Evidence-based Practice Center Technical Brief Protocol

Project Title: *Healthcare Industry Waste and Lifecycle Assessment*

I. Background and Objectives for the Technical Brief

Clinicians are increasingly aware of the environmental impacts of healthcare processes and procedures, however the path to reducing that impact is often unclear or complex. Life cycle analysis (LCA) provides a pathway to evaluate products, processes, and procedures within a healthcare setting and to support evidence-based decision making. Drivers for adoption of LCA include comparison of single-use and reusable devices and evaluation of material efficiency in processes and procedures.[1-8] The framework for LCA is described in ISO 14040.[9] To assess the impacts associated with a procedure or process requires a detailed audit of the materials and methods used, in the form of a LCA conducted in accordance with ISO 14044.[10] The method explores the energy, water, environmental impacts associated with each phase of the raw material extraction, manufacturing, transportation, use, and end-of-life pathways. A system boundary is established to determine the variables in a product's life cycle that will be included in the analysis and what will be excluded, or outside the system boundary. The system boundary is defined by the scope of the LCA and may include the full life cycle of a product (cradle to grave) or a subset of the process (e.g., cradle to gate, gate to gate, or gate to grave). Cradle is defined as the raw material extraction phase of the product manufacturing. Gate is defined as the boundary of the specific module or process (e.g., include the impacts before a product leaves the factory gate). Grave describes the end-of-life phase of a product. A limitation in the analysis may be unknown associated impacts at various points from cradle to grave, and stages of the product life cycle therefore the scope of this technical brief will highlight the type of system boundary boundaries used in the healthcare studies might be limited to only a portion of the life cycle, such as LCA studies are often product- or facility-focused which can serve as a pathway to raise awareness about environmental impacts with a particular healthcare procedure or process.[11] However, facility-focused studies present limitations in that it is not always possible to replicate the same strategies to reduce impacts, due to the differences in products, policies, and procedures within each facility. In addition, LCA includes geographical contexts in the form of operational energy supply, and increasingly operational water supply, adding further challenges in comparison between facilities to support decision-making. The challenge remains on how to translate case-studies to sector-wide change, without regulation or standardized guidance.

Increasingly, commercial companies present their own life cycle analyses to market and promote adoption of their product. This can result in confusion in the decision-making process, as a facility may opt into a product due to the perceived financial and environmental benefits without knowledge of the broader clinical process in which the product is used. While industry data is necessary to understand the impacts associated

with a product's life cycle, third-party certified data is a preferred method to demonstrate transparent, comparable, and objective quantitative data.

Multiple drivers aid in decision-making within a healthcare system, including compliance with regulatory bodies, facility resources including staffing, individual preferences and behaviors. There is further need for policy and procedures for single-use and reusable devices, with established pathways for recycling.[12] In addition to environmental benefits and resource efficiency can lead to cost savings for a healthcare facility. Through LCA studies and evidence-based strategies, the health care sector can increase organizational commitment to sustainable practices.[13] Scientific barriers include the need to evaluate interventions to reduce waste and provide evidence of no impact or increased risk to patient safety. Non-scientific barriers include a lack of risk awareness, insufficient training in waste management, improper staffing and resources.[12] Embedded procedures within health care education translate into resource intensive practice, which leads to increased waste. Absence of national guidance leads to development and adaption of knowledge at local level,[14] which does not translate to system wide change.

Healthcare waste includes medical, biomedical, clinical, or facility waste, which is approximately one to two percent of total urban waste.[12] The majority of the waste generated (85%) is non-hazardous, whereas the remaining waste includes infectious, radioactive, or toxic healthcare waste.[12, 15] The healthcare waste management process is highly reliant on initial sorting and segregation of the waste, to ensure correct collection, transportation, storage, treatment, and disposal.[12] To maintain the level of quality, this process requires cohesion between multiple stakeholders, including, staff, waste management, administration, facilities operations.[12] Exposure risk extends across the use and end-of-life phases, including patients, healthcare and waste management staff, as well as the general public in cases where healthcare waste is not properly disposed.[12] Improper disposal of pharmaceutical waste is impacting drinking water, with antibiotics, hormone, non-steroidal anti-inflammatory, beta blockers, lipid regulators, and anti-depressant drugs the most prevalent pharmaceuticals found in the environment.[12, 16] There have been negative impacts to wildlife, as well as the development of environmental bacteria leading to evolution of antibiotic-resistant strains.[12] Microplastics have been found in human blood and lungs.[16, 17]

Understanding the full life cycle of a product or processes includes a clear understanding of the end-of-life pathways. Treatments of waste are used to disinfect and sterilize infectious and sharp waste.[12] Incineration of waste is used to remove hazardous waste and reduce the volume into ashes and gases, however the method includes exposure risk to staff if the operational requirements are not met.[1, 12] These are all energy intensive processes. Chemical treatment can also be used to breakdown waste.[12] While effective at sterilization of personal protective equipment and medical devices, the use of Ethylene Oxide is being reviewed by the U.S. Environmental Protection Agency to assess and limit the release of the air pollutant under the Clean Air Act, to reduce the airborne pollutant in the communities where reprocessing plants are located.[18, 19] Municipal solid waste, or non-hazardous waste is unregulated, with end-of-life pathways of recycling or landfill.[12, 16] Diversion of waste products includes composting and recycling as end-of-life pathways.[16] Limitations include that with patient information must be shredded to comply with HIPAA policies.

Reprocessing is another pathway, which reflects increased development of circular supply chains.[20] This includes reusable devices, which are collected and reprocessed, including sterilization and disinfection, before reuse.[16] Aversion is another methodology for reduction of waste, through improved procurement processes, including purchase of reusable products and medical devices, to reduce extraction of raw materials and contribution to waste streams.[16] Also reduction of unnecessary supplies, such as prepackaged surgical trays, which result in disposal of unused items, as well as economic loss.[16] Use of waste as an energy source is emerging, with pyrolysis of healthcare waste used to produce liquid fuels with properties similar to diesel, as well as organic waste (e.g., medical cotton) used to produce biogas,[12] and excess heat used in energy generation.[1]

For a life cycle assessment (LCA) study to be used to support policy and decision-making requires that the study is reliable and has addressed any variation in modelling parameters, methods, data collection and databases that may lead to uncertainty in the interpretation of the results.[21-26] Addressing uncertainty is particularly important when evaluating end-of-life pathways to support waste management decision-making. There are varying methods that can be used to evaluate uncertainty, including discernibility analysis, impact category relevance, overlap area of probability distributions, null hypothesis significance testing.[27] The gap in uncertainty analysis in health care LCA studies has been identified as a barrier for further comparison and replication of the studies.[11] Furthermore, assessment of uncertainty within the LCA is essential to accurately capture the multi-life cycles and material re-use[28, 29] through circular economy strategies and pathways.[28, 29]

Therefore, in addition to understanding the environmental impacts associated with a process, the analysis also must simultaneously evaluate the benefit and risk to patient care and safety.[14] The focus on patient safety has led to a rise in single-use devices and a planned obsolescence of reprocessed devices.[2] Single-use devices and equipment are often comprised of single-use plastics and their rising use is increasing waste generation.[12] In addition to the individual products and processes, some LCA studies have focused on organizational sustainability, with a lack of guidance at the practitioners' level.[16]

Performing a LCA and acting on the results requires considering the complex, multilevel nature of healthcare organizations and engaging with stakeholders both within and outside of the organization, including manufacturers, suppliers, clinicians, non-clinical administrative, facilities, and leadership personnel, waste disposal services, and government. Factors to consider within an organization or facility when identifying potential levers for change include clinical practice, supply purchasing, facility design and operation, and governance, standards, and policies.

This technical brief was commissioned by the Agency of Healthcare Research and Quality (AHRQ) Evidence-based Practice Center (EPC) Program, initiated by the AHRQ Climate Workgroup. The objective of this technical brief is to assess the current use of LCA frameworks in healthcare research and practice, understand the components of those frameworks, and assess gaps in research and practice to guide future directions.

II. Guiding Questions

The brief will be facilitated by guiding questions (GQs), documenting research and Key Informant input.

GQ1. Frameworks for Life Cycle Assessment (LCA)

- What LCA frameworks have been developed or adapted for healthcare settings, products, and procedures?
    i. What data sources, measures/indicators, and methods are used to inform these frameworks?
    ii. Which components of the frameworks are thought to have the greatest association with carbon footprint?
    iii. What limitations of these frameworks have been described?

GQ2. Studies of LCA

- How are LCAs applied in healthcare research?
    i. What topic areas have been studied and for what settings?
    ii. What data sources, measures/indicators, and methods were used in the analysis?
    iii. What outcomes have been studied, and what were the findings?
    iv. What were cited limitations of the research?

GQ3. Gaps in the knowledge and future research needs

- Are there frameworks that are being developed or have been developed but not yet implemented?
- What are possible areas of future research?

III. Methods

The methods for this technical brief will follow the Methods Guide for the Evidence-based Practice Center (EPC) Program. The guiding questions will help formulate the overarching methods and facilitate the search strategy for this technical brief, which are outlined in this protocol. This technical brief and answers to the guiding questions will be informed by interviews with key informants, grey literature searches, and published literature searches, as detailed below.

1. Data Collection:

A. Discussions with Key Informants

Key informant interviews will provide input on the state of the research and practice of LCA in healthcare. For this project we selected six scopes of interest (with the option of expanding to further content areas) for which we identified suitable representatives: LCA frameworks, operations, tools for healthcare organizations/providers, researchers, organizational policy, and medical technology industry.

For this technical brief, we will use the key informants as a source of information not yet captured in the scientific literature. We will seek the help of the key informants in

understanding the conceptual complexity of healthcare industry waste as well as practical support by asking for input to refine the guiding questions, the search strategy, and our suggested approach to document the findings in this technical brief. The planned questions are documented in Table 1.

Table 1 Potential Key Informant Questions

Topic	Question
Guiding questions	• To fully assess the current state of the science for this topic, are we asking the right questions? • Are we addressing the most important decisional dilemmas and knowledge gaps?
Current status	• Are there specific frameworks for LCAs in healthcare that you find most valuable and explain why you would recommend? • What is the contribution of LCAs to decarbonization of healthcare? • Are there any lessons learned from LCAs in other industries? • Are there specific institutions or organizations that you would highlight that are utilizing LCAs in healthcare? • What do you think is needed to advance the field of the use of LCA in healthcare? • How can LCAs be applied more broadly in healthcare, beyond a single study?
Barriers	• What are the barriers and/or challenges to conducting LCA in healthcare and applying results? • What are the major gaps in the research of LCAs in healthcare?
Search and sources	• Do you have any comments or additions to the search strategy? • Are there new sources of information and/or data? • Are there non-research/non-academic data sources that you use?
Analysis and result presentation	• Do you have any comments regarding the planned synthesis of the findings? • Do you have any suggestions on how best to organize the findings?

Abbreviations: LCA life cycle analysis

The key informant interviews will follow a semi-structured format. key informants interviews will be conducted as web conferences, and we will invite key informants to a small group meeting or individual interviews as their schedule allows. Key informant interviews will be documented during each call by a designated member of the project team. Notes will be reviewed and discussed by the investigators to evaluate how the input provides insight on the key questions.

The interviews will be supported by an online survey that informs KIs of our questions in advance and that will also give participants the opportunity to add information which may have been lost during the call. This procedure ensures that in the case of group interviews, all key informants feel heard and have the opportunity to provide their perspective to ensure that a few participants do not dominate discussions. The structured approach to questions will allow us to provide a systematic overview of responses.

B. Gray Literature Search

While the published research literature on LCA in healthcare is still limited in volume, there are multiple grey literature sources that need to be searched systematically to fully

explore the existing evidence base and applied use of LCA. A key resource we will explore is Healthcare LCA, a repository of existing healthcare LCAs and methods that is used by researchers and other audiences for literature searches and other purposes. We will also ask key informants whether they are aware of additional non-academic or non-research data sources that may be searched.

We will also search the research registries ClinicalTrials.gov, National Institutes of Health (NIH) RePORTER, Environmental Protection Agency (EPA) Health and Environmental Research Online (HERO), European Research Council projects, and the International Clinical Trials Registry Platform for ongoing research. We will review the proceedings of the 2023 CleanMed conference for ongoing research.

Finally, AHRQ will set up a portal for submissions of Supplemental Evidence And Data for Systematic Reviews (SEADS) and publish a notice on the Federal Register to encourage SEADS submissions.

C. Published Literature Search

We will search a combination of biomedical (PubMed), environmental (Agricultural & Environmental Science Collection; Environmental Science Database; Environment Index), and technical research (Web of Science, Scopus) databases as this is an interdisciplinary research topic. We will discuss the implications in more detail with the KIs, but we suggest searching databases without publication year restriction to get a complete overview of the existing literature. While the large majority of studies has been published fairly recently, considerations for sustainability have been published as early as 2005,[30, 31] in particular in Scandinavian countries. The frameworks and analyses appear comparable, and restricting searches further will miss foundational work.

We will also use existing systematic reviews to identify studies. However, not many research syntheses on the topic have been published to date and most include only a small number of studies.[11, 32-37] Nonetheless, we will systematically identify all existing reviews by searching PubMed using a systematic review filter, the Cochrane Database of Systematic Reviews, the repository of the Campbell Collaboration, and the review registry PROSPERO. We will document the existing reviews as a resource collection and add the studies included in the reviews to our database of primary research studies to gain a complete overview.

The draft search strategy for research databases is documented in the appendix. The search strategy will undergo peer review to ensure relevant resources for this technical brief are identified.

Table 2 below describes the eligibility criteria in a Population, Concept, Context, Other limiters framework.

Table 2. Criteria for Inclusion/Exclusion of Studies in the Review

Domain	Inclusion	Exclusion
Population	• GQ1: Publications that include a figure or detailed description of a life cycle assessment framework • GQ2: Publications that describe the methods and results of a life cycle assessment study • GQ3: Registered research of life cycle framework development or assessment	• Publications citing existing frameworks without further conceptual contribution to the framework and publications describing only the need or future plans of conducting a life cycle assessment
Concept	Life cycle assessments that address either scope 1, scope 2, scope 3 emissions. Scope 1: Direct emissions (facilities, anesthetics, fleet and leased vehicles), Scope 2: Indirect emissions (electricity, stream). Scope 3: Other indirect emissions (food and catering, business services, medical devices, medicines, water, metered-dose inhalers, energy [well-to-tank], business travel [public transit, gray fleet], staff commuting, manufacturing [products, chemicals, gases], waste, information technology, Health Care Organization (HCO) investments, construction, and freight transport) • GQ1: Frameworks for life cycle assessments, including logic models, analytic frameworks, or other conceptualization • GQ2: Published life cycle assessments, life cycle assessments do not need to meet ISO (International Organization for Standardization) 14040 standards but need to describe a goal, scope, and boundaries; assessment can describe partials or full cradle to grave cycles • GQ3: Ongoing research, development of frameworks and assessments	• Frameworks, assessments, ongoing research not including life cycle assessments
Context	• Healthcare: healthcare delivery organizations, health insurance, or manufacturers/suppliers that directly contribute to the delivery of healthcare (e.g., supply of personal protective equipment) including scope 1, scope 2, and scope 3 emissions	• Studies in contexts not specific to healthcare
Other limiter	• Information published in English-language journal manuscripts, trial records, and gray literature in the public domain from the outlined sources	• Data reported in abbreviated format (e.g., conference abstracts) will be excluded; systematic reviews will be retained for reference mining

Abbreviations: GQ guiding questions; HCO health care organization; ISO International Standards Organization

Literature searches targeted to each guiding question will be designed, executed, and documented by the EPC Medical Librarian. For databases, we will use controlled vocabulary where applicable as well as text words as not to miss newer studies not indexed yet. Searches will be conducted without date restriction.

Literature screening and data abstraction will be conducted in an online database designed for systematic reviews (DistillerSR). Literature reviewers will screen citations supported by machine learning. All citations that at least one reviewer determines to be potentially relevant to the Technical Brief will be obtained as full text. Full text studies will be screened by two independent reviewers against the explicit eligibility criteria; disagreements will be resolved by consensus. The literature searches will be updated

during the Peer Review process before finalization of the Technical Brief. Any identified data meeting the eligibility criteria will be incorporated into the final Technical Brief.

2. Data Organization and Presentation:

A. Information Management

We will abstract data from published studies, gray literature from the outlined sources, and online research registries using online software for literature reviews.

The technical brief will systematically identify frameworks that have been suggested in the context of healthcare (**GQ1**). This will include conceptual publications as well as empirical literature applying LCAs. We will broadly characterize the frameworks by described scope (e.g., cradle to grave). In addition, we will describe the frameworks in terms of components, suggested data sources, indicators informing the assessment, and applied methods and analyses. Frameworks are difficult to summarize, and we will use a combination of qualitative (e.g., type of components) and quantitative (e.g., complexity of the model) domains to provide a comprehensive and useful overview. We will abstract any information on the anticipated impact on carbon footprint and we will document the limitations of the frameworks noted by the authors. While a full critical appraisal of frameworks is beyond the scope of the technical brief, we will provide some information regarding the source (e.g., endorsement by a professional organization), stakeholder involvement in the development of the framework, evidence-based status (e.g., the components are based on empirical data), defined population (framework target described in detail), and validity testing status (e.g., goodness of fit assessed, applied in different contexts).[38, 39] Where publications depict a conceptual framework, analytic framework, or theoretical model visually, we will seek permission to include the model in an appendix as a resource. Many publications are now created under creative commons agreements and figures can be used with appropriate attribution. For others, publishers need to agree on the use of the figure, which sometimes comes with a small fee but is rarely denied.

GQ2 will analyze empirical LCA studies in the context of healthcare. LCAs have been applied in a range of healthcare areas - within and across healthcare delivery organizations, and within and across different healthcare disciplines (e.g., focused on surgical equipment specifically or personal protective equipment generally).[11, 32-37] We will abstract the study identifier and publication year together with contextual information such as the geographic region, healthcare setting, and discipline. It is critical to understand the context for the analyses, as circumstances are different in developed compared to developing countries and healthcare systems and existing mandates (e.g., UK vs US). We will broadly organize studies by healthcare discipline, building on categories established for the Healthcare LCA database. Furthermore, we will document existing studies by LCA scope. For this, we will establish a categorization system grounded in the identified literature and discussions with key informants. Our preliminary literature review indicates that most studies in healthcare focus on use in the healthcare facility. We will highlight any identified cradle to grave analyses and document the relative frequency of the different start and endpoints of the analyses employed in the studies. We will abstract the data sources, indicators, and analytic

methods employed in the study. We will document the outcomes and the author's conclusion. In addition, we will abstract any limitations the authors have reported.

For **GQ3** we will document ongoing research studies and identified gaps in research and implementation. We will abstract the study identifier and source, the type of project (e.g., framework development or assessment), the scope (e.g., cradle to grave lifecycle), and the expected completion date or stage of the framework development or assessment.

B. Data Presentation

We will document published frameworks, life cycle assessment publications, and registered ongoing research in concise evidence tables, accompanied by a narrative synthesis. The technical brief will provide a trend analysis showing the interest in LCAs over time.

The characteristics of the identified frameworks (**GQ1**) will be documented across studies, summarizing the abstracted data outlined above. Where publications depict a conceptual framework, analytic framework, or theoretical model visually, we will seek permission to include the model in an appendix as a resource. We will display figures created under creative commons agreements with appropriate attribution and ask publishers for permission to use the figure.

We will summarize the abstracted features of the identified LCAs (**GQ2**) in a summary of findings table and a narrative synthesis. We will summarize the expected research, stratified by type (framework, assessment), organized by scope (starting with cradle to grave LCAs), and highlighting research close to completion.

We will summarize forthcoming research (**GQ3**) and conduct a formal gap analysis to clearly outline the presence and absence of research for relevant topics. Using an evidence gap map format, we will pinpoint the most important lack of research. The analysis will be supported by the content experts and KI input to ensure that the lack of research represents research needs that need to be filled. We will use the established eligibility criteria framework to formulate recommendations for research. Research needs will be organized by domain (e.g., type of intervention, context) and will be sufficiently detailed for future research to advance the field.

The project data will be shared via SRDRPlus.

IV. References

1. Kumar V, Gaurav G, Khan V, et al. Life cycle assessment and its application in medical waste disposal. Materials Today: Proceedings. 2023. doi: 10.1016/j.matpr.2022.12.255.

2. Sherman JD, Hopf HW. Balancing Infection Control and Environmental Protection as a Matter of Patient Safety: The Case of Laryngoscope Handles. Anesth Analg. 2018 Aug;127(2):576-9. doi: 10.1213/ANE.0000000000002759. PMID: 29324490.

3. Gordon D. Sustainability in the Operating Room: Reducing Our Impact on the Planet. Anesthesiol Clin. 2020 Sep;38(3):679-92. doi: 10.1016/j.anclin.2020.06.006. PMID: 32792191.

4. Le NNT, Hernandez LV, Vakil N, et al. Environmental and health outcomes of single-use versus reusable duodenoscopes. Gastrointest Endosc. 2022 Dec;96(6):1002-8. doi: 10.1016/j.gie.2022.06.014. PMID: 35718068.

5. Hennein R, Goddard E, Sherman JD. Stakeholder perspectives on scaling up medical device reprocessing: A qualitative study. PLoS One. 2022;17(12):e0279808. doi: 10.1371/journal.pone.0279808. PMID: 36584081.

6. Kenters N, Tartari E, Hopman J, et al. Worldwide practices on flexible endoscope reprocessing. Antimicrob Resist Infect Control. 2018;7:153. doi: 10.1186/s13756-018-0446-6. PMID: 30564309.

7. Pang S, England RW, Solomon A, et al. Single-Use versus Reusable Endoscopes for Percutaneous Biliary Endoscopy with Lithotripsy: Technical Metrics, Clinical Outcomes, and Cost Comparison. J Vasc Interv Radiol. 2022 Apr;33(4):420-6. doi: 10.1016/j.jvir.2021.12.028. PMID: 34958859.

8. Bhutta MF. Our over-reliance on single-use equipment in the operating theatre is misguided, irrational and harming our planet. Ann R Coll Surg Engl. 2021 Nov;103(10):709-12. doi: 10.1308/rcsann.2021.0297. PMID: 34719955.

9. ISO 14040:2006. Environmental management — Life cycle assessment — Principles and framework. Switzerland: International Organization for Standardization; 2006. https://www.iso.org/standard/37456.html. Accessed on August 23, 2023.

10. ISO. ISO 14025:2006 Environmental labels and declarations — Type III environmental declarations — Principles and procedures. Zurich, Switzeland: International Standards Organization. 2006.

11. Drew J, Christie SD, Tyedmers P, et al. Operating in a Climate Crisis: A State-of-the-Science Review of Life Cycle Assessment within Surgical and Anesthetic Care. Environmental Health Perspectives. 2021;129(7):1-18. doi: 10.1289/EHP8666. PMID: 151964607.

12. Janik-Karpinska E, Brancaleoni R, Niemcewicz M, et al. Healthcare Waste-A Serious Problem for Global Health. Healthcare (Basel). 2023 Jan 13;11(2). doi: 10.3390/healthcare11020242. PMID: 36673610.

13. Osorio D, Ribera A, Solans-Domenech M, et al. Healthcare professionals' opinions, barriers and facilitators towards low-value clinical practices in the hospital setting. Gac Sanit. 2020 Sep-Oct;34(5):459-67. doi: 10.1016/j.gaceta.2018.11.007. PMID: 30745093.

14. Fournier KA, Dwyer PA, Vessey JA. De-adopting low-value care: The missing step in evidence-based practice? J Pediatr Nurs. 2023 Mar-Apr;69:71-6. doi: 10.1016/j.pedn.2022.12.020. PMID: 36669294.

15. World Health Organization. Health-care waste. February 8, 2018. https://www.who.int/news-room/fact-sheets/detail/health-care-waste. Accessed on May 15, 2023.

16. Schenk EC, Johnson S, Kelley-Gustafson B, et al. Nursing Waste Reduction for a Healthy Environment. Journal of Radiology Nursing. 2023;42:57-61. doi: 10.1016/j.jradnu.2022.12.008.

17. Jenner LC, Rotchell JM, Bennett RT, et al. Detection of microplastics in human lung tissue using muFTIR spectroscopy. Sci Total Environ. 2022 Jul 20;831:154907. doi: 10.1016/j.scitotenv.2022.154907. PMID: 35364151.

18. United States Environmental Protection Agency. Regulation of Ethylene Oxide (EtO) Under the Federal Insecticide, Fungicide, and Rodenticide Act. https://www.epa.gov/ingredients-used-pesticide-products/regulation-ethylene-oxide-eto-under-federal-insecticide. Accessed on May 16, 2023.

19. United States Environmental Protection Agency. FACT SHEET: EPA'S Proposal to Reduce Toxic Air Pollution from the Synthetic Organic Chemical Manufacturing Industry and the Polymers and Resins Industry: Overview https://www.epa.gov/ingredients-used-pesticide-products/regulation-ethylene-oxide-eto-under-federal-insecticide. Accessed on May 16, 2023.

20. MacNeill AJ, Hopf H, Khanuja A, et al. Transforming The Medical Device Industry: Road Map To A Circular Economy. Health Aff (Millwood). 2020 Dec;39(12):2088-97. PMID: 33284689.

21. Bamber N, Turner I, Arulnathan V, et al. Comparing sources and analysis of uncertainty in consequential and attributional life cycle assessment: review of current practice and recommendations. The International Journal of Life Cycle Assessment. 2020 2020/01/01;25(1):168-80. doi: 10.1007/s11367-019-01663-1.

22. Barahmand Z, Eikeland MS. Life Cycle Assessment under Uncertainty: A Scoping Review. In World

23. Björklund AE. Survey of approaches to improve reliability in lca. The International Journal of Life Cycle Assessment. 2002 2002/03/01;7(2):64-72. doi: 10.1007/BF02978849.

24. Guo M, Murphy RJ. LCA data quality: sensitivity and uncertainty analysis. Sci Total Environ. 2012 Oct 1;435-436:230-43. doi: 10.1016/j.scitotenv.2012.07.006. PMID: 22854094.

25. Magrassi F, Del Borghi A, Gallo M, et al. Optimal Planning of Sustainable Buildings: Integration of Life Cycle Assessment and Optimization in a Decision Support System (DSS). Energies. 2016;9(7):490. PMID: doi:10.3390/en9070490.

26. Wei W, Larrey-Lassalle P, Faure T, et al. How to conduct a proper sensitivity analysis in life cycle assessment: taking into account correlations within LCI data and interactions within the LCA calculation model. Environ Sci Technol. 2015 Jan 6;49(1):377-85. doi: 10.1021/es502128k. PMID: 25436503.

27. Mendoza Beltran A, Prado V, Font Vivanco D, et al. Quantified Uncertainties in Comparative Life Cycle Assessment: What Can Be Concluded? Environmental Science & Technology. 2018 2018/02/20;52(4):2152-61. doi: 10.1021/acs.est.7b06365.

28. Malabi Eberhardt LC, van Stijn A, Nygaard Rasmussen F, et al. Development of a Life Cycle Assessment Allocation Approach for Circular Economy in the Built Environment. Sustainability. 2020;12(22):9579. PMID: doi:10.3390/su12229579.

29. Matsuno Y, Adachi Y, Kondo Y. Application of Markov Chain Model to Calculate the Average Number of Times of Use of a Material in Society. An Allocation Methodology for Open-Loop Recycling. Part 1: Methodology Development (7 pp). The International Journal of Life Cycle Assessment. 2006 2006/09/01;11(5):354-60. doi: 10.1065/lca2006.05.246.1.

30. Karlsson M, Ohman DP. Material consumption in the healthcare sector: Strategies to reduce its impact on climate change - The case of Region Scania in South Sweden. Journal of Cleaner Production. 2005;13(10-11):1071-81. doi: 10.1016/j.jclepro.2004.12.012. PMID: WOS:000228788100011.

31. . Climate impact of material consumption in the health care sector - case study region scania. 4th International Symposium on Environmentally Conscious Design and Inverse Manufacturing (EcoDesign 05); 2005 Dec 12-14; Tokyo, JAPAN.

32. Pinho-Gomes AC, Yoo SH, Allen A, et al. Incorporating environmental and sustainability considerations into health technology assessment and clinical and public health guidelines: a scoping review. International Journal of Technology Assessment in Health Care. 2022 Dec;38(1). doi: 10.1017/s0266462322003282. PMID: WOS:000898498400001.

33. Keil M, Viere T, Helms K, et al. The impact of switching from single-use to reusable healthcare products: a transparency checklist and systematic review of life-cycle assessments. European Journal of Public Health. doi: 10.1093/eurpub/ckac174. PMID: WOS:000892005800001.

34. Shoham MA, Baker NM, Peterson ME, et al. The environmental impact of surgery: A systematic review. Surgery. 2022 Sep;172(3):897-905. doi: 10.1016/j.surg.2022.04.010. PMID: 35788282.

35. Perry H, Reeves N, Ansell J, et al. Innovations towards achieving environmentally sustainable operating theatres: A systematic review. Surgeon. 2023 Jun;21(3):141-51. doi: 10.1016/j.surge.2022.04.012. PMID: 35715311.

36. Seifert C, Koep L, Wolf P, et al. Life cycle assessment as decision support tool for environmental management in hospitals: A literature review. Health Care Manage Rev. 2021 Jan/Mar;46(1):12-24. doi: 10.1097/HMR.0000000000000248. PMID: 31116121.

37. Emara Y, Lehmann A, Siegert MW, et al. Modeling pharmaceutical emissions and their toxicity-related effects in life cycle assessment (LCA): A review. Integr Environ Assess Manag. 2019 Jan;15(1):6-18. doi: 10.1002/ieam.4100. PMID: 30242966.

38. Ferguson L, Gruskin S, Bolshakova M, et al. Frameworks and measures for HIV-related internalized stigma, stigma and discrimination in healthcare and in laws and policies: a systematic review. J Int AIDS Soc. 2022 Jul;25 Suppl 1(Suppl 1):e25915. doi: 10.1002/jia2.25915. PMID: 35818866.

39. Brunton G, Oliver S, Thomas J. Innovations in framework synthesis as a systematic review method. Res Synth Methods. 2020 May;11(3):316-30. doi: 10.1002/jrsm.1399. PMID: 32090479.

V. Definition of Terms

Acronym	Definition
AHRQ	Agency for Healthcare Research and Quality
EPA	Environmental Protection Agency
EPC	Evidence-based Practice Center
GQ	Guiding Questions
HERO	Health and Environmental Research Online
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
SEADS	Submit Supplemental Evidence and Data for Systematic Reviews

VI. Summary of Protocol Amendments

There are no amendments.

VII. Key Informants

Key Informants are the end users of research, including patients and caregivers, practicing clinicians, relevant professional and consumer organizations, purchasers of health care, and others with experience in making health care decisions. Within the EPC program, the Key Informant role is to provide input into the decisional dilemmas and help keep the focus on Key Questions that will inform healthcare decisions. The EPC solicits input from Key Informants when developing questions for the systematic review or when identifying high-priority research gaps and needed new research. Key Informants are not involved in analyzing the evidence or writing the report. They do not review the report, except as given the opportunity to do so through the peer or public review mechanism.

Key Informants must disclose any financial conflicts of interest greater than $5,000 and any other relevant business or professional conflicts of interest. Because of their role as end-users, individuals are invited to serve as Key Informants and those who present with potential conflicts may be retained. The AHRQ Task Order Officer (TOO) and the EPC work to balance, manage, or mitigate any potential conflicts of interest identified.

VIII. Peer Reviewers

Peer reviewers are invited to provide written comments on the draft report based on their clinical, content, or methodological expertise. The EPC considers all peer review comments on the draft report in preparation of the final report. Peer reviewers do not participate in writing or editing of the final report or other products. The final report does not necessarily represent the views of individual reviewers.

The EPC will complete a disposition of all peer review comments. The disposition of comments for systematic reviews and technical briefs will be published 3 months after the publication of the evidence report.

Potential peer reviewers must disclose any financial conflicts of interest greater than $5,000 and any other relevant business or professional conflicts of interest. Invited peer reviewers with any financial conflict of interest greater than $5,000 will be disqualified from peer review. Peer reviewers who disclose potential business or professional conflicts of interest can submit comments on draft reports through the public comment mechanism.

IX. EPC Team Disclosures

EPC core team members must disclose any financial conflicts of interest greater than $1,000 and any other relevant business or professional conflicts of interest. Related financial conflicts of interest that cumulatively total greater than $1,000 will usually disqualify EPC core team investigators.

X. Role of the Funder

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Appendix 1. Draft Search Strategy

PUBMED
Results – 3013

ALCA or BLCA or CLCA or DLCA or ICLA or LCAM or LCC OR LCSA or OLCA or O-LCA or PLCA or SLCA OR LCIA OR "ISO 14040" OR lifecycle OR "life cycle"
AND
Healthcare OR health care OR primary care OR practice OR hospital OR clinician OR physician OR doctor OR nurse OR medical care[Title/Abstract]
AND
Impact OR emissions OR carbon OR greenhouse OR environment* OR waste OR climate change OR (climate AND change)

EMBASE
Results – 421

(alca:ti,ab,kw OR blca:ti,ab,kw OR clca:ti,ab,kw OR dlca:ti,ab,kw OR icla:ti,ab,kw OR lcam:ti,ab,kw OR lcc:ti,ab,kw OR lcsa:ti,ab,kw OR olca:ti,ab,kw OR 'o lca':ti,ab,kw OR plca:ti,ab,kw OR slca:ti,ab,kw OR lcia:ti,ab,kw OR 'iso 14040':ti,ab,kw OR lifecycle:ti,ab,kw OR 'life cycle':ti,ab,kw)
AND
('health care delivery'/de OR 'medical care'/de OR healthcare:ti,ab,kw OR 'health care':ti,ab,kw OR 'primary care':ti,ab,kw OR hospital:ti,ab,kw OR clinician:ti,ab,kw OR physician:ti,ab,kw OR doctor:ti,ab,kw OR nurse:ti,ab,kw OR 'medical care':ti,ab,kw)
AND
(((environment* NEAR/4 (impact OR impacts)):ti,ab,kw) OR emissions:ti,ab,kw OR carbon:ti,ab,kw OR greenhouse:ti,ab,kw OR environment*:ti,ab,kw OR waste:ti,ab,kw OR 'climate change':ti,ab,kw OR (climate:ti,ab,kw AND change:ti,ab,kw))

Web of Science
Results – 731

Editions: ESCI, SCI-EXPANDED, SSCI

#1
TS=(ALCA or BLCA or CLCA or DLCA or ICLA or LCAM or LCC OR LCSA or OLCA or O-LCA or PLCA or SLCA OR LCIA OR "ISO 14040" OR lifecycle OR "life cycle")
#2
TS=(Healthcare OR "health care" OR "primary care" OR hospital OR clinician OR physician OR doctor OR nurse OR "medical care")
#3

TS=(environment* NEAR/4 Impact OR emissions OR carbon OR greenhouse OR environment* OR waste OR climate change OR (climate AND change))

#4
#1 AND #2 AND #3

SCOPUS
Results – 406

(TITLE-ABS-KEY (healthcare OR "health care" OR "primary
care" OR hospital OR clinician OR physician OR doctor OR nurse OR "medical care"))
AND
(TITLE-ABS-
KEY (emissions OR carbon OR greenhouse OR environment* OR waste OR climate A
ND change OR (climate AND change)))
AND
(TITLE-ABS-
KEY (alca OR blca OR clca OR dlca OR icla OR lcam OR lcc OR lcsa OR olca OR o-
lca OR plca OR slca OR lcia OR "iso 14040" OR lifecycle OR "life cycle"))

Agricultural & Environmental Science Collection (Proquest)
Results - 658

Limited by: Peer reviewed

noft(healthcare OR "health care" OR "primary care" OR hospital OR clinician OR physician OR doctor OR nurse OR "medical care") AND noft(emissions OR carbon OR greenhouse OR environment* OR waste OR climate AND change OR (climate AND change)) AND noft(alca OR blca OR clca OR dlca OR icla OR lcam OR lcc OR lcsa OR olca OR o-lca OR plca OR slca OR lcia OR "iso 14040" OR lifecycle OR "life cycle")

Environmental Science Database (Proquest)
Results – 228

Limited by: Peer reviewed

noft(healthcare OR "health care" OR "primary care" OR hospital OR clinician OR physician OR doctor OR nurse OR "medical care") AND noft(emissions OR carbon OR greenhouse OR environment* OR waste OR climate AND change OR (climate AND change)) AND noft(alca OR blca OR clca OR dlca OR icla OR lcam OR lcc OR lcsa OR olca OR o-lca OR plca OR slca OR lcia OR "iso 14040" OR lifecycle OR "life cycle")

Environment Index (EbscoHOST)
Results – 120

Filter: Academic Journals

TI ((healthcare OR "health care" OR "primary care" OR hospital OR clinician OR physician OR doctor OR nurse OR "medical care") OR AB ((healthcare OR "health care" OR "primary care" OR hospital OR clinician OR physician OR doctor OR nurse OR "medical care") OR SU ((healthcare OR "health care" OR "primary care" OR hospital OR clinician OR physician OR doctor OR nurse OR "medical care") OR KW ((healthcare OR "health care" OR "primary care" OR hospital OR clinician OR physician OR doctor OR nurse OR "medical care")
AND
emissions OR carbon OR greenhouse OR environment* OR waste OR climate AND change OR (climate AND change)) OR SU (emissions OR carbon OR greenhouse OR environment* OR waste OR climate AND change OR (climate AND change)) OR AB (emissions OR carbon OR greenhouse OR environment* OR waste OR climate AND change OR (climate AND change)) OR KW (emissions OR carbon OR greenhouse OR environment* OR waste OR climate AND change OR (climate AND change)
AND
alca OR blca OR clca OR dlca OR icla OR lcam OR lcc OR lcsa OR olca OR o-lca OR plca OR slca OR lcia OR "iso 14040" OR lifecycle OR "life cycle") OR SU (alca OR blca OR clca OR dlca OR icla OR lcam OR lcc OR lcsa OR olca OR o-lca OR plca OR slca OR lcia OR "iso 14040" OR lifecycle OR "life cycle") OR AB (alca OR blca OR clca OR dlca OR icla OR lcam OR lcc OR lcsa OR olca OR o-lca OR plca OR slca OR lcia OR "iso 14040" OR lifecycle OR "life cycle") OR KW (alca OR blca OR clca OR dlca OR icla OR lcam OR lcc OR lcsa OR olca OR o-lca OR plca OR slca OR lcia OR "iso 14040" OR lifecycle OR "life cycle"

Cochrane Database of Systematic Reviews (take out health terms)
Results - 3

#1
(ALCA or BLCA or CLCA or DLCA or ICLA or LCAM or LCC OR LCSA or OLCA or O-LCA or PLCA or SLCA OR LCIA OR "ISO 14040" OR lifecycle OR "life cycle"):ti,ab,kw (Word variations have been searched)
#2
(Impact OR emissions OR carbon OR greenhouse OR environment* OR waste OR "climate change" OR (climate AND change)):ti,ab,kw (Word variations have been searched)
#3
#1 AND #2

Campbell Collaboration
Results - 0

Tried *intext:*for both search strings (separately)

PROSPERO
Results – 9

(ALCA or BLCA or CLCA or DLCA or ICLA or LCAM or LCC OR LCSA or OLCA or O-LCA or PLCA or SLCA OR LCIA OR "ISO 14040" OR lifecycle OR "life cycle"):KW