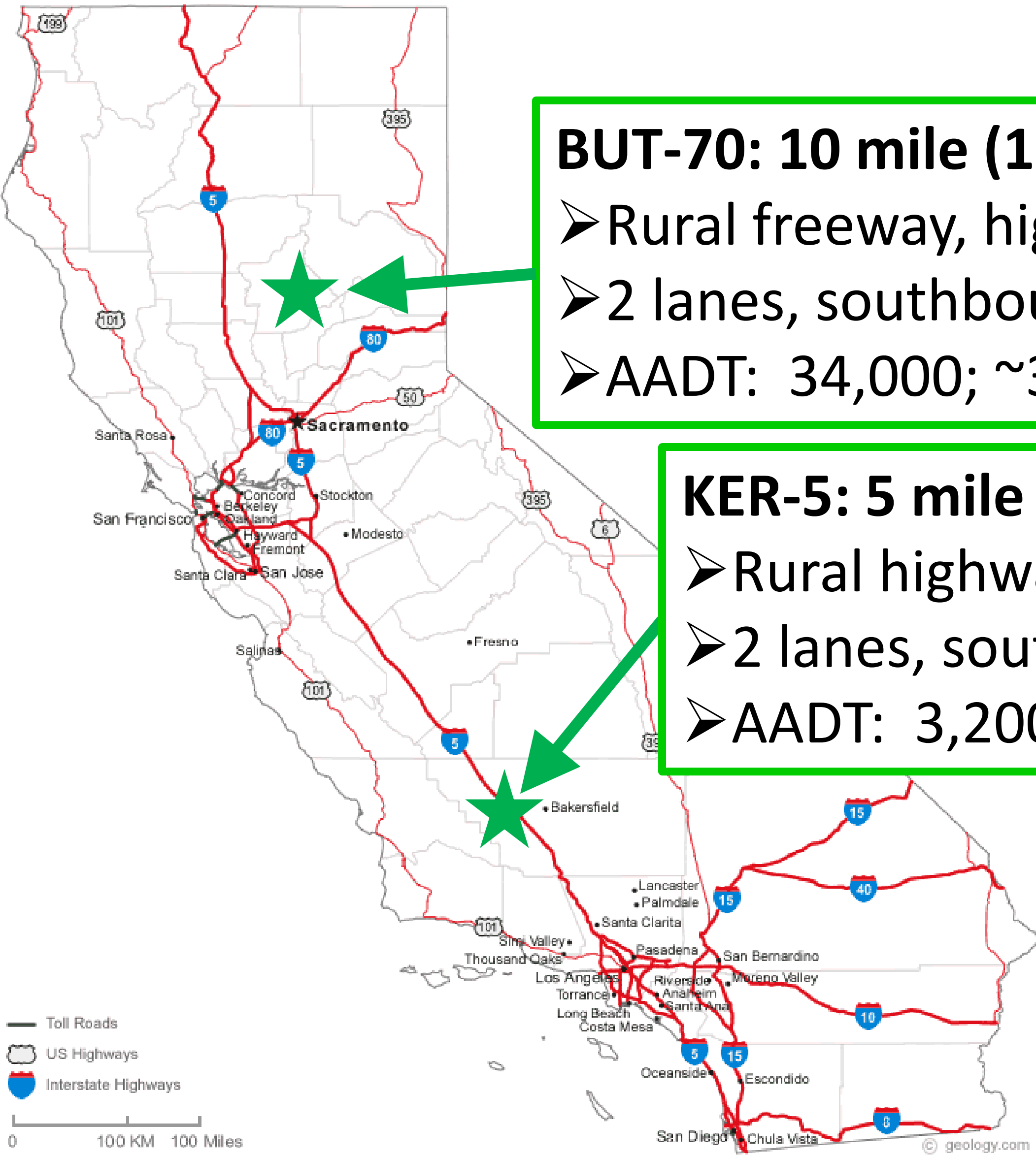
Project-level comparison of FDR strategies (without use phase, different performance)

Item	Functional Unit	Life Cycle Phase	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]
FDR (25 cm milled + no stabilization) w. 6 cm RHMA OL	1 ln-km	Material	3.33E+04	3.27E+03	2.21E+01	79%	53%	81%
		Transport	3.32E+03	5.30E+02	1.06E+00	8%	9%	4%
		Construction	5.44E+03	2.40E+03	4.27E+00	13%	39%	16%
		Total	**4.20E+04**	**6.20E+03**	**2.74E+01**	**100%**	**100%**	**100%**
FDR (25 cm milled + 3% FA + 1% PC) w. 6 cm RHMA OL	1 ln-km	Material	9.31E+04	4.03E+04	3.33E+04	91%	93%	100%
		Transport	3.88E+03	6.18E+02	1.24E+00	4%	1%	0%
		Construction	5.44E+03	2.40E+03	4.27E+00	5%	6%	0%
		Total	**1.02E+05**	**4.33E+04**	**3.33E+04**	**100%**	**100%**	**100%**
FDR (25 cm milled + 2% PC) w. 6 cm RHMA OL	1 ln-km	Material	8.96E+04	6.50E+03	4.42E+01	91%	69%	89%
		Transport	3.60E+03	5.74E+02	1.15E+00	4%	6%	2%
		Construction	5.44E+03	2.40E+03	4.27E+00	6%	25%	9%
		Total	**9.87E+04**	**9.48E+03**	**4.96E+01**	**100%**	**100%**	**100%**
FDR (25 cm milled + 4% PC) w. 6 cm RHMA OL	1 ln-km	Material	1.46E+05	9.74E+03	6.64E+01	94%	76%	92%
		Transport	3.88E+03	6.18E+02	1.24E+00	2%	5%	2%
		Construction	5.44E+03	2.40E+03	4.27E+00	4%	19%	6%
		Total	**1.55E+05**	**1.28E+04**	**7.19E+01**	**100%**	**100%**	**100%**

Project Level Goals

- Answer these questions:
  - What is effect of construction smoothness on GWP?
  - What is effect of pavement materials on GWP?
  - What is effect of traffic level on GWP?

Project-level asphalt case studies



BUT-70: 10 mile (16 km) segment (low traffic)

- Rural freeway, high traffic volume
- 2 lanes, southbound
- AADT: 34,000; ~35% trucks

KER-5: 5 mile (8 km) segment (high traffic)

- Rural highway, low traffic volume
- 2 lanes, southbound
- AADT: 3,200; ~15% trucks

Compare:
- *Do Nothing (min maint)*
- 5 year overlay
    -HMA, RHMA

Construction Scenarios: KER-5

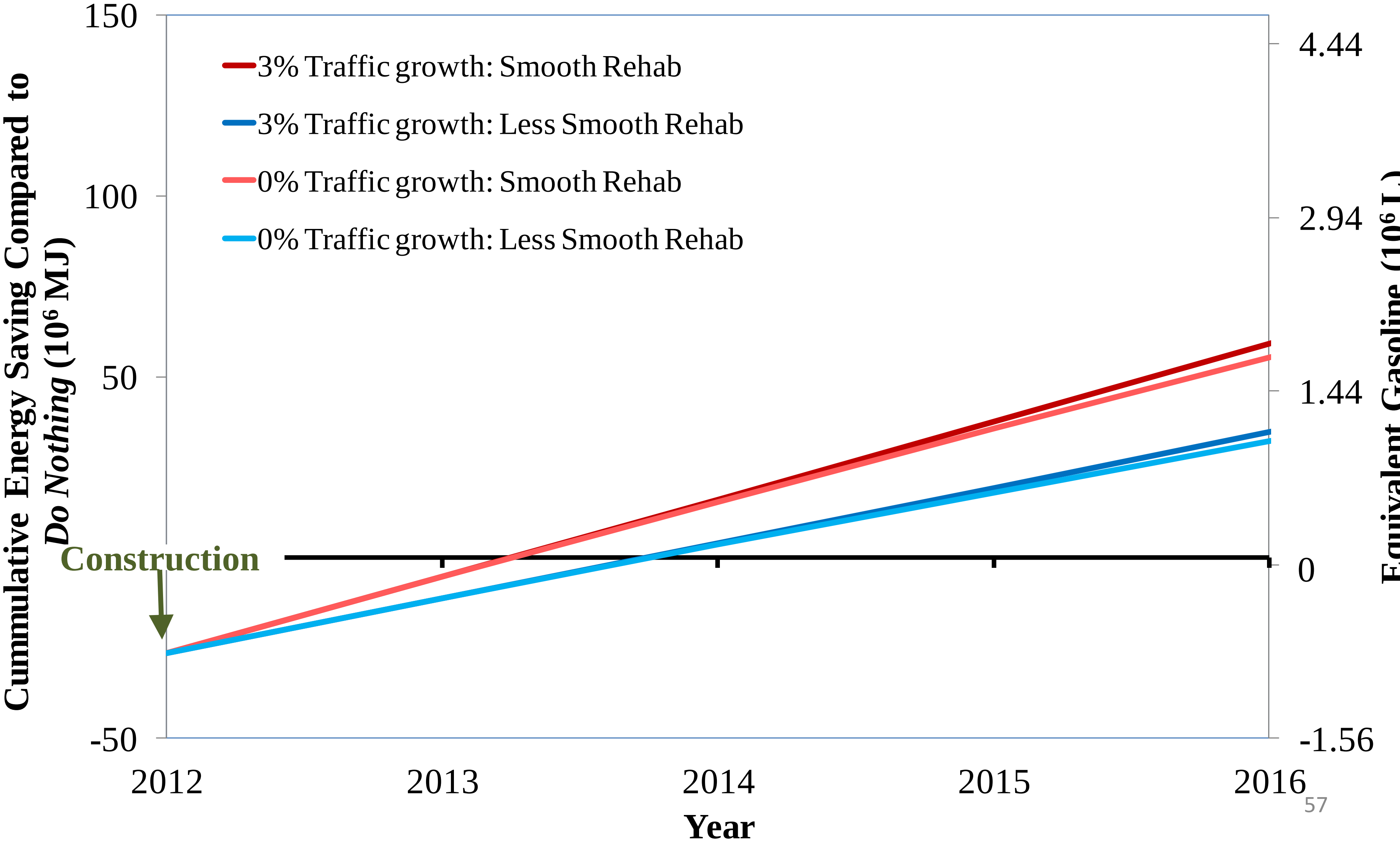
HMA Type	Design life	Treatment	Cross Section	Smoothness
CAPM, HMA	5 Years	Mill & Overlay	45 mm (0.15') Mill + 75 mm (0.25') HMA with 15% RAP	Smooth Rehab
				Less smooth Rehab
CAPM, RHMA	5 years	Mill & Overlay	30 mm (0.1') Mill + 60 mm (0.20') RHMA	Smooth Rehab
				Less smooth Rehab

KER-5 summary table: Saving compared to "*Do Nothing*" for 5 years

Material	Traffic Growth	Initial IRI m/km	Feed stock (10^6 MJ)	Material Production (Avg value, 10^6 MJ)	Construction (Avg value, 10^6 MJ)	Use phase (10^6 MJ)	Net Energy Saving (10^6 MJ)	Equivalent Gasoline Saving (10^6 liter)	GHG Reduction (Tonne CO2-e)
HMA	3%	1	-33	-20	-7.0	110	81	2.5	5,726
		1.67				76	50	1.6	3,477
	0%	1				100	75	2.3	5,283
		1.67				72	45	1.4	3,165
RHMA	3%	1	-49	-18	-5.4	110	84	2.6	6,176
		1.67				76	53	1.7	3,927
	0%	1				100	78	2.4	5,733
		1.67				72	49	1.5	3,615

Note: A positive number means saving, and a negative one means consumption.

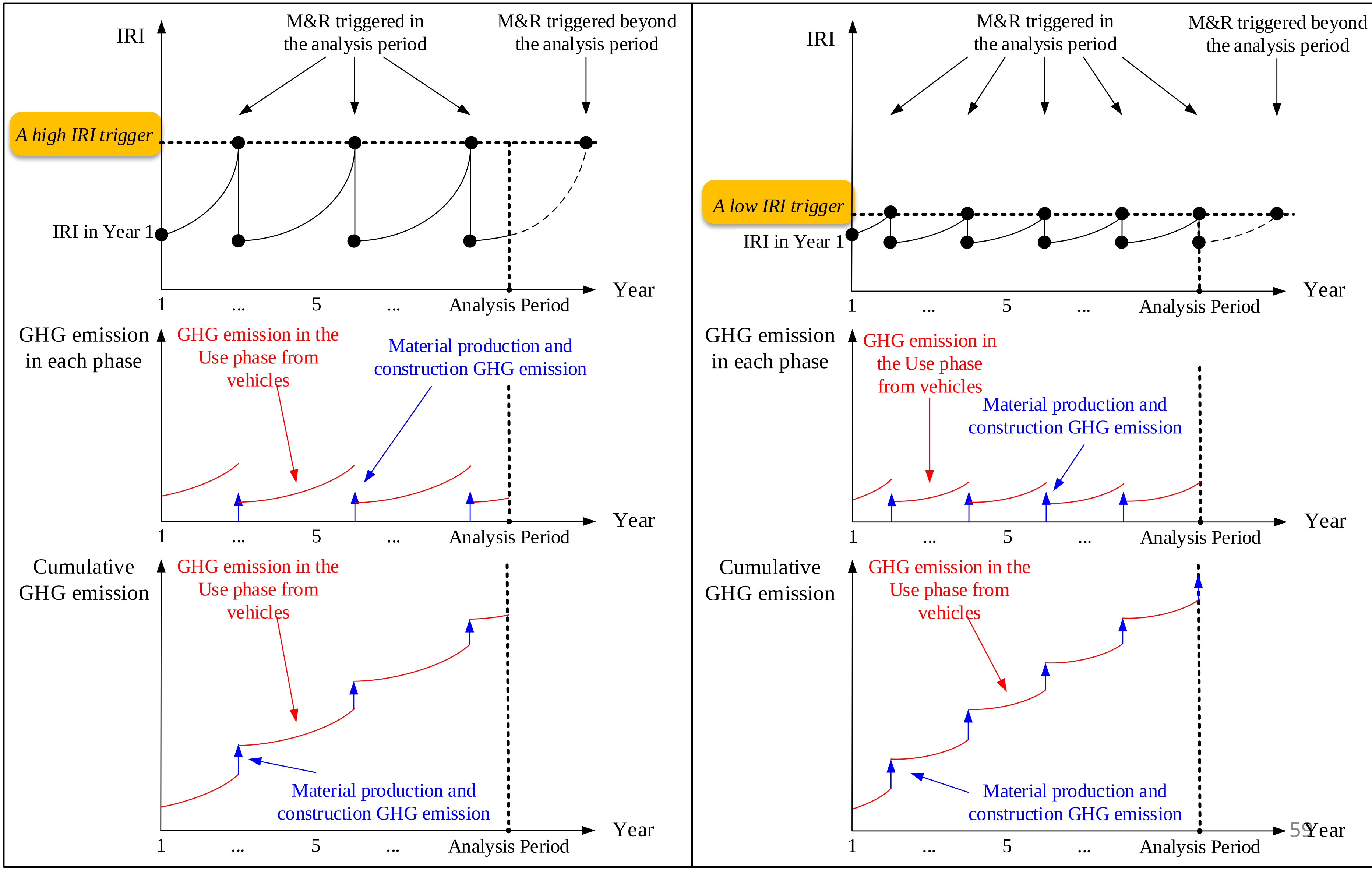
KER-5 (**HMA**): Cumulative life cycle energy savings compared to *Do Nothing*



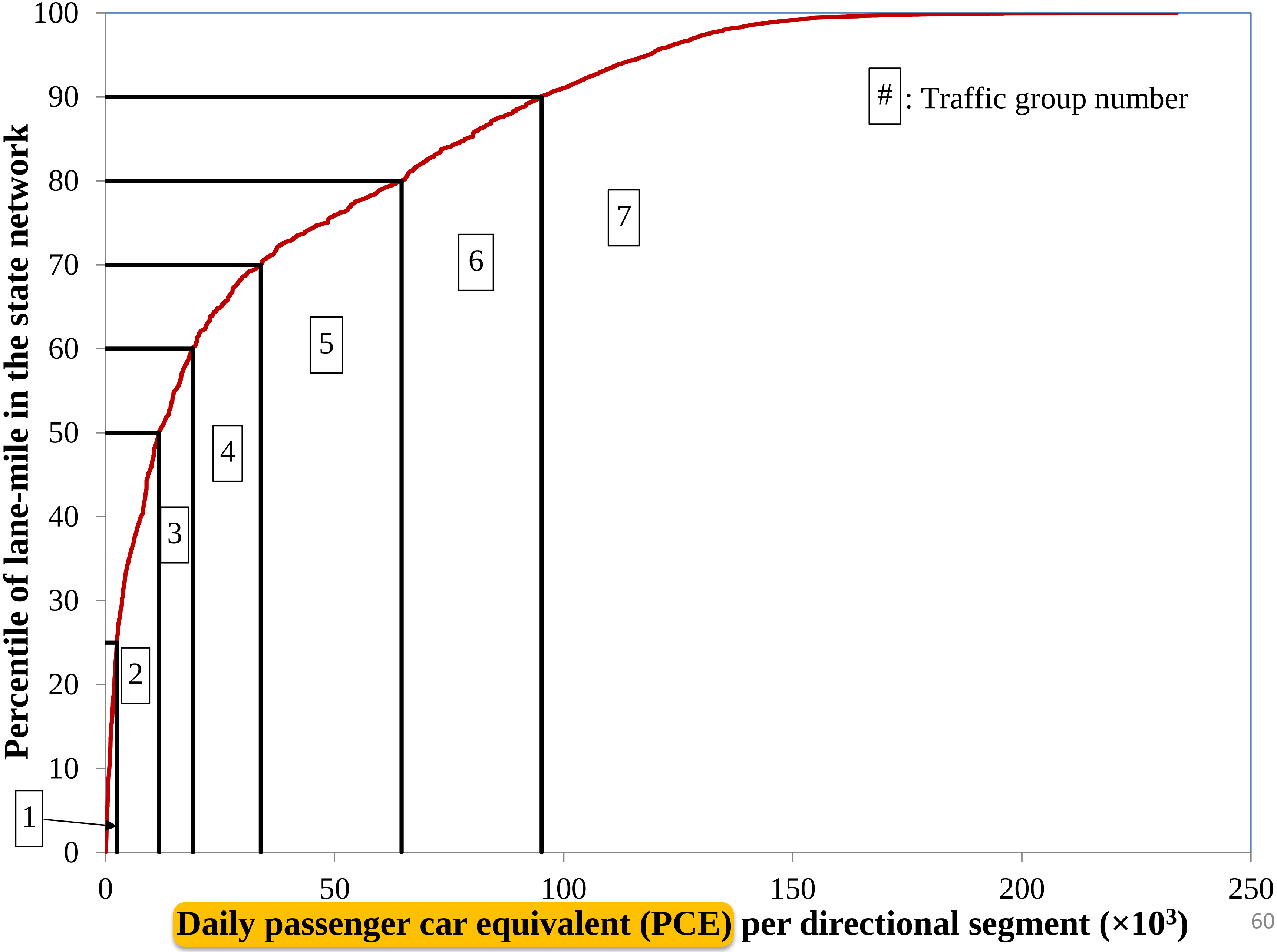
Application of Project-Level Case Studies to Pavement Management System

- Apply results from the case studies to the pavement network
- Questions to answer:
  - Optimal IRI triggers to minimize the life cycle GHG emission on California highway network.
  - Cost-effectiveness of treatments and IRI trigger for each traffic level.
- Approach now implemented in Caltrans PMS

Different IRI triggers (high vs. low)



Method: Divide network based on traffic level



Result: Optimal trigger by traffic group

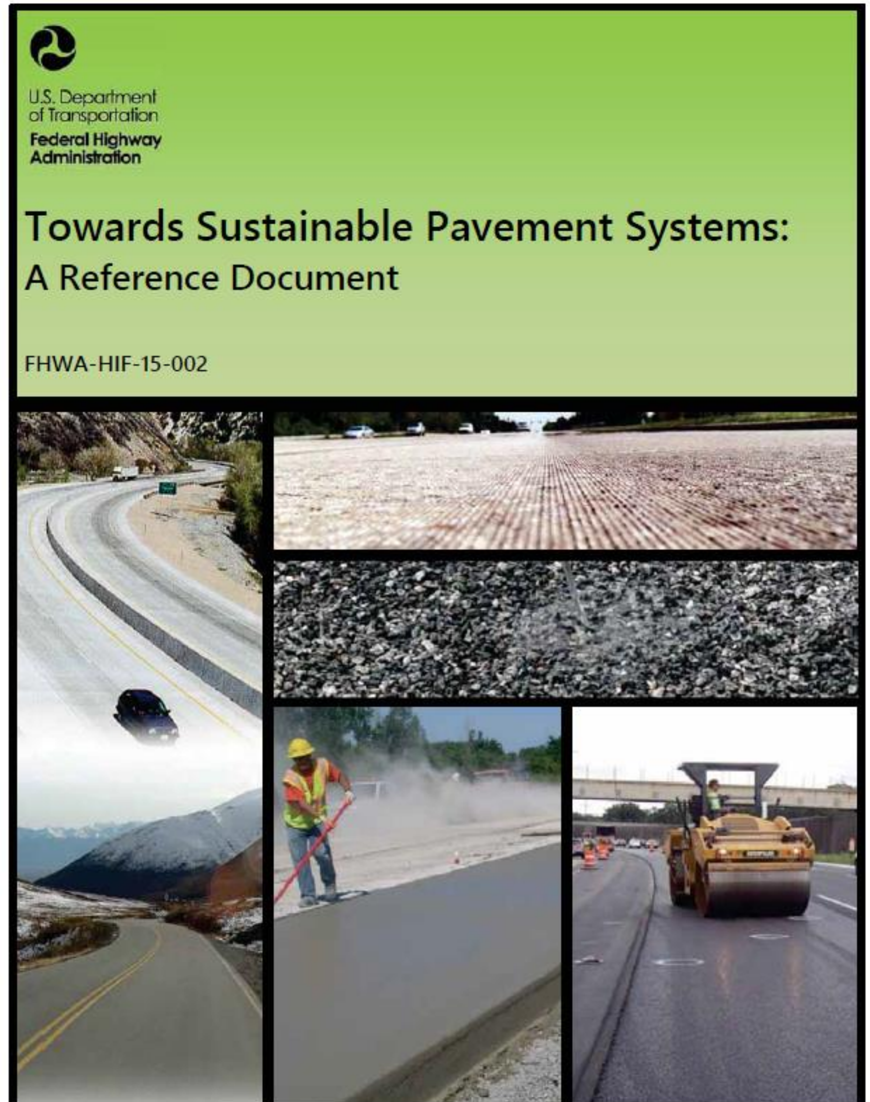
Traffic group	Daily PCE of lane-segments range	Total lane-miles	Percentile of lane-mile	Optimal IRI triggering value (m/km, inch/mile in parentheses)	Annualized CO_2-e reductions (MMT)	Modified total cost-effectiveness ($/t$CO_2$-e)
1	<2,517	12,068	<25	-----	0	N/A
2	2,517 to 11,704	12,068	25~50	2.8 (177)	0.141	1,169
3	11,704 to 19,108	4,827	50~60	2.0 (127)	0.096	857
4	19,108 to 33,908	4,827	60~70	2.0 (127)	0.128	503
5	33,908 to 64,656	4,827	70~80	1.6 (101)	0.264	516
6	64,656 to 95,184	4,827	80~90	1.6 (101)	0.297	259
7	>95,184	4,827	90~100	1.6 (101)	0.45	104
Total					**1.38**	**416**

Takeaways

- Environmental considerations measured by LCA will increase as market drivers, considering all life cycle phases
- New materials and structures are beginning to be benchmarked on their environmental impact with LCA

State of the knowledge on improving pavement sustainability

- http://www.fhwa.dot.gov/pavement/sustainability/ref_doc.cfm
- Recommendations for improving sustainability across entire pavement life
- Organized around LCA framework
- Other information available at same web site
  - Tech briefs
  - Literature database



The Future?

World-wide Benchmarking and Standardization

- Growing world use of LCA for pavement
- Standardization of approaches
- Comparison across methods and data
- Localization of
  - Life cycle inventories
  - Calculation of impacts

Gaps – Technical Issues

- Life Cycle Inventory data for much of world is sparse:
  - Proprietary sources of data that may be high quality, but costly
  - Not regionally applicable, especially for materials production, construction, recycling treatments
  - May not be up to date, especially for warm mix asphalt, concrete additives, and asphalt production
- Use phase modeling gaps currently being filled:
  - Deflection energy dissipation model validation
  - Urban Heat Island modeling confirmation
- End of Life approach
  - Environmental impact accounting can vary based on allocation approach

Gaps – Implementation Issues

- Project delivery environment may affect LCA implementation
  - Europe: Design-Build or Design-Build-Maintain
  - US: Design-Bid-Build (low-bid)
- Decisions regarding what LCA should be used for
  - Policy development
  - Guidance
    - Design guidance (project-level)
    - Project management guidance (network-level)
  - Design selection like Life Cycle Cost Analysis (LCCA)
  - Part of procurement (like Netherlands, France)

Recommendations

- Use LCA to evaluate benefits and unintended consequences of pavement policy decisions before implementation
- Integrate LCA principles and calculations into pavement design, procurement policies and pavement management systems (PMS)
- Encourage and facilitate an active and comprehensive market for LCA data
  - PCRs and widespread creation of EPDs
  - Support and incentivize use and improvement of public LCI databases
  - Need for an authority and guidelines to resolve conflicts in PCRs between industries

Recommendations for South Africa and for ISAP

- Southern Africa
  - Use experience with LCCA as model
  - Identify most important issues and goals
  - Begin applying “LCA thinking” where can have most impact to meet goals
- Role of ISAP
  - Spread knowledge
  - Facilitate international benchmarking and standardization
  - Support development of PCRs and EPDs to make data lower cost and more accessible

Questions?

Reports downloadable free at
www.ucprc.ucdavis.edu

LEEDv4 (USA, 2013)

- Major non-governmental organization setting standards for building "sustainability"
  - Particularly strong for building industry
  - Many governmental agencies now require LEED certified buildings
- Previously awarded points on an arbitrary basis
  - Heavy criticism
- LEEDv4 requires use of LCA for whole building and EPD for differentiating building products, leading many pavement materials producers to move towards PCR/EPD

Radical Industrialists

4 ways LEED v4 will change business

Mikhail Davis and Melissa Vernon

Friday, October 18, 2013 - 2:15am

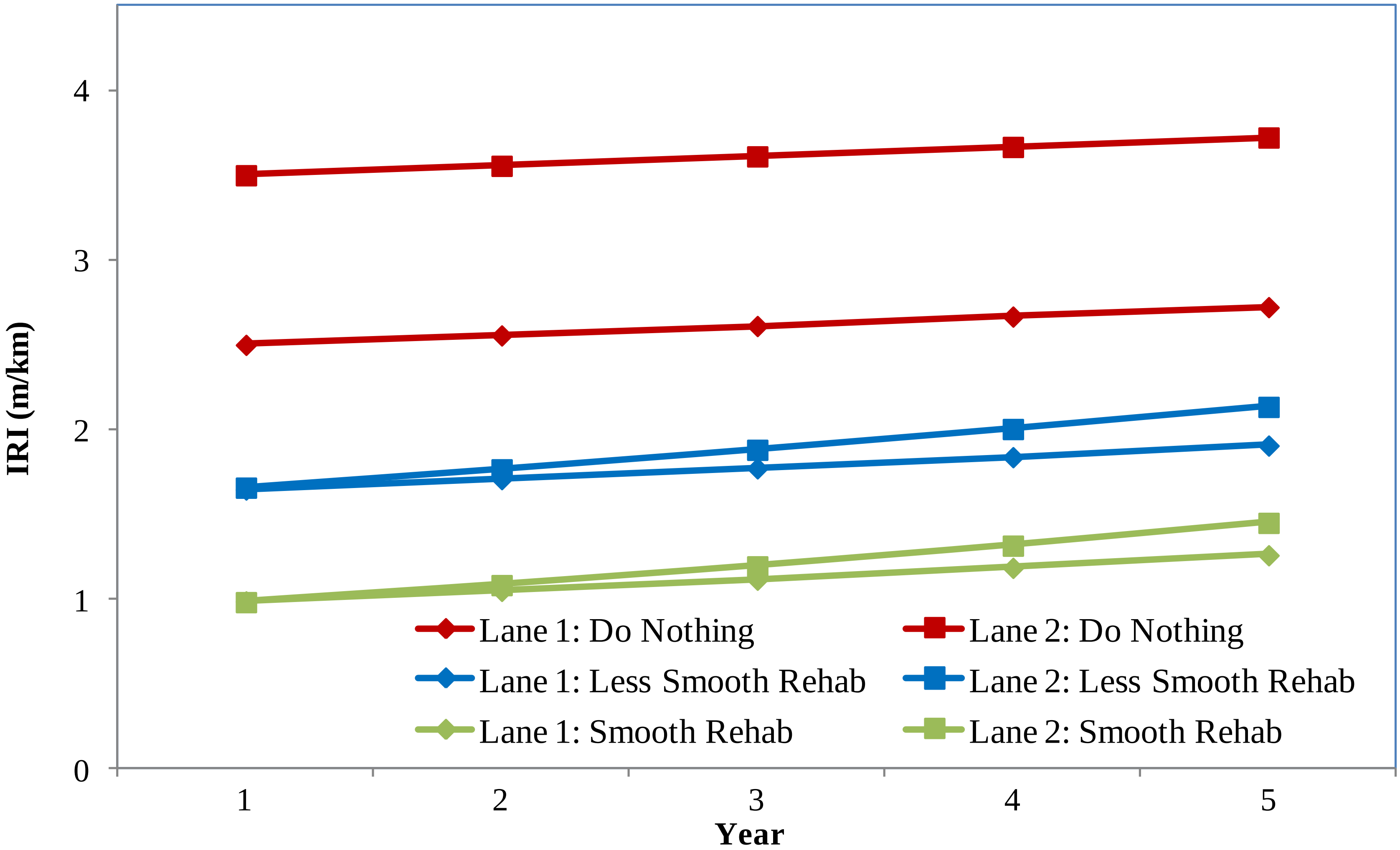
Mix Designs: KER-5

	HMA	RHMA
Course Aggregate	31 %	63 %
Fine Aggregate	46 %	25 %
Dust	4.0 %	4.6 %
Bitumen	4 %	6 %
RAP	15 %	---------
Crumb Rubber	---------	1.5 %

Equipment Operation (hours): KER-5

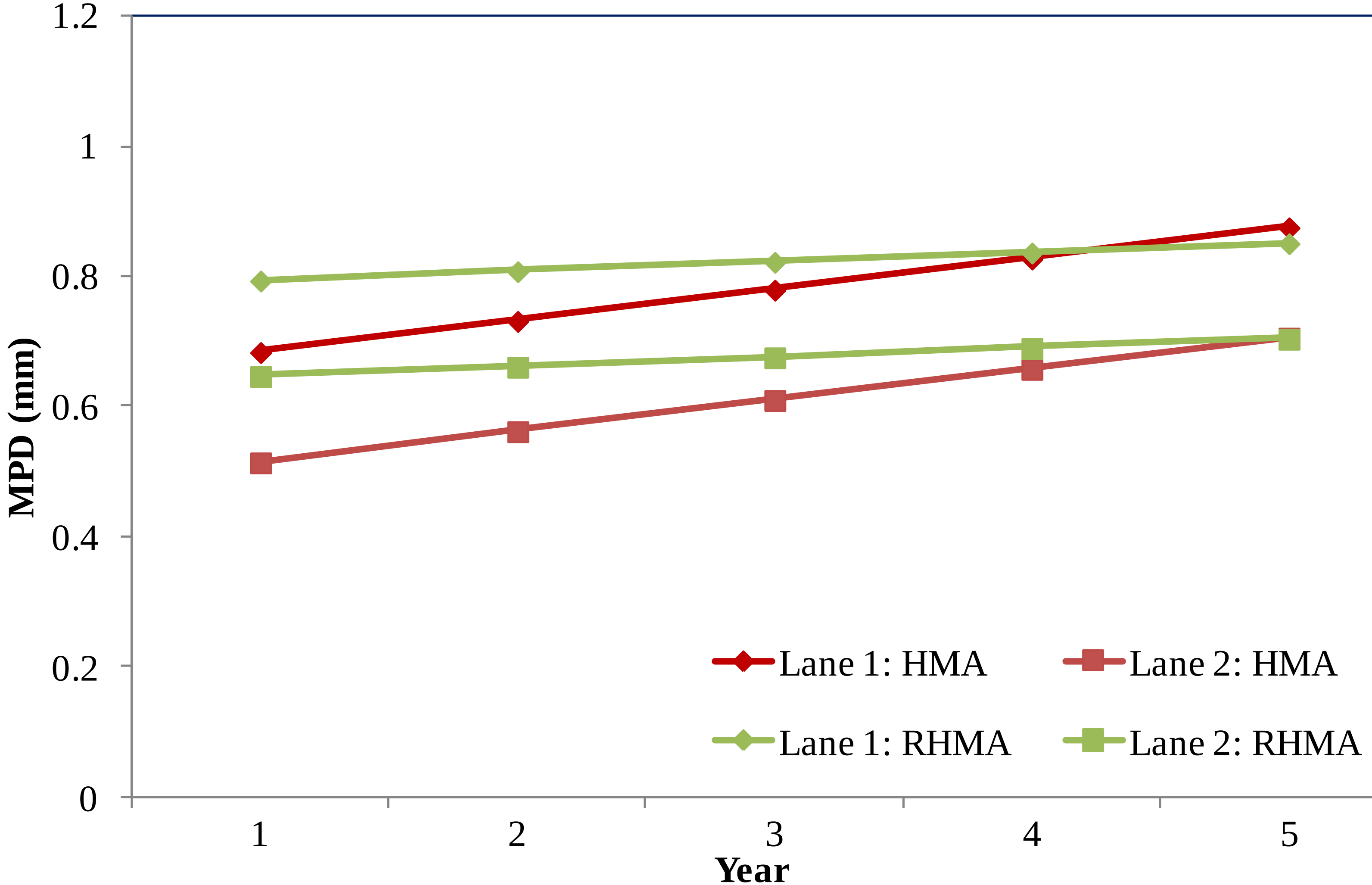
Activity	Equipment	HMA		RHMA	
		Operation	Idle	Operation	Idle
Total Closure for Construction		36 x 9-h Night		27 x 9-h Night	
Milling	Milling Machine	124		86	
	Demo Hauling Truck	1,761		1,244	377
	Pay Loader	216		162	
	Grader	216		162	
	Compactor	216		162	
HMA	AC Paver	216		162	
	R/HMA Delivery Truck	3,098	492	2,456	390
	Roller (vibratory/static)	432		324	
	Roller (pneumatic tire)	216		162	
	Drum Plant (metric ton)	20,628		16,510	
	Drum Plant Operation	108		81	
General	Truck (General + Tack)	870	138	652	104
	Generator	648		486	

KER-5 IRI Scenarios over 10 years*



* 1st draft from empirical data, needs review and modeling

KER-5 MPD Progression from CA data*
(For rehabilitated lanes)



* 1st draft from empirical data, needs review and modeling

International Benchmarking Study Comparisons of Pavement Design and LCI

Inventory/Design	California R-value design	France LCPC catalog design	South Africa standard design	China national catalog design
ECORCE	X	X	X	X
UCPRC[1]	X	X	X	X
ECORCE adjusted to local country conditions*	X	-	X	X
UCPRC adjusted to local country conditions*	-	X	X	X

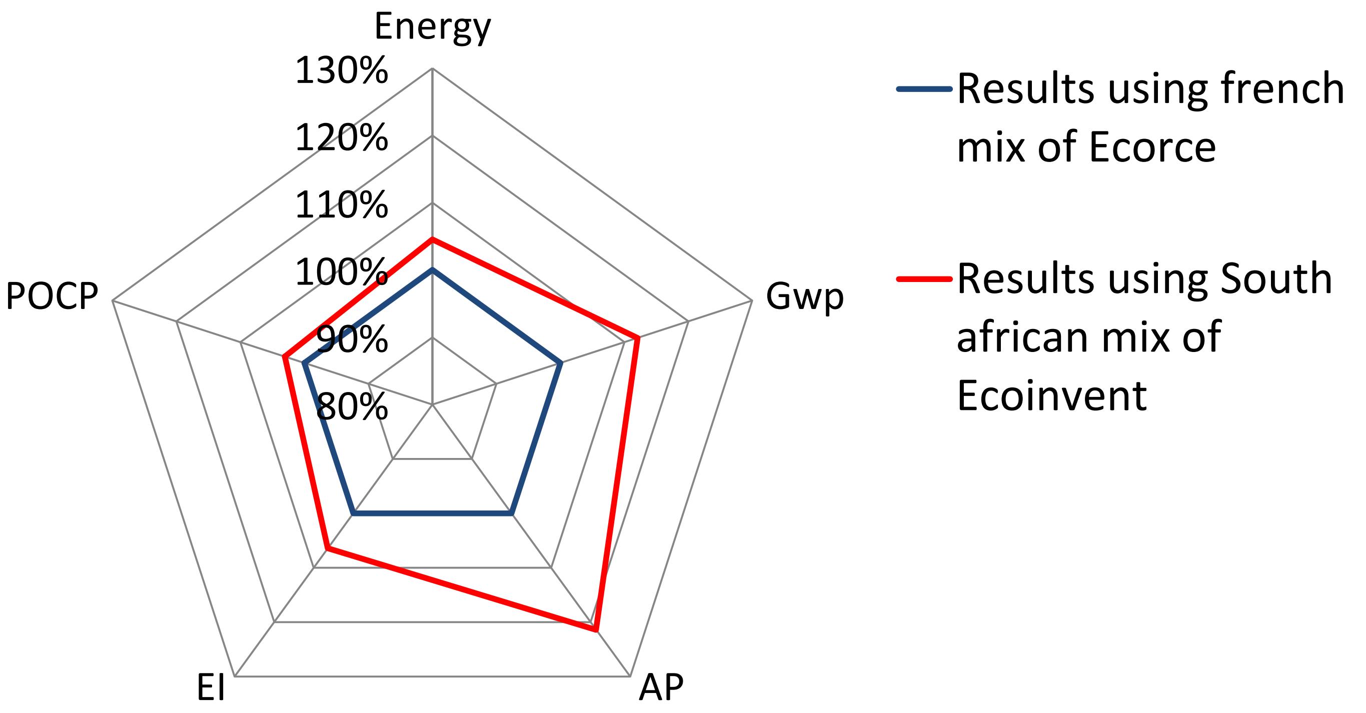
* Change of electrical supply mix and asphalt mixing plant fuel (natural gas or fuel oil)

Electricity Mix in California, US, France, South Africa and China

Type	California	France	South Africa	China
Coal	7.7%	4.5%	85.6%	66.0%
Natural Gas	41.9%	4.1%	5.5%	3.3%
Hydro	10.8%	12.5%	1.4%	21.7%
Nuclear	13.9%	78.0%	4.3%	1.1%
Oil (Pumped Storage)	0.02%	-	3.2%	-
Wind (Renewable)	13.7%	Included in the Hydro percentage	0.01%	5.3%
Solar (Renewable)	-	Included in the Hydro percentage	-	0.3%
Other	12.0%	0.9%	-	< 2%

Change of electricity mix and asphalt plant fuel (oil to natural gas)

South African case results



Harvey et al. Pavement LCA 2014 paper

From generic to local specificity

Global Warming
Ozone Layer depletion

Aquatic and terrestrial acidification
Photochemical ozone formation
Aquatic and terrestrial Eutrophication

Human toxicity
Ecotoxicity

Land Use
Water Use
Biotic and abiotic resources use

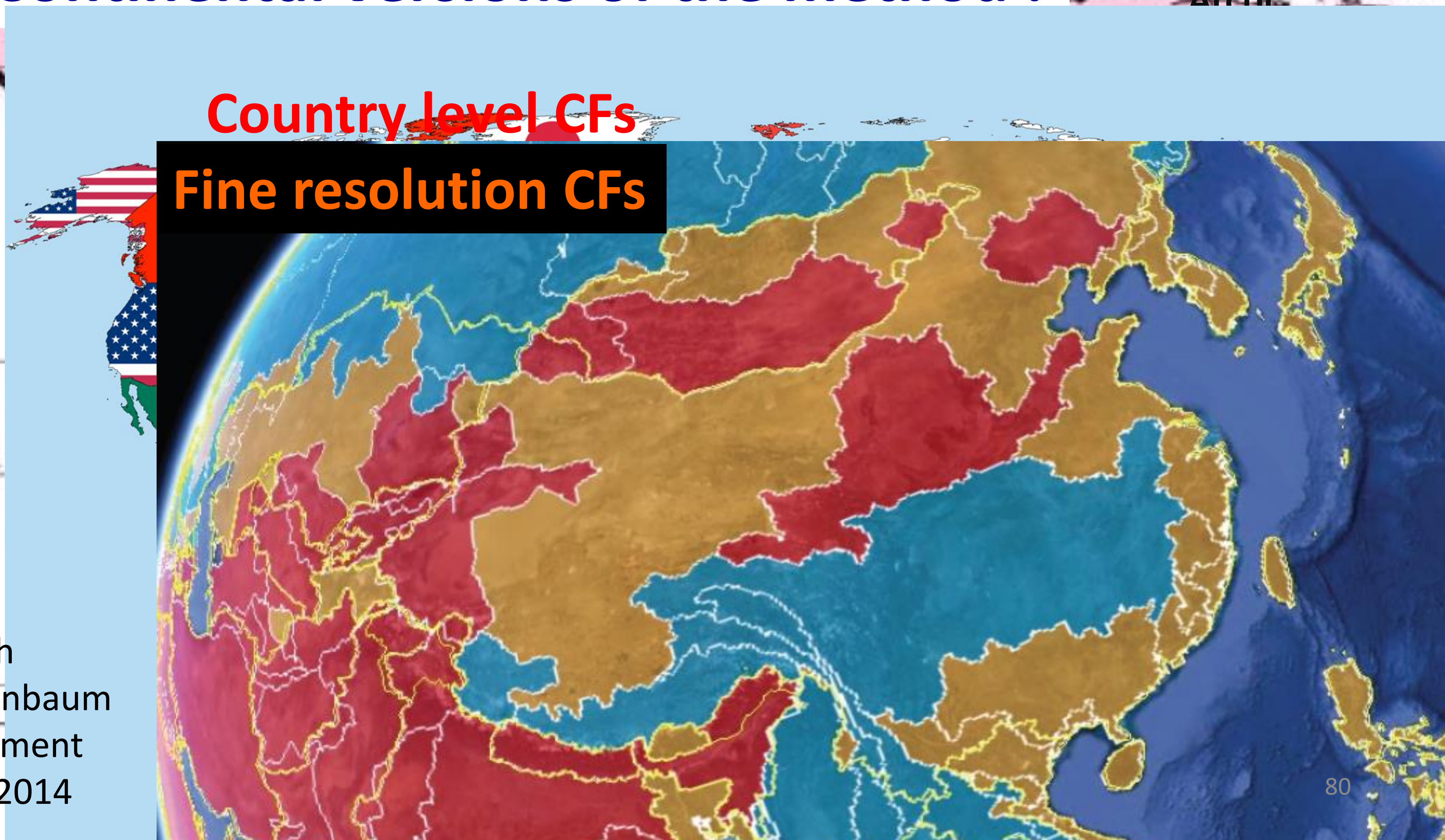
Global Impacts, independent from emission site

Regional and local impacts with strong dependency on emission site

IMPACT World+ the first regionalised LCIA method

Global default Method : IMPACT World +

Continental versions of the method :



Ralph Rosenbaum Pavement LCA 2014