Perspective

Risk Assessment and Alternatives Assessment: Comparing Two Methodologies

Margaret H. Whittaker*

The selection and use of chemicals and materials with less hazardous profiles reflects a paradigm shift from reliance on risk minimization through exposure controls to hazard avoidance. This article introduces risk assessment and alternatives assessment frameworks in order to clarify a misconception that alternatives assessment is a less effective tool to guide decision making, discusses factors promoting the use of each framework, and also identifies how and when application of each framework is most effective. As part of an assessor’s decision process to select one framework over the other, it is critical to recognize that each framework is intended to perform different functions. Although the two frameworks share a number of similarities (such as identifying hazards and assessing exposure), an alternatives assessment provides a more realistic framework with which to select environmentally preferable chemicals because of its primary reliance on assessing hazards and secondary reliance on exposure assessment. Relevant to other life cycle impacts, the hazard of a chemical is inherent, and although it may be possible to minimize exposure (and subsequently reduce risk), it is challenging to assess such exposures through a chemical’s life cycle. Through increased use of alternatives assessments at the initial stage of material or product design, there will be less reliance on post facto risk-based assessment techniques because the potential for harm is significantly reduced, if not avoided, negating the need for assessing risk in the first place.

KEY WORDS: Alternatives assessment; green chemistry; hazard; risk; risk assessment

1. INTRODUCTION

The concept of synthesizing and selecting chemicals and materials with less hazardous human health and/or environmental profiles is becoming more mainstream, with phrases such as “Cradle to Cradle,” “green chemistry,” and “informed substitution” used by both industry-funded trade groups and nongovernmental organizations. This concept reflects a paradigm shift from reliance on risk minimization through exposure controls to hazard avoidance. Much as formal risk assessment found its footings in the 1980s with the dissemination of reports such as the U.S. National Research Council (NRC) publication “Risk Assessment in the Federal Government: Managing the Process” (“the Red Book”) and the Royal Society’s report titled “Risk Assessment: A Study Group Report,” the concept of alternatives assessment has developed into a decision-making methodology that recognizes the importance of adhering to a transparent, rigorous framework and drawing a clear distinction between hazard reduction and hazard management in the selection of alternatives.

This introductory article is one of three articles in this issue of Risk Analysis relating to alternatives assessment, and is designed to introduce risk assessment and alternatives assessment frameworks in order to dismiss a common misconception about chemical alternatives assessment and identifies how and when application of each framework is most effective. In the second article of this series, Malloy et al. discuss the value of alternatives assessments to

*Address Correspondence to Margaret H. Whittaker, ToxServices LLC, 1367 Connecticut Avenue, N.W., Suite 300, Washington, D.C. 20036, USA; tel: (202) 429-8787; mwhittaker@toxservices.com.
guide decision making for regulated chemicals when selecting safer alternatives. In the third article in this series, Geiser et al. presents a detailed discussion of the chemical alternatives assessment process and clearly establishes the utility of alternatives assessment methods to guide and inform decisionmakers.

2. A COMPARISON OF FRAMEWORKS

Risk assessment is designed to answer the question: “Is this chemical or product safe enough for the intended use?” in contrast to an alternatives assessment, which is intended to answer the question: “Which chemical or product poses a lower hazard?” The steps taken to answer these two questions are quite different, but it is important to recognize that both frameworks are intended to provide a standardized approach to organizing knowledge and comparing alternatives. Hazard has always held a prominent place in risk assessment, and the widespread adoption of the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) has compelled even fervent advocates of risk assessment to spend more time in the pursuit of quality hazard analysis. GHS grew out of the 1992 U.N. Conference on Environment and Development (“the Earth Summit”), and since its adoption by the United Nations in 2002, its use around the world has increased steadily, with 67 countries now adhering to GHS. GHS is focused on classifying chemicals and mixtures of chemicals by types of hazard (with the exception of risk-based labeling of consumer products for chronic health effects in GHS Annex 5) and promotes a harmonized system of communicating hazards on labels and safety data sheets. Because hazards are communicated when following GHS, there is a stimulus to find less hazardous or safer chemical ingredients.

2.1. Risk Assessment

Terminology used in the risk assessment community of practice is well defined, as detailed in Table I. Risk can be defined as the probability of suffering harm (injury, disease, death) from a hazard. As specifically relating to adverse effects following exposure to a hazardous substance, risk is defined as the likelihood that the toxic properties of a substance will be produced in a population of individuals under their actual conditions of exposure. Hazard is the inherent capacity of a substance or action that can cause harm. Risk assessment is the actual practice of estimating the severity and likelihood of harm to human health or the environment occurring from exposure to a chemical substance, biological organism, radioactive material, or other potentially hazardous substance or activity. The four distinct steps of a risk assessment first outlined in the 1983 NRC Red Book are still used in current risk assessments: hazard identification, dose-response assessment, exposure assessment, and risk characterization. In short order, risk assessment methods found widespread adoption around the world, first by governments and related organizations (such as the European Union), followed by intergovernmental organizations such as the United Nations and its related agencies including the World Health Organization, along with industry-funded trade organization such as the European Chemical Industry Council (CEFIC) and the American Chemistry Council, and then more recently, nongovernmental organizations (NGOs) such as Friends of the Earth, Greenpeace, and the Natural Resources Defense Council, among others.

Risk assessment follows an established framework that when applied correctly can estimate how likely a chemical will harm a target (e.g., a child, adult, organism in the environment) under specific conditions of exposure. For example, risk assessment methods can adequately estimate the likelihood that a worker will develop cancer following exposure to asbestos under certain occupational exposure scenarios, predict whether a shampoo with high levels of 1,4-dioxane poses an unreasonable cancer risk to consumers, or assess whether a PCB-contaminated site has been adequately remediated.

Risk assessment methods have matured over the past 30 years; however, this maturation has not been without growing pains, as detailed in the National Research Council report titled “Science and Decisions,” which gives examples of risk assessments (e.g., the U.S. EPA’s formaldehyde risk assessment) taking more than a decade to complete and identifies major shortcomings in the ability of risk assessments to adequately inform decision making both in terms of timeliness and answering questions that help guide decisionmakers.

2.1.1. Factors Advancing the Practice of Risk Assessment

The practice of risk assessment was originally driven by regulatory authorities to fulfill legislative mandates pertaining to human health or environmental protection, but is now equally practiced by
Table I. Risk-Assessment-Related Terminology

| Term                | Definition                                                                                                                                 |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Risk                | The likelihood that an adverse effect will occur                                                                                           |
| Hazard              | An intrinsic property of a substance, activity, or risk source that enables it to cause harm                                                  |
| Exposure            | Contact with a chemical or physical agent and a target                                                                                     |
| Dose                | Fraction of an exposure to a chemical that actually enters the body following absorption from one or more routes of exposure                   |
| Exposure assessment | Estimate or direct measurement of quantities of risk agents received by individuals, populations, or ecosystems                               |
| Risk assessment     | The characterization of the probability of potentially adverse effects from human exposure to environmental hazards                            |
| Risk analysis       | A process for controlling situations where an organism, system, or (sub)population could be exposed to a hazard; the risk analysis process consists of three components: risk assessment, risk management, and risk communication |
| Risk management     | The process of identifying, selecting and implementing actions to reduce risk to human health and ecosystems                                   |

industry and NGOs to evaluate process, product, or site remediation safety, prioritize risk reduction measures, or demonstrate regulatory compliance (or lack thereof). At the international level, risk assessment has been advanced by the E.U.’s REACH regulation (registration, evaluation, authorization, and restriction of chemicals) that came into force in 2008 and requires that all nonexempt substances imported into or produced by E.U. countries undergo registration, with assessment of hazard and lifecycle risk, and subsequent determination of whether safe use can be established. In the United States, legislation such as the Toxic Substances Control Act (TSCA) of 1976 and Clean Air Act (CAA) Amendments of 1990 firmly affixed risk assessment as part of the U.S. federal government’s chemical evaluation process. Although most would agree that the U.S. EPA’s restriction of toxic substances under Section 6 of TSCA has been ineffective (only five substances were actually restricted based on an unreasonable risk determination: polychlorinated biphenyls, fully halogenated chlorofluoroalkanes, dioxin, asbestos, and hexavalent chromium), TSCA’s inclusion of the undefined phrase “unreasonable risk” was an early factor entrenching the role of risk assessment at the federal level. The CAA Amendments included authorization in the United States for the Presidential/Congressional Commission on Risk Assessment and Risk Management to identify proper use of risk assessment and risk management in regulatory programs under various federal laws to prevent cancer and other chronic human health effects that may result from exposure to hazardous substances.

The CAA Amendments of 1990 also authorized the U.S. EPA to engage with the National Academy of Sciences to review methods used by the U.S. EPA to estimate risk.

Public-sector funding at the national and international level subsidized risk-related research, and in a relatively quick manner created a risk assessment community of practice, with hundreds of toxicologists, statisticians, environmental scientists, and chemists working together to create standardized approaches to assessing human health and ecological risks, as evidenced by more than 70 reports and guidelines issued by U.S. EPA’s Risk Assessment Forum from 1986 onwards (“the Purple Books”), and equal number of risk-related publications and guidelines issued by the World Health Organization’s International Programme on Chemical Safety from the 1970s onwards.

At the U.S.-state level, California’s Proposition 65 requirement to label consumer products that contain Proposition 65 listed carcinogens or reproductive/developmental toxicants has propelled the use of quantitative methods to estimate exposure and subsequent risk because of the Proposition 65 provision that exempts products from labeling when safe harbor can be established using prescribed risk assessment procedures.

2.2. Chemical Alternatives Assessment

Chemical alternatives assessment is a newer methodology than risk assessment, and can be defined in its most simple form as a system to identify alternative chemicals, materials, or product designs to substitute for the use of hazardous substances.
Table II. Alternatives-Assessment-Related Terminology

| Term                        | Definition                                                                                                                                 |
|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Alternatives assessment     | A process for identifying and comparing potential chemical and nonchemical alternatives that can be used as substitutes to replace chemicals or technologies of high concern on the basis of their hazards, performance, and economic viability.⁸,⁴³ |
| Chemical hazard assessment  | A systematic process of assessing and classifying hazards across an entire spectrum of endpoints and levels of severity.⁴⁴                                                               |
| Comparative chemical hazard assessment | A type of hazard assessment that evaluates hazards from two or more agents, with the intent to guide decision making toward the use of the least hazardous options via a process of informed substitution.⁴⁵ |
| Informed substitution       | An approach for replacing chemicals of concern with safer chemicals or nonchemical alternatives.⁴⁶                                                                                   |
| Regrettable substitution    | Selecting an alternative that turns out to pose an equal or greater hazard than the original toxic substance.⁴                                                                            |

A publication that is often cited as introducing the formal concept of alternatives assessment is a book titled *Making Better Environmental Decisions: An Alternative to Risk Assessment.*³² What is often forgotten is that the U.S. National Environmental Policy Act of 1969 actually advocated the concept of alternatives assessment when making environmental decisions, as called out in a book review published in 2000 in *Risk Analysis* that misguidedly paints O’Brien’s book in poor light.³³ Just as many entrenched and traditional risk assessors were not interested in learning about the principles of green chemistry,³⁴ informed substitution,³⁵ or comparative hazard assessment,³⁶ which are integral parts of an alternatives assessment, early alternatives assessors were not keen to be part of the risk assessment community. Most of the early discord between alternatives assessors and risk assessors can be explained by recognizing a philosophical difference between the two methodologies: many alternatives assessors place great value on hazard avoidance, while risk assessors place great value on exposure controls, despite the human health and/or environmental harm posed by the substance undergoing assessment. As more risk assessors are trained in alternatives assessment methods (and vice versa), this discord has lessened based on a greater understanding of the scientific basis underlying each methodology.

Because it is a newer discipline than risk assessment, terms used by alternatives assessors are still undergoing definition. Key terms used by alternatives assessors are defined in Table II. Although there are multiple alternatives assessment frameworks (discussed in detail later in this issue in the article by Tickner), alternatives assessments all use standardized procedures to assess whether potential alternatives have improved human health and environmental profiles compared to a conventional ingredient. In addition, an alternatives assessment will address whether chemical or nonchemical alternatives are commercially available, perform adequately, and are cost effective. When properly conducted, an alternatives assessment provides the means to avoid regrettable substitution, and promotes the selection of safer chemicals or materials. Examples of completed alternatives assessments using frameworks such as the U.S. EPA’s Design for the Environment (DfE) Alternatives Assessment Criteria,³⁷ the IC2 Alternatives Assessment Guide,³⁸ and the Lowell Center for Sustainable Production’s Alternatives Framework³⁹ are available online.⁴⁰–⁴² These alternative assessments examples include selection of less hazardous halogenated flame retardants, copper-containing antifungal boat paints, and substitutes for lead, formaldehyde, and perchloroethylene, among others. The recent (2014) NRC report “A Framework to Guide Selection of Chemical Alternatives” evaluates the strengths and weaknesses of seven different alternatives assessment frameworks as part of its proposed alternatives assessment framework.⁴

### 2.2.1. Factors Advancing Alternatives Assessment

The recent NRC report “A Framework to Guide Selection of Chemical Alternatives” identifies major drivers advancing alternatives assessment.⁴ These include U.S. state initiatives in California, Washington, and Maine that identify chemicals of concern. A number of large U.S. retailers have begun to track such lists and now encourage substitution/phaseout of chemicals of concern throughout the supply chain. At the international level, the E.U.’s Substances of Very High Concern (SVHC) list (Annex XIV of REACH) (currently, 31 chemicals) and the SVHC
Table III. Green Chemistry Principles

| Number | Principle (hazard-based principles are shaded) |
|--------|-----------------------------------------------|
| 1      | Prevent waste                                 |
| 2      | Atom economy                                  |
| 3      | Less hazardous chemical syntheses             |
| 4      | Design safer chemicals and products           |
| 5      | Use safer solvents and auxiliaries            |
| 6      | Design for energy efficiency                  |
| 7      | Use of renewable raw materials/feedstocks     |
| 8      | Reduce derivatives                            |
| 9      | Use catalytic reagents not stoichiometric reagents |
| 10     | Design chemicals and products to degrade after use |
| 11     | Analyze in realtime for pollution prevention  |
| 12     | Minimize the potential for accidents through safer process chemical selection |

Fig. 1. Decisions empowered by alternatives assessment and risk assessment frameworks

candidate list (currently, 163 chemicals as of the last official update in June 2015) are spurring many manufacturers and responsible parties to move away from listed substances and find a safer substitute in lieu of requesting an authorized use for that listed chemical. Another list that has begun to promote the implementation of alternatives assessment is ECHA’s Community Rolling Action Plan (CoRAP) list. Inclusion on the CoRAP list (currently, 267 chemicals as of November 2015) means that an E.U. member state has or will evaluate the chemical for its potential health or environmental risks (where hazard and exposure are each considered).

3. COEXISTENCE OF RISK ASSESSMENT AND ALTERNATIVES ASSESSMENT FRAMEWORKS

Instead of viewing risk assessment and alternatives assessment frameworks as competing paradigms, it is critical to recognize that they are intended to perform different functions. Admittedly, each framework incorporates an exposure
assessment component, but unlike a risk assessment, an alternatives assessment uses differentiation provided by the alternatives assessment process to select environmentally preferable chemicals and materials, not just incrementally better ones.

For a business trying to select safer chemicals, an alternatives assessment provides a more realistic framework with which to make decisions because of an alternatives assessment’s primary reliance on assessing hazards, and secondary reliance on exposure assessment. Relevant to other life cycle impacts, the inherent hazard of a chemical cannot be changed, and although it may be possible to reduce or minimize exposure (and subsequently reduce risk), it is challenging to accurately, precisely, or realistically assess such exposures under all phases of a chemical’s life cycle.\(^{34,50}\) Five of the 12 principles of green chemistry are focused on hazard reduction (shaded in Table III), and when followed as part of an alternatives assessment, promote the design (or redesign) of materials and products that reduce or eliminate the use or generation of hazardous substances. This is the definition of green chemistry, and when practiced as part of a chemical alternatives assessment, benefits not only the company selecting the less hazardous alternative, but also the world at large.

As illustrated in Fig. 1, alternatives assessment and risk assessment methods each function to empower decisionmakers, but facilitate quite different end goals.

4. CONCLUSION

In his book titled Risk, U.K. geographer John Adams describes risk by quoting turn of the century U.S. economist Frank Knight: “If you don’t know for sure what will happen, but you know the odds, that’s risk.”\(^{51}\) Particularly for materials, products, or contaminated sites that contain inherently hazardous substances, risk assessment is a powerful tool to assess the likelihood of harm, and if misused, has the potential to promote the continued use of substances that at sufficient levels of exposure may result in adverse human health and/or environmental effects. In contrast, an alternatives assessment begins with a different end game, and that is to inform the selection of less hazardous chemicals and materials so that the concept of acceptable risk is eliminated from the equation altogether. Ideally, through increased adoption of alternatives assessment methods at the initial stage of material or product design, there will be less reliance on post facto risk-based assessment techniques because the potential for harm is significantly reduced, if not avoided, in the first place.

REFERENCES

1. National Research Council (NRC). Risk Assessment in the Federal Government: Managing the Process. Committee on the Institutional Means for Assessment of Risks to Public Health. Commission on Life Sciences. Washington, DC: National Academies Press, 1983.
2. The Royal Society. Risk Assessment. A Study Group Report. London: Royal Society, 1983.
3. Jasanoff S. Civic epistemology. Pp. 247–271 in Designs on Nature: Science and Democracy in Europe and the United States. Princeton, NJ: Princeton University Press, 2007.
4. National Research Council (NRC). A Framework to Guide Selection of Chemical Alternatives. Committee on the Design and Evaluation of Safer Chemical Substitutions: A Framework to Inform Government and Industry Decisions. Washington, DC: National Academy Press, 2014.
5. United Nations. Globally Harmonized System of Classification and Labelling of Chemicals (GHS), 2015. Available at: http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html, Accessed November 7, 2015.
6. United Nations. GHS Implementation, 2015. Available at: http://www.unece.org/trans/danger/publi/ghs/implementation_e.html, Accessed November 7, 2015.
7. Colhess JF, Covello VT. Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Risks. U.S. Council on Environmental Quality (CEQ). Washington, DC: Executive Office of the President, 1989.
8. Davies JC. Comparing Environmental Risks. Tools for Setting Government Priorities. Washington, DC: Resources for the Future, 1996.
9. ENVIRON. Elements of Toxicology and Chemical Risk Assessment, rev. ed. Arlington, VA: ENVIRON Corporation, 1998.
10. Rodricks JV. From dose to toxic response. Pp. 54–90 in Calculated Risks, 2nd ed. Cambridge University Press, 2007.
11. van Leeuwen CJ. General introduction. Pp. 1–18 in van Leeuwen CJ, Hermens JLM (eds). Risk Assessment of Chemicals: An Introduction, 2nd ed. The Netherlands: Kluwer Academic Publishers, 2007.
12. International Programme on Chemical Safety (IPCS). Principles for the Assessment of Risks to Human Health from Exposure to Chemicals. Environmental Health Criteria 210. Geneva: World Health Organization, 1999. Available at: http://www.inchem.org/documents/ehc/ehc/ehc210.htm, Accessed November 7, 2015.
13. Jäger J. Risk assessment in the global management of environmental risks. Pp. 7–30 in Learning to Manage Global Environmental Risks, Vol 2: A Functional Analysis of Social Responses to Climate Change, Ozone Depletion, and Acid Rain. Cambridge: MIT Press, 2001.
14. National Research Council (NRC). Science and Decisions. Advancing Risk Assessment. Committee on Improving Risk Analysis Approaches Used by the U.S. EPA. Washington, DC: National Academies Press, 2009.
15. Robinson L, Thorn I. Handling chemicals in the workplace. Pp. 100–114 in Toxicology and Ecotoxicology in Chemical Safety Assessment. Boca Raton, FL: CRC Press, 2005.
16. European Commission Scientific Steering Committee (SSC). First Report on the Harmonisation of Risk Assessment Procedures. Scientific Steering Committee. European Commission, Brussels, Belgium, 2000.
17. Fjeld RA, Eisenberg NA, Compton KL. Introduction. Pp. 1–22 in Quantitative Environmental Risk Analysis for Human Health, Hoboken, NJ: Wiley, 2007.
18. International Programme on Chemical Safety (IPCS). IPCS Risk Assessment Terminology: IPCS Harmonization Project Document No. 1: Part 1 IPCS/OECD Key Generic Terms and Part 2 IPCS Glossary of Key Exposures (Harmonization Project Documents). Geneva: World Health Organization, 2004. Available at: http://www.inchem.org/documents/harmprof/harmprof1.pdf, Accessed November 7, 2015.

19. Fjeld RA, Eisenberg NA, Compton KL. Exposure assessment. Pp. 199–218 in Quantitative Environmental Risk Analysis for Human Health. Hoboken, NJ: Wiley, 2007.

20. International Union of Pure and Applied Chemistry (IUPAC). Glossary of Terms Used in Toxicology, 2nd ed. Pure and Applied Chemistry, 2007; 79(7):1153–1344.

21. ENVIRON. Elements of Chemical Exposure Assessment. May 1991. Arlington, VA: ENVIRON Corporation, 1991.

22. World Health Organization (WHO). Human exposure assessment. Environmental Health Criteria 214, 2000.

23. National Research Council (NRC). Science and Judgement in Risk Assessment. Committee on Risk Assessment of Hazardous Air Pollutants. Washington, DC: National Academies Press, 1994.

24. Gerard S, Petts J. Isolation or integration? The relationship between risk assessment and risk management. Pp. 1–20 in Hester R, Harrison R (eds). Risk Assessment and Risk Management. Issues in Environmental Science and Technology (Book 9). Cambridge: Royal Society of Chemistry, 1998.

25. The Royal Society. Risk: Analysis, Perception and Management — Report of a Royal Society Study Group. London: Royal Society, 1992.

26. European Environment Agency (EEA). The use of risk assessment in environmental management. In Environmental Risk Assessment — Approaches, Experiences and Information Sources. Copenhagen: European Environment Agency, 1998.

27. The Presidential/ Congressional Commission on Risk Assessment and Risk Management. Risk Assessment and Risk Management in Regulatory Decision-Making, Vol. 2. Final Report, 1997.

28. U.S. Environmental Protection Agency (U.S. EPA). Risk Assessment Forum (RAF): Publications, 2015. Available at: http://www2.epa.gov/osa/basic-information-about-risk-assessment-guidelines-development, Accessed November 7, 2015.

29. World Health Organization (WHO). Listing of IPCS Publications and Projects on Risk Assessment Methodology, 2015. Available at: http://www.who.int/ipcs/publications/ech/methodology_alphabetical/en/, Accessed November 7, 2015.

30. Office of Environmental Health Hazard Assessment (OEHHA). Proposition 65: Process for Developing Safe Harbor Numbers. February 2001. State of California Environmental Protection Agency (CalEPA), 2001. Available at: http://oehha.ca.gov/prop65/policy_procedure/pdf_zip/2001SafeHarborProcess.pdf, Accessed November 7, 2015.

31. Office of Environmental Health Hazard Assessment (OEHHA). Chemicals Known to the State to Cause Cancer or Reproductive Toxicity. List dated August 25, 2015. State of California Environmental Protection Agency (CalEPA). Available at: http://oehha.ca.gov/prop65/prop65_list/Newlist.html, Accessed November 7, 2015.

32. O’Brien M. Making Better Environmental Decisions: An Alternative to Risk Assessment. Cambridge: MIT Press, 2000.

33. Albert RE. Book review: Making Better Environmental Decisions. An Alternative to Risk Assessment. Risk Analysis, 2001; 21(4):801.

34. Anastas PT, Warner JC. Green Chemistry: Theory and Practice. New York: Oxford University Press, 1998.

35. Geiser K. Materials Matter: Toward a Sustainable Materials Policy. Cambridge: MIT Press, 2001.

36. Heine L, Franjevic SA. Chemical Hazard Assessment and the GreenScreen for Safer Chemicals. Pp. 129–156 in Hester R (ed). Chemical Alternatives Assessment. Cambridge: Royal Society of Chemistry, 2013.

37. U.S. Environmental Protection Agency (U.S. EPA). Design for the Environment Program Alternatives Assessment Criteria for Hazard Evaluation, Version 2.0, 2011. Available at: http://www2.epa.gov/saferchoice/alternatives-assessment-criteria-hazard-evaluation, Accessed November 7, 2015.

38. Interstate Chemicals Clearinghouse (IC2). Alternatives Assessment Guide, Version 1.0, 2013. Available at: http://theic2.org/alternatives_assessment_guide, Accessed November 7, 2015.

39. Lowell Center for Sustainable Production. Alternatives Assessment Framework of the Lowell Center for Sustainable Production, Version 1.0. 2006. Available at: http://www.chemicalspolicy.org/publications.reports.alternativesassessment.php, Accessed November 7, 2015.

40. U.S. Environmental Protection Agency (U.S. EPA). Partnership to Evaluate Flame Retardant Alternatives to DecaBDE, 2014. Available at: http://www2.epa.gov/saferchoice/partnership-evaluate-flame-retardant-alternatives-decabe, Accessed November 7, 2015.

41. ToxServices LLC. Assessing Alternatives to Copper Antifouling Paint: Piloting the Interstate Chemicals Clearinghouse (IC2) Alternatives Assessment Guide. Available at: http://theic2.org/alternatives_assessment_guide, Accessed November 7, 2015.

42. Toxic Use Reduction Institute (TURI). Five Chemicals Alternatives Assessment Study, 2006. Available at: http://www.turi.org/TURI_Publications/TURI_Methods_Policy_Reports/Five_Chemicals_Alternatives_Assessment_Study_2006, Accessed November 7, 2015.

43. Chemical Commons. The Commons Principles for Alternatives Assessment. Addressing Chemicals of Concern to Human Health or the Environment, 2013. Available at: http://www.bizongo.com/alternatives-assessment/commons-principles-alt-assessment, Accessed November 7, 2015.

44. Whittaker MH, Heine L. Chemicals Alternatives Assessment (CAA): Tools for Selecting Less Hazardous Chemicals. Pp. 1–43 in Hester R (ed). Chemical Alternatives Assessments. Cambridge: Royal Society of Chemistry, 2007. Available at: http://www.chemicalspolicy.org/publications.reports.alternativesassessment-criteria-hazard-evaluation, Accessed November 7, 2015.

45. Clean Production Action (CPA). GreenScreen for Safer Chemicals Chemical Hazard Assessment Procedure, Version 1.2, 2013. Available at: http://www.greenscreenchemicals.org/method/full-greenscreen-method, Accessed November 7, 2015.

46. U.S. Environmental Protection Agency (U.S. EPA). Safer Choice Standard, 2015. Available at: http://www2.epa.gov/sites/production/files/2013-12/documents/standard-for-safer-products.pdf, Accessed November 7, 2015.

47. European Chemicals Agency (ECHA). Authorization List (Annex XIV of REACH), 2015. Available at: http://echa.europa.eu/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list, Accessed November 7, 2015.

48. European Chemicals Agency (ECHA). Statistics on Received Applications, 2015. Available at: http://echa.europa.eu/addressing-chemicals-of-concern/authorisation/applications-
49. European Chemicals Agency (ECHA). Substance Evaluation-CoRAP, 2015. Available at: http://echa.europa.eu/information-on-chemicals/evaluation/community-rolling-action-plan/corap-table, Accessed November 7, 2015.

50. BizNGO. BizNGO Chemical Alternatives Assessment Protocol, April 12, 2012. http://www.bizngo.org/static/ee_images/uploads/resources/BizNGOChemicalAltsAssessmentProtocol_V1.1_04_12_12-1.pdf, Accessed November 7, 2015.

51. Adams J. Risk and the Royal Society. Pp 7–28 in Risk. London: Routledge, 1995.