Discussion Paper: Integrating Life Cycle Considerations in Alternatives Assessment Processes[1]

"Essentially, all models are wrong, but some are useful."

— George E. P. Box

Why consider life cycle in the context of alternatives assessment?

The first electric, household refrigerators used refrigerants, such as ammonia, that are acutely hazardous. Although consumers were unlikely to have direct contact with these chemicals in the course of owning and operating a refrigerator, the consequences of an accidental exposure (for example, as the result of puncturing a coolant line while scraping frost out of a fridge) could be severe. The use of ammonia and other common refrigerants presented a range of issues to manufacturers and consumers alike. Not surprisingly, the discovery that chlorofluorocarbons (CFCs) such as Freon® are good refrigerants, are very stable, are nonflammable, and have low acute toxicity led to their rapid deployment in commercial refrigerators. Many decades passed before scientists recognized that some of the attributes that conferred stability and low acute toxicity upon CFCs also made them potent destroyers of stratospheric ozone.

The use of CFCs as refrigerants and propellants is an iconic example of negative unintended consequences of chemical substitution when hazards across the life cycle of a chemical are not recognized or considered. Unfortunately, there is no dearth of other examples: PCBs as dielectric fluids in electrical transformers, methyl tertiary-butyl ether (MTBE) as an octane booster and oxygenate in gasoline, nonylphenol ethoxylate (NPE) surfactants in laundry and other detergents. The list goes on. In some cases, the then-state of the science arguably did not support the selection of better alternatives as, for example, the research on the ozone depleting potential of CFCs had not been conducted.[2] In other cases, unintended consequences may be attributable to the failure to take known attributes of chemicals into account. The first issue (lack of knowledge) is arguably more vexing than the second (lack of perspective), but various developments—including simple heuristics like *beware of very persistent chemicals*, the proliferation of *in vitro* toxicological assays and high-throughput screening, and the continued evolution of modeling techniques from structure-activity relationships to multi-compartment fate and transport models—offer some hope. The desire to avoid negative unintended consequences of chemical substitution due to lack of perspective has engendered the development of methods to reduce, if

[1] The Interstate Chemicals Clearinghouse (IC2) under the auspices of the Northeast Waste Management Officials' Association (NEWMOA) carried out this project for the Lowell Center for Sustainable Production at the University of Massachusetts at Lowell.

[2] Admittedly, the phrase "better alternatives" begs the question *better in what sense?* And the answer necessarily depends on the context: less toxic, less destructive of stratospheric ozone, less apt to partition into groundwater, etc. As the saying goes, hindsight is 20/20. The challenge underlying this project is learning to anticipate, in the course of AA, the ways in which alternatives to a chemical of concern may themselves be of concern in other contexts.

not eliminate, blind spots by structuring and systematizing chemical, material, or process selection. Life cycle assessment (LCA) and alternatives assessment (AA) are two such methods.

Although the term "life cycle assessment" was not coined until 1990, the methodology we now know as LCA has developed, over the last 40 years or so, to compare manufactured items, processes, and services across a broad range of impact categories and throughout their entire life cycles.[3] Alternatives Assessment (AA), on the other hand, is a process for identifying, comparing, and selecting safer alternatives to chemicals of concern (including those used in materials, processes, or technologies) on the basis of their hazards, performance, and economic viability.[4] The goal of AA is to avoid replacing a hazardous or toxic chemical with another of equal or greater concern—an outcome known in the alternatives assessment community as a *regrettable substitution*. While AA in its original and simplest form focuses on alternatives to a chemical of concern in a particular functional context, practitioners increasingly seek to avoid a broader set of negative consequences of chemical substitutions (e.g., "upstream" or "downstream" chemical impacts, resource depletion, or climate change) by incorporating life cycle considerations. However, a consensus regarding how best to integrate life cycle considerations into AA systematically and consistently has not yet emerged.

Tools can be described by what they are designed to do and not to do. To take a trivial example, a hammer can be described as a tool that pounds nails and as a tool that does not turn screws or cut wood. Similarly, alternatives assessment was developed as a tool to compare alternative chemicals in specific applications and across a limited set of "impact categories" (generally, hazard, cost, and performance), and not as a tool to compare items (chemicals, materials, multi-component manufactured products) across a much broader range of impact categories and throughout their entire life cycles. Life cycle assessment, on the other hand, was developed for just that purpose but was not designed to make detailed comparisons of the human and environmental health hazards of chemicals, materials, etc. The idea that one should use tools designed for each purpose suggests that one should use both AA and LCA to evaluate the different aspects of a chemical, material, product, or process; unfortunately, the often significant expense (in time, money, and expertise) required to perform an AA and LCA of even a single chemical makes this approach impractical for most organizations in most cases. Thus, the principal question underlying this project: *How can alternatives assessment integrate life cycle considerations without resorting to full life cycle assessment?*

The goal of this paper is to identify key questions and research needs pertinent to the role of life cycle considerations in alternatives assessment in order to guide the methodological development and practice of this science policy field.[5] This project was conceived and executed to advance this conversation within the growing alternatives assessment community of practice. Strengthening alternatives assessment by elucidating its approach to life cycle considerations

[3] http://www.gabi-software.com/international/news/news-detail/article/a-brief-history-of-life-cycle-assessment-lca/

[4] Given these descriptions, readers may be forgiven for not immediately apprehending the distinction between LCA and AA. Some key differences will be described below.

[5] While this paper focuses on chemical-for-chemical substitution, life cycle thinking is arguably as or more important in the context of material-for-chemical and material-for-material substitutions, because the scope of such assessments is likely to be wider.

will help advance the informed substitution of chemicals of concern with safer alternatives, thereby reducing the hazards associated with chemicals and materials in commerce.

In addition to discussions and contributions of the project Advisory Group[6], this paper builds on the work of the Interstate Chemicals Clearinghouse (IC2), State of California, National Academy of Sciences, and other groups that have explored the role of life cycle thinking in alternatives assessment.

Differences between alternatives assessment and life cycle assessment

Life cycle assessment and alternatives assessment represent two approaches to comparing the suitability, hazards, and trade-offs among alternative chemicals, product designs, or processes. Both are techniques for modeling and comparing chemicals, products, and processes so as to predict their ramifications within a set of embedded systems (natural, industrial, economic, social). A primary function of models is to simplify the complexity inherent in complex systems like these in order to make it tractable. Alternatives assessment and life cycle assessment differ in how they effect this simplification, which is to say in what aspects or which dimensions of systems they focus on and what they ignore. Furthermore, having been designed by different groups of practitioners with different objectives, they do not ask or answer the same questions. LCA and AA both evaluate the human and ecosystem toxicity of chemicals but diverge in most other respects, including their approaches to evaluating chemical hazard.

It is worth highlighting several key differences between life cycle assessment and alternatives assessment.

First, the two methodologies ask different questions. LCA asks, *what are the total impacts of a product or process from raw material extraction through refining, manufacturing, transportation, use, and disposal?* Whereas AA asks, *what inherently safer alternatives to a chemical of concern satisfy a given set of functional requirements (performance, cost, etc.) in a specific application?* Because each starts with a different question, the two disciplines give different answers. LCA affords perspective on the trade-offs across a broad array of impacts and facets of the life cycles of the items being compared. AA, in contrast, delves deeply into human and ecological toxicity for specific use scenarios, allowing more in-depth analysis of trade-offs based on hazard and exposure potential.

A second crucial difference is that LCA tends to focus on the impact of emissions of hazardous substances throughout the life cycle of a product. LCA is typically used and considered most robust to measure climate change potential of specific emissions; however, LCA measures a range of impacts extending well beyond climate change potential (ecotoxicity, eutrophication, human toxicity, water resource depletion, etc.), many of which derive from emissions. Alternatives assessment, in contrast, was designed to evaluate and compare the human and environmental toxicity of individual chemicals in particular applications or functional uses (that is, as used in specific products or processes). Rather than consider emissions, AA tends to focus on identifying and comparing hazards of chemicals as incorporated in a given product or used in a specific process, rather than evaluating the building blocks or breakdown products of a

[6] See the appendix for a list of Advisory Group members.

chemical across its life cycle, or how the chemical's use will affect other life cycle attributes such as water or energy use or transport.

Third, because LCA was designed to give a broad perspective on primary, secondary, tertiary, etc. impacts associated with the production, use, and disposal of items, it does a relatively poor job of predicting human and ecological toxicity for many health endpoints. (Put another way, LCA reflects a choice of breadth over depth.) In contrast, because alternatives assessment was designed to provide deep perspective on inherent (primary) hazards, it generally gives little perspective on considerations other than toxicity and exposure potential, based on physical properties such as vapor pressure and octanol-water partition coefficient (a proxy for bioaccumulation potential) (see figure 1).[7]

Finally, LCA typically encompasses all criteria or impact categories jointly, whereas alternatives assessment, as applied, typically weighs at least some attributes of alternatives in a prescribed sequence. LCA as routinely practiced is more dependent on models to help compare impacts across a range of categories. While the use of decision analysis tools like multi-criteria decision analysis (MCDA) is growing in AA, their use is still not routine compared with LCA.

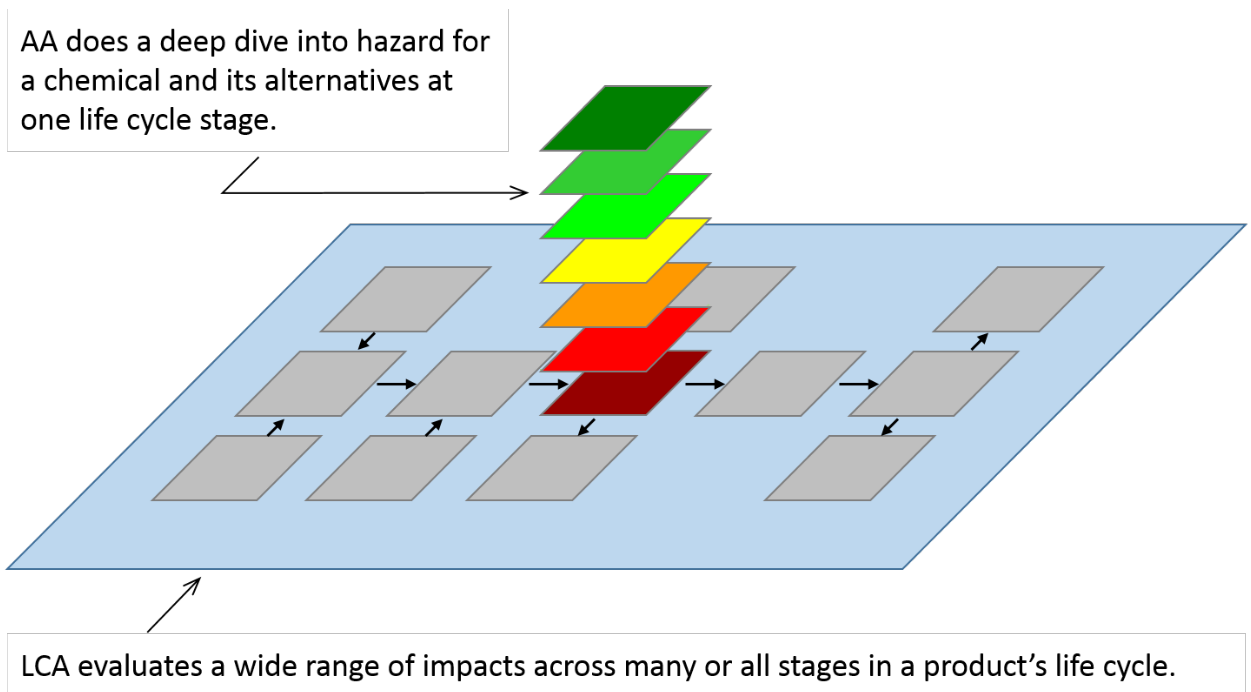
Summary table: key differences between AA and LCA		
	AA	**LCA**
Question asked	What inherently safer alternatives to a chemical of concern satisfy a given set of functional requirements (performance, cost, etc.) in a specific application?	What are the total impacts of a product or process from raw material extraction through refining, manufacturing, transportation, use, and disposal?
Analytical focus	Focuses on the human and environmental toxicity of chemicals in particular applications or functional uses (i.e., as used in specific products or processes)	Focuses on the impact of emissions of hazardous substances throughout the life cycle of a product
Perspective	Designed to provide deep perspective on inherent (1°) toxicological hazards; conversely, provides little perspective on considerations other than toxicity and exposure potential (i.e., favors depth over breadth)	Designed to give a broad perspective on 1°, 2°, 3°, etc. impacts associated with the production, use, and disposal of items; conversely, a relatively poor predictor of human and ecological toxicity for many health endpoints (i.e., favors breadth over depth)

[7] Some argue that the current state of the science of alternatives assessment is biased toward human toxicity and that more and better methodologies for hazard assessments for non-human organisms are sorely needed. A related critique is that awareness of exposures of non-human organisms to consumer product ingredients is inadequate and that this shortcoming has been a key driver in regrettable substitutions because awareness of exposure drives decision-making and the selection of relevant factors for alternatives assessment comparisons.

Order of operations	Typically evaluates at least some attributes of alternatives in a prescribed sequence (i.e., sequentially)	Typically encompasses all criteria or impact categories jointly

The objective of LCA in particular and life cycle thinking in general is (as the names suggest) to consider and compare the life cycle impacts of products, from raw material extraction to manufacturing to transportation to use to disposal or reuse. [8] In order for such a broad perspective to be tractable, even with the aid of computers and large data sets, this approach typically involves "flattening" or reducing the complexity embedded in each life cycle stage—for example, by normalizing a broad array of toxicological endpoints by converting them to a standard such as disability-adjusted life years (DALYs). In contrast, this is precisely the complexity that AA is intended to elucidate.

Represented visually, one might view this difference thus:



This is not to suggest that alternatives assessment is only concerned with a product's use phase, and the dominant chemical hazard assessment methodology, the GreenScreen for Safer Chemicals®, comprises hazard traits such as environmental persistence and bioaccumulation and includes byproducts formation. However, within the alternatives assessment community of practice there is recognition that more work is needed to enhance and routinize methodological consideration of life cycle impacts such as global warming potential, energy use, or eutrophication.

[8] "Products" could be simple products; complex, multi-component products; processes; or services.

Many alternatives assessment frameworks, including the IC2 *Alternatives Assessment Guide,* the NAS Framework, and the BizNGO Chemical Alternatives Assessment Protocol, are hierarchical or semi-hierarchical, meaning that they at least partly specify an order in which alternatives assessment should be carried out. For example, most AA frameworks focus first on implementing less toxic alternatives to the chemical of concern in a particular product or process. The NAS framework specifies that alternatives must, at minimum, be safer in the endpoint that was of concern for the original priority chemical. In part, this preference for some degree of hierarchy reflects a desire to simplify the analysis so as to render it more accessible to non-expert practitioners. A hierarchical approach such as the IC2 *Alternatives Assessment Guide's* sequential framework allows practitioners to compare alternatives based on single attributes (or, at least, a subset of attributes), eliminate unacceptable candidates at each step, and thereby avoid more complex and difficult multi-criteria decision problems. Unlike alternatives assessments, life cycle assessments are not typically hierarchical; standard LCA methods instruct practitioners to evaluate all impact categories simultaneously or in parallel, rather than in series, as AA practitioners generally do.

In essence, AA is often done hierarchically, but LCA is typically not hierarchical; it looks at all criteria jointly. This often makes it hard for those interpreting LCA results to make decisions involving many trade-offs. The simplification of a hierarchical or semi-hierarchical approach involves a collective judgment on the part of the alternatives assessment community concerning the priority of the attributes (i.e., hazard, performance, or cost). Because chemical alternatives assessment is typically defined as a means to reduce hazard, most methodological frameworks emphasize and prioritize hazard (as an inherent property of a chemical) over other attributes—although performance and cost are also very important and may, in practice, trump hazard in some cases. This is not so for LCA. LCA can be used to compare two or more alternative products or processes, but the comparison is frequently made on the basis of a wide range of attributes or impacts. Because LCA was designed to cast a much wider net than AA, it embodies a trade-off between breadth and analytical depth at each life cycle node and does not delve as deeply into toxicological hazard of alternative chemicals as AA.

Alternatives assessment is a relatively new discipline, and practitioners are still building a methodological framework for AA that balances standardization, rigor, flexibility, and effort or cost. It should not be a surprise that folding life cycle considerations into alternatives assessment raises questions and presents real challenges. It is heartening (especially in light of the inevitable comparisons that arise in this context between AA and LCA) to consider that similar concerns have troubled LCA practitioners. As the 1997 introduction to ISO Standard 14040 declared, "If LCA is to be successful in supporting environmental understanding of products, it is essential that LCA maintains its technical credibility while providing flexibility, practicality and cost effectiveness of application. This is particularly true if LCA is to be applied within small- and medium-sized enterprises".[9]

In spite of the differences between LCA and AA, there is a complementarity between the two disciplines. To summarize, LCA and AA are both specialized methods that require extensive training and background. LCA involves a broad analysis of many issues, including carbon intensity and water use, whereas AA involves a deep assessment of a few issues, especially hazard. LCA examines trade-offs across a wide spectrum of endpoints; AA deeply analyzes

[9] ISO 14040:1997(E), p. iii.

toxicity for specific use scenarios. Researchers, practitioners, and users benefit from training in both approaches. At the same time, alternatives assessment and life cycle assessment are distinct methodologies that answer different questions (as discussed above). However, just because life cycle thinking can provide additional insights in the context of alternatives assessment does not mean that LCA should be routinely done as a part of AA. In fact, where decisions regarding substitution are needed in a relatively short timeframe or are to be completed by individuals without significant expertise in environmental assessments, detailed, quantitative LCA may inhibit progress.

Integrating life cycle considerations into alternatives assessment processes

As asserted above, alternatives assessment is not and was not designed to be a form of life cycle assessment. The strength and value of AA is its deep perspective on chemical hazard in specific functional use scenarios. It is action-oriented, meaning that its results need to support informed and timely decision-making regarding substitutes. But one consequence of this depth is the challenge, in the course of conducting an AA, of identifying potential negative unintended consequences in other parts of the product life cycle. At the same time, using both AA and LCA is too resource-intensive to be practical in most cases. How, then, should AA practitioners seek to include life cycle considerations in their work? We suggest the following general approach and more specific suggestions: *incorporate and cultivate life cycle considerations in the alternatives assessment process from the outset and, only if needed, apply more comprehensive LCA strategies later in the assessment*.

Understand and map product life cycles at the beginning of alternatives assessments

As a practical technique to build life cycle thinking into AAs from the beginning, there is value in creating product or process maps as one of the first steps in an assessment. A good alternatives assessment requires a product map, which is also a fundamental tool in life cycle assessment. Although approaches to alternatives assessment like the NAS Framework and the IC2 *Alternatives Assessment Guide* include specific steps for life cycle thinking (step 9 in the NAS Framework and the last optional module in the *Alternatives Assessment Guide*), effective life cycle thinking should begin at the outset of an alternatives assessment processes, in mapping a product system and formulating the goals and scope of the assessment. Ideally, defining the scope of an AA should involve some consideration of upstream and downstream hazards of raw materials, intermediates, and byproducts. This prescription is echoed by the NAS Framework's declaration that "Fundamental to any life cycle analysis, including LCT [life cycle thinking], is mapping the product system."[10]

Furthermore, mapping a product system and using that map to visualize and formulate the alternatives assessment scope is similar in many respects to the NAS Framework recommendation to incorporate comparative exposure assessment into alternatives assessment. From this perspective, comparative exposure assessment—which asks whether the exposure potential of the alternatives is substantially equivalent to the original chemical—can be viewed as a scoping exercise. If yes (that is, if the exposure potentials are judged to be equivalent), the

[10] National Research Council. *A Framework to Guide Selection of Chemical Alternatives*. Washington, DC: The National Academies Press, 2014. doi:10.17226/18872, p. 139. http://www.nap.edu/catalog/18872/a-framework-to-guide-selection-of-chemical-alternatives

alternatives assessor can confidently focus on the hazard(s) of the alternatives and set evaluation of different exposures aside (i.e., stipulate that exposure assessment is out of scope). Just as LCA practitioners may simplify life cycle assessments by excluding life cycle subdomains that are substantially equivalent across alternatives, so also can mapping help simplify alternatives assessment by giving AA practitioners confidence that, in some cases, they are justified in either including or excluding exposure assessment.

Insist on supply-chain transparency

Whether or not one represents it visually (as a map), understanding a product's life cycle can be a significant challenge. This is often true even in the case of a single chemical, let alone a multi-ingredient or multi-component product. Supply-chain transparency (or, to be precise, the lack thereof) is a major obstacle to developing product maps that are useful for alternatives assessment. Product manufacturers frequently report that they have difficulty convincing suppliers to disclose the composition of their ingredients or components, and, as a rule, longer and more complex supply chains only amplify these difficulties. Consequently, actors within supply chains are often not aware of or familiar with the synthetic histories of the chemicals they use. For this reason, among others, it may be important for alternatives assessment practitioners to see their work as an iterative process of incremental improvement afforded by more and better information and experience with each iteration. Product or process maps provide a foundation for this iteration, especially when possible substitutions change the process—the map—upstream and downstream of the point of substitution.

Understand the "synthetic histories" of chemicals

AA practitioners should, to the extent possible, elucidate the synthetic histories of a chemical of concern and its alternatives and seek to understand, at least qualitatively, the hazards associated with each step in the synthesis—i.e., with the feedstocks and intermediates for each chemical. Understanding the synthetic histories of alternatives may be key to incorporating life cycle considerations in AA, for high-hazard chemicals may be derived from relatively non-toxic feedstocks and intermediates and vice versa. And by integrating and illustrating its synthetic history, the flow diagram or product map for a synthetic chemical is a crucial first step in recognizing and understanding the embedded life cycle hazards.

In theory, product maps could be populated with the results of hazard assessments of the feedstocks, contaminants, catalysts, intermediates, products, and by-products involved in the production of the chemicals being assessed to produce "heat maps"—i.e., maps of each product's life cycle that show human or environmental health hotspots—that could greatly assist the routinization of life cycle thinking in alternatives assessment. This would require development of a methodology for aggregating the hazards of all the chemicals associated with each node in a product map. A library of publicly available chemical hazard assessments[11] could be a great asset in this regard and serve a role similar to that of life cycle inventory (LCI) databases in the context of LCA.

Populating product maps with hazard information would not add other life cycle considerations typically captured by LCA, such as carbon intensity or water use. These life cycle considerations can and should be used to gain broader perspective (i.e., highlight potential unintended consequences) and to compare and distinguish alternatives that appear to be generally equivalent

[11] Such as that envisioned for the Chemical Commons: http://chemicalcommons.info/.

when viewed through the lens of AA, but life cycle attributes beyond toxicological hazard should not be considered before hazard or used to justify the selection of more toxic over less toxic alternatives. Typically, the analytical rigor and the resources and cost involved in an analysis are inversely related. This has important consequences for the application of alternatives assessment in a business context.[12] AA practitioners frequently reach a point at which they have all the information available at the level of resources or effort they (or their employer) are willing or able to expend. If, at that point, a preferred alternative is not apparent based on hazard, life cycle considerations may provide another means to choose.

Consider the role of geographic location in life cycle impacts

As software tools and data sets for both LCA and AA evolve and grow, building screening-level heat maps that incorporate chemical hazard and other life cycle attributes may become quicker, easier, and less costly. At the same time, however, AA practitioners should remember that life cycle attributes such as global warming potential, water use, or mercury emissions associated with a chemical are not necessarily inherent properties in the same way that toxicological hazard is. Rather, many life cycle attributes reflect choices such as where and how to produce a chemical, with ramifications for the mix of energy sources used or the degree to which worker health and safety is protected. Therefore, it may be useful to distinguish aspects of synthetic history that are location and process-independent (such as inherent toxicity of chemicals) from aspects that depend on where and how a chemical is produced. In this way, consideration of intrinsic versus extrinsic attributes might be viewed as another facet of assessment scope—in this case related to influence over one's supply chain.

Think of adaptability and transparency as two sides of the same coin

Because alternatives assessment can be applied in so many different contexts, flexibility is essential. As the IC2 *Alternatives Assessment Guide* states, "The Guide is designed to meet the needs of a wide range of users, each with unique needs. As a result, the final product is complex and comprehensive. The *Guide* does not provide a single, specific framework for conducting an alternatives assessment." Similarly, the authors of the NAS Framework specifically mention flexibility as one of its goals. In addition to the need to provide utility across a wide range of product and process types, alternatives assessment methodologies must be adaptable to fit the practitioner's expertise and resources.

A corollary to this need for flexibility is the importance of transparency. The choices and assumptions made during an AA should be communicated explicitly. To quote the NAS Framework, "Many decisions about the selection of alternatives are not purely technical, but rather are value-driven or context-dependent. It is important to explicitly articulate and document those assumptions and constraints—which often take the form of decision rules that flow from an organization's goals and principles."[13] Every analyst must make choices about what to include and what to exclude (i.e., where to draw analytical boundaries). Making these choices explicit helps practitioners recognize potential blind spots or biases in their analyses and are essential in allowing others to interpret the results in their proper context.

[12] That many organizations will likely hire consultants to perform AAs, rather than undertake them "in-house", does not obviate the perceived trade-off between analytical rigor and resources consumed by the assessment; it may simply shift the required resources from technical to financial.

[13] NAS Framework, p. 4.

Recommendations for research and alternatives assessment method development

Our research, discussions, and analysis suggest the following short list of research and practice needs to enhance life cycle considerations in alternatives assessment.

1. Develop techniques and guidance to illuminate life cycle stages and impact categories that contribute most to the differences in cradle-to-grave impacts among the chemical of concern and its alternatives. Systematically incorporating life cycle considerations into an alternatives assessment can be challenging and extremely resource intensive. Screening methods to identify key life cycle stages and impacts that help distinguish a chemical of concern and its alternatives could go a long way toward integrating life cycle considerations into alternatives assessment in a manner that focuses assessments on the impacts of greatest concern and supports more robust comparisons of alternatives. Developing additional guidance focused on the scoping and problem formulation stage of alternatives assessment appears to be one promising approach. Other examples include:
    a. Streamline identification of common, toxic chemicals—for example, by publishing libraries of comprehensive hazard assessments for high-volume feedstocks, intermediates, and commodity chemicals.
    b. Develop and publish simple methodologies to aggregate hazards along synthetic pathways.
    c. Assemble libraries of unit processes[14]—perhaps analogous to life cycle inventory (LCI) databases—to facilitate faster, cheaper assembly of "modular" synthetic histories.
    d. Develop guidance regarding how to distinguish aspects of synthetic history that are location or process-independent from those that likely depend on where and how a chemical is produced.
2. Enhance and encourage training in and—especially—experience with LCA as well as AA. A familiarity with both methodologies can confer significant benefit on practitioners struggling to incorporate life cycle considerations into AA. This is not necessarily due to knowledge of specific LCA techniques so much as practice thinking about product life cycles. Given the wide range of contexts in which AA can be used (which makes the development of methodological approaches all the more difficult), there is a strong intuitive element to identifying potential "hot spots" in products' life cycles that may harbor previously unrecognized hazards. Knowledge of LCA, in addition to AA, may not only strengthen analysts' abilities to visualize and map product life cycles but also the experience to know when and where restricting the scope of an analysis is appropriate.
    a. Clarify and document the purpose of existing tools and approaches. The AA community of practice would benefit from a clearer shared understanding of the

[14] A unit process can be visualized as a discrete step in a product map or flow diagram. "Unit processes inside of the system boundary link together to form a complete life cycle picture of the required inputs and outputs (material and energy) to the system" ("Life Cycle Assessment: Principles and Practice" ("LCA 101"). U.S. Environmental Protection Agency. EPA/600/R-06/060, May 2006. http://www.epa.gov/nrmrl/std/lca/lca.html [accessed 2015-02-25], p. 19).

intended use, expected outputs, and strengths and limitations of the available methods, including AA and LCA but possibly also risk assessment and others. Practitioners, as well as those commissioning studies, need more guidance regarding what methods and tools should be used for which type of assessment.

b. Publish case studies to enhance understanding of what tools (e.g., LCA vs. AA) should be used, for what purposes, and why.

3. Develop methods to integrate disparate life cycle impact assessments into alternatives assessment. Separate, distinct assessment tools are used to evaluate impacts such as hazard and other attributes of concern in an alternatives assessment, and there is no standard method that defines how these diverse assessment results should be integrated to support comparisons to identify an overall "safer" substitute. However, given limited resources, AA practitioners will rely on existing data wherever available, and LCAs may provide readily available comparisons of alternatives for impacts not currently addressed in AA tools, such as global warming potential, energy use, water use, etc.

   a. Develop and test guidance for how impact results from a life cycle assessment should be integrated into the alternatives assessment framework in order to better reveal differences among the alternatives.

   b. Develop guidance to help practitioners navigate impact and hazard trade-offs. Simplified decision analysis techniques are needed, given the number of attributes that are often compared and the need to be explicit and transparent about the values embedded in the final decisions about which alternative is deemed "safer".

Finally, future research might also investigate whether the concept of *functional unit* (used in LCA) is meaningful in the context of AA as well.[15] The idea of the *functional use* of a chemical is common in alternatives assessment, and adding the "unit" concept to quantify the function could, for example, facilitate apples-to-apples comparisons in situations in which a potential substitute for a chemical of concern is less hazardous than the incumbent but is less effective so that a larger quantity must be used to achieve the required function. Further, as alternatives to the function of many chemicals of concern may be material, process, or product design changes, practitioners need methods to compare chemical and non-chemical options in a manner that still facilitates informed, efficient decision-making. It is in this area of "functional substitution" that we will see a much greater intersection of alternatives assessment and life cycle methods in the future.

[15] In section 5.1.2.1 ("Function and functional unit"), ISO Standard 14040 has this to say about functional unit:

> The scope of an LCA study shall clearly specify the functions of the system being studied. A functional unit is a measure of the performance of the functional outputs of the product system. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results. Comparability of LCA results is particularly critical when different systems are being assessed to ensure that such comparisons are made on a common basis.
>
> A system may have a number of possible functions and the one selected for a study is dependent on the goals and scope of the study. The related functional unit shall be defined and measurable.
>
> (ISO International Standard 14040: "Environmental management – Life cycle assessment – Principles and framework", Reference number IS0 14040: 1997(E), p. 5).

Appendix: Brief Description of the Project and Advisory Group

IC2/NEWMOA carried out this project for the Lowell Center for Sustainable Production. The project comprised a number of elements:

- background research;
- management of an Advisory Group of experts in alternatives assessment and life cycle assessment;
- facilitation of two conference calls of the Advisory Group;
- discussions with individual members of the advisory group; and
- preparation of this briefing paper.

The conference call notes, along with the results of one-on-one conversations with most of the members of the Advisory Group, are the basis for the insights and guidance in this briefing paper. The IC2 thanks the members of the Advisory Group for their contributions:

• Matt Eckelman	Northeastern University
• Pam Eliason	Toxics Use Reduction Institute
• Jack Geibig	Ecoform
• Kathy Hart	U.S. EPA DfE Program
• Greg Morose	UMass Lowell/Lowell Center for Sustainable Production
• Greg Norris	International Living Future Institute
• Valentina Prado-Lopez	Arizona State University
• Cory Robertson	Hewlett-Packard
• Julie Schoenung	UC Davis
• Alex Stone	Washington State Department of Ecology
• Joel Tickner	UMass Lowell/Lowell Center for Sustainable Production
• Anahita Williamson	New York State Pollution Prevention Institute
• Kate Winnebeck	New York State Pollution Prevention Institute
• Martin Wolf	Seventh Generation