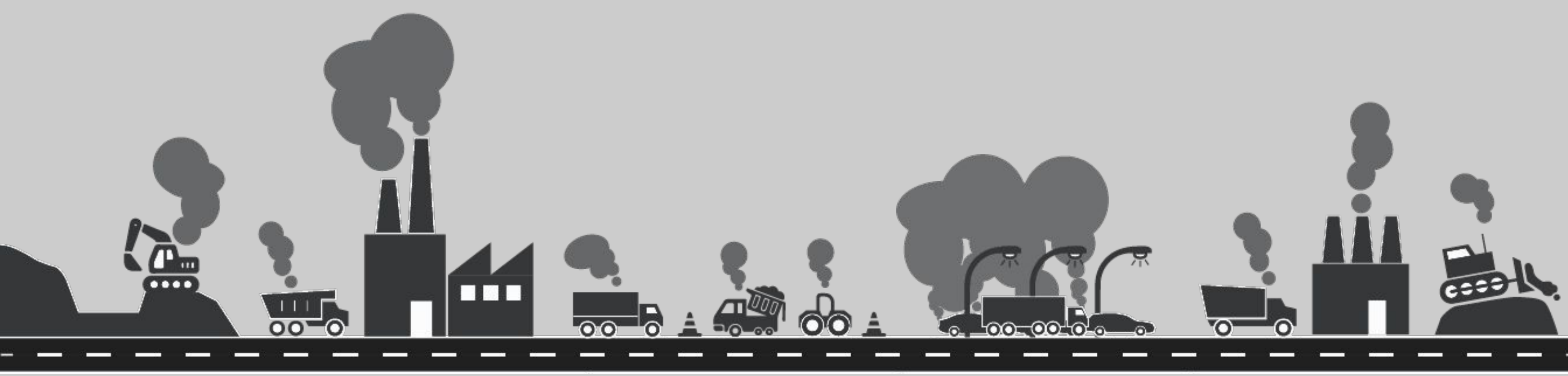
PART III:

Strategies to Reduce Embodied Carbon in Roadway Infrastructure



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Embodied Carbon Toolkit For Roadway Infrastructure

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Strategies to Reduce Embodied Carbon in Roadway Infrastructure

Roadway infrastructure results in significant ***embodied carbon***, the greenhouse gas (GHG) emissions released due to the extraction and manufacturing of materials and all other processes necessary to build and maintain the infrastructure. Parts I and II of this toolkit describe why embodied carbon is critical to address and how to account for roadway embodied carbon. This toolkit provides an overview of strategies for reducing embodied carbon in roadways.

Existing and proposed roadway carbon reduction strategies can be broken into several broad categories:

1. **Project design and delivery strategies:** Early design and planning decisions at project level that prioritize carbon reduction -among other sustainability metrics- as a goal.
2. **Specifications, contracting, and procurement strategies:** Stakeholder level strategies that encourage, incentivize, or mandate the use of low carbon materials.
3. Emissions reduction strategies categorized according to LCA stage:
    - **Material production strategies** (A1-A3): Practices to extract, manufacture, and produce materials with lower upstream embodied carbon.
    - **Construction activities strategies** (A4-A5): Practices that reduce fossil fuel consumption from on and off road equipment and improve construction quality.
    - **Use phase and end-of-life strategies** (B and C): Practices that maintain roadway performance during lifecycle and sustainable waste management practices.

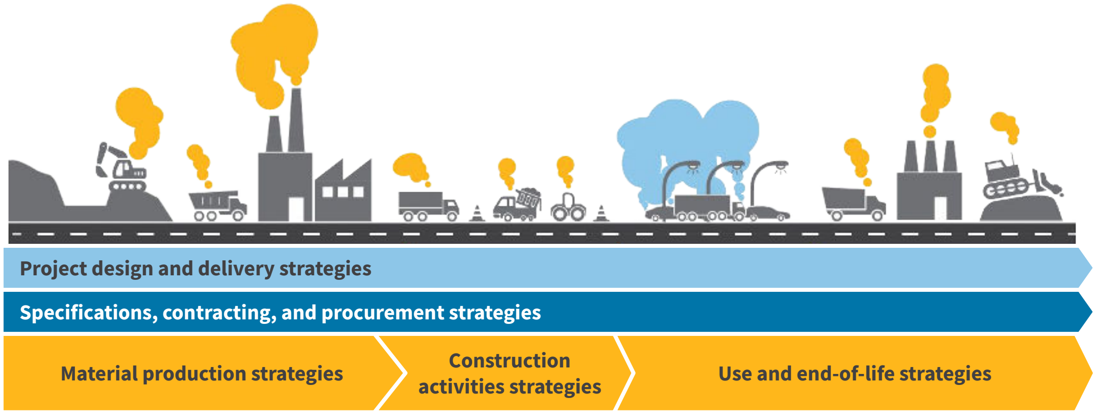

Figure 1. Existing and proposed roadway carbon reduction strategies can be broken into several broad categories that together present opportunities to reduce embodied carbon across the entire life cycle of roadways. *Graphic Credit: Meghan Lewis. © Carbon Leadership Forum*

Agencies and other stakeholders should consider embodied and operational carbon reduction strategies in conjunction with other roadway goals related to, e.g., financial (e.g., life cycle cost,) environmental (e.g., biodiversity,) and social (e.g., justice, health) aspects.

A four-step recipe for carbon reduction

A successful carbon reduction strategy for a transportation agency (and potentially any other agency) is an iterative process that may involve four steps described on the following page.[1] However, depending on agency goals and capacities, these steps can be modified, expanded, and even become a more linear process.

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1 Tracy J. *Quantifying and Reducing Greenhouse Gas Emissions from Local Government Cement and Asphalt Purchasing Urban Design and Planning*. University of Washington; 2015.

Step 1: Establish embodied carbon inventories (baselining)

The first step in reducing embodied carbon is to measure it. An embodied carbon inventory that mimics the state of the practice in roadway construction acts as a baseline for evaluating the effectiveness of reduction strategies. Embodied carbon inventories can then be aggregated by roadway classification (i.e., whole roadway embodied carbon benchmarks) or by product type (i.e., material baselines.)

Step 2: Establish embodied carbon reduction targets

Goal setting is a crucial step in navigating carbon reduction strategies. Targets are key to alerting the public and all members of the team (e.g. engineers, builders, consultants) that embodied carbon is a priority. They can also ensure that discussions happen early enough in the process (e.g., during the planning stage of a project) to act on the strategies suggested below.[2] Globally, there is broad agreement that a net-zero carbon state by the year 2050 is necessary to prevent the catastrophic impacts of climate change.

Many organizations at the local or state level established their own reduction targets that are somewhat aligned with the globally accepted targets. For example, the state of Washington sets the following carbon reduction targets (RCW 70A.50):

- 45% below 2005 levels by 2030
- 70% below 2005 levels by 2040
- 95% below 2005 levels by 2050

Most transportation agencies have not yet established reduction targets tailored to address embodied carbon, but the establishment of embodied carbon reduction targets for roadways is an area of current research. For example, in 2023 the Carbon Leadership Forum conducted a comprehensive LCA study[3] for roadways owned and operated by the Washington State DOT (WSDOT) and developed proposed reduction targets that demonstrate that reductions at the order of magnitude of Washington's targets are feasible. Other states and agencies could perform similar studies that could substantiate individual reduction targets.

Step 3: Implement policies and measures

Once targets are established and reduction strategies developed, policies are needed to successfully implement. Implementing policies requires adjustments to technical specifications, training for roadway designers and builders, and balancing carbon reduction requirements with performance requirements and construction limitations.

Step 4: Monitor and verify progress

This step is to magnify that carbon reduction is an iterative process. That means the actions taken prior to this step should be monitored and tracked over time to modify baselines, verify progress in meeting reduction targets, continuously revise action plans, and update policies to reflect advancements in material production, construction practices, and the effectiveness of already implemented carbon reduction strategies. This way, the shortcomings within each step can be identified and addressed consistently and proactively.

Carbon reduction strategies

The following sections dive into proposed strategies to reduce embodied carbon. This toolkit focuses on embodied carbon reduction, and therefore does not cover every aspect of sustainable roadways. However, some strategies to reduce the operational carbon of roadways are included in cases where drawing a line between embodied and operational carbon is difficult. Most of these strategies are related to pavements, where research is more mature.

Moreover, this document does not cover *whether* to build a roadway: the assumption is that transportation studies have already taken place that justify and support the construction or maintenance of a roadway infrastructure. Rather, this toolkit provides recommendations on strategies to reduce embodied carbon for a decision that has already been drawn from a transportation planning and feasibility study justifying the construction of a road segment as opposed to the "do nothing" scenario (e.g., the U.S. Route 277.)

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The strategies in the following tables are categorized according to two factors:

1. **Impact on carbon reduction.** The strategies resulting in the largest reductions:
   - High impact strategies are listed first and are highlighted in blue.
2. **Technological, practical, and policy availability of strategies**
   - Widely available at the time of this writing
   - Feasible, but not yet widely implemented
   - Require further research

References to published journal articles and research reports used to summarize these strategies are included throughout. Financial cost implications of implementing these strategies are not considered in our categorization. However, some aspects of financial investments required to adopt strategies are considered when categorizing based on technological availability.

Project design and delivery strategies

Strategy	Description	Availability
Earthwork balance	Minimize cut and fill operations by balancing the quantities of excavated and embankment areas to reduce soil movement.[5,9]	Widely available
Use prefabricated elements	Manufacture certain components or sections of roadways off-site. Prefabricated elements reduce on-site energy use, are faster to install, and can use materials more efficiently.[5,6]	Widely available
Work zone traffic control	Design a work zone traffic control scheme that improves traffic operations and better informs users about road closures and detours.[9]	Widely available
On-site recycling and reuse	Evaluate design alternatives that reuse or recycle materials on-site. Examples are crack-and-seat and rubblization, full-depth reclamation (FDR), cold or hot in-place recycling (CIPR), and reusing existing milled asphalt or concrete pavements as sub-layers for new pavements.[11]	Widely available
Reduce material use	Design roadway alignments to minimize the amount of earthwork and construction materials. Design asphalt pavements with thinner layers while ensuring load-bearing and durability requirements and more frequent maintenance. Higher binder intensity in concrete can reduce paste volume.[4-8]	Widely available
Adaptive reuse of structures	Repurpose existing structures, such as bridges, for new transportation uses. For example, consider transforming an out of service bridge into multi-modal paths.[7,10]	Widely available
Perpetual pavement design	Consider high quality pavements (i.e., thicker top and sub layers with higher quality materials) for roadway sections with high traffic volume to avoid work zone traffic emissions due to maintenance activities.[11]	Widely available
Trenchless drainage rehabilitation	A method of repairing or replacing underground drainage systems that eliminates the requirement for open-cut surface excavation. Cured in-place pipe lining, slip lining, and fold and form methods are examples of trenchless drainage rehabilitation.[9]	Widely available
Permeable pavements	Permeable pavements allow water to infiltrate and reduce the need for extensive drainage infrastructure and materials used to build them.[11]	Widely available
Avoid overdesign	Mostly applicable to structural elements of roadways such as bridges, avoiding overdesign refers to more optimized design alternatives that use less materials.[4-8,10]	Feasible, but not yet widely implemented
Early team engagement	Include carbon reduction as one of the project goals.[7,9]	Feasible, but not yet widely implemented

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5 Karlsson I, Rootzén J, Johnsson F. Reaching net-zero carbon emissions in construction supply chains – Analysis of a Swedish road construction project. *Renew Sustain Energy Rev*. 2020;120:109651. doi:10.1016/j.rser.2019.109651

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Specifications, contracting, and procurement strategies

Strategy	More information	Availability
Require rating system certifications	Require third-party rating system certifications on roadway construction projects. Rating systems provide guidelines and incentives for more sustainable designs. INVEST, Envision, and Greenroads are example rating systems that offer certifications in the U.S.[9]	✓
Require EPDs and establish GWP limits	EPDs provide a snapshot of the carbon footprint of materials and products. Requiring EPDs for primary materials such as asphalt, concrete, and steel helps collect sufficient information to eventually establish limits on embodied carbon.[7,10]	✓
Integrate sustainable procurement rules	This could include requirements on EnergyStar products, recycled content of products, energy from renewable energy in materials manufacturing, bio-based materials, and alternative fuels for vehicles.[7,9,10]	✓
Green procurement policies	The establishment of green procurement policies, often referred to as Buy Clean, is an important tool for delivering low carbon construction materials and construction practices.[7,9,10]	✓
Best-value procurement (BVP)	Select contractors or suppliers based on a combination of factors beyond the lowest bid price. This approach attempts to balance cost-effectiveness with other factors such as sustainability, innovation, and long-term performance.[7,9]	✓
Establish embodied carbon inventories	Collect and report material quantities and properties used in projects (e.g., ton of asphalt or cubic yard of concrete with their mix designs) in the form of a database, and perform life cycle assessment to create embodied carbon inventory databases. This will help establish embodied carbon baselines.[7]	✓
Higher in-place density specifications	Typical in-place densities range from 91 to 92 %. An increase to 93 to 94% is possible using a combination of methods (e.g., more rollers/passes, higher asphalt content, more consistent paving, etc.) and it is shown to improve long-term pavement performance.[9,12]	✓
Contractor Training	Training programs targeted at carbon reduction strategies and approaches would help increase awareness of and participation in decarbonization pathways efforts by contractors.[9,10]	✓
Pavement smoothness specifications	*[Operational carbon strategy:]* Provide incentives and disincentives for smoothness of newly constructed pavements.[9,11]	✓
Performance incentives	Encourage procurement practices by providing monetary incentives (e.g., by applying pay factors similar to those for smoothness and density) that use lower carbon materials.[7,9]	✓
Performance-based specifications	Incorporate performance-based metrics into pavement mix design as an alternative to traditional volumetric designs. For example, balanced mix design for asphalt.[7]	✓

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Material production strategies (A1-A3 stages)

Strategy	More information	Availability
General strategies		
Cleaner fuel in plants	Promote the transition from fossil fuels to cleaner energy sources (e.g., natural gas, renewable natural gas, hydrogen, bio-fuels, and full electrification) in material production facilities including asphalt and concrete plants.[4,6,7,10,11,13,14]	🔍
Carbon capture, utilization, and storage (CCUS)	Although the technology is not available for widespread implementation, CCUS can potentially reduce GHG emissions due to the manufacturing of asphalt binder, clinker, and steel.[4,5,7,10,11,13,14]	🔍
Asphalt materials		
Asphalt recycling	Allow and encourage higher reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) in asphalt mixes while ensuring durability.[5,11,14-18]	✔
Cold-mix asphalt	Use emulsified asphalt which is in a liquid state at room temperature to produce asphalt mixtures. This will eliminate the need for high heat to melt regular asphalt.[5,11,14]	✔
New and modified asphalt materials	Use polymer modifiers to enhance the properties of asphalt binder. Consider using a new generation of bio-based asphalt binders. Using recycled plastic in asphalt binder is another area undergoing research.[4,5,11,14,17]	🔍
Warm mix asphalt	The use of warm mix asphalt (WMA) technologies reduces the heat required to produce hot mix asphalt.[4,5,11,14,16,17]	✔
Stockpile management	The use of stockpile covers prevents excessive moisture content from entering aggregates and therefore reduces the heat required to dry aggregates.[5,14]	✔
Synthetic aggregates	These are produced by combining waste carbon dioxide with calcium which is also typically sourced from waste products. The primary type is synthetic limestone aggregate.[4,5]	🔍
Concrete materials		
Alternative and supplementary cementitious materials (SCMs)	SCMs reduce the need for portland cement production. Fly ash (a by-product of coal combustion), microsilica and silica fume (by-products of silicon metal), ground granulated blast furnace slag (GGBFS; a by-product of iron production), pozzolans (e.g., volcanic ash and glass), portland limestone cement (PLC or Type IL cement), and limestone calcinated clay cement (LC3) are among the most commonly used and cited cement alternatives or substitutes.[4,5,7,10,13,15,18]	✔
Recycled concrete materials	Although not suitable for use in new asphalt or concrete mixtures, RCMs can be used as a fill or backfill material, embankment, or pavement sublayers.[5,7,10]	✔
Steel materials		
Purchase low carbon steel	Use steel product EPDs to identify low carbon alternatives for use in your project. There are several carbon reduction strategies already being implemented by the steel manufacturing industry (e.g., using hydrogen as steel reduction agent, top gas recycling, recycled reinforcement steel, etc.) to produce low carbon products.[5,11,13,15,19,20,21]	✔

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Construction activities strategies (A4-A5 stages)

Strategy	More information	Availability
Transport to site (A4) emissions		
Local materials	Encouraging the use of local material supplies not only can stimulate local economic growth but also reduces fuel consumption by trucks. Incentives can be in place to reward projects that use locally sourced materials based on minimum limits.[5]	
Optimize material transportation	Practices that minimize fuel consumption by trucks per quantity of materials. For example, double cycling of hot mix asphalt and reclaimed asphalt pavement can result in reduced total fuel consumption; in that, same trucks can be used to deliver HMA from plants to job sites and deliver RAP back to the plant instead of returning unloaded.[5]	
Construction and installation (A5) emissions		
Accelerated construction	Reduce construction time to reduce user delay and fuel consumption of vehicles. More applicable to bridge construction by using prefabricated structural elements.[9]	
Full road closure	Closing an entire roadway (one or two directions) to improve worker productivity and reduce construction time. This will result in reduced work zone traffic and tailpipe emissions from vehicles.[9]	
Alternative fuels	Transition to cleaner fuel requirements for on and off-road equipment.[5-7]	
Workzone connectivity	Leverage digital and communication technologies to create a more connected and informed construction work zone in order to reduce traffic queue due to construction activities.[9]	
Ground improvement	Techniques to improve ground conditions for pavement construction and thus improving service life. Example techniques are deep compaction, grouting, and reinforced soil structures.[9]	
Automated grade control in paving	Use hybrid laser-GPS systems that are capable of controlling paving and milling grades with high precision. This would help minimize the use of new materials.[9]	
Vehicle idling policy	Limit engine idling for trucks and construction equipment on-site. Although many states have regulations in place that limit idling, federal laws are non-existent.[18]	

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Use phase and end-of-life strategies (B and C stages)

Strategy	More information	Availability
Use phase (B) emissions reduction strategies		
Optimize pavement maintenance	Leverage pavement management system databases and advanced data analysis methods to predict and then trigger maintenance activities for pavements that minimizes the need for new materials.[11]	✓ (blue)
Improved roughness	The rolling resistance of pavements when interacting with tires results in more fuel consumption from vehicles. Conduct a whole life carbon assessment on pavements and select material alternatives and maintenance frequencies that maintain roughness within acceptable ranges.[11]	✓ (yellow)
Roadway lighting	*[Operational carbon strategy:]* A Full transition to LEDs for roadway lighting can save operational energy.[16]	✓ (blue)
Reduce the urban heat island effect	*[Operational carbon strategy:]* There are design and material selection strategies that help reduce the urban heat island effect. This is mainly an issue in metropolitan areas with high population density. Example strategies are: the use of light-colored surface materials or coatings (concrete is a better alternative than asphalt), permeable pavements, reduce hardscape by improving green infrastructure, among others.[11]	✓ (blue)
End-of-life (C) emissions reduction strategies		
Minimize transportation at the end-of-life	Use the same material delivery trucks to return demolished materials to recycling facilities to cut transportation-related fuel consumption.	✓ (blue)
Leverage carbon uptake	Concrete sequesters a limited amount of CO_2 during its curing process if the temperature and moisture content are above certain levels. Spreading demolished concrete over land after being crushed offers a higher carbonation rate and can be considered as an alternative to landfilling.[11]	🔍
Site recycling and waste management plan	Develop site recycling and waste management plans that outline how waste materials will be managed, recycled, and disposed of throughout the project's life cycle (i.e., circular economy concept). These documents should set recycling and landfill diversion goals.[7,10,11,18]	✓ (blue)
Design for deconstruction / disassembly	Less common for roadways. Some applications in concrete pavement blocks and precast concrete panels.[9]	✓ (yellow)

Read more: carbonleadershipforum.org/clf-roadway-infrastructure-toolkit

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