DRAFT

Cost-Benefit Analysis Support for California EPA's Green Chemistry Initiative

Project: Green Chemistry Initiative Life Cycle Thinking (Award 10-T1100)

Report Prepared in August 2012

Developed by:

Arpad Horvath, Ph.D. †
Professor

Jennifer Stokes, Ph.D. †
Research Engineer

† University of California, Berkeley
Department of Civil and Environmental Engineering

Contract Manager:

Bob Boughton
California Environmental Protection Agency
Department of Toxic Substances Control
Office of Pollution Prevention and Green Technology

Green Chemistry Initiative image source: California Department of Toxic Substances Control.

Table of Contents

Background 1
Summary of Cost-Benefit Analysis Methodology 2
Related and Complementary Methodologies 5
Cost-effectiveness Analysis 5
Life-cycle Cost Accounting 5
Conventional LCCA 5
Environmental LCCA 5
Societal LCCA 6
Life-Cycle Assessment 6
Socio-Economic Analysis 6
Comparison between Methods 7
Existing Guidelines Review 7
Existing CBA Guidelines Summary 8
U.S. Office of Management and Budget 8
European Centre for Ecotoxicology and Toxicology of Chemicals 8
European Chemicals Agency 9
European Commission 9
U.S. Environmental Protection Agency 10
Organization for Economic Cooperation and Development 10
Existing LCCA Guidelines Summary 10
U.S. Department of Transportation 10
North Atlantic Trade Organization 10
Society of Environmental Toxicology and Chemistry (SETAC) 11
Environmental Valuation Guidance and Data Sources Summary 11
U.S. Environmental Protection Agency 11
Environment Canada Data 12
United Nations Environment Programme 12
World Business Council for Sustainable Development 12
Guidance Matrix 13
Incorporating Existing Guidelines for CBA 15

Incorporating Existing Guidelines for LCCA 16
Tools summary 16
Tool for Cost-Benefit Analysis 16
Tools for Life-cycle Cost Accounting 16
Tools Matrix 17
Case Study 18
Selecting a material for baby bottles 19
Establishing key assumptions 19
Identify costs and benefits, including direct, indirect, external, and unquantifiable effects 21
Monetize and discount costs and benefits, as needed and as possible 27
Compare results 28
Discuss sensitivity and uncertainty 28
Recommendations for Future Work 30
List of Abbreviations 31
Glossary 32
References 35

List of Tables and Figure

Table 1: Some Sources of Direct and External Costs for all Life-cycle Phases 3
Table 2: Possible Scenarios for CBA Analysis 4
Table 3: Cost Methodology Summary [adapted from (Hunkeler, Kichtenvort et al. 2008)] 7
Table 4: CBA and LCCA Guidance Comparison Matrix 14
Table 5: CBA and LCCA Tool Matrix 18
Table 6: Criteria Screening Table for Baby Bottle Case 22
Table 7: Total costs to produce 1.5 million bottles annually 23
Table 8: Summary of Total Annual Environmental Effects and Associated Environmental Costs 24
Table 9: Summary of Energy Use per bottle 26
Table 10: Human Health Effects of Baby Bottles 27
Table 11: Summary of Costs per bottle produced over a 10-year period 28
Table 12: Results of Sensitivity Analysis 29
Table 13: Uncertainty Estimates for Input Parameters 29
Figure 1: Uncertainty Results with Error Bars 30

Background

The California Department of Toxic Substance Control (DTSC) established the Green Chemistry Initiative in 2007 to provide a framework for understanding and reducing the impacts of products containing toxic chemicals in the state. California's Assembly Bill 1879 (AB 1879) gives the DTSC authority to regulate chemicals of concern in consumer products. However, changing product design or switching out problem chemicals may have environmental and human health implications. Alternative assessment (AA) should employ a life-cycle perspective when evaluating products, processes, and decisions that influence the use of chemicals in products to avoid regretful substitutions or unintended consequences. The analysis should at a minimum consider the following:

(A) Product function or performance.
(B) Useful life.
(C) Materials and resource consumption.
(D) Water conservation.
(E) Water quality impacts.
(F) Air emissions.
(G) Production, in-use, and transportation energy inputs.
(H) Energy efficiency.
(I) Greenhouse gas emissions (GHGs).
(J) Waste and end-of-life (EoL) disposal.
(K) Public health impacts, including potential impacts to sensitive subpopulations, including infants and children.
(L) Environmental impacts.
(M) Economic impacts.

Cost-benefit analysis (CBA) is among the methodologies that can be used for AA to evaluate the listed criteria, alone or in conjunction with other methodologies. CBA can be used to compare options on the basis of a common unit, the net present value (NPV). NPV is determined by assigning monetary values to benefits and costs, discounting future benefits and costs appropriately, and subtracting the total discounted costs from the total discounted benefits. Alternatives with a positive NPV are preferred while a negative NPV indicates an option that is not. CBA encourages a comprehensive enumeration of benefits and costs even when monetization is not possible, ideally using a life-cycle lens.

Professor Arpad Horvath and Dr. Jennifer Stokes of the University of California at Berkeley (UC Berkeley) assisted DTSC by preparing supporting information about using CBA and a related methodology, life-cycle cost assessment (LCCA), to compare alternatives using a life-cycle lens. This included summarizing existing guidelines and data sources, developing a CBA and LCCA tools comparative matrix, and describing relevant case studies. The supporting information provides documentation and support to green chemistry AA practitioners.

Summary of Cost-Benefit Analysis Methodology

Cost-benefit analysis or assessment, also referred to as benefit-cost analysis (BCA), compares alternatives, primarily in monetary terms, by calculating the ratio or sum of the alternative's favorable outcomes and the associated opportunity costs. The following description is summarized from the U.S. government guidance document on CBA (OMB 1992; USEPA 2010a).

A CBA should include a base-case or "no action" scenario which incorporates inevitable changes in future conditions independent of alternative selection. This base case is equivalent to the initial product containing the chemical of concern to be compared to alternatives in AA. The analysis should cover a specific time frame with a stated start and end date commensurate with the product life cycle. For each alternative, costs and benefits which occur at different points within the time frame should be discounted to account for the time-value of money. CBA results are commonly reported as a net benefit, subtracting the costs from the benefits when both are in terms of NPV or annualized value. CBA results may also be reported as a ratio of benefits and costs. However, the benefit-cost ratio (BCR) should be used with care because magnitude data will be lost, possibly skewing the results. See box below for more information.

An AA as required by AB1879, whether conducted using CBA alone or a combination of methodologies, should incorporate a life-cycle perspective, assessing the effects of manufacturing upstream, production, and downstream effects, including EoL impacts (e.g., disposal or reuse) if relevant. Table 1 lists many sources of costs associated with an alternative which may need to be included in the assessment, as quantified values or qualitative discussion [adapted from (USEPA 1995)]. This table is for guidance and is not intended to be exhaustive. To help focus on the differences, only costs that vary between alternatives in either magnitude or timing must be included in the AA if the results are reported as NPV or an annualized value.

What about Benefit-Cost Ratio?

Some CBAs report results in terms of a BCR, or the total benefits are divided by the total costs. If the BCR is greater than one, the alternative is preferred. If the BCR is less than one, the alternative is not. Many formal guidance documents caution against the use of the BCR metric because it loses important information about the magnitude of the results. For example, comparing two alternatives of costs and benefits (all in NPV):

- Alternative 1 has costs of $2,000 and benefits of $3,000. The BCR is 1.5. The net benefit is $1,000.
- Alternative 2 achieves the same goal with costs of $10,000 and benefits of $15,000. Again the BCR is 1.5. However, the net benefit is $5,000.

Though the BCR is the same, the alternatives are not equivalent. Alternative 2 has a higher NPV and would generally be preferred. On the other hand, perhaps short-term capital is limited or another budgetary constraint is present. In that case, Alternative 1 might be preferable. This distinction could not be made if the BCR is the only metric used. Furthermore, if using the BCR, ALL costs and benefits should be enumerated so the ratio is not skewed. When NPV is used, particular costs and/or benefits which are of equal magnitude and timing for all the considered alternatives can be excluded from the analysis, reducing the data requirements and making the analysis and calculations simpler. If the BCR metric is used in an analysis, attention should be paid to these possible pitfalls associated with its use.

Table 1: Some Sources of Direct and External Costs for all Life-cycle Phases

AA criteria	Upstream Activities (Production Phase)	On-site Activities (Use Phase)	Downstream Activities (Disposal Phase)
Note: Direct costs are listed in normal text. External or potentially hidden costs are shown in italics.			
(A) Product function.	Changes in yield rates	—	Co-products/ by-product value
(B) Useful life.	• Change in costs of raw material with different life • *Associated transport*	• Change in costs of input material with different life • *Associated transport*	• Changes in disposal costs of used products • *Associated transport*
(C) Materials & resource consumption.	• Changes in mass/volume of inputs manufactured • *Associated transport*	• Changes in mass/volume of materials processed • *Associated energy use (e.g., additional handling, pumping)*	—
(D) Water conservation.	• Upstream variations (e.g., process water recycling) • *Water scarcity conditions*	• Water requirements • Recycling/ reuse capacity • *Water scarcity conditions*	—
(E) Water quality impacts.	• *Upstream process emissions* • *Receiving water sensitivity*	• *On-site process emissions* • *Receiving water sensitivity*	• *Disposal emissions/leaks* • *Receiving water sensitivity*
(F) Air emissions.	• *Upstream process emissions* • *Sensitivity of local and/or regional air quality*	• *On-site process emissions* • *Sensitivity of local and/or regional air quality*	• *Disposal emissions/leaks* • *Sensitivity of local and/or regional air quality*
(G) Production, in-use, & transport energy inputs.	*Upstream and supplier transport emissions and energy use*	*Onsite transport emissions and energy use*	*Disposal transport emissions and energy use*
(H) Energy efficiency.	• *Energy consumption and recovery of upstream process* • *Upstream energy mix differences* • *Energy mix emissions*	• Energy consumption and recovery of on-site process • *Plant energy mix emissions*	• *Downstream energy consumption and recovery* • *Downstream energy mix differences and emissions*
(I) Greenhouse gas emissions.	*Emissions from upstream processes/ transport*	• Process emissions • *Electricity and vehicle/transport emissions*	*Emissions from downstream processes/ transport*
(J) End-of-life.	Disposal costs (see also Downstream Activities column)		--
(K) Public health impacts.	• *Carcinogenic & non-carcinogenic emissions* • *Effects of intermediates in production process*	• *On-site carcinognic and non-carcinogenic emissions* • *Intermediates effects* • *Process leaks*	• *Carcinognic and non-carcinogenic disposal emissions* • *Effects of intermediates of decay/ decomposition*
(L) Environmental impacts.	*Potential habitat change on sensitive flora/fauna*	*Potential habitat change on sensitive flora/fauna*	*Potential habitat change on sensitive flora/fauna*
(M) Economic impacts.	• Design • Facility construction • Capital equipment • Regulatory (e.g., permitting, reporting) • Insurance • Pollution prevention • *Training* • *Emergency response* • *Remediation* • *Legal*	• Market gains/losses • Labor • Supplies/consumables • Utilities • Marketing costs due to changes • Regulatory • *Personal injury damage* • *Legal fees, penalties, fines* • *Product's social acceptance* • *Image changes (e.g., customers, community, employees, lenders)*	• Closure/ decommissioning • Salvage value • *Post-closure care*

Adapted from: (USEPA 1995)

Table 2 provides examples of scenarios where CBA can be used to quantify the impacts of the criteria set forth in AB1879.

Table 2: Possible Scenarios for CBA Analysis

Assessment Criteria	Examples of scenarios where further analysis needed. If certain alternatives:
(A) Product function or performance	- function worse or better in some applications - affect sales or market share due to performance
(B) Useful life	- have shorter or longer life spans - require additional maintenance to achieve the same life - are more likely to be reused, offseting future sales.
(C) Materials and resource consumption	- consumes more (or less) volume of materials - use of a limited, non-renewable resource - are more likely to recycle waste during manufacture
(D) Water conservation	- require different water volumes for manufacturing or maintenance/ cleaning - need higher quality water (i.e., further treatment) - can reuse water, reducing overall consumption
(E) Water quality impacts	- discharge chemicals/contaminantsto water during manufacture, use, or disposal - may be disposed directly to water (e.g., plastic bags)
(F) Air emissions	- emit chemicals/contaminants to air during product manufacture, use, or disposal
(G) Production, in-use, & transportation energy	- have different energy needs in manufacture or use - require different fuel input due to material weight, transport mode, and/or distance
(H) Energy efficiency	- have potential for energy efficiency or recovery compared to other options
(I) Greenhouse gas emissions (GHGs)	- emit GHGs to air directly during manufacture or use - emit GHGs due to energy consumption during manufacture or use
(J) Waste and end-of-life disposal	- will be reused or recycled - produce hazardous or non-hazardous wastes during manufacture, disposal, or use - cause emissions during normal disposal
(K) Public health impacts	- will expose consumers to health impacts due to ingestion, inhalation, or dermal contact - creates an unsafe environment for workers or consumers, not categorized elsewhere
(L) Environmental impacts	- have different impacts to ecology (e.g.,habitat change, species loss) or other environmental impacts not captured by other criteria categories
(M) Economic impacts	- affect the price and/or life-cycle cost - will be affected by taxes or subsidies, etc.

Some challenges to the valuation process in CBA include:

- Identifying relevant internal and external costs and benefits, including changes to economic activity, consumer behavior, or technology due to the base case scenario and each alternative.
- Placing costs and benefits accurately in time.
- Defining the time frame to capture all costs and benefits without diluting the effects over time.
- Selecting an appropriate discount rate, especially for intergenerational effects.
- Avoiding double-counting of costs and benefits.
- Finding applicable valuation estimates for environmental costs and benefits.
- Selecting the best valuation for benefits when the effects vary across the population or location.

- Identifying and describing sources of uncertainty and sensitivity.

The reader should refer to the case studies in this report as well as other publicly-available documents to find guidance in addressing these challenges (see "Existing Guidelines Review" section of this report).

Related and Complementary Methodologies

Cost-effectiveness Analysis

In a cost-effectiveness analysis (CEA), the benefits of all alternatives under consideration are assumed to be the same (i.e., all meet the same goals with no additional positive or negative effects). The CEA can then focus on identifying the least cost alternative or combination of alternatives. It is primarily applicable in a regulatory setting. See (OMB 1992)**.**

Life-cycle Cost Accounting

Life-cycle cost accounting is used to analyze capital investments with trade-offs between up-front costs, long-term operation or maintenance (O&M) costs, and EoL costs. Like CBA, it accounts for costs over time and discounts them to a common unit, usually NPV or annualized costs. One good reference for LCCA was published by SETAC (Hunkeler, Kichtenvort et al. 2008). LCCA results are a useful input to CBA.

SETAC defines three useful categories for LCCA studies: Conventional LCCA, Environmental LCCA, and Societal LCCA, each described in the following sections. Because of the overlap between components of LCCA and CBA, certain tools and guidance documents about LCCA are described in this report.

Conventional LCCA

Conventional LCCA (CLCCA) is the best developed but least comprehensive methodology. A CLCCA is limited in scope, only considering the internal costs paid by one actor, generally the one performing the LCCA (e.g., the manufacturer, user, or consumer). Costs paid by other actors are ignored. As a result, life-cycle stages may be excluded if the main actor is not responsible for their costs. In the case of consumer products, this often includes EoL costs and use costs. CLCCA does not quantify life-cycle environmental effects such as water conservation, water quality impacts, air emissions, GHGs, disposal effects, or public health impacts. However, the guidance documentation for CLCCA can be helpful when identifying and analyzing the economic costs for CBA.

Environmental LCCA

Environmental LCCA (ELCCA) expands the scope of CLCCA by evaluating and quantifying the external costs and environmental effects. ELCCA evaluates the full life-cycle, regardless of who pays the costs, and therefore includes the perspectives of multiple actors (e.g., the supply chain: manufacturers, consumers, users). Essentially it combines CLCCA with life-cycle assessment (LCA, described below). The final results, however, are not in a single unit. Environmental effects are usually not monetized and, therefore, are reported separately.

Societal LCCA

Societal LCCA (SLCCA) has a societal perspective and attempts to capture the full range of costs: internal costs, external costs, and externalities. It covers the full life-cycle and may require a separate LCA (see following section for discussion) to identify those effects. Suggestions about ways to combine LCCA and LCA results can be found in Module J of Life-cycle Initiative's LCA Training Kit online. Ideally, all costs are monetized and can be discounted and reported in a single unit (e.g., dollars in a particular year). SLCCA is similar to CBA in scope if benefits are considered as negative costs. For the purpose of this report, SLCCA will be considered equivalent to CBA.

SLCCA is the least developed and most controversial form of LCCA due to the challenges, biases, and uncertainties inherent in monetizing externalities using environmental valuation. Environmental valuation is a subset of environmental economics which focuses on valuing and monetizing environmental or social goods. Several methods are used to estimate these values: market-based methods (e.g., producer/consumer surplus, defensive expenditures), surrogate market methods (e.g., hedonic pricing, travel cost method), and non-market methods (e.g., survey methods like contingent valuation and choice experiments). For more, see NOAA's website on environmental valuation and documents described in the valuation section. As examples, monetary estimates of air emission costs are found in two papers: (Matthews and Lave 2000) and (Matthews, Hendrickson et al. 2001).

Life-Cycle Assessment

Life-cycle assessment is a well-established methodology for systematically quantifying the environmental effects of a product, process, or decision from cradle to cradle (or grave). LCA focuses on the environmental inputs (e.g., energy, water, materials) and outputs (e.g., air, water, and land emissions, products, byproducts) of an alternative and it considers both direct and indirect (i.e., supply chain) effects. LCA often analyzes only environmental and human health effects. It does not include economic analysis. A summary of LCA and its applicability to the green chemistry field was previously published (Horvath and Chester 2011) and can be found at on the DTSC website.

Socio-Economic Analysis

Socio-economic analysis (SEA), like CBA and SLCCA, aims to compare the benefits and costs of a decision in primarily monetary terms. However, unlike a pure CBA, practitioners may report results in illustrative terms so that the social costs and distributional effects can be more clearly seen. In other words, it does not treat all dollars spent as equal, an implicit effect of CBA. CBA and SEA methodologies overlap significantly. Sometimes, they are virtually indistinguishable. It is not uncommon for the terms to be used interchangeably. SEA is required by the European Union (EU) Registration, Evaluation, Authorization, and restriction of Chemical substances (REACH) regulation, instituted June 2007. Several guidance documents for this methodology specifically geared toward the chemical industry and chemical [e.g.,(European Chemicals Agency 2011)] are included in the description of CBA guidance documents.

Comparison between Methods

Table 3 summarizes the main characteristics and components of each of these methodologies. Table 3 was adapted from a more detailed table found in (Hunkeler, Kichtenvort et al. 2008).

Table 3: Cost Methodology Summary [adapted from (Hunkeler, Kichtenvort et al. 2008)]

Aspect	CLCCA	LCA	ELCCA	*CBA and SLCCA*	SEA
Evaluates required criteria?	If combined with environmental analysis	If combined with economic analysis	Yes	*Yes*	Yes
Values quantified	Internal costs	Environmental effects (e.g., emissions, material/energy use, toxicity)	Internal costs and certain external costs that may be internalized	*Societal value-added internal costs and externalities (i.e., transfer payments excluded)*	Societal value-added internal costs and externalities using monetary or ranking/ weighting scale
Result	Single cost	Multiple emissions, impact categories, and/or single weighted value	Single cost plus separate, non-monetized LCA results	*Single cost plus enumeration of non-monetized costs*	Results presented separately to clarify tradeoffs for audience
Perspective	One main actor (either manufacturer, user, or consumer)	One or more actors (e.g., manufacturer, supplier, consumer)	One or more actors	*Society, including governments*	Society, including governments
Life cycle	Incomplete (phases ignored if costs not borne by main actor, e.g., use phase)	Complete, unless contribution of phase is insignificant (e.g., design phase)	Complete	*Complete (not necessarily implemented)*	Complete
Analysis model	Generally quasi-dynamic model	Steady-state model	Steady-state model	Generally quasi-dynamic model	Generally quasi-dynamic model
Reference unit	Item, product	Functional unit	Functional unit	*Functional Unit or System*	System
Discount cash flows	Recommended	NA	Recommended	*Recommended*	Recommended
Discount final result	Recommended (not necessarily applied)	NA	Not recommended, some results unmonetized	*Recommended*	Recommended for monetized values
Difference from CBA?	Excludes external oportunity costs and credits	Economic costs ignored; environmental effects quantified but not monetized	Simultaneous, consistent product LCA & sustainability assessment; environmental effects quantified but not monetized	--	Opportunity costs or credits considered; May be based on ranking rather than costs; results itemized so tradeoffs can be evaluated

Note: NA = Not applicable

Existing Guidelines Review

The CBA methodology has been formalized for the purposes of analyzing the effects of U.S. federal government regulations for three decades with the Office of Management and Budget's (OMB) Circulars A-4 and A-94. Other countries, states, agencies and non-governmental organizations have created

similar guidelines. Some guidelines are generally applicable while others are specific to particular components of the AA These existing guidelines provide detailed background reference material to help practitioners understand the CBA methodology and steps. Practitioners can use these and other available guidelines to adapt CBA to the AA process. A review of established, frequently-referenced, and readily-available guidance documents is provided below.

Existing CBA Guidelines Summary

The following list of selected guidelines, grouped by the guideline's developer, includes a summary of contents, a description of relevance to AA, and a link to the document's online location as of the publication of this report. With the exception of a few early documents defining the methodology, the selected guidelines were published recently. Guidelines for SEA analyses are also included because of the substantial overlap between these methodologies.

U.S. Office of Management and Budget

Circular A-4: Regulatory Analysis (September 2003)
Though the first sections of this document are not applicable outside of the regulatory environment, Sections D and E describe the analytical approaches, including CBA, and discuss how to identify and measure benefits and costs.
Link: http://www.whitehouse.gov/omb/circulars_a004_a-4/
Cite: (OMB 2003)

Circular A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs (October 1992)
The document's stated purpose is that it "provides general guidance for conducting benefit-cost and cost-effectiveness analyses. It also provides specific guidance on the discount rates to be used in evaluating Federal programs whose benefits and costs are distributed over time." Circular A-94 also provides a glossary of technical terms associated with the analysis; summarizes the elements of a CBA or CEA: rationale, explicit assumptions, alternative evaluation, and verification; requires inclusion of costs and benefits to society, not just to the government, including incremental benefits and costs (i.e., ignoring sunk costs) and interactive effects; recommends annually-updated discount rates for CBAs; and describes treatment of uncertainty and sensitivity analyses.
Link: http://www.whitehouse.gov/omb/circulars_a094/
Cite: (OMB 1992)

European Centre for Ecotoxicology and Toxicology of Chemicals

Environmental Impact Assessment for Socio-Economic Analysis of Chemicals (August 2011)
This guidance document was prepared by an industry group to help European companies use SEA to bring together risk assessment and economic considerations and comply with REACH requirements. Of particular interest, Appendix A to this document contains a questionnaire for systematically assessing possible substitute chemicals which, though created for REACH, can be adapted with minor changes. The text contains a case study CBA of banning of tributylin (TBT) (see appendix of this report) and includes a sample questionnaire for this and other chemicals.
Links: PDF available upon request at http://www.ecetoc.org/publications
Cite: (ECETOC 2011)

European Chemicals Agency

Guidance on the Preparation of Socio-Economic Analysis as Part of an Application for Authorisation (January 2011)

This document describes SEA, an umbrella term applied to CBA, CEA, and multi-criteria analysis (MCA). Generally speaking, CBA is the recommended approach when effects are mostly easily monetized and MCA when most impacts do not lend themselves to monetization. CEA can be used when alternatives have different costs but the same benefits or vice versa. The SEA method recommends the inclusion of distributional effects in the social costs, though not necessarily monetized. This is often, though not always, included in a CBA. The guidance document includes a checklist and a template for an SEA report, regardless of the approach chosen. Because this document was written for the REACH legislation, it includes examples and applications that apply to the AA process.

Link: http://guidance.echa.europa.eu/docs/guidance_document/sea_authorisation_en.pdf

Cite: (European Chemicals Agency 2011)

Assessing the Health and Environmental Impacts in the Context of Socio-Economic Analysis under REACH (2 volumes; Part 1: Literature Review and Recommendations and Part 2: The Proposed Logic Framework and Supporting Case Studies)

This pair of documents applies specifically to REACH but can be generally applied to other methodologies, like CBA, for which health and environmental impacts are important. Part 1 contains a specific description of the REACH compliance process which will not apply outside the EU. However, this is followed by a literature review relevant for evaluating human health impact using human and animal studies, identifying environmental risks, quantifying exposure, and economic valuation of the impacts- all of which can be applied to the California context with some modification. Part 2 contains case studies and step-by-step examples of a SEA as applied to tris(2-chloroethyl) phosphate (TCEP) and hexabromocyclododecane (HBCDD), two flame retardant chemicals. The former case study focuses on human health impacts while the latter emphasizes the environmental effects.

Links: http://echa.europa.eu/doc/reach/sea/reach_sea_part1.pdf and http://ec.europa.eu/environment/chemicals/reach/pdf/REACH%20SEA%20Part%202%20LogicFrame%20Final%20publ.pdf

Cite: (Risk and Policy Analysts Limited 2011a; Risk and Policy Analysts Limited 2011b)

European Commission

Technical Report of Methodology: Cost Benefit Analysis and Policy Responses (2000)

This report, prepared for the Environment Directorate-General, provides the background of and general methodology for assessing environmental issues using cost-benefit assessment, specifically it describes the methods used to prepare a 2001 report entitled *European Environmental Priorities: An Integrated Economic and Environmental Assessment*. Table A1.1 provides a summary of benefit estimates of a number of environmental problems in Euros, including climate change, acidification, tropospheric ozone, waste management, particulate matter (PM) or dust, and nuclear risks. It discusses the concepts of willingness-to-pay and willingness-to-accept as a means of estimating benefits.

Link: http://ec.europa.eu/environment/enveco/priority_study/pdf/methodology.pdf

Cite: (Pearce and Howarth 2000)

U.S. Environmental Protection Agency

Guidelines for Preparing Economic Analyses (December 2010)
These guidelines summarize CBA, as well as economic impacts analysis and distributional analysis and recommend environmental costs and benefits often be treated separately or with different models. The document includes detailed descriptions and examples of intergenerational and intragenerational discounting techniques, including shadow price of capital; a comprehensive glossary of relevant terms; and guidance on selecting and analyzing mortality, morbidity, and ecological benefits, including a literature review of studies on methodologies; and addresses the challenges of valuing social costs over time and assigning numeric values to social costs. It recommends using a default value of a statistical life of $7.9 million (2008$).
Link: http://yosemite.epa.gov/ee/epa/eed.nsf/pages/Guidelines.html
Cite: (USEPA 2010a)

Organization for Economic Cooperation and Development

Cost-Benefit Analysis and the Environment: Recent Developments- Executive Summary (February 2006)
This document is not intended to be a manual for CBA, unlike many others listed, but is a forum for discussing the issues surrounding CBA in evaluating environmental issues. It provides a summary of the history and theoretical foundations of CBA, as well as a brief discussion of the methodological steps, including determining standing, decision rules, valuation techniques, discounting, equity, sustainability and CBA, and benefits transfer. The full document, which was not reviewed, is available for purchase from OECD.
Link: http://www.oecd.org/document/62/0,3746,en_2649_34281_36144679_1_1_1_1,00&&en-USS_01DBC.html#Executive
Cite: (Pearce, Atkinson et al. 2006)

Existing LCCA Guidelines Summary

U.S. Department of Transportation

Life-cycle Cost Analysis Primer (August 2002)
This primer describes the steps to complete a CLCCA. It is written for analyzing transportation infrastructure, including examples and guidance that are specific to that application. However, much of the methodology applies more generally.
Link: http://isddc.dot.gov/OLPFiles/FHWA/010621.pdf
Cite: (USDOT 2002)

North Atlantic Trade Organization

Code of Practice of Life Cycle Costing (September 2009)
This manual for CLCCA implementation is intended for multinational programs, especially weapons and military systems. However, there are practical suggestions for any LCCA practitioner. The manual presents alternatives for breaking down costs and suggestions for presenting results. It includes a summary of cost forecasting models over the product life-cycle, including EoL, and discusses uncertainty and risk.
Link: http://ftp.rta.nato.int/public//PubFullText/RTO/TR/RTO-TR-SAS-069///$$TR-SAS-069-ALL.pdf
Cite: (North Atlantic Treaty Organization 2009)

Society of Environmental Toxicology and Chemistry (SETAC)

Environmental Life-cycle Costing (2008)

This is a comprehensive manual for performing conventional, environmental, and societal LCCA. It focuses primarily on the middle type, ELCCA, which combines elements of LCCA and LCA and reports economic and environmental results separately. ELCCA was previously discussed in the Related Methods section. It outlines forecasting and discounting, including long-term discounting for SLCCA. For ELCCA, it explores the challenges of units, boundaries, allocation, aggregation, and uncertainty for both LCC and LCA. An updated version of this manual with the same title was released in 2011.

Link: http://www.crcnetbase.com/doi/book/10.1201/9781420054736

Cite: (Hunkeler, Kichtenvort et al. 2008)

Environmental Valuation Guidance and Data Sources Summary

Several clearinghouses of environmental economic and valuation studies and data exist which may be useful to obtain case study information or results which can be applied to CBAs. However, prior to application of results to other situations, review the challenges of benefits transfer in one of the CBA guidance documents (e.g., [USEPA 2010, Pearce 2006]).

U.S. Environmental Protection Agency

National Center for Environmental Economics Internet Links and Reports

The "internet links" site contains a list of websites which are relevant for environmental evaluations, the list contains U.S. government documents, non-U.S. government documents, non-profit documents, professional associations and newsletters, academic and research groups, and journals. This extensive list contains most of the other data sources listed below and many others as well. The reports website catalogs over 300 downloadable reports both prepared by and prepared for EPA on the topic of environmental valuation, including past studies on specific regulations, guidance manuals, and valuations of basic resources (e.g., drinking water).

Links: http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/InternetLinks.html and http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/EnvironmentalEconomicsReports.html

Valuing the Protection of Ecological Systems and Services: A Report of the EPA Science Advisory Board

This document was written by academics for the EPA to address issues around ecological valuation. It addresses such challenges as creating a conceptual model of the underlying ecology, understanding the ecosystem services, supporting valuation using indicators and meta-analysis, and benefits transfer. It also addresses uncertainty and results communication. The concept is illustrated using an EPA-prepared assessment of the Concentrated Animal Feeding Operations (CAFOs) regulations and other examples. Each section about a valuation methodology is followed by a list of recommended further reading.

Link: http://yosemite.epa.gov/sab/SABPRODUCT.nsf/F3DB1F5C6EF90EE1852575C500589157/$File/EPA-SAB-09-012-unsigned.pdf

Cite: (USEPA 2009)

Valuing Mortality Risk Reductions for Environmental Policy: A White Pater DRAFT (December 2010)

This document contains a thorough literature review and meta-analysis of economic studies to determine the value of human life and includes stated preference and hedonic wage studies and addresses the challenges of benefits transfers, altruism, and cancer differential, among others.
Link: http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0563-1.pdf/$file/EE-0563-1.pdf
Cite: (USEPA 2010b)

Cost of Illness Handbook

This document contains estimates of costs associated with a variety of diseases, including cancers (stomach, kidney, lung, colorectal, and bladder), developmental effects (low birth weight, cleft lip and palate, limb reductions, cardiac abnormalities, spina bifida, cerebral palsy, down syndrome, and lead exposure), respiratory illnesses (asthma and acute respiratory diseases), and other symptoms (dry, itching eyes, headaches, sore or dry throat, unusual tiredness, sinus congestion, and dry or itchy skin).
Note: EPA is no longer updating this handbook.
Link: http://www.epa.gov/oppt/coi/index.html

Environment Canada Data

Environmental Valuation Reference Inventory

This database contains empirical environmental and human health valuation studies. Guidance on benefits transfer is available. It was created by Environment Canada in collaboration with EPA and the environmental agencies of Canada, Australia, France, the United Kingdom, and New Zealand.
Link: https://www.evri.ca/Global/HomeAnonymous.aspx

United Nations Environment Programme

The Economics of Ecosystems and Biodiversity in Business and Enterprise Edited by Joshua Bishop

The Economics of Ecosystems and Biodiversity (TEEB) book series was created to discuss the justification for and process of valuing impacts on ecosystems. This volume is specifically geared towards business applications. TEEB identifies four services that ecosystems and biodiversity can provide and which may be affected by businesses: provisioning services (providing, for example, food, timber, and freshwater); regulating services (e.g., climate regulation, water filtration, disease and pest control, flood protection); cultural services (e.g., recreation, spiritual inspiration); and supporting services (e.g., nutrient cycling). TEEB for Business and Enterprise includes guidance on how to identify a business's impacts and need for ecosystem services; measure and report those impacts; and scale the impacts to a business, rather than regional or national, scope. It can be used to inform valuation of water conservation, water quality impacts, air emissions, energy use, GHGs, and general environmental impacts.
Link: Draft online (as of January 2012): http://www.teebweb.org/ForBusiness/tabid/1021/Default.aspx.
The final version can be purchased from Routledge.com
Cite: (TEEB 2012)

World Business Council for Sustainable Development

Guide to Corporate Ecosystem Valuation: A Framework for Improving Corporate Decision-Making

Like the TEEB document described above, the corporate ecosystem valuation (CEV) focuses on valuing the environmental impacts to incorporate into a CBA. The CEV contains guidance for screening your business decision to determine whether ecosystem impacts will be important and then conducting an analysis, if needed. It contains a list of example companies and products that have completed CEVs using

this method which the WBCSD refers to as "road testers." This document also contains a list of additional guidance documents and data sources. The CEV guide can inform valuation of water conservation, water quality impacts, air emissions, energy use, GHGs, and other environmental impacts. Link: http://www.wbcsd.org/work-program/ecosystems/cev/downloads.aspx

Guidance Matrix

Table 4 presents a matrix of the significant characteristics of each document reviewed above. The table specifies guidance documents that were written for a regulatory context. These are useful for providing the background for and economic basis of CBA and to give U.S.-specific data to use in CBA. However, many aspects of a regulatory analysis (e.g., tax implications) are irrelevant for AAs. Other documents are written to assess a product, generally chemicals for the EU's REACH legislation, but the specifics of this regulation differ from the requirements of an AA. The practitioner will likely need to obtain information from documents within both categories for an AA. For example, the U.S.-based regulatory documents contain applicable guidance for selecting discount rates and values for life and health outcomes applicable in the United States. The REACH guidance gives examples of how the SEA methodology can be applied to chemicals and to the consumer products which utilize them. The environmental valuation guidance is intended to provide general resources for obtaining economic values for human health and environmental impacts which may be needed to complete a CBA for an AA.

Table 4: CBA and LCCA Guidance Comparison Matrix

Tool Name	Organization	Analyzes:	Geographic Focus	Description
Cost-Benefit Analysis Guidelines				
Circular A-4: Regulatory Analysis	OMB	Regulations	U.S.	General guidance/ background for CBAs
Circular A-94: Guidelines and Discount Rates for BCA…	OMB	Regulations	U.S.	Discount rate guidance is applicable to broader CBAs
Environmental Impact Assessment for SEA of Chemicals	ECETOC	Chemical Products	Europe	Includes questionaire about possible chemical substitutes and case studies
Guidance on the Preparation of SEA as Part of an Application for Authorisation	ECHA	Chemical Products	Europe	Specifies requirements of chemical alternatives analysis for REACH legislation
Assessing the Health and Environmental Impacts in the Context of SEA under REACH	ECHA	Chemical Products	Europe	Includes discussion of evaluating human health, environmental risks, and economic valuation
Technical Report of Methodology: CBA and Policy Responses	European Commission	Regulations	Europe	Contains cost estimates associated with certain environmental problems
Guidelines for Preparing Economic Analyses	EPA	Regulations	U.S.	Discusses environmental valuation techniques and challenges
CBA and the Environment: Recent Developments	OECD	Environmental Assessment	Developed Countries	Discusses evaluating environmental issues with CBA
Life-cycle Cost Accounting Guidelines				
Life-cycle Cost Analysis Primer	U.S. DOT	Infrastructure systems	U.S.	Provides general guidance for conventional LCCA
Code of Practice of Life-cycle Costing	NATO	Military systems	U.S./ Europe	Describes conventional LCCA; includes guide for presenting results
Environmental Life-cycle Costing	SETAC	Products	None.	Comprehensive manual for ELCCA
Environmental Valuation Data Sources				
National Center for Environmental Economics	EPA	Varies	U.S.	Portal for environmental valuation research.
Valuing the Protection of Ecological Systems and Services	EPA	Ecological valuation	U.S.	Discusses creating a model ecosystem services and associated valuation
Valuing Mortality Risk Reductions for Environmental Policy	EPA	Human health valuation	U.S.	Summarizes literature regarding value of human life.
Cost of Illness Handbook	EPA	Human Health	U.S.	Provides estimates of costs associated with many diseases
Environmental Valuation Reference Inventory	Environment Canada	Varies	U.S. and others	Database of studies valuing environmental & health benefits.
Economics of Ecosystems and Biodiversity in Business and Enterprise	UNEP	Ecological valuation	None.	Discusses valuing an ecosystem's provisioning, regulating, cultural, and supporting services
Guide to Corporate Ecosystem Valuation: A Framework for Improving Corporate Decision…	WBCSD	Ecological valuation	None.	Assists in including the value of environmental costs in business decisions and provides examples

Incorporating Existing Guidelines for CBA

The CBA methodology varies depending on the document but typically includes defining the goals and assumptions; identifying costs and benefits, including those which cannot be quantified; monetizing and discounting costs and benefits; and assessing uncertainty and sensitivity. Unfortunately, there is no perfectly applicable guidance document for using CBA for AA. The documents generally fall into two categories, those that apply to meeting U.S. regulation requirements and to analyzing European chemicals to comply with REACH. As a result, the practitioner must pick and choose among the documents, ignoring sections of irrelevant material to find useful information. As an example, two guidance documents, one with each focus, were selected to demonstrate what is required. To perform a CBA as part of an AA, the most helpful documents will likely be:

- Guidelines for Preparing Economic Analyses, USEPA, December 2010; and
- Guidance on the Preparation of SEA as Part of an Application for Authorisation, ECHA, January 2011.

These guidelines thoroughly describe the details of conducting a CBA and provide a thorough background of the methodology for practitioners. Though Guidelines for Preparing Economic Analyses is written for a regulatory application, it thoroughly describes the issues and challenges inherent in any CBA. Several chapters apply primarily to regulators (e.g., Chapters 1-4, 9). Later sections discuss how to set a baseline scenario; discounting cost and benefits, including social and intergenerational discounting; analyzing and valuing benefits, including economic value of human health and ecological benefits; benefits transfer; addressing non-monetized benefits; defining types of social costs; evaluating costs over time; distributional considerations (e.g., environmental justice and effects on children); and presenting results. Appendices outline the economic basis for CBA and certain valuation estimates.

As mentioned earlier, the Guidance from the ECHA specifically addresses the requirements of REACH, and therefore SEA. Some parts of the document are not applicable for AA. It includes many relevant topics such as setting boundaries; assessing economic, human health, and environmental impacts while focusing on the differences between scenarios; discounting and placing costs and benefits in time; comparing both monetized and non-monetized results; addressing uncertainty; and discussing specific challenges like avoiding double-counting and converting between currencies. The appendices include more detail on estimating impacts using quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs) and unit external cost estimates for various pollutants; valuation techniques, sensitivity and scenario analyses; and different methodologies within SEA (e.g., CBA, MCA). Appendix G is a checklist which may guide practitioners as they identify impacts.

Some other documents include discussions of the economic basis of CBA [e.g., (OMB 2003; Pearce, Atkinson et al. 2006)], comprehensive literature review [e.g., (Risk and Policy Analysts Limited 2011a)], specific examples or case studies [e.g., (ECETOC 2011; Risk and Policy Analysts Limited 2011b)] or useful valuation estimates [e.g., (Pearce and Howarth 2000)] which the practitioner might find helpful. These guidelines present or mention additional literature which may prove useful to practitioners. The

additional documents may address specific analytical issues, provide relevant examples, or include necessary valuation estimates.

Incorporating Existing Guidelines for LCCA

Life-cycle cost assessment focuses on the economic direct costs incurred through the lifetime of the process or product. It makes up an important component of a CBA. Several guidelines which discuss LCCA were identified. The most useful guideline is SETAC's *Environmental Life-cycle Costing*. It includes discussions of the history and development of the method; LCCA's limitations; modeling techniques (e.g., steady-state, dynamic, quasi-dynamic); uncertainty in cost data; discounting, including long-term effects; setting boundaries; identifying and monetizing external effects, and provides an overview of literature on life-cycle costing studies; and several specific case studies. The other guidelines, a transportation-oriented manual from DOT and a military-focused document from NATO, are more limited in applicability but include helpful information of presenting results. In addition, these documents may refer to additional documents or data sources that may be helpful with the LCCA aspects of the analysis.

Tools summary

This section summarizes several tools found to assist with CBA. The identified tools, especially the LCCA tools, could be useful to address specific aspects of an AA. No comprehensive tools were found.

Tool for Cost-Benefit Analysis

Few useful tools for CBA are publicly-available. No tools were identified which would guide a user through a CBA for a green chemistry AA. A tool which tracks costs and benefits is described below.

Cost-Benefit Analysis Template (by Engineering Solutions On-line)

This tool is an Excel-based calculator for CBA over a 10-year period. Costs and monetized benefits may be entered on separate worksheets. However, the tool does not provide guidance for identifying costs or benefits. The tool results include NPV, internal rate of return (IRR), and payback schedule. The free tool cannot be edited. To modify the tool, the user must pay a small fee.
Link: http://download.cnet.com/Cost-Benefit-Analysis-Template/3000-2077_4-10921909.html

Tools for Life-cycle Cost Accounting

LCCA tools can be used to assess the economic costs for some aspects which may be relevant to an AA.

Building Costs

Building Life-cycle Cost Program (BLCC 5.3) by National Institute of Standards and Technology

This tool was designed for analyzing federally-financed buildings (both new and existing) and has specific templates for certain applications and contracts. The previous version (BLCC4) software allowed the user to analyze private sector buildings. At the time of publication, the Department of Energy (DOE) website states that a module for the private sector will be added to BLCC5 in the future. In the meantime, many default values can be changed so the software can be applicable outside of the federal

context. BLCC can be used to analyze non-building investments, as long as the initial capital investment costs are lower than operating costs. The tool analyzes capital costs as well as energy, water, and O&M costs and provides results in terms of NPV and annual costs and can be downloaded free.
Link: http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc

DEEP Life-Cycle Cost Analysis Tool by Procura+ of ICLEI Europe

This Excel-based tool was developed to encourage Energy Efficient Procurement and is part of a toolkit is available online for free. Though developed in Europe, it allows the user to specify the currency and includes U.S. dollars. It can be used to analyze buildings and other facilities and includes a worksheet "Calculator" which can perform LCCA on specific pieces of equipment. In addition to NPV at the EoL, the tool calculates life-cycle energy and water use as well as carbon dioxide (CO_2) emissions. Results are presented in tabular and graphical format. This is the only tool that extends beyond CLCCA.
Link: http://www.procuraplus.org/index.php?id=4614 under "The Tools" section

Equipment Costs

Lean Maintenance: Life-cycle Cost (LCC) Calculator by World Class Manufacturing

This tool analyzes the LCC associated with a particular asset/equipment by analyzing investment and installation, maintenance, and energy costs. A simple, free tool is available on the web. An Excel-format tool is also available for a small fee. In addition, tools that estimate maintenance costs are also listed.
Link: http://world-class-manufacturing.com/LCC/lcc_calculation.html

Life-cycle Cost Analysis Tool (LCAT) for Chem/Bio Protection of Buildings by National Institute of Standards and Technology

This tool was developed to assist facility owners and manages in identifying cost-effective strategies to respond to and mitigate chemical and biological hazards, both natural and man-made. It includes four-office building case studies and covers protection costs (e.g., filter replacements, electricity for fan motors, heating and cooling) and event-related costs, based on the probability of an annual event. The tool may be useful in evaluating the distinction in costs between alternatives that require different degrees of chemical protection. The tool is free but registration is required.
Link: http://www.nist.gov/el/economics/lcat.cfm

Tools Matrix

Table 5 summarizes important aspects of the identified publicly-available CBA and LCCA tools. The table indicates whether the tool can be used to evaluate environmental costs in addition to economic costs. The DEEP LCC Tool is the only one that specifically evaluates environmental costs and it is limited to only energy consumption, water use and GHGs. Most tools will only help the practitioner assess costs associated with specific parts of the analysis (scope) which may not be relevant in all AAs, such as buildings and equipment.

Table 5: CBA and LCCA Tool Matrix

Tool Name and Developing Organization	Scope	Costs included		Fee Required	Results	Description and Applicability
		Financial	Environ-mental			
CBA Template by Engineering Solutions Online	General	X	X	Free; fee to edit.	NPV; IRR	• Can calculate any costs & benefits • Provides no guidance for monetizing costs & benefits
Building LCC Program (BLCC5.3) by National Institute of Standards and Technology	Buildings	X		Free	NPV; annual cost	• Evaluates LCCs of buildings; at the time of publication, the tool currently does not analyze private sector buildings • Does not independently evaluate all criteria outlined in AB 1879
DEEP LCC Analysis Tool by ICLEI Procura+ Campaign	Equip-ment	X	X	Free	NPV; limited LCA	• Evaluates LCC of water &/or energy consuming equipment; may apply to simple manufacturing processes • Calculates life-cycle energy, water use, & CO_2 emissions • Does not independently evaluate all criteria outlined in AB 1879
Lean Maintenance: LCC Calculator by World Class Manufacturing	Equip-ment / None	X		Free online; fee for Excel tool	NPV	• Analyzes installation, maintenance & energy costs for an asset/equipment • Provides guidance to estimate maintenance costs • Does not independently evaluate all criteria outlined in AB 1879
LCCA Tool (LCAT) for Chem/Bio Protection of Buildings by National Institute of Standards and Technology	Safety Equip-ment	X		Free\	NPV	• Accounts for capital & maintenance costs of protective devices (e.g., filters, fans) & of negative events (e.g., spills & releases) • Does not independently evaluate all criteria outlined in AB 1879
Acronym List:						
AB: Assembly bill CBA: Cost-benefit analysis ICLEI: International Council for Local Environmental Inititative IRR: Internal rate of return LCCA: Life-cycle cost accounting NPV: Net present value O&M: Operation and maintenance						

Case Study

The case study that follows was adapted from available literature to assist practitioners to apply CBA in AAs for safer products. It is a fictitious example that follows the steps of a typical CBA process, including: 1) establishing key assumptions, 2) identifying cost and benefits, 3) monetizing and discounting costs and benefits, 4) comparing results, and 5) discussing sensitivity and uncertainty. The case study is not meant to be comprehensive nor to explain the detailed steps for completing a CBA. It is intended to outline the basic principles that a practitioner should consider at each step. They are provided purely for illustrative purposes and does not necessarily represent real-world conditions or indicate how a chemical or product will be viewed, reviewed and evaluated by the DTSC or other regulating agency.

Two additional case studies, adapted from partial CBAs in publicly-available literature, are presented in the Appendix to illustrate specific aspects of the CBA process. For additional detail and step-by-step analytical assistance, practitioners should refer to the Existing Guidelines Review section of this report.

Selecting a material for baby bottles

Several years ago, consumers began to critique manufacturers for using polycarbonate (PC) in baby bottles. Studies have determined that PC bottles can leach a controversial chemical, bisphenol-A (BPA) into breastmilk, formula, and water in the bottles. Low-dose exposure to BPA, especially in fetuses, infants, and children, has been linked to a variety of health concerns, including genetic defects, cancer, impaired immunity, early-onset puberty, diabetes, obesity, aggression, reproductive problems, and hyperactivity (Environment California 2007).

BPA was banned in bottles and sippy cups nationwide in July 2012. This case study is a hypothetical but realistic CBA which could be conducted by a bottle manufacturer. Though some data used in this case study are based on relevant publications, most are based on a combination of data adapted from similar materials or processes, educated estimates, and assumptions. Data sources and uncertainties are described. *As stated earlier, this is a hypothetical case study and should not be cited as if it is a formal CBA of these materials or of baby bottles.*

The following steps to a CBA are specifically outlined in this report:

1) Establishing key questions and assumptions.
2) Identify costs and benefits, including direct, indirect, external, and unquantifiable costs.
3) Monetize and discount costs and benefits, as needed and as possible.
4) Compare results.
5) Discuss sensitivity and uncertainty.

Establishing key assumptions

Four categories of key assumptions are discussed in this section: goal and scope, discount rate, evaluation period, and functional unit.

Goal and Scope

The goal is to compare possible materials for baby bottles. It is a hypothetical CBA, but could have been created by a major bottle manufacturer who currently produces bottles made of PC. Due to a recent consumer and media campaign raising awareness of possible health concerns associated with BPA, a chemical which studies have shown to leach from PC bottles, the manufacturer wants to evaluate the long-term costs and benefits of continuing to manufacture PC bottles, the baseline or “do-nothing” scenario. They will also assess retrofitting their manufacturing plant, located in the U.S., to manufacture bottles made of an alternative plastic, polypropylene (PP), or glass for comparison.

In order to produce a comprehensive AA, the analysis will consider the criteria from AB1879 listed in the Introduction (A-M). For all thirteen of these criteria, each alternative will be assessed considering the full product life-cycle, specifically considering product manufacture, use, and disposal.

Discount Rate

The results of this CBA are reported in NPV. Current and future costs are in equivalent dollar values through a process called discounting. Discounting captures the time value of money, i.e., $1000 received

today is worth more than $1000 promised several years from now because it can be invested and earn interest and gain value over the time span. All costs in this case study are reported in 2012$.

In accordance with several guidance documents, the results will be bounded using discount rates of 3% and 7% (USEPA 2010a). The 3% rate estimates the value when spending offsets private consumption (i.e., costs are passed to customers who forego alternate purchases). It is based on the interest rate on government bonds. The 7% rate represents the future value if money were invested by the customer or manufacturer in capital assets based on the long term earnings of private investments. These discount rates are typical in the guidance documents described earlier in this report.

Though not relevant in the baby bottle case, the EPA recommends using a lower interest rate when the time horizon is intergenerational (i.e., when costs are paid by one generation and benefits accrue to another), estimated to be a period of over 50 years. A description of methods for intergenerational discounting, including using time-declining discount rates, are described in detail in (USEPA 2010a).

Evaluation Period

The manufacturer expects that whichever material is selected in this CBA process will be manufactured at this facility for the foreseeable future. However, if new materials are developed or new information is discovered about the risks associated with existing materials, the design and formulation of baby bottles may change. Accordingly, the analysis will use a mid-term evaluation period of 10 years.

Functional Unit

A common unit, known as the functional unit, must be selected for each of the three manufacturing scenarios (i.e., using PC, PP, and glass) to ensure that each is being evaluated on a level playing field. This study will assess the costs and benefits of producing one 10-ounce (~300 mL) bottle.

Alternate ways to frame a CBA

A CBA practitioner has options when framing a reasonable, defensible analysis. The best choice for a particular analysis depends on the study's purpose, audience, intended use, planning horizon (e.g., intergenerational), data available, and other factors. Other choices which could be used for this or other CBA analyses include:

- Adding a time component in the scenarios. For example, the manufacturer might consider a scenario that would maintain the status quo for five years and then adopt a new formulation for the remainder of the evaluation period, for instance, if a technology was still under development.
- Changing the functional unit, which in this example is one bottle. A CBA could also use a functional unit of:
  - The number of bottles necessary to hold a particular volume (e.g., one liter) Is an appropriate selection if the bottles produced would be of varying volumes, to avoid the uncertainty of scaling the bottle volumes.
  - A particular mass of bottles, regardless of volume held, e.g., one kg of manufactured bottles, a useful unit if interested in the comparing the materials and not the use of the product.
  - The demand for/ sales of bottles over a specified period, e.g., annually or monthly. This might be useful if the user wanted to report results in larger, more easily understood units. In this example, the results could be reported by the annual production of 1.5 million bottles.

Identify costs and benefits, including direct, indirect, external, and unquantifiable effects

In any CBA, distinguishing between costs and benefits can be challenging and may depend on the goal and perspective guiding the analysis. Different approaches for identifying and categorizing costs and benefits are discussed in the guidance documents. In this analysis, the factors are grouped together rather than defining "costs" and "benefits" separately. Costs will be identified with a positive value; benefits will be accounted as a negative value for each option. The final result is a total cost. In the final result, the preferred alternative will be the one with the lowest overall cost.

Why all costs and no benefits?

In this example, the avoided negative effects could have been considered benefits to some alternatives, rather than costs to others. The analysis results would have been the same if a different convention was used. It is simply necessary to explain the convention for defining what is a cost or benefit, be consistent, and avoid double-counting the effects.

AB1879 requires that AAs consider thirteen criteria. Not all criteria will be relevant to every AA. In some cases, the alternatives evaluated will have identical or negligible effects for certain criteria. Those criteria can be left unquantified and unmonetized, reducing the effort needed to complete the CBA.

Table 6 lists all thirteen required criteria and indicates the reasoning used to determine which criteria will be further explored in the case study. Table 2 provides examples of other scenarios where these criteria may be important. Certain criteria (E, F, G, H, I, J, K, and M) will be further evaluated based on the results of this qualitative screening process. These will be categorized into economic costs (subpoint M) and environmental and social costs (all other subpoints) and will be discussed in that order.

Table 6: Criteria Screening Table for Baby Bottle Case

Assessment Criteria	Further analysis for baby bottles needed?
(A) Product function or performance	No, performance and function will be unaffected.
(B) Useful life	No, life will be unaffected.
(C) Materials and resource consumption	Data available was insufficient to make this comparison.
(D) Water conservation	No, water use is not significantly different.
(E) Water quality impacts	Yes, water quality may be affected by manufacture and/or disposal.
(F) Air emissions	Yes, manufacture or disposal may affect air quality.
(G) Production, in-use, and transportation energy inputs	Yes, process and transport energy needs are different.
(H) Energy efficiency	No, all options have similar potential.
(I) Greenhouse gas emissions (GHGs)	Yes, materials may affect GHGs during manufacture and disposal.
(J) Waste and end-of-life disposal	Yes, materials may have different recycling rates and impacts for normal disposal.
(K) Public health impacts	Yes, risks to infants and children have been quantified.
(L) Environmental impacts	No, impacts identified were captured elsewhere.
(M) Economic impacts	Yes, economic impacts are always evaluated.

Economic Costs and Benefits

For baby bottles, the economic effects of a product decision for the baby bottle manufacturer include the effect on sales and profit margins for the three alternative materials: PC, PP, and glass. In a real-world business decision, the assessment should include a detailed business assessment (e.g., potential sales, market surveys) specific to the market and product and is best conducted by a knowledgeable professional. Though the results of this assessment may inform the CBA, the details are outside the scope of a typical CBA methodology. For simplicity, we assumed the total sales for the baby bottle market is unaffected by the material choice (i.e., the total number of bottles sold in the U.S., regardless of material or manufacturer, will not be changed with this decision) and total 1.5 million bottles.

The economic costs of producing 1.5 million bottles of PC, PP, and glass are presented in Table 7. They are categorized into five groups: capital costs, start-up costs, O&M costs, EoL costs, and indirect costs. The manufacturing facility currently produces PC bottles so there are no associated capital and start-up costs. The existing building must be expanded to accommodate the glass manufacturing process, increasing the capital and startup costs of that alternative. All costs are fictional and are merely intended to illustrate some costs that should be included in a complete CBA.

Table 7: Total costs to produce 1.5 million bottles annually

	Total Cost ($1000)[1]			
Cost Category	**PC**	**PP**	**Glass**	**Frequency**
Capital costs				
Facility expansion	0	0	4,000	Year 1
Equipment retrofit	0	1,500	1,200	Year 1
Startup costs				
Sales losses due to conversion	0	50	75	Year 1
Additional marketing costs	0	20	25	Year 1
Permitting costs	0	7	7	Year 1
Safety/ Pollution control	0	3	1	Year 1
Training	0	3	3	Year 1
Operation and maintenance costs				
Labor	0	75	0	annually
Material costs[2]	2,800	3,250	3,850	annually
Maintenance costs	125	75	50	annually
System upgrades	200	150	80	Year 5
Insurance costs	12	12	10	annually
Utilities				
Electricity	314	209	261	annually
Natural gas	210	125	200	annually
Water	170	100	120	annually
Other	200	140	150	annually
Transportation to distributors	115	80	180	annually
End-of-Life Costs				
Equipment salvage value	-50	-200	-350	Year 10
Indirect costs				
Disposal costs to customers	13	7.5	4	annually
Recycling costs to customers	5	7	8	annually

Notes:

[1] All costs are fictional and reported in terms of 2012$.

[2] Costs exclude the collar, nipple, & cap, all assumed to be independent of bottle material selection.

Environmental and Social Costs and Benefits

In addition to the economic costs, there are costs associated with the environmental and social impacts of these alternatives. Many of these are external costs borne by society rather than by the manufacturer and, as such, are typically excluded from a traditional business analysis.

The environmental emissions associated with manufacturing the PC, PP, and glass bottles were evaluated using publicly-available LCA data and are presented in Table 8 (see Table notes for references). For more information on the LCA methodology, see (Horvath and Chester 2011).

Table 8: Summary of Total Annual Environmental Effects and Associated Environmental Costs

		Annual effects[2]						Emission Cost[5]
		PC		PP		Glass		
	Units[1]	UP[3]	MANU[4]	UP	MANU	UP	MANU	($/unit)
(E) Water quality impacts								
Eutrophication potential	kg PO_4 eq	5.7E+01	*3.3E+03*	4.6E+01	*2.4E+03*	6.9E+02	2.9E+02	*$9.2*
(F) Air emissions								
Ozone depletion potential	g CFC-11 eq	1.2E-02	*1.5E+00*	*9.9E-03*	*1.5E+01*	*1.5E-02*	*8.6E-02*	*$0.31*
Acidification potential	g SO_2 eq	4.6E+02	*1.4E+02*	3.8E+02	*8.5E+01*	3.3E+02	6.2E+02	$0.0019
Photooxidizing chemical potential	g Ethene eq	9.9E+01	*5.2E+02*	5.7E+01	*2.3E+01*	3.2E+01	3.2E+01	*$0.26*
Particulate matter	kg	1.9E+00	*4.2E+00*	3.7E+01	*1.9E+01*	3.4E+01	1.5E+01	$2.9
(I) Greenhouse gases (GHGs)	kg CO_2 eq	2.5E+05	2.9E+04	1.2E+05	3.7E+04	8.4E+04	6.9E+04	$0.014
(J) Waste and end-of-life disposal								
Non hazardous	kg	1.2E+02	4.2E+03	1.5E+03	7.3E+03	*1.1E+02*	*3.0E+02*	*$0.06*
Hazardous	kg	*8.9E+03*	*3.7E+04*	3.1E+02	*1.4E+04*	1.6E+04	6.8E+03	*$0.78*

Acronyms:

CFC = Chlorofluorocarbon
CO_2 = Carbon dioxide
eq = equivalent
g = grams
kg = kilograms
MANU = Manufacturing effects
MJ = Million joules
PC = Polycarbonate
PO_4 = Phosphate
PP = Polypropylene
SO_2 = Sulfur dioxide
UP = Upstream effects

Notes:

1 Results normalized to representative compound; see [Horvath and Chester 2011] for more on impact assessment

2 The annual effects were estimated with documented data, when available; data gaps were filled with fictitious data. Fictitious data is identified in italics. Use phase impacts not estimated because they will be the same for all options.

3 Upstream impacts are based on a LCA of producing and transporting raw materials inputs (PC, PP, glass) for bottles. Sources:
- Polycarbonate (PC) Eco-profile and Environmental Product Declarations of European Plastics Manufacturers, Plastics Europe, March 2011
- Environmental Product Declaration: Polypropylene (PP). Plastics Europe
- Danish EPA, Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks, Report #401, Ministry of Environment and Energy- Denmark, 1998

Plastics Europe reports found at: http://www.plasticseurope.org/plastics-sustainability/eco-profiles/browse-by-list.aspx

4 Manufacture includes onsite emissions during manufacturing and transport to the consumer. Manufacture data, excluding final transport, for plastics is from "Injection Moulding of PVC, HDPE, and PP", Plastics Europe, Feb 2010. PVC data used for PC. Glass data are from the Danish EPA report. Transport to consumer uses data from Facanha and Horvath, "Evaluation of life-cycle air emissions or freight transportation, *Environmental Science & Technology*, 41(20):7138-7144, 2007.

5 Documented external costs for GHGs, PM, and SO_2 are from (Matthews and Lave 2000) and inflated using a 3% annual rate.

Published data was used to provide representative results, but they should not be considered accurate. The studies used applied to, and were not adjusted to account for, different:

- scope (e.g., the glass bottles were intended to be refilled and resold after the original use, though we attempted to remove the effects of transportation associated with reuse),
- geography (e.g., both used European data which, for example, affects the emissions associated with electricity production),
- materials (e.g., the manufacturing process associated with PC bottle was approximated using information for producing a PVC product because no better data was available), and
- products (e.g., the glass bottle results are for soft drink bottles of a different size and thickness).

Since this example is only intended to illustrate the CBA process, little effort was made to adjust the available information. In a real-world CBA, product-specific data should be developed or the published data should be corrected for these differences. When this is not possible, as in this case, the limits of the data should be specifically identified.

Table 8 also includes estimates of the external costs associated with the environmental emissions. The costs for GHGs, PM, and acidification potential (in terms of SO_2 emissions) were estimated using median estimates from (Matthews and Lave 2000), which were converted to 2012$ using a 3% annual inflation rate. Other emission unit costs, shown in italics, are fictitious.

A requirement of the AB 1879 regulation is to analyze energy use of each alternative (subpoint G). The energy consumption for each material is summarized in Table 9. It is reported separately because the upstream and direct emissions attributed to this energy consumption are already included in the emissions results Table 8. Data shown in italics are fictitious.

Another source of external costs is the health effect of exposure to BPA and other contaminants during the bottle's use. Several studies have confirmed that BPA can leach into the contents of baby bottles. A literature review in (Environment California 2007) reported that the PC bottles leached between 5-10 ppm into bottles per test; the experiment conditions (e.g., liquid in the bottle, temperature, test duration) varied. A more recent study, (Kubwabo, Kosarac et al. 2009) established that PC bottles can leach almost 1.8 ppm in a 24-hour period, though the study is criticized for using boiling water in the bottles. Non-PC plastic bottles leached BPA at much lower rates (<0.10 ppm). Li (2011) determined that an infant might have uptake rates of approximately 1340 ng/day at 40°C, the approximate body temperature of the mother.

Note: There is significant debate about the long-term effects of exposure to BPA from PC bottles. The Environmental Working Group, an advocacy group, states on their website that the concentrations leached into bottles are lower than EPA's lowest adverse effect level (LOAEL; 50 μg/kg/d) at normal use temperatures (see http://www.ewg.org/node/25572) . For the sake of illustration, the remainder of this study is fictitious based on the controversial and possibly false assumption that BPA has a long-term effect on the quality of life of those exposed as infants through baby bottle use. Also, to enhance the

What other benefits might be important?

One limitation of selecting baby bottles as a case study is that there is no good substitute for it. The value to a baby's caretaker is virtually infinite when breastfeeding is not an option or may be close to zero when it is. In other words, the option to not purchase baby bottles is not realistic for many parents. As a result, the benefits of baby bottles are also enormous (e.g., survival of countless children) but are not included because they apply to the alternatives equally.

However, there could be cases where the existence of a particular alternative does accrue broad social benefit that should be credited. Perhaps a particular fragrance, when added to a cosmetic, personal care, or cleaning product, has been shown to increase well-being, calmness, and/or confidence in its users. The CBA might include a willingness-to-pay analysis of that fragrance to monetize the benefit of using that scent.

illustration, the external costs of the alternatives are likely exaggerated in this case study.

Table 9: Summary of Energy Use per bottle

	Energy Consumption (MJ per bottle)[1]					
	PC		PP		Glass	
Fuel type	**UP[2]**	**MANU[3]**	**UP**	**MANU**	**UP**	**MANU**
Electricity	*3.9*	0.33	*2.4*	0.21	*4.4*	*0.27*
Transport fuel	--	0.18	--	0.19	--	0.44
Total Energy	4.3	1.3	3.0	1.0	5.0	0.78

Acronyms:

MANU = Manufacturing effects
MJ = Million joules
PP = Polypropylene
UP = Upstream effects

Notes:

1 Consumption was estimated with documented data when available; data gaps were filled with fictitious data (in italics). Use phase impacts will be the same for all options.

2 Upstream impacts are evaluated based on a LCA of producing and transporting the raw material inputs (PC, PP, or glass) for the bottles. Sources (see Table 11 note for reference): PC: Polycarbonate (PC) Eco-profile, Plastics Europe 2011; PP: Environmental Product Declaration: Polypropylene (PP). Plastics Europe; Glass: Danish EPA 1998

3 Effects include onsite emissions during the manufacturing and transport to the consumer. Manufacture data, excluding final transport, for plastics is from "Injection Moulding of PVC, HDPE, and PP", Plastics Europe, 2010. PVC data used for PC. Glass from (Danish EPA 1998). Transport to consumer is from (Facanha & Horvath 2007).

Mortality costs are evaluated using an estimate of the value of a premature death of $7.9 million in 2008$ (USEPA 2010a). In 2012$, this corresponds to $8.9 million, assuming a discount rate of 3% and $10.5 million using a 7% discount rate. Morbidity costs and all other italicized values are fictitious. Table 10 summarizes the human health effects associated with each bottle alternative.

Unquantifiable Costs

Some costs were identified but could not be quantified. Examples include:

- Bottle breakage was implicitly assumed to be negligible in this assessment. If breakage of glass bottles is significant, it may decrease the useful life and/or increase the costs of glass bottles over the plastic alternatives. Associated injury costs may also increase costs.
- Bottles were assumed to be used for one infant. Bottles of a particular material may be more likely to be reused, thus offsetting additional purchases and decreasing annual sales.
- Glass bottles may be boiled for sterilization, reducing contamination by pathogens and possibly avoiding disease. The avoided diseases are a benefit to glass bottles but were not quantified. Conversely, the energy and water costs of boiling the bottles would increase costs as well.

If these costs could have been quantified, the effect on the final result would likely be negligible.

Table 10: Human Health Effects of Baby Bottles

Disease/Effect	Dose µg/kg/d	Human Health Effects per 1.5 million bottles PC	PP	Value (2012$, unless noted)
Toxicological Studies - Mortality Effects		**Premature Deaths Caused**		**per death[1]**
Increased breast cancer[2]	250 - 250,000	*0.39*	*0.035*	$ 7,900,000
Increased prostate cancer risk/treatment interference	NA	*0.051*	*0.0030*	$ 7,900,000
Toxicological Studies - Morbidity Effects		**DALYs**		**per DALY**
Damage to developing eggs[3]	20	*0.96*	*0.013*	*$ 2,100*
Early onset of puberty[2]	2.4 - 50	*0.92*	*0.019*	*$ 950*
Obesity at birth and in adulthood[2]	100	*2.7*	*0.063*	*$ 5,500*
Obesity in offspring[2]	2.4 - 500	*6.2*	*0.14*	*$ 5,500*
Diabetes[3]	10	*0.52*	*0.0082*	*$ 2,600*
Hyperactivity[2]	30	*0.82*	*0.019*	*$ 300*
Aggression[4]	2 - 40	*0.64*	*0.013*	*$ 300*
Changed response to fear/pain[2]	40	*0.91*	*0.021*	*$ 300*
Impaired learning and memory[2]	100	*2.6*	*0.069*	*$ 300*
Changed gender difference in brain/ behavior[2]	30	*0.70*	*0.017*	*$ 450*
Decreased maternal behavior[2,3]	10	*0.26*	*0.005*	*$ 650*
Altered play and socio-sexual behaviors[2]	40	*0.88*	*0.049*	*$ 600*
Impaired immunity[2]	2.5 - 300	*3.7*	*0.13*	*$ 800*
Sperm defects[2]	20	*1.2*	*0.088*	*$ 1,750*
Sperm defects[4]	2	*0.99*	*0.069*	*$ 1,750*
Sperm defects[3]	5-100	*3.4*	*0.044*	*$ 1,750*
Female reproductive development[2]	0.1	*0.26*	*0.0120*	*$ 1,850*

Notes: Values in italics are fictitious.

[1] The value of $7.9 million is in 2008$ (USEPA 2010). It was inflated to 2012$ using the 3% and 7% rate to analyze the final mortality results.

[2] In adult mice or rats

[3] In offspring of doses to pregnant and/or lactating mice or rats

[4] In infant or young mice or rates

Monetize and discount costs and benefits, as needed and as possible

The monetized results, using annual discount rates of 3% and 7% to bound the likely results, are shown in Table 11.

Table 11: Summary of Costs per bottle produced over a 10-year period

	Cost Category	NPV per bottle produced ($, 3% discount rate) PC	PP	Glass	NPV per bottle produced ($, 7% discount rate) PC	PP	Glass
Economic Costs	Capital	$ -	$ 0.10	$ 0.35	$ -	$ 0.10	$ 0.35
	Startup	$ -	$ 0.0055	$ 0.0074	$ -	$ 0.0055	$ 0.0074
	O&M	$ 2.26	$ 2.32	$ 2.75	$ 1.86	$ 1.91	$ 2.26
	End-of-Life	$ (0.028)	$ (0.11)	$ (0.20)	$ (0.023)	$ (0.094)	$ (0.16)
	Indirect	$ 0.010	$ 0.0082	$ 0.0068	$ 0.0084	$ 0.0068	$ 0.0056
Environmental and Social Costs	Water Quality	$ 0.018	$ 0.013	$ 0.0051	$ 0.014	$ 0.011	$ 0.0042
	Air Emissions	$ 0.00010	$ 0.00011	$ 0.000090	$ 0.000084	$ 0.000087	$ 0.000074
	GHGs	$ 0.0023	$ 0.0013	$ 0.0013	$ 0.0019	$ 0.0011	$ 0.0010
	Waste/end-of-life	$ 0.021	$ 0.0066	$ 0.010	$ 0.017	$ 0.0054	$ 0.0083
	Health: Mortality	$ 2.31	$ 0.201	--	$ 1.90	$ 0.166	--
	Health: Morbidity	$ 0.039	$ 0.00099	--	$ 0.032	$ 0.00081	--
Economic Cost Subtotal		$ 2.24	$ 2.32	$ 2.91	$ 1.84	$ 1.93	$ 2.46
E & S Cost Subtotal		$ 2.39	$ 0.223	$ 0.017	$ 1.97	$ 0.184	$ 0.014
Total		**$ 4.62**	**$ 2.54**	**$ 2.92**	**$ 3.81**	**$ 2.11**	**$ 2.47**

Acronyms: GHGs = Greenhouse gas NPV = Net present value O&M = Operations and maintenance
PC = Polycarbonate PP = Polypropylene

Note: All costs are fictitious.

Compare results

The results in Table 11 illustrate that though the economic costs of PC bottles are the lowest, when environmental and social costs are included in the analysis, it is the least preferable alternative. In fact, the external costs of PC are greater than the economic costs. This illustrates the importance of including these external costs in the analysis.

Discuss sensitivity and uncertainty

Sensitivity and uncertainty are important to the analysis. A CBA requires the practitioner to select a single value estimate for many variables (e.g., economic costs, production emissions) and/or controversial inputs (e.g., chemical exposure risk from manufacturing emissions, value of health effects).

A sensitivity analysis tests the robustness of the results to particular assumptions. Some of the selected parameters can have a significant effect on the final result. The sensitivity to discount rate has already been analyzed by testing two reasonable discount rates, 3% and 7%.Two other input parameters were selected for sensitivity analysis: the value estimates for premature death and morbidity effects. These estimates are highly uncertain and, in the case of premature death, are the largest contributors to the

non-economic cost results. The sensitivity was tested by assuming each parameter value was changed by ±15%. The final results considering these assumptions are shown in Table 12.

Table 12: Results of Sensitivity Analysis

Sensitivity Assumptions	NPV per bottle produced ($, 3% discount rate)			NPV per bottle produced ($, 7% discount rate)		
	PC	pp	Glass	PC	PP	Glass
Original Results	$ 4.62	$ 2.54	$ 2.92	$ 3.81	$ 2.11	$ 2.47
Premature Death Valuation (-15%)	$ 4.28	$ 2.51	$ 2.92	$ 3.90	$ 2.12	$ 2.47
Premature Death Valuation (+15%)	$ 4.97	$ 2.57	$ 2.92	$ 4.60	$ 2.18	$ 2.47
Morbidity Effects Valuation (-15%)	$ 4.62	$ 2.54	$ 2.92	$ 3.80	$ 2.11	$ 2.47
Morbidity Effects Valuation (+15%)	$ 4.63	$ 2.54	$ 2.92	$ 3.81	$ 2.11	$ 2.47

Note: All results are fictitious.

The effect of a small change in the value of premature death has an appreciable effect on the final results. This effect, however, is not enough to change the final conclusions of the results. Because no health effects were associated with glass bottles, those results did not change.

For parameters that are uncertain, an estimate of the degree of their variability is helpful to understand and contextualize the results. Table 13 shows fictitious estimates of uncertainty of input parameters. For context, a formal uncertainty analysis (e.g., Monte Carlo analysis) can be conducted to evaluate how the results can change when multiple combinations of values within the reasonable range are used in the analysis. If conducted, the results of a formal uncertainty analysis might be illustrated by Figure 1.

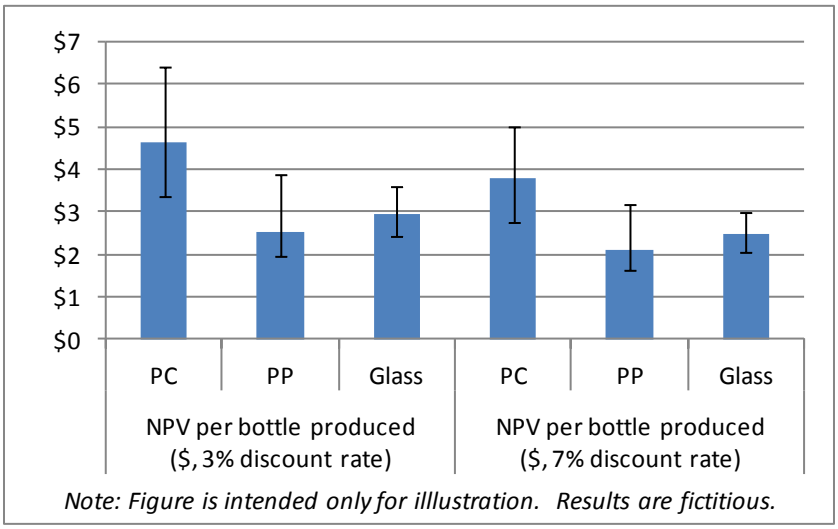
Table 13: Uncertainty Estimates for Input Parameters

Parameter	Lower Bound (%)	Upper Bound (%)
Economic Costs	-15%	+25%
Environmental Emission Estimates	-15%	15%
Environmental Emission Valuations	-25%	+25%
Health Effect Estimates	75%	+25%
Health Effect Valuations	175%	+25%

Note: All values are fictitious.

The results of the uncertainty analysis show that PC results are higher and more uncertain than other alternatives. This is because PC has higher external costs than the other alternatives; external effects tend to be more uncertain (see Table 13). Glass has the greatest certainty. Though the “average” result is higher for glass than PP, the highest and lowest estimates are within the range of PP.

Figure 1: Uncertainty Results with Error Bars



Recommendations for Future Work

This report was completed during the initial stages of the California Green Chemistry Initiative. Future projects can expand the tools and resource materials available for CBA's use in AA. The tools, guidelines, and case studies discussed herein describe the CBA framework and relevant resources. Additional resources will strengthen and ease AA implementation. Recommendations for additional work follow:

- Develop a method to guide a practitioner to identify all the relevant costs and benefits for their scenario and alternatives. This may a checklist or included in a decision-support tool.
- Create a decision-support tool to help quantify, track, and value costs and benefits for AAs. Though many guidance documents on CBA and LCCA exist, few CBA tools readily available. Ideally a tool could be made to automate the steps of identifying costs and benefits, tracking costs, placing them in time, discounting values, presenting the results, and assessing sensitivity and uncertainty.
- Appropriate valuation data is difficult to find and apply to specific situations. Developing a comprehensive database of valuation studies which are appropriate for industry in California for use in CBAs would make the AA process more efficient.
- Because the external life-cycle effects must be evaluated in an AA, as mentioned by (Horvath and Chester 2011), "the availability of California product-specific LCA data will be needed and the Green Chemistry Initiative should explore the possibility of developing and maintaining a database for practitioners.

List of Abbreviations

AA	Alternatives Assessment
AB1879	California Assembly Bill 1879
BCA	Benefit-cost Analysis (or CBA)
BCR	Benefit/Cost Ratio
£	British pound
BPA	Bisphenol-A
CBA	Cost-benefit Analysis (or BCA)
CEA	Cost effectiveness analysis
CEV	Corporate Ecosystem Valuation
CLCCA	Conventional LCCA
CO_2	Carbon dioxide
d	day
DALY	Disability-adjusted life-year
DOE	Department of Energy
DOT	Department of Transportation
DTSC	Department of Toxic Substances Control
€	Euro
ECHA	European Chemical Agency
ELCCA	Environmental LCCA
EoL	End of Life
EPA	Environmental Protection Agency
EU	European Union
g	grams
GHGs	Greenhouse gases
IRR	Internal Rate of Return
kg	kilograms
L	Liter
LCA	Life-cycle assessment or analysis
LCC	Life-cycle Costing
LCCA	Life-cycle cost assessment or accounting
LOAEL	Lowest Adverse Effect Level
MCA	Multi-criteria analysis
µg	micrograms
MJ	Megajoules
ml	Milliliters
NA	Not applicable
NATO	North Atlantic Treaty Organization
ng	Nanograms
NOAA	National Oceanic & Atmospheric Administration
NO_x	Nitrogen oxides
NPV	Net Present Value
OECD	Organization for Economic Cooperation & Development
OMB	Office of Management and Budget
PC	Polycarbonate
PM	Particulate matter (dust)
PP	Polypropylene
ppm	parts per million
PVC	Polyvinyl chloride
O&M	Operations and maintenance
QALY	Quality-adjusted life-year
REACH	Registration, Evaluation, Authorization & Restriction of Chemical Substances
SEA	Socio-economic Analysis
SETAC	Society of Environmental Toxicology & Chemistry
LCCA	Societal LCCA
SO_2	Sulfur dioxide
TBT	Tributyl tin
TEEB	The Economics of Ecosystems & Biodiversity
tonne	metric ton
UNEP	United Nations Environmental Programme
VOC	Volatile organic compound
WBCSD	World Business Council for Sustainable Development

Glossary

Definitions below are guided by the purpose and scope of this report. Some terms may have broader meaning or implications not discussed because they are not relevant to this report.

Annual cost: The sum of the annualized non-recurring costs and yearly operating costs. Calculating annualized costs requires that non-recurrent (e.g., capital, plant down-time) costs of an alternative are equalized over its lifetime using an appropriate discount rate. (Based on [European Commission 2011])

Baseline scenario: A term to describe the status quo or "business as usual" case that would occur if no action was taken. It should always be included in comparison with alternative scenarios. (Based on [European Commission 2011] and (USEPA 2010a))

Benefits: The positive outcomes, both direct and indirect, resulting from an alternative. (Based on [European Commission 2011])

Benefit/cost ratio (BCR): The ratio of the NPV of benefits associated with a project or proposal, relative to the NPV of the costs of a project or proposal. The ratio indicates the benefits expected for each dollar of costs. Note that this ratio is not an indicator of the magnitude of net benefits as two projects with the same BCR may have vastly different estimates of costs and benefits. (USEPA 2010a)

Capital Asset: Tangible property, including durable goods, equipment, buildings, installations, and land. (Based on (OMB 1992))

Capital costs: Costs to purchase capital assets, generally one-time or infrequent costs.

Conventional Life-cycle Costing: An assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the life cycle. ((Hunkeler, Kichtenvort et al. 2008)

Costs: The negative outcomes, both direct and indirect, resulting from an alternative, including both financial and non-financial information. (Based on [European Commission 2011])

Cost benefit analysis (CBA): Analysis which quantifies, in monetary terms if possible, costs and benefits of an alternative , including items for which the market does not provide a satisfactory measure of economic value. The calculation of net benefits helps ascertain the economic efficiency of a regulation. (Based on [European Commission 2011]) and (USEPA 2010a). Also referred to as Benefit Cost Analysis.

Cost effectiveness analysis (CEA): A systematic quantitative method used to identify the least-cost alternative (or combination of alternatives) to achieving the same benefits of objective. (Based on [European Commission 2011] and (OMB 1992))

Discounting: A method used to convert future or past costs and benefits to present values (or a common point in time) using a discount rate. (Based on [European Commission 2011] and (Hunkeler, Kichtenvort et al. 2008))

Discount rate: A value used to convert a future income (or expenditure) stream to its present value. It indicates the annual percentage rate at with the present value of a future dollar, or other currency, is assumed to decrease over time. (Based on [European Commission 2011])

Distributional impacts: These show how an alternative may differentially affect different regions, workers, consumers, or industries in the supply chain. (Based on [European Commission 2011])

End of life (EoL): EoL processes include all processes after the use phase in the life cycle of a product, such as collection, disassembly, re-use, recycling, composting, landfill, and/or incineration. (Hunkeler, Kichtenvort et al. 2008)

Environmental impacts: Impacts on all environmental compartments. Covers all use and non-use values of all the affected environmental compartments. (Based on [European Commission 2011])

Environmental cost: Two definitions exist: 1) environmental damage expressed in monetary terms, the cost of externalities and external effects. 2) The market-based cost of measures to prevent environmental damage, including EoL, processes. Market-based costs are part of life-cycle costing. (Hunkeler, Kichtenvort et al. 2008)

Environmental life-cycle costing: An assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle (e.g., supplier, manufacturer, user or consumer, or EoL actor) with complementary inclusion of externalities that are anticipated to be internalized in the decision-relevant future. Environmental LCC requires an accompanying LCA and a consistent pillar of sustainability. (Hunkeler, Kichtenvort et al. 2008)

External cost: Two definitions exist: 1) Cost of externalities, as welfare effects. Being non-market effects, they are measured by other means, as through surveys of WTP. 2) Cost, as market cost, not directly borne by an organization in terms of costs of labor, capital, and tazes, but as costs for purchases from other firms in the system, covering the internal costs of these other firms. (Hunkeler, Kichtenvort et al. 2008)

Externalities: The non-market impacts of an activity not borne by those who generate them and not included in the price. (Based on [European Commission 2011) and (Hunkeler, Kichtenvort et al. 2008))

Health impacts: Impacts on human health, including morbidity and mortality effects and related health-related welfare effects, lost production due to workers' illness, and health care costs. (Based on [European Commission 2011])

Internal costs: Costs directly borne by an individual or organization in supplying or consuming a product, as value added by the firm (capital and labor costs). Complement of second definition of external cost. (Hunkeler, Kichtenvort et al. 2008)

Internal Rate of Reture (IRR): The discount rate that sets the NPV of the stream of benefits equal to zero. The IRR may have multiple values with the stream of benefits alternates from negative to positive more than once. (Based on (OMB 1992)

Life-cycle (LC): All processes or activities involved in having a unit of function of a product, including all life-cycle stages, from primary materials production and manufacturing through use to final disposal activities (physical life cycle concept). (Hunkeler, Kichtenvort et al. 2008)

Multi-criteria analysis (MCA): A technique that involves assigning weights to criteria, and then scoring options in terms of how well they perform against those weighting criteria. Weighted scores are summed and used to rank alternatives. (Based on [European Commission 2011])

Net present value (NPV): Present value is the difference between discounted value of a stream of future costs and discounted future benefits. NPV is the value today of a project, an investment, or policy. It is calculated as the sum of discounted streams of costs and benefits related to the activity in question. (Based on [European Commission 2011] and (OMB 1992))

Opportunity cost: The maximum worth of a good or input among possible alternative uses.

Private costs: The costs to a group or sector of implementing a policy, as opposed to social costs. (Based on [European Commission 2011])

Real or Constant Dollar Values: Economic units measured in terms of constant purchasing power. The real value is not affected by general price inflation. Real values can be estimated by deflating nominal values with a general price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index.

Sensitivity analysis: A "what-if" type of analysis to changes in parameters. If a small change in a parameter causes a relatively large change in outcome, the outcomes are said to be sensitive to that parameter. (Based on [European Commission 2011])

Shadow Price: An estimate of what the price of a good or input would be in the absence of market distortions, such as externalities of taxes. For example, the shadow price of capital is the present value of the social returns to capital (before corporate income taxes) measured in units of consumption. (Based on (OMB 1992))

Social costs: Denotes the opportunity cost to society and includes also external costs or externalities. (Based on [European Commission 2011])

Social impacts: All relevant impacts which may affect workers, consumers, and the general public and are not covered under health, environmental, or economic impacts (e.g., employment, working conditions, job satisfaction, worker education, and social security). (Based on [European Commission 2011])

Societal life-cycle costing (SLCC): An assessment of all costs, including costs of externalities, associated with the life cycle of a product that are covered by any actor in society. Transfer payments are not considered in societal LCC. (Hunkeler, Kichtenvort et al. 2008)

Socio-economic analysis (SEA): A tool to evaluate what costs and benefits an action will create for society by comparing what will happen if this action is implemented as compared to the baseline scenario. (Based on [European Commission 2011])

Supply chain: The system of organizations, people activities, information, and resources involved in moving a substance from supplier to consumer, including manufacturers and distributors for all component parts. (Based on [European Commission 2011])

Transfer payment: (or "transfers") The transfer of money or goods between sections of society. They do not represent an overall cost to society, simply a redistribution of value, e.g., taxes and subsidies. (Based on [European Commission 2011])

Uncertainty: A state present in a situation where related parameters are not known, fixed, or certain due to a lack of information, scientific knowledge, or ignorance. It is present in all predictive assessments. Uncertainty can significantly affect the type and amount of evidence in a CBA and must be taken into account when communicating the outcome. (Based on [European Commission 2011])

Willingness to Accept (WTA): The amount of compensation an individual is willing to take in exchange for giving up some good or service or, in the environmental context, to forego improvement or endure the decrement of a situation.

Willingness to Pay (WTP): The maximum amount an individual would be willing to give up in order to secure a change in the provision of a good or service. (Based on (OMB 1992))

References

ECETOC (2011). Environmental Impact Assessment for Socio-Economic Analysis for Chemicals: Principles and Practice. Brussels, Belgium, European Centre for Ecotoxicology and Toxicology of Chemicals.

Environment California (2007). Toxic Baby Bottles: Scientific study finds leaching chemicals in clear plastic baby bottles. R. L. Gibson.

European Chemicals Agency (2011). Guidance on the Preparation of Socio-Economic Analysis as Part of an Application for Authorisation. Helsinki, Finland.

Horvath, A. and M. Chester (2011). Life Cycle Assessment Support for California EPA's Green Chemistry Initiative. Sacramento, Department of Toxic Substances Control.

Hunkeler, D., K. Kichtenvort, et al. (2008). Environmental Life Cycle Costing. Environmental Life Cycle Costing, CRC Press**:** 35-57.

Kubwabo, C., I. Kosarac, et al. (2009). "Migration of bisphenol A from plastic baby bottles, baby bottle liners and reusable polycarbonate drinking bottles." Food Additives & Contaminants: Part A **26**(6): 928-937.

Matthews, H. S., C. Hendrickson, et al. (2001). External Costs of Air Emissions from Transportation, ASCE.

Matthews, H. S. and L. B. Lave (2000). "Applications of Environmental Valuation for Determining Externality Costs†." Environmental Science & Technology **34**(8): 1390-1395.

North Atlantic Treaty Organization (2009). Code of Practice for Life Cycle Costing, Reseach and Technology Organisation.

OMB (1992). Circular A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. Office of Management and Budget. Washington, D.C.

OMB (2003). Circular A-4: Regulatory Analysis. U.S. Office of Management and Budget. Washington, D.C.

Pearce, D., G. Atkinson, et al. (2006). Cost-Benefit Analysis and the Environment: Recent Developments. Paris, France, Organisation for Economic Co-operation and Development.

Pearce, D. W. and A. Howarth (2000). Technical Report on Methodology: Cost Benefit Analysis and Policy Responses. European Environmental Priorities: an Integrated Economic and Environmental Assessment. Bilthoven, Netherlands, Environment Directorate-General of the European Commission.

Risk and Policy Analysts Limited (2011a). Assessing the Health and Environmental Impacts in the Context of Socio-Economic Analysis under Reach, Part 1: Literature Review and Workshop Discussions. Norfolk, UK, European Commission Directorate- General Environment.

Risk and Policy Analysts Limited (2011b). Assessing the Health and Environmental Impacts in teh Context of Socio-Economic Analysis Under REACH- Part 2: The Proposed Human Health Logic Framework Norfolk, UK, European Commission Directorate- General Environment.

TEEB (2012). The economics of ecosystems and biodiversity in business and enterprise / edited by Joshua Bishop. London ; New York :, EarthScan.

USDOT (2002). Life-cycle Cost Analysis Primer, U.S. Department of Transportation, Federal Highway Administration, Office of Asset Management.

USEPA (1995). An Introduction to Environmental Accounting as a Business Management Tool: Key Concepts and Terms. Environmental Protection Agency Office of Pollution Prevention and Toxics. Washington, D.C.

USEPA (2009). Valuing the Protection of Ecological Systems and Services: A Report of the EPA Science Advisory Board. Washington, D.C., Science Advisory Board.

USEPA (2010a). Guidelines for Preparing Economic Analyses. National Center for Environmental Economics Office of Policy. Washington, DC, United States Environmental Protection Agency.

USEPA (2010b). Valuing Mortality Risk Reductions for Environmental Policy: A White Paper DRAFT SAB Review Draft. N. C. f. E. Economics.

Appendix: Additional Case Studies

Case Study Selection 1
Case Study #1: Selecting Paper Board Sizing Chemical 1
Figure A-1: Process Diagram for Manufacturing Product C (WBCSD 2012) 3
Table A-1: Assessed environmental costs for sizing chemicals (WBCSD 2012) 3
Sample calculations 4
Table A-2: Assumed emissions and costs due to sizing chemical needed to produce one tonne of solid board (WBCSD 2012) 4
Case Study #2: Banning Tributyl Tin 5
Costs 5
Table A-3: Key Cost Variables for TBT Case Study (from [ECETOC 2011]) 6
Benefits 7
Appendix References 8

Case Study Selection

The two case studies included in this appendix were adapted from available published literature to assist practitioners when applying cost-benefit analysis (CBA) in alternative assessments (AAs) for safer products. They were selected to highlight specific challenges of the CBA process, but are not complete CBAs themselves. The case studies are not meant to be comprehensive nor to explain the detailed steps for completing a CBA. They are intended to outline the basic principles that a practitioner should consider at particular steps. For additional detail and step-by-step analytical assistance, practitioners should refer to the Existing Guidelines Review section of this report. These case studies are provided purely for illustrative purposes and do not necessarily represent real-world conditions. In addition, these case studies do not indicate how a chemical or product will be viewed, reviewed and evaluated by the DTSC or any other regulating agency.

Case Study #1: Selecting Paper Board Sizing Chemical

The following describes the costing of the environmental impacts associated with three alternative sizing chemicals used in paper and board manufacturing. The economic costs of manufacturing, distributing, using, and disposing of these products are not discussed. Though not a complete CBA, it illustrates how to include and monetize indirect environmental costs, such as transportation effects, water consumption, and different manufacturing processes. The comparative analysis was conducted by AkzoNobel subsidiary Eka Chemicals with the help of the World Business Council for Sustainable

Development (WBCSD) (WBCSD 2012). The original case study description can be found online at http://www.wbcsd.org/work-program/ecosystems/cev/roadtesters.aspx.

Eka manufactures bleaching and other chemicals used in the pulp and paper industry. They conducted a trade-off analysis to compare three alternative internal sizing chemicals, which are used to develop water resistance in paper and board. The three chemicals evaluated were:

1. Product A is produced from tallow (livestock and crops)
2. Product B is petrochemical-based (note: analysis excluded emulsification process)
3. Product C is composed of gum rosin (plantations) and tall oil rosin, a pulp mill by-product

Each sizing chemical is assumed to be equally effective in the final paper or board product, though a different volume of each was needed in the manufacture process. The process of inventorying the life-cycle carbon, energy, and water footprints of using these chemicals is described in (Triantou 2009).

The published analysis was limited to comparing the societal costs of environmental externalities due to greenhouse gases (GHGs), sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), dust (PM), and ammonia (NH_3) emissions. The steps of the corporate ecosystem valuation (CEV) are summarized below:

- Inventorying impacts: Priority ecosystem services for gum rosin obtained from China and Indonesia. Water consumption, and associate risk in areas of water stress, identified using critical supplier reports and the WBCSD's Global Water Tool. Other externalities were identified through a life-cycle assessment (LCA) (Triantou 2009), based on the amount of chemical needed to size one metric ton (tonne) of solid board. The LCA's system boundary was cradle to delivery at the board mill. A process diagram of the production of Product C is shown in Figure 1.
- Valuing impacts: Benefits transfer was used to value the externalities of GHG, SO_2, NO_x, PM, and VOC emissions during the manufacture and distribution of three alternatives. Emission cost references are provided on the WBCSD website.
- Testing sensitivity: The analysis included three iterations. The costs per ton of emission were independent of geographic location for GHGs.
    1. For SO_2, NO_x, NH_3, PM, and VOCs, average cost per ton emitted for 25 European Union countries was used.
    2. SO_2, NO_x, NH_3, and PM emissions were compiled per country (or at sea) and the associated costs were calculated. The VOC contribution was insignificant and excluded.
    3. Compared to Iteration 2, only Product C data were changed. The environmental loads for one raw material (crude tall oil rosin) were lowered because the original study (Triantou 2009) had been based on high estimates for this material.

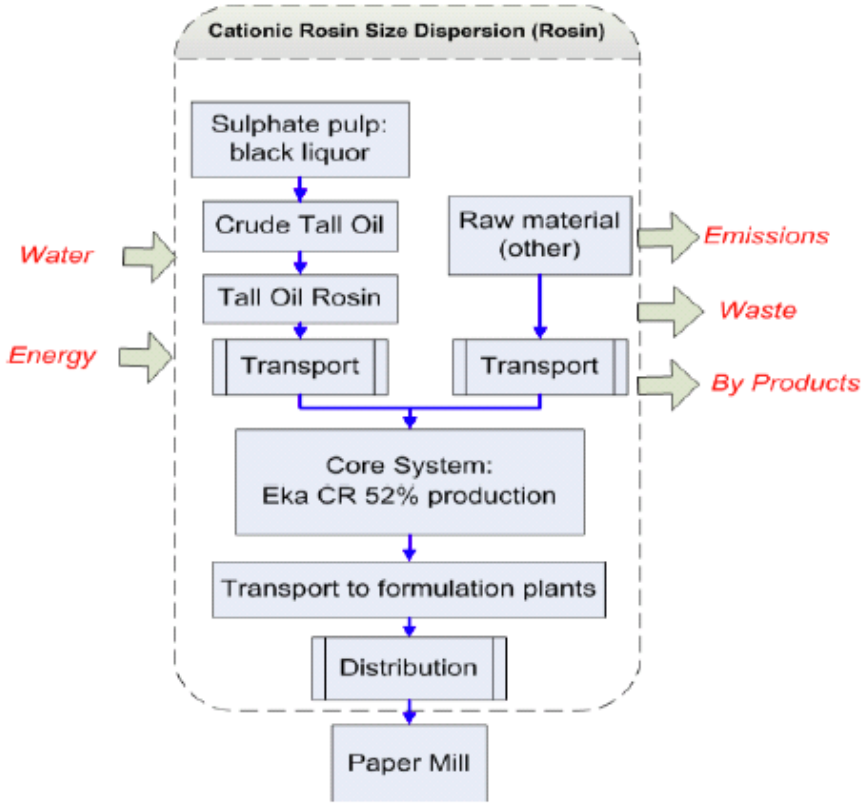


Figure A-1: Process Diagram for Manufacturing Product C (WBCSD 2012)

The total valuation results are presented in Table A-1. The minimum and maximum values are given to account for the range of assumptions made.

Table A-1: Assessed environmental costs for sizing chemicals (WBCSD 2012)

	Product A	Product B	Product C
Iteration 1 [Euro]	0.24 – 0.68	0.32 – 0.93	1.7 – 4.7
Iteration 2 [Euro]	0.29 – 0.84	0.34 – 1.0	1.5 – 4.3
Iteration 3 [Euro]	As iteration 2	As iteration 2	1.1 – 3.1
EPS [ELU[1]]	7.6	5.6	8.4

[1] ELU is short for Environmental Load Unit

Unit: Euro per the amount of sizing chemical required to produce one ton solid board

In Iteration 2, the emission costs were calculated by country. This resulted in higher cost for Product A and Product B but lower costs for product C. Product C includes an assumption of sea transport of rosin from Asia to Europe and benefits associated the relatively low cost for emissions released at sea.

Sample calculations

The intermediary LCA data which specifies the emission mass for each compound are unpublished. As a result, the calculation step cannot be perfectly recreated using actual data. Ideally, the report would have provided the concentrations of each emission, the costs per emission assumptions, the base year for the results, and the discount rates that may have been applied in intermediate steps. Instead, to demonstrate the method, hypothetical data has been created to illustrate how Iteration 1 may have been calculated. *These numbers do not represent actual costs for the Eka Chemicals products and the analysis shown may not include the same steps included in Eka's analysis.*

A few notes about the hypothetical sample calculations:

- Emissions and cost estimates were assumed to be in 2005$.
- Only GHGs, SO_x, NO_x, NH_3, and PM were evaluated. The original case study indicates that the emissions of VOCs were not significant in the final results.
- The GHG emissions for solid board production were from (Triantou 2009). A LCA study of paper production was used to establish the order of magnitude of SOx, NOx, NH_3, and PM relative to GHGs. Then the values were updated to fit the final results published online.
- The case study provided the source of the emission valuations (see website for details). We used the Value of Life-Year (VOLY) values.
- Given the data provided and these assumptions, we could not recreate the results in Table A-2 for all three products. Only recreated results for Product A are shown.

Table A-2 shows the valuation results for the emissions included in our analysis. All values are assumed to be in Year 2005 Euros, though in some cases the base year is unknown.

Table A-2: Assumed emissions and costs due to sizing chemical needed to produce one tonne of solid board (WBCSD 2012)

Emission	Product A Assumed Emission (kg emitted from sizing chemical per tonne of solid board)		Assumed Valuation (€ per tonne emitted; see Note)		Product A Total Societal Cost (€ per tonne of solid board)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
GHG	6.0	9.5	$ 8	$ 26	$ 0.05	$ 0.25
SO_2	0.0089	0.0093	$ 5,600	$ 11,000	$ 0.05	$ 0.10
NO_x	0.019	0.023	$ 4,400	$ 8,200	$ 0.08	$ 0.19
NH_3	0.00067	0.00091	$ 11,000	$ 21,000	$ 0.01	$ 0.02
PM	0.0019	0.0024	$ 26,000	$ 51,000	$ 0.05	$ 0.12
Total	--	--	--	--	*$ 0.24*	*$ 0.68*

Note: GHG estimate is from (WBCSD 2012); the source states the maximum value is likely underestimated. Other values are from the European Integrated Pollution Prevention and Control Bureau 2006 Annex 12, Table 6 found at http://eippcb.jrc.es/reference/ecm.html. Estimates use the VOLY method.

Case Study #2: Banning Tributyl Tin

A frequently-cited example of CBA is the assessment of a ban of antifouling paint made from tributyl tin (TBT, sometimes spelled tributyltin) and primarily used on boats. TBT is a broad spectrum organometal pesticide primarily used starting the early 1970s as a component of anti-fouling self-polishing copolymer paint to control the growth of mollusks on the bottoms of marine vessels. Other applications include use as a wood preservative and in industrial water treatment systems. The marine application was thedominate route for TBT compounds to enter the environment and reach sensitive receptors. TBT is a known endocrine disruptor at low concentrations and has empirically reduced the productivity of nearby shellfisheries. Applying TBT-based anti-fouling paint was banned worldwide by the International Maritime Organization in 2003; previously-applied paints were required to be removed by 2008. An *ex post facto* analysis of the ban of TBT was conducted.

Early CBAs of TBT's environmental effects focused on the Bay of Arcachon in Southern France (ECETOC 2011). Other publications discuss costs and benefits separately and cover broader geographic scope (Evans, Birchenough et al. 2000; Champ 2003) as well as a study of the benefits of the partial ban on TBT-based paints in the UK (Giacomello, Guha et al. 2006).

This analysis was not specific to one manufacturer, as would be the case with the AAs, but looked at geographically-specified areas of use. Also, the costs and benefits of this product were published in different documents which addressed varying geographic scope. They were never summarized into a formal CBA. Many identified costs and benefits were never monetized, even when it was possible.

Even when the costs and benefits were quantified, they were never discounted or compiled into a final CBA results. However, the TBT case demonstrates the depth and breadth of issues that should be addressed in an AA for a chemical. It also illustrates a case where the primary external cost of the chemical (or benefit of the ban, depending on the perspective of the study) is an ecological one. In addition, this example gives a good example of how to describe costs and/or benefits that were identified but not quantified.

Costs

The costs of a ban on TBT-based anti-fouling paints fall into several categories: remediation; enforcement; the economic and environmental costs of fuel consumption; and the economic and environmental costs of alternative anti-fouling paints. Several studies identify and, in some cases, enumerate the costs associated with banning TBT. The costs of remediation are addressed in (Champ 2003). The increased fuel and maintenance costs are covered in (Evans, Birchenough et al. 2000). The possible environmental implications of alternative anti-fouling measures are discussed in (Evans, Birchenough et al. 2000). Using the data in Table A-3, some of the costs and benefits could have been monetized. This was not done due to the complications of differing geographic scales of the study.

Table A-3: Key Cost Variables for TBT Case Study (from [ECETOC 2011])

Potential key input variables	Information	Comment
Number of ships in commerce with TBT anti-fouling paint	28,038 ships in global commerce, 70-80% containing TBT	Only historical data are readily available; figures for specific country are estimated from global figures.
Remediation method for hulls with TBT	Options: direct removal; over-coating; over-coating with sealer	No information on costs or effectiveness
Removal of TBT containing anti-fouling paints and salts from ship hulls via washing in dry dock with discharge to local waterways	>100,000 gal. of hydroblasting fluid to remove paint on large ship; removed in particles <10 μ; 24-30 manhours for washdown to remove salt; TBT Concentrations in shipyard wastewaters up to 5 million ppt; in washdown & hydroblasting wastewater: up to 6 million ppt	
Dredging TBT-contaminated sediments	Dispose 150,000 cy at hazardous waste site via barge and rail from Staten Island to Utah for $17 million	Current cost figures not available, but existing costs could be adjusted for inflation
Monitoring/ enforcement	Underwater hull inspection; monitoring costs	No cost or effectiveness information
Increased fuel consumption, increased frequency of drydocking to repaint ships hulls due to ban of TBT	$5.7 billion extra cost and 22 million tonnes of CO_2 and 0.6 million of SO_2 generated per year due to increased fuel use; fouling effects on ship performance & costs estimated by making an international journey when anti-fouling coat was failing & another with fresh antifouling. Additional expenses: $78,000, 58%-77% higher	One report has detailed estimates of daily operating costs at port & at sea (e.g., wages, pension, repairs, fuel, insurance, etc.) obtained when costs for two ships travelling internationally with and without fouled hulls were tabulated
PNEC for impact on oysters or cause of imposex in gastropods	PNEC for the most sensitive oyster species is ~2 ppt; PNEC varies by species of marine organisms but are <0.1 ppm	Most severe impacts on shellfish involve mollusks: French oyster beds are best documented
"Lag period" for benefits from lower TBT concentration	Oyster farming in Arcachon Bay returned to previous production levels within 2 years of the 1982 French ban	
Alternative anti-fouling paints	One study discusses adverse environmental impacts of several alternatives	Sparse information about effectiveness and adverse effects of alternatives
Service life of anti-fouling paints	Self-polishing co-polymer formulations have a 3 to 5 year life vs. approximately 18 months with earlier anti-foulants	Compares an established and an emerging technology; the service life of the latter is uncertain
Costs of applying anti-fouling paints to hull	Cost of one anti-fouling paint application for a ship >25 m is ~$157,838	

Notes: Original data sources are provided in (ECETOC 2011). gal. = gallon μ = micron ppt = parts per trillion

Benefits

Giacomello (2006) quantified two benefits: 1) the commercial value of shellfish (e.g., native oysters, pacific oysters, whelks, cockles, scallops, and mussels) and 2) the value of the environmental improvement created when shellfish more quickly remove contaminants from marine sediments, bring new nutrients to the surface, and process organic sediments into smaller particles and dissolved substances. The latter functions are known as nutrient cycling, and represent an important ecological function of the TBT-affected species.

Additional benefits were not quantified due to a lack of physical and/or monetary data. These include:

1. Value of shellfish collected for personal consumption, recreation, and as bait.
2. Indirect impacts on commercial catch of fish due to more shellfish as food source.
3. Indirect impacts on recreational catch rates of other species for same reason.
4. Recreational bird watching of birds that feed on shellfish.
5. Waste treatment services performed by invertebrates. Reducing the number of such species would have reduced the waste treatment ability and the water quality. This increases costs to water companies and industrial users who have to treat water to a certain standard before use.
6. By bioturbating sediments, marine invertebrates bury contaminants more quickly and bring new sediments to the surface while processing organic matter into smaller particles and dissolved substances, a process known as nutrient cycling.
7. TBT caused the local extinction of some species with an option value attached to them. Valuable commercial applications may result from better understanding their properties.
8. Non-use values may exist for species and landscapes affected by the presence of TBTs.

Results

A dose-response relationship between shellfish production and TBT concentration could have been helpful to valuing the shellfish loss. Since TBT concentrations were not tracked before the ban, the data needed to establish this relationship was unavailable. Instead, researchers compared shellfish catch rates before the ban on TBT paint (1972-1986) to the catch rates after the ban (1986-2001) and attributed the difference to the ban. A default assumption for the effects of pre- and post-ban conditions was based on one study in the upper Crouch estuary where a 94% reduction in TBT concentrations between 1986 and 1992 corresponded to a 50% increase in native oysters. However, a sensitivity analysis was conducted assuming that the ban caused a 10% increase and a 100% increase to test the bounds of possibility. Other factors that may have affected the shellfish catch, including price, product quality, and other market changes, led the study's authors to make ad hoc adjustments. The final benefits were determined to be £7-11 million, which corresponds to $12.6 to 19.8 million (2006$).

Nutrient cycling was also valued using an assumption of 50% decline in functions based on the Crouch estuary study. In the UK, the affected area was 0.5 million hectares and, based on a US study, the value of nutrient cycling services was $21,000/hectare/year. These assumptions resulted in benefits of £43 million. The total benefits estimated for a partial ban were approximately £51 million, with a range of £10 million to £102 million. Eighty-five percent of the results are due to nutrient cycling effects.

The study also quantified possible costs of the ban, including alternative anti-fouling expenses. For most recreational users, it was assumed that the substitute's cost was similar to the TBT paint so there was no net cost increase. However, for racing boats the tolerance for fouling is much lower. Two coats of paint needed per year compared to one for the boats cost an additional £400 per boat; total cost, £37 million.

This study has been criticized for reasons that include:

- The authors looked at gross, rather than net, gains. For example, they should have subtracted out additional operational costs needed to create the gains.
- The nutrient cycling benefits are uncertain, in part because the source study has been questioned itself and because the benefits transfer of this US-based study to the UK is suspect.
- Many of the identified costs and benefits were unquantified in physical or monetary terms without any discussion of whether some of these may be as significant as the ones which were. In particular, items 2, 4, and 5 from the above list are likely important.

Though not a complete CBA, this study of a chemical ban illustrates the thinking process, the process of assessing ecological impacts, and the way to detail the unquantified effects.

Appendix References

Champ, M. A. (2003). "Economic and environmental impacts on ports and harbors from the convention to ban harmful marine anti-fouling systems." Marine Pollution Bulletin **46**(8): 935-940.

ECETOC (2011). Environmental Impact Assessment for Socio-Economic Analysis for Chemicals: Principles and Practice. Brussels, Belgium, European Centre for Ecotoxicology and Toxicology of Chemicals.

Evans, S. M., A. C. Birchenough, et al. (2000). "The TBT Ban: Out of the Frying Pan into the Fire?" Marine Pollution Bulletin **40**(3): 204-211.

Giacomello, A. M., P. Guha, et al. (2006). The Benefits of Chemicals Regulation, from http://svhctesting.com/uploaded/Benefits%20of%20Chemical%20Regulation.pdf

Triantou, A. D. (2009). Carbon, energy and water footprint of three AkzoNobel internal sizing chemicals: a cradle to gate LCA related study, Skolan för industriell teknik och management, Kungliga Tekniska högskolan.

WBCSD. (2012). "AkzoNobel: Corporate Ecosystem Valuation (CEV) Road Test Summary (Work in Progress)." Retrieved January 31, 2012, from http://www.wbcsd.org/work-program/ecosystems/cev/roadtesters.aspx.