Determinants of Material Intensities and Environmental Impacts of Roadway Designs

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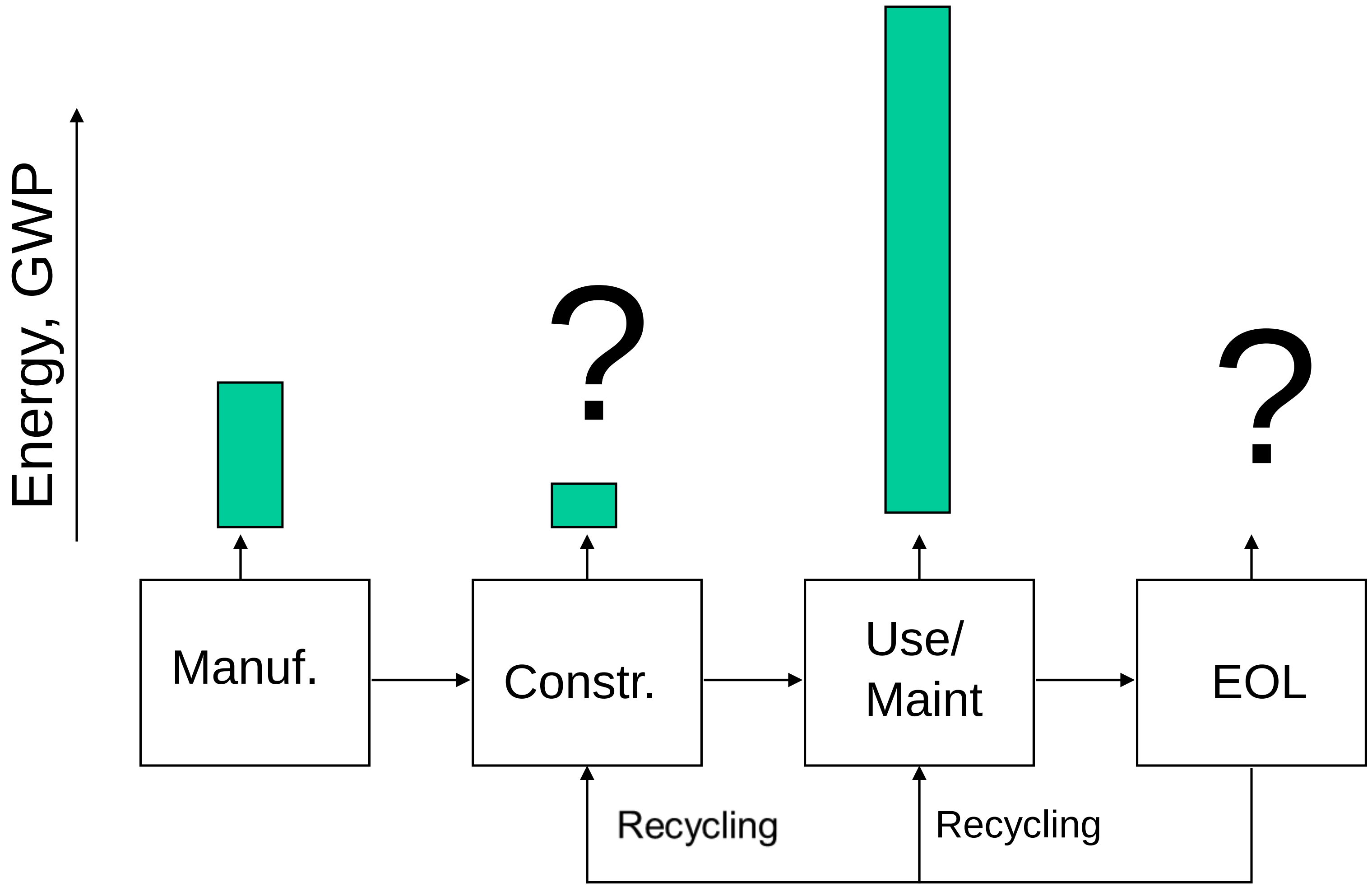
Roadway Issues to Discuss

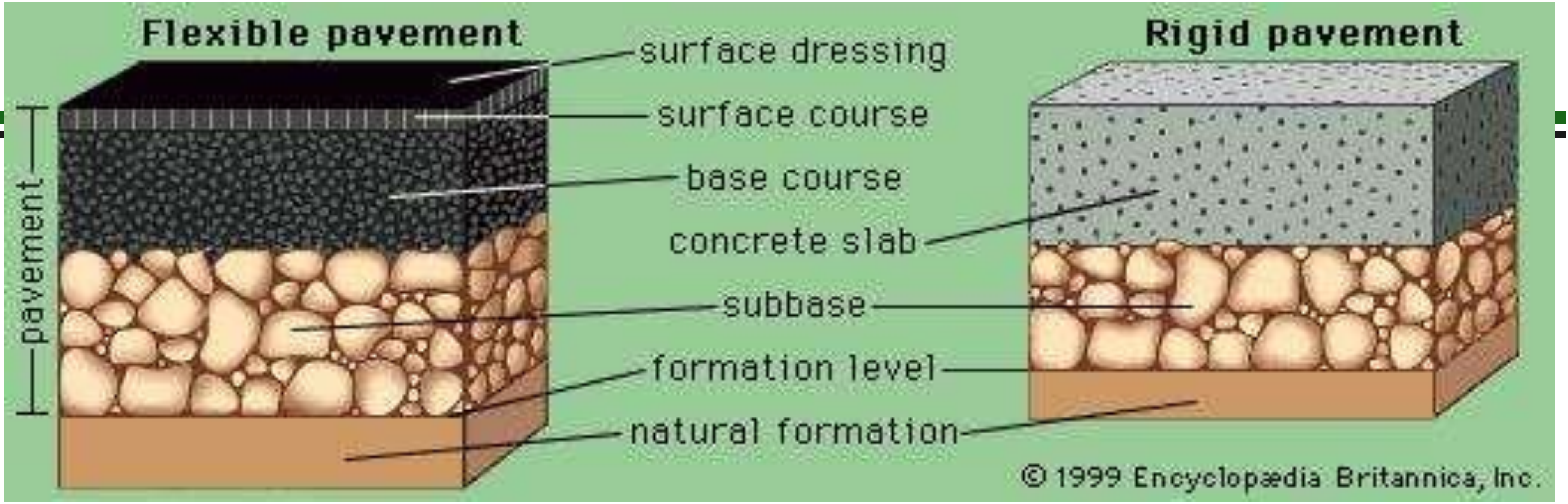
Like all life-cycle and supply chain problems, we need to understand the technologies involved, the project-level data, and the expected trends:

- Roadways versus pavements
- Life cycle
- Design
- Material selection
- Material sourcing and supply chains
- Pavement management systems
- Pavement–vehicle interactions

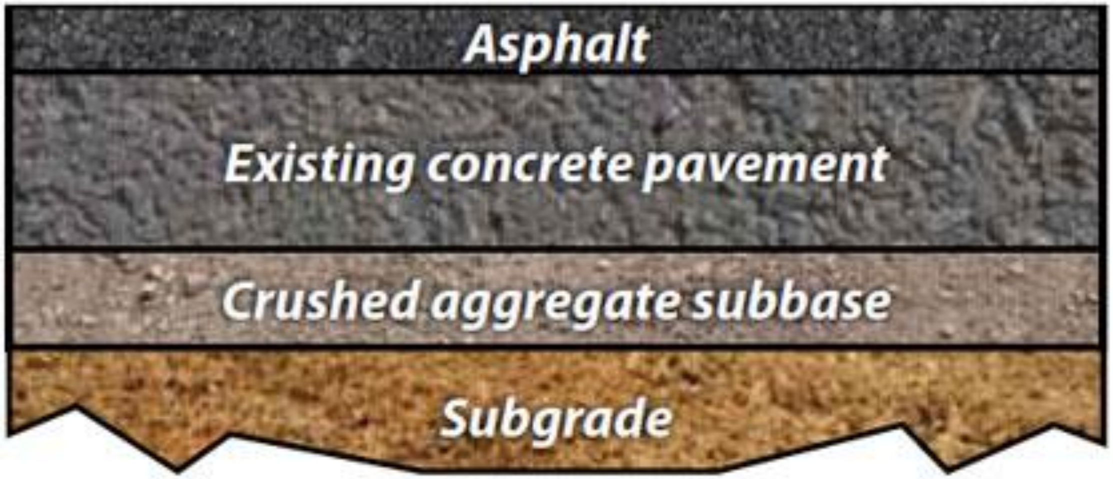
Understanding Life-cycle Effects



Asphalt v. Concrete v. Composite Roadways



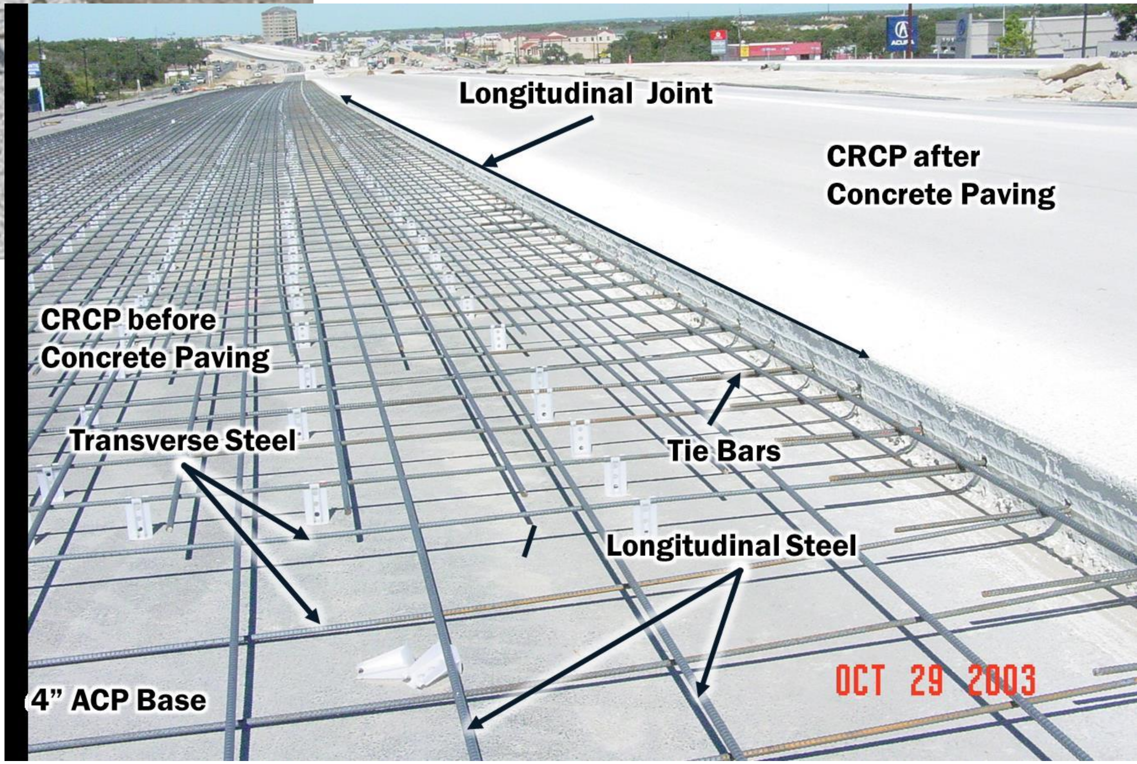
>90% of US pavements are asphalt



https://www.britannica.com/technology/road/The-modern-road; 3/02/18

http://www.cts.umn.edu/Publications/catalyst/2013/march/pavements

Concrete Pavement Design Differences

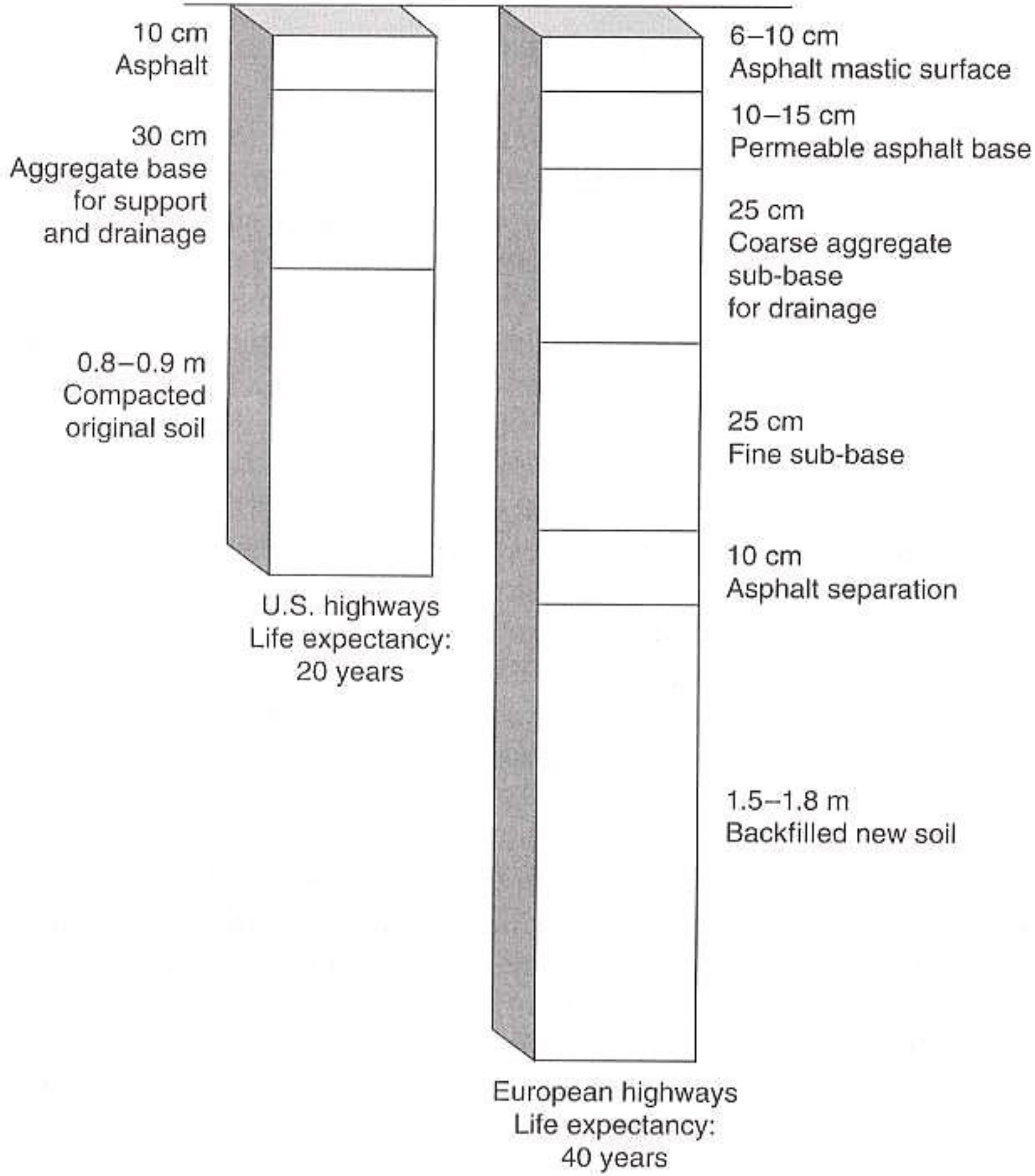


https://engineering.purdue.edu/JTRP/Highlights/reducing-joint-spacing-for-high-performance-concrete-pavement; 3/02/18

http://onlinemanuals.txdot.gov/txdotmanuals/pdm/rigid_pave_design.htm; 3/02/18

Evolving Pavement Technologies

- Use of supplementary cementitious materials (chiefly fly ash) in place of cement
- Warm-mix asphalt
- Asphalt recycling technologies
  - Hot in-place recycling
  - Hot-mix plant recycling
  - Cold in-place recycling
- Concrete recycling technologies
  - » Crushing old pavements into aggregates
  - » Carbonation
- Maintenance
- Transportation



Typical Design for Roadways in the U.S. and Europe

Graedel & Allenby, "Industrial Ecology and the Automobile." Prentice-Hall, 1998, p. 67

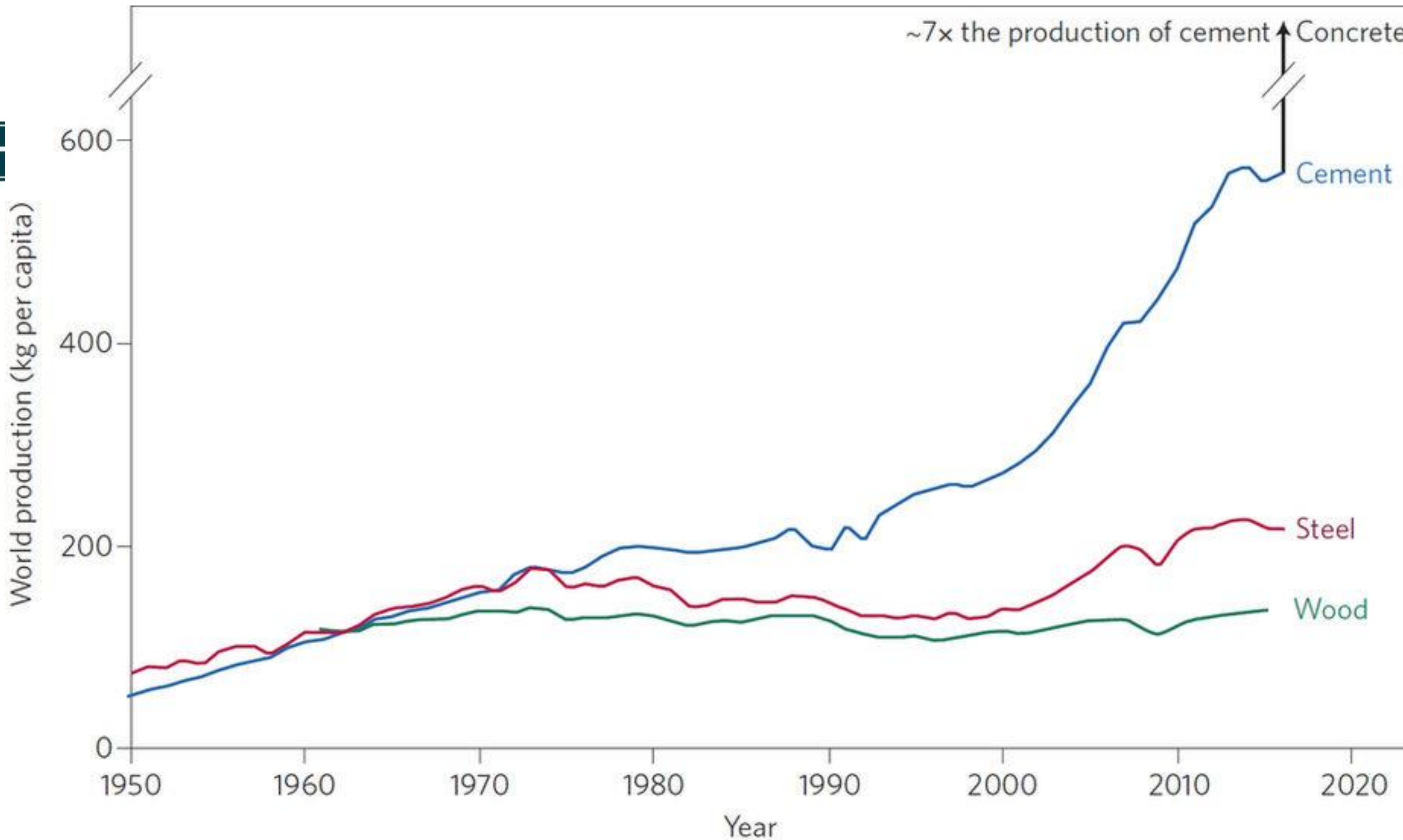
Great Variability in Design

Table 1
Goal and scope variations as function of the assessed region.

Region	Study reference	Functional unit (FU)	Lane width (m)	Shoulder width (m)[a]	Thickness (cm)[b]	Roadway type	Type and number of pavement			Analyzed period (years)
							Conventional concrete	Asphalt	Other	
North America										
Colorado	(Liu et al., 2014)	1 km lane of a four lane road	–	3.66, 3.05	33, 20.3	Interstate highway	2	1	–	40
Illinois	(Aurangzeb et al., 2014)	1 Mile lane of a road	–	1.8	30.5	–	–	4	–	45
Missouri	(Noshadravan et al., 2013)	Not mentioned	3.6	3.6	28, 34.3	Interstate highway	1	1	–	50
Michigan	(Zhang et al., 2010; Qian et al., 2013)	10 km of a 4 lane road	3.6	1.2, 2.7	17.5, 19, 10	Interstate highway	1	1	1[c]	40
California	(Wang et al., 2012)	4 different FUs[d]	–	–	–	Interstate highway	2	2	–	5 (asphalt); 10 (concrete)
Virginia	(Santos et al., 2014a)	5.89 km long of a two lane road	3.6	0.6–0.9, 2.4–3	30	Interstate highway	–	2	–	50
USA	(Chen et al., 2015)	1 km of a two lane road	3.6	1.2, 2.7	17.8–30.5, 10.2–27.9	–	8	6	–	40
British Columbia	(Reza et al., 2013)	Access to 400 acres residential area that will provide 2310 residential units	3.4	1.5	10	–	–	2	–	50
Europe										
Italy	(Celauro et al., 2015)	1 km of a two-lane road	3.5	1.25	20	Rural carriageway	–	9	–	30
Portugal	(Santos et al., 2014b)	1 km of 6 two lanes road	3.75	1.5, 3	10–32	Interurban motorway	–	6	–	40
Spain	(Vidal et al., 2013)	1 km of a two lanes road	–[e]	–	8	–	–	4	–	40
Rest of the world	(Araújo et al., 2014)	1 km of a two-lane road	3.5	1	20–22	–	–	4	–	20
Total							14	42	1	–

[a] In case of two digits, the first one belongs to inner shoulder.
[b] In case of more than one digit, the order of thickness is similar to the type of pavement.
[c] refers to engineered cementitious composite.
[d] Two of the FUs include 10 miles length of two lanes road with 34,000 and 86,000 annual average daily traffic with 35 and 25% truck traffic, respectively. The other FUs consist of 5 miles length of two and four lanes roads and supporting 3200 and 11,000 annual average daily traffic, which include 15 and 29% truck traffic, respectively.
[e] Total road width including lanes and shoulders were implicitly mentioned 13 m.

AzariJafari, H., Yahia, A. and Ben Amor, M. (2016) "Life Cycle Assessment of Pavements: Reviewing Research Challenges and Opportunities." *J. of Cleaner Production*, 112, 2187-2197.

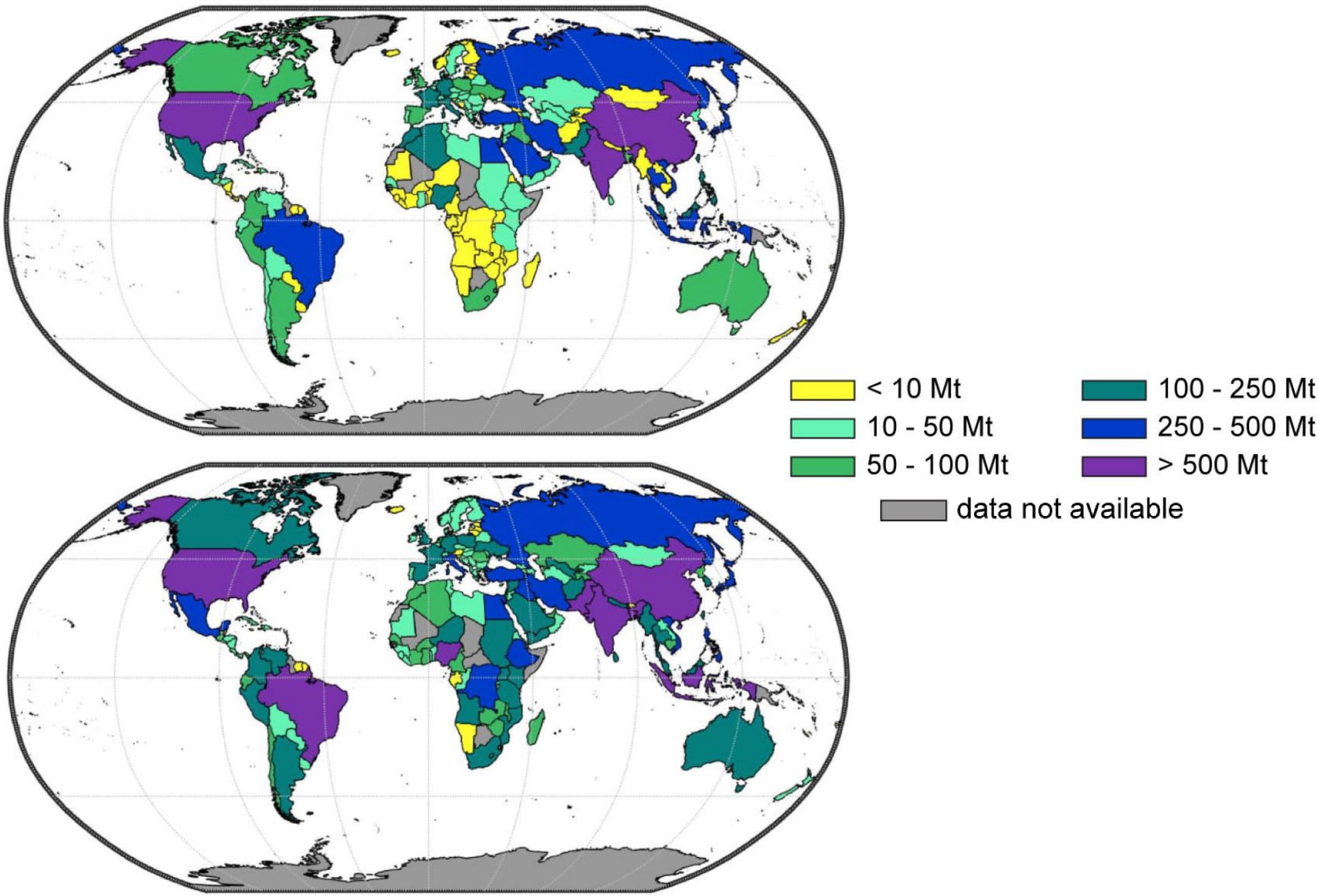


Monteiro, P. J. M., Miller, S. A. and Horvath, A. (2017) “Towards Sustainable Concrete.” *Nature Materials*, 16(1), 698-699.

Concrete Production Globally

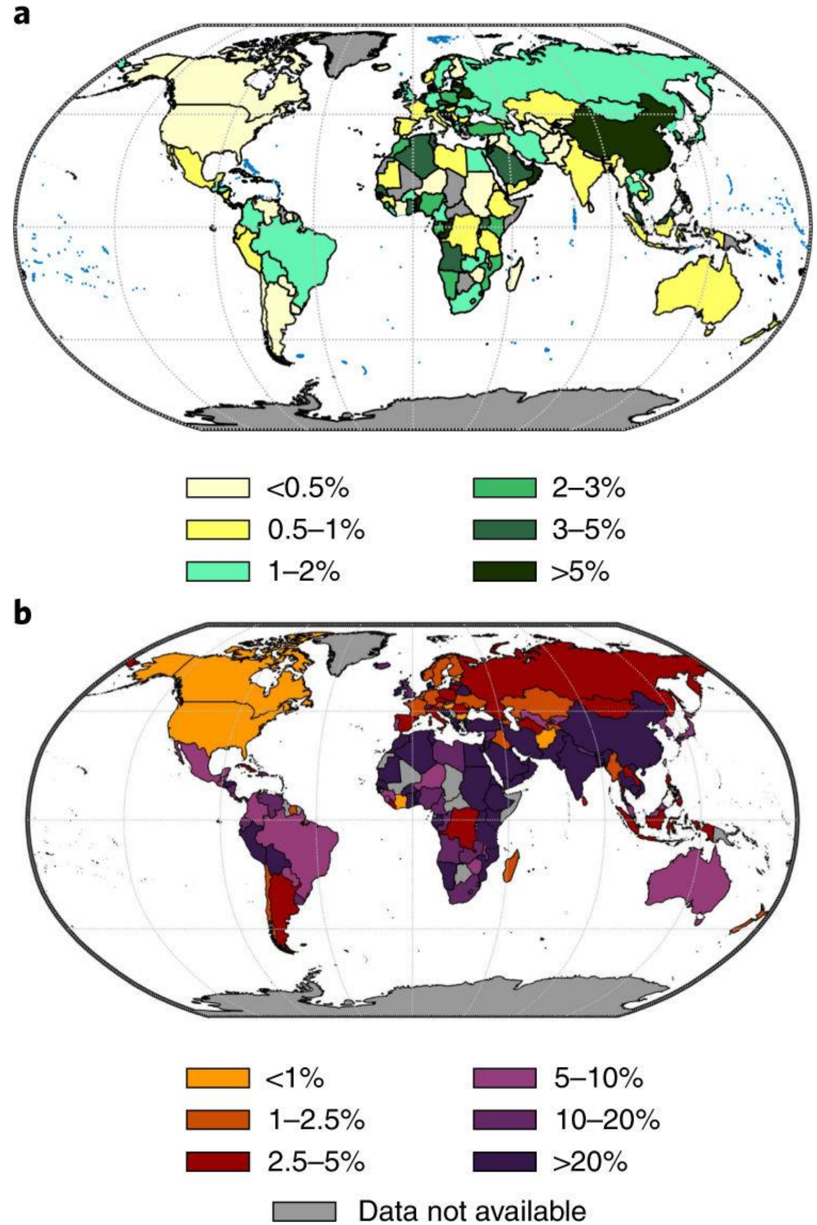
2012

2050



Miller, S. A., Horvath A., Monteiro, P. J. M. (2018) “Impacts of Booming Concrete Production on Water Resources Worldwide.” *Nature Sustainability*, 1, 69-76.

Water withdrawal for the production of concrete to total water withdrawal (**a**) and industrial water withdrawal (**b**)



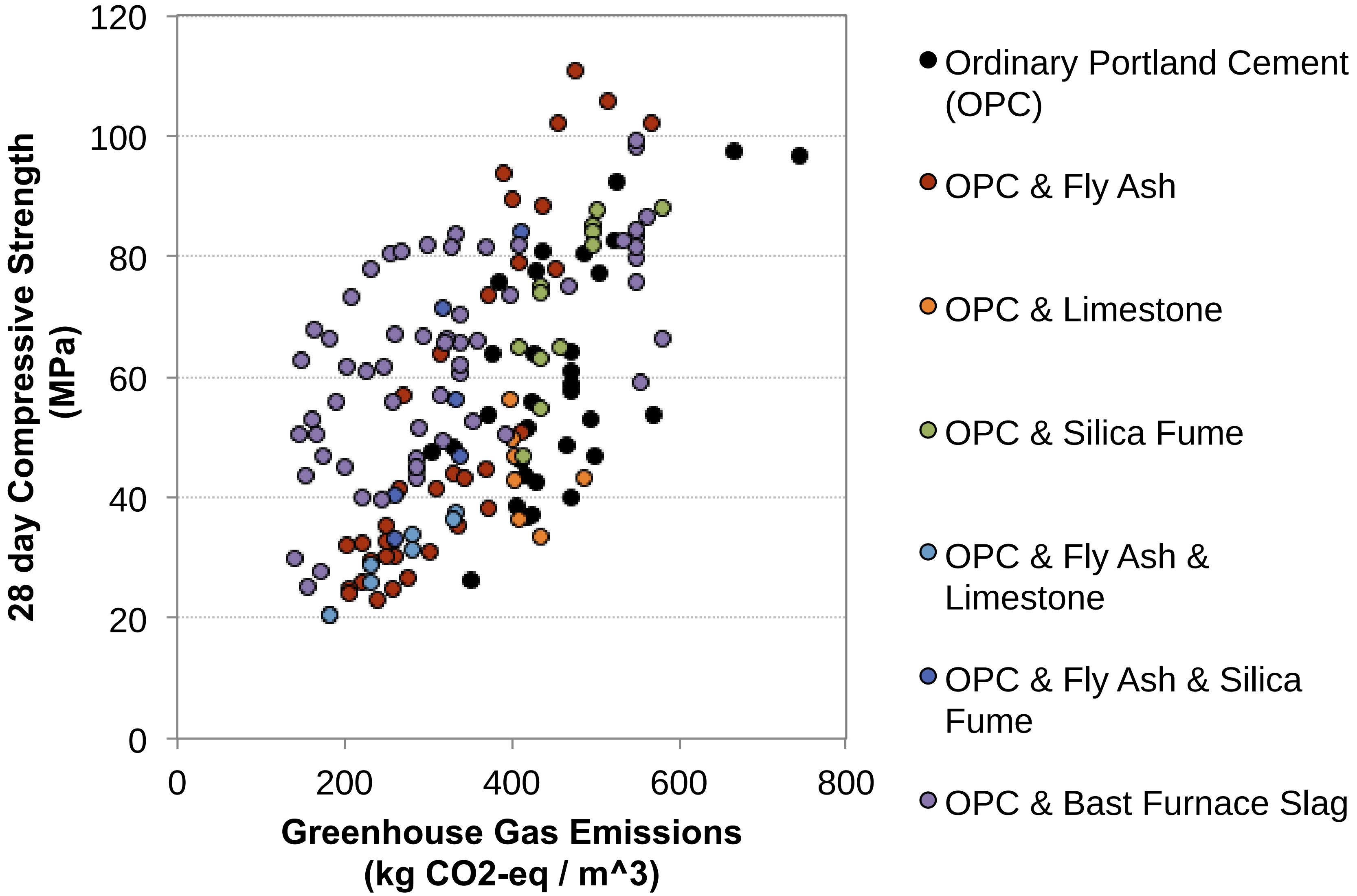
Miller, S. A., Horvath A., Monteiro, P. J. M. (2018) “Impacts of Booming Concrete Production on Water Resources Worldwide.” *Nature Sustainability*, 1, 69-76.

Revealed: Qatar in new quagmire as an unlikely natural resource runs out

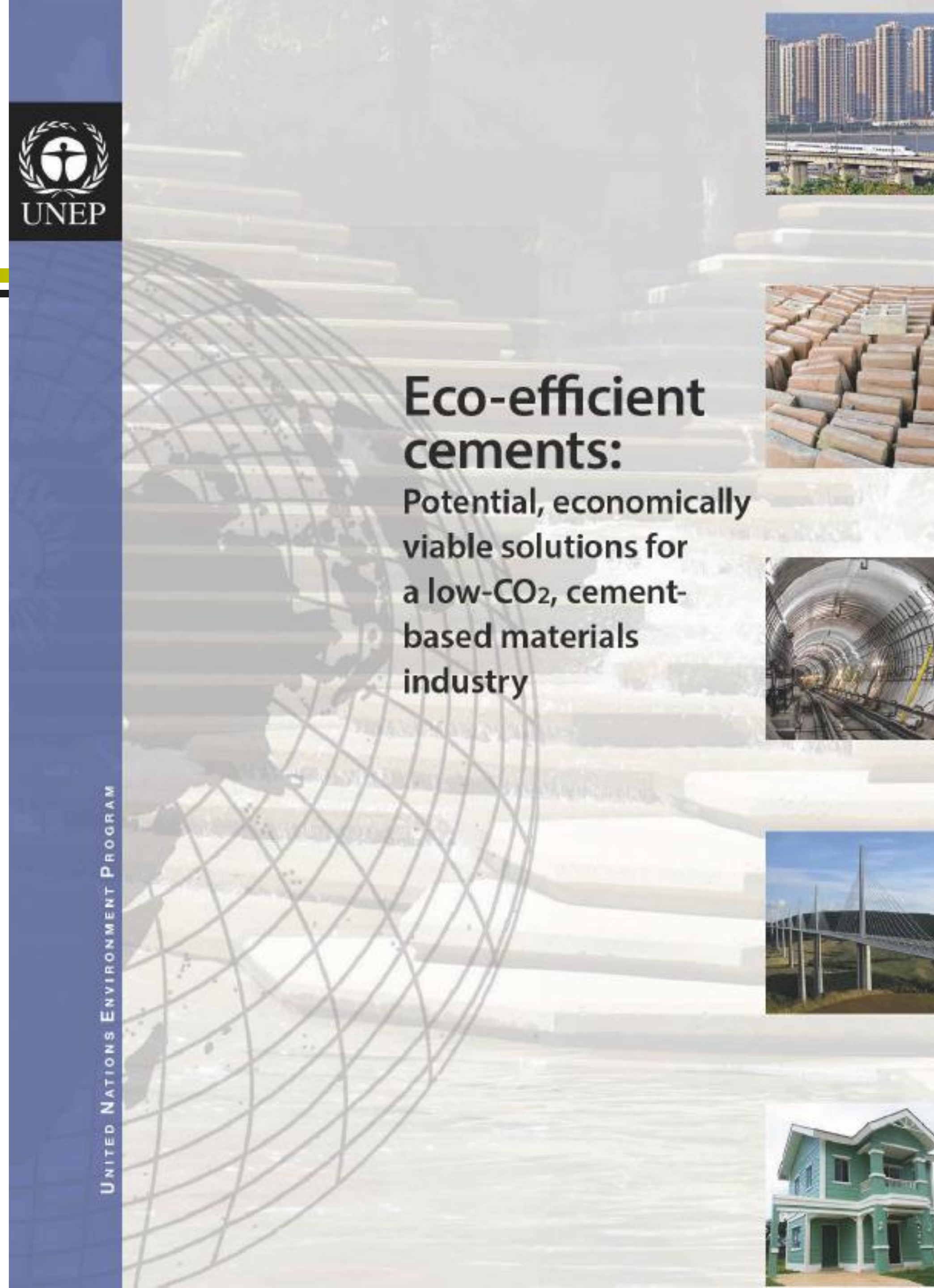
Qatar has built up significant stockpiles of sand and other construction materials but, it is unclear how much sand Qatar has. (Shutterstock)

http://english.alarabiya.net/en/features/2017/11/29/Revealed-Qatar-s-race-against-time-as-it-runs-out-of-an-unlikely-commodity.html

Comparison Indices: Strength vs. Global Warming Potential



Miller, S. A., Monteiro, P. J. M., Ostertag, C. P. & Horvath, A. *Comparison Indices for Design of Concrete taking Environmental Impacts into Account*, Cement and Concrete Composites (2016), **68,** 131-143.

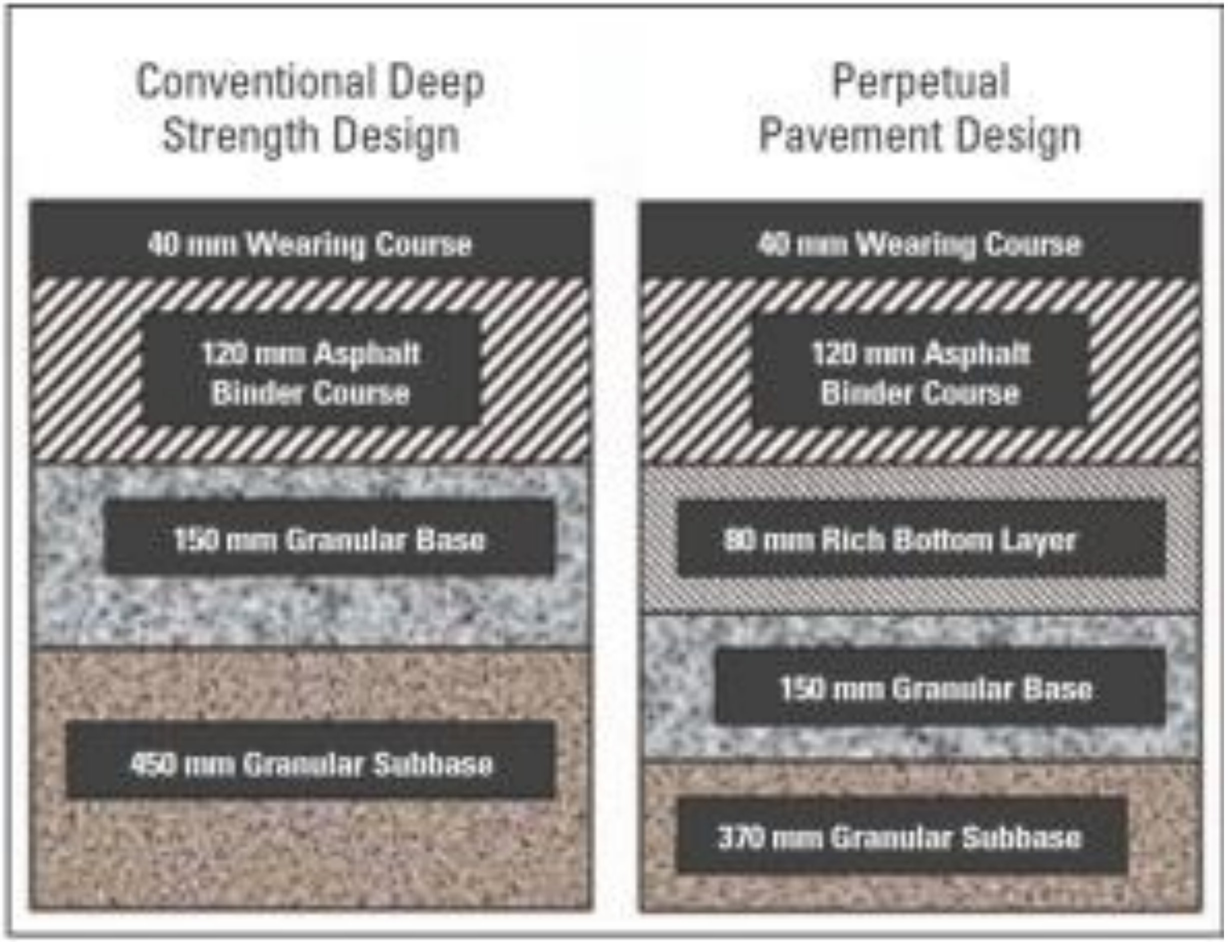


https://lmc.epfl.ch/files/content/users/184559/files/2016-UNEP%20Report-Complete6.pdf

Pavement Management Systems

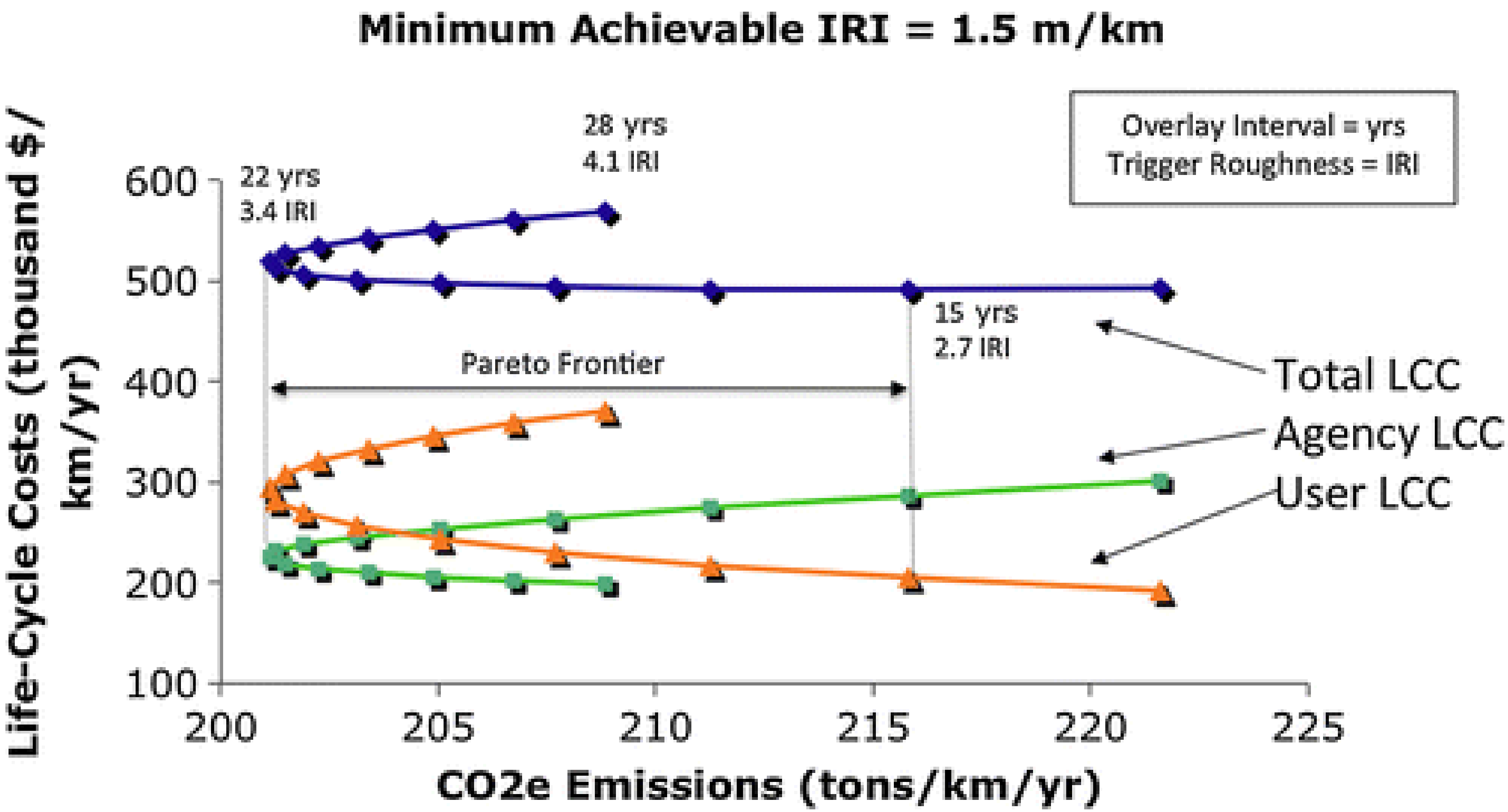
- Pavement management systems are maturing in term of:
  - » Measuring service
  - » Planning over long periods of time, over multiple cycles
  - » Allocating money
  - » Seeing pavements as a component of societal environmental strategies
  - » Decision-support tools (e.g., for environmental assessment *PaLATE* – Pavement Life-cycle Assessment Tool for Environmental and Economic Effects**;** contact A. Horvath)
  - » Available case studies for validation

Designing "Perpetual" Asphalt Pavements

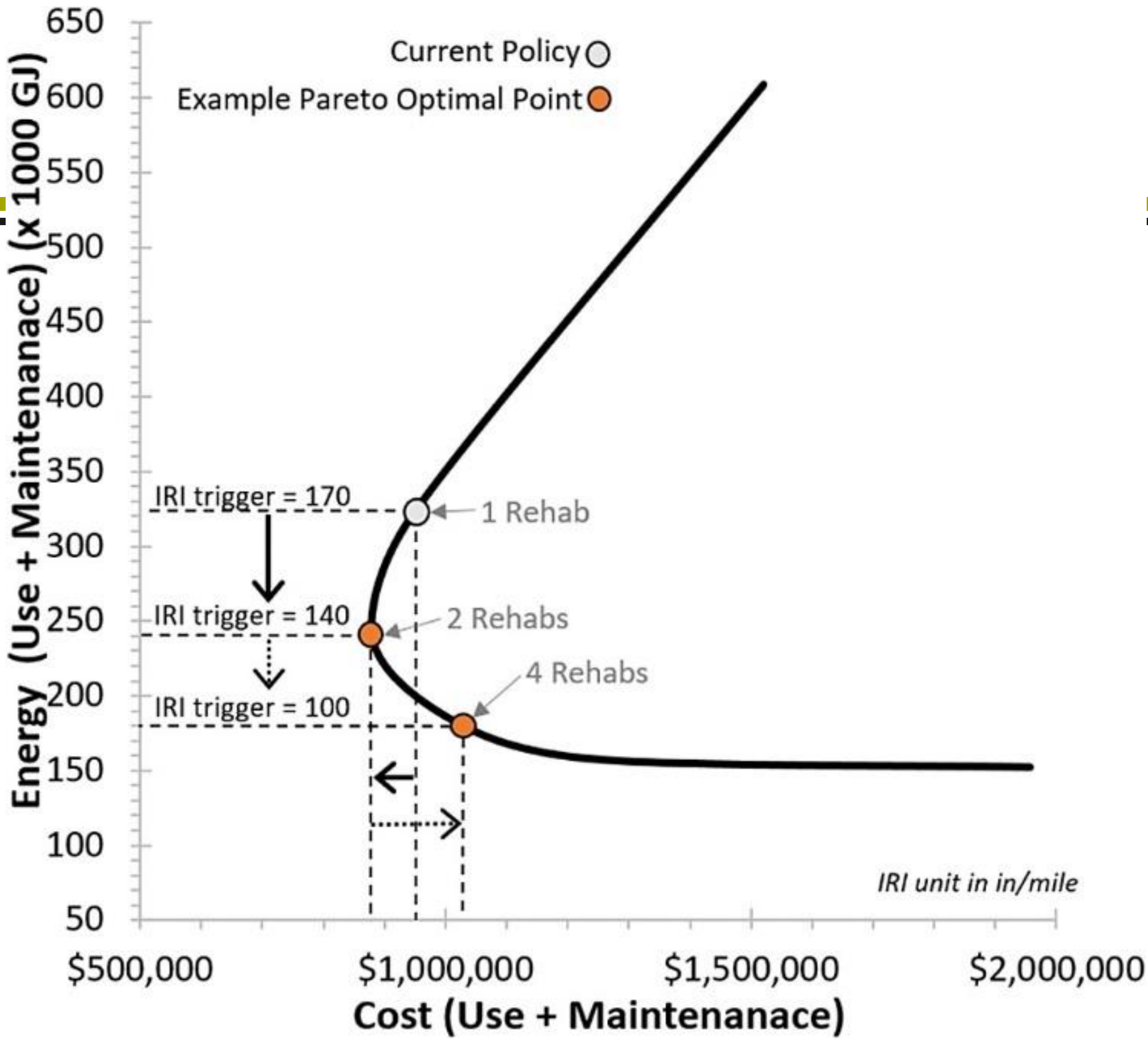


https://www.canadianconsultingengineer.com/features/perpetual-pavement/; 3/03/18

How Often Should We Replace Pavements?



Lidicker, J. Sathaye, N., Madanat, S. and Horvath, A. (2013) "Pavement Resurfacing Policy for Minimization of Life-Cycle Costs and Greenhouse Gas Emissions." *J. of Infrastructure Systems*, 19(2), 129-137.



Ziyadi, M., Ozer, H., Kang, S. and Al-Qadi, I. L. (2018) "Vehicle Energy Consumption and A n Environmental Impact Calculation Model for the Transportation Infrastructure Systems." *J. of Cleaner Production*, 174, 424-436.

Increase in Trucking and Load Consolidation

- Worldwide increase in trucking
- Increased maximum weight limits
- Increase in load for a given axle causes exponential pavement damage
- 4th Power Law: The damage caused by a particular load is related to the load by a power of four.

Source: American Association of State Highway and Transportation Officials (1993) *AASHTO Guide for Design of Pavement Structures*

- Freight consolidation centers
- Consequences need to be better understood. See, e.g.,:

Sathaye N., Horvath A. and Madanat S. (2010), "Unintended impacts of increased truck loads on pavement supply-chain emissions." *Transportation Research Part A*, 44, 1-15.

www.epa.gov 10/04/14

http://img.wikinut.com/img/1bkcp4u8uvcpceh_/jpeg/0/Commercial-Trucks-On-The-Road.jpeg/ 10/04/14

Other Drivers

- Permeable asphalt pavements
- Carbonation
- Albedo