Background: Evaluation Framework Development

DECEMBER 2025

Our evaluation framework draws on the conceptual pathways and criteria from the technology and adoption readiness level tools developed by the Department of Energy (DOE) and other agencies as well as the lifecycle analysis (LCA) framework and the whole building lifecycle analysis (WBLCA) approach.

Lifecycle Assessment Framework and Whole Building Lifecycle Approach

An LCA is a systematic assessment of the environmental impact of a product, material or process over the course of its entire life cycle in adherence with International Standards Organization Standards and Frameworks (ISO 2006b, 2006c). It evaluates carbon dioxide and other greenhouse gas emissions across four life stages, A to D (see figure 1). Since data are rarely available across the entire lifecycle (Stages A-D -- cradle to cradle), the LCA typically focuses on the manufacturing contributions to embodied carbon (Stage A -- cradle to gate). An EPD reports the results of an LCA in a standardized format for a particular product. In some cases, the EPD may be verified by a third-party thereby validating the information being reported in the EPD. EPD data and LCA requirements are guided by Product Category Rules (PCR) which are established prior to developing the EPD. Principles and procedures for LCAs and Type III EPDs are in turn based on ISO standards (ISO 2006a, 2006b).

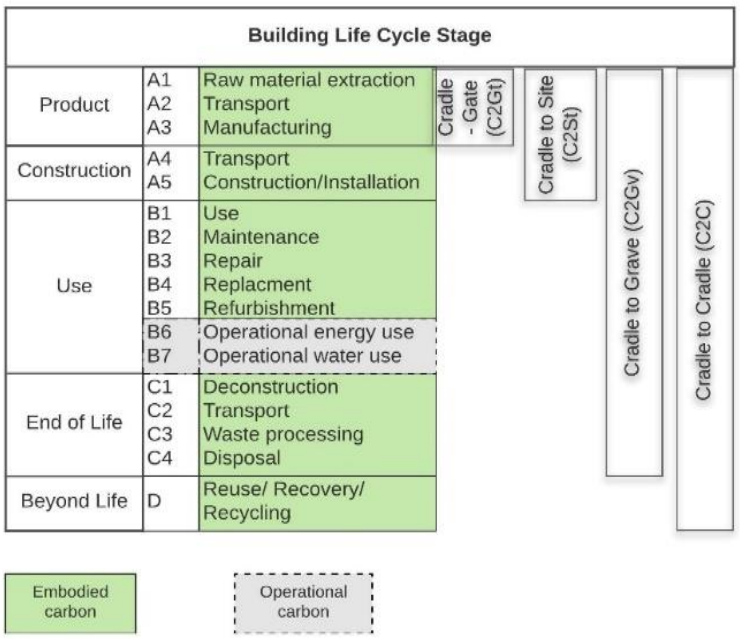

Figure 1. Building lifecycle embodied carbon. Source: Esram & Hu 2021 (adapted Pomponi & Moncaster 2016).

A more holistic approach should be applied to low-embodied-carbon materials to understand, measure, and validate lifecycle impacts of such materials within other contexts (besides those considered in the PCR and EPD development processes). WBLCA not only brings both embodied carbon and operational carbon into the evaluation but also illustrates the tradeoffs between the two. WBLCAs focus on the

whole building system, in which designers analyze the impact of material reuse, systems design (mechanical, electrical, plumbing), potential for carbon sequestration (construction materials absorbing CO_2 over its lifetime), operational versus embodied carbon, or other comparative designs for sustainability and efficiency. Some WBLCAs can also compare new construction versus retrofit of a building to help designers understand which path offers the least impact and is more efficient (IMPEL 2024).

Technology and Adoption Readiness Levels (TRLs/ARLs)

The **Technology Readiness Level (TRL) Framework** is used to assess the maturity of a new and evolving technology. Under this scheme a technology evolves through nine levels of maturity, starting with basic research (TRL 1-2) then culminating in deployment or commercialization in the marketplace (TRL 8-9) (DOE 2015). To get to deployment, a technology must be completely de-risked, and each player in the value chain must have an economic value proposition to participate in the technology adoption process. Thus, evaluating an innovative technology solely based on its TRL is insufficient (DOE 2024).

Therefore, to assess the adoption risks of a technology and translate it into a 'readiness for adoption by the market' score, DOE's Office of Technology Transitions developed the **Adoption Readiness Level (ARL) Framework** to complement TRLs (see figure 2). The ARL scheme comprises four core risk areas and 17 dimensions namely: (1) value proposition including delivered cost, functional performance, ease of use/complexity; (2) market acceptance, demand maturity/market openness, market size, downstream value chain; (3) resource maturity, considering capital flow, project development, integration and management, infrastructure, manufacturing and supply chain, material sourcing and workforce; and (4) societal non-economic risks considering the regulatory and policy environment, permitting/siting, environmental and safety, and community perception (DOE 2024).

The TRL and ARL assessment schemes can be used complementarily to better understand the readiness of an innovative technology as seen in figure 2. As a technology moves from bottom to top and from left to right in the graph (based on technical, market and cost attributes), it is considered more ready for commercial deployment and use in the marketplace at scale in real world projects.

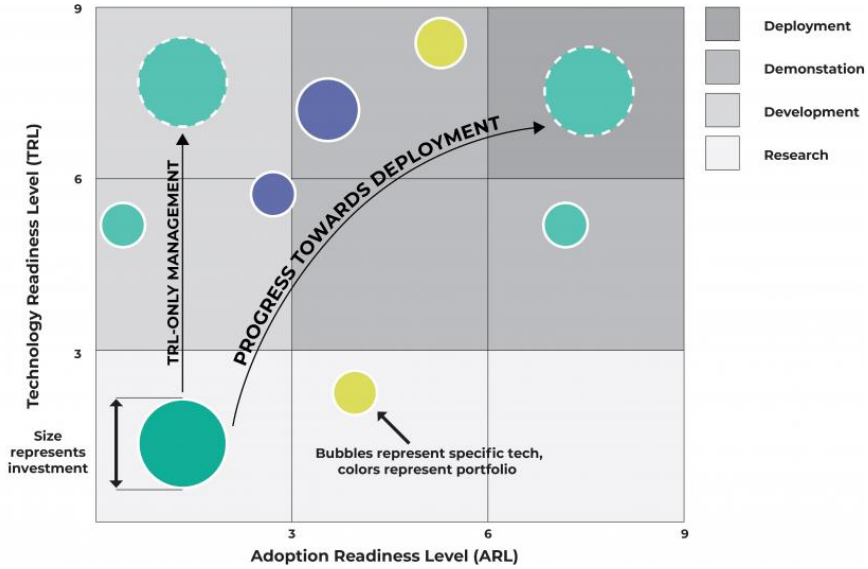

Figure 2. Combined TRL and ARL assessment matrix. Source: DOE 2024.

To learn more about our evaluation framework, please visit our website.

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