TOWARD A PRODUCT-LEVEL STANDARD: LIFE CYCLE ANALYSIS OF GREENHOUSE GAS EMISSIONS

INTRODUCTION

The business value of product-level GHG inventory

Since the *GHG Protocol Corporate Standard* was published by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) in 2001, many businesses, NGOs and governments worldwide have used the standard as the basis of accounting and reporting the greenhouse gas (GHG) emissions of their organizations. As stated in that publication, well-designed and maintained entity-level GHG inventories serve several business goals, including:

- Managing GHG emissions as risks/liabilities
- Identifying reduction opportunities
- Public reporting and participation in voluntary reporting programs
- Participating in GHG markets
- Recognition for early, voluntary action

More recently, there has been a groundswell of interest on the part of consumers in the GHG emissions associated with individual products and services. Responding to such interest, as well as to the likelihood or existence of regulatory regimes that cap or tax GHG emissions, there is demand among investors and businesses for a standard that will enable reporting of GHG emissions at the level of products or services. Inventories conducted according to a product-level standard would facilitate additional business goals beyond those of entity-level, including:

- Managing GHG emissions throughout supply and distribution chains
- Recognition and financing from investors concerned with truly sustainable development
- Social marketing and participation in consumer-facing initiatives

Who would use a product-level standard?

A product-level standard that carefully circumscribes included emissions and provides a consistent basis for measurement and reporting could become the foundation for management of GHGs across a large part of the global economy. Such a standard would be used by businesses to quantify and manage GHG emissions associated with the products or services they manufacture or provide, and by NGOs, investors and policy makers as a basis for their own product-level accounting, reporting requirements, and investment decisions.

At present, product-level inventories are laborious and costly, because businesses conducting such inventories must cross operational and organizational boundaries in order to acquire necessary data. Where such data is guarded by suppliers as proprietary or is untraceable due to commodity trading practices, today's product-level inventories must resort to less accurate secondary sources of data. The product-level standard we envision, achieving widespread adoption, would alleviate these difficulties, as businesses throughout supply chains would precisely account for GHGs emitted during their manufacture of a product, and pass this information along with the product. Thus, whether the product became an intermediate material for another production system or a finished good to be consumed, simple arithmetic could provide information about the emissions over its complete life cycle as well as the marginal impacts at each stage of production.

It should be recognized that a product-level standard is currently under development by the Carbon Trust, the U.K. Department of Environment, Food and Rural Affairs (Defra), and the British Standards Institution (BSI), and pilot studies of that standard are also underway with nine different companies. Where possible, we have noted the position of the draft standard on the issues addressed herein.

Relationship to other GHG Programs
Like entity-level inventories conducted according to the *GHG Protocol Corporate Standard*, a product-level standard should encourage and support—but need not require—reporting of results. Rather, a program/policy-neutral standard could serve as an expanded framework for internal management decisions as well as participation in existing reporting programs, including:

- Voluntary GHG reduction programs, e.g. the World Wildlife Fund (WWF) Climate Savers, the U.S. Environmental Protection Agency (EPA) Climate Leaders

- National and regional industry initiatives, e.g., New Zealand Business Council for Sustainable Development, Taiwan Business Council for Sustainable Development, and Association des enterprises pour la reduction des gaz à effet de serre (AERES)

- Sector-specific protocols developed by a number of industry associations, e.g., International Aluminum Institute, International Council of Forest and Paper Associations, International Iron and Steel Institute, the WBCSD Cement Sustainability Initiative, and the International Petroleum Industry Environmental Conservation Association (IPIECA)

- Investor-led programs, e.g. Ceres Sustainability Reporting, the Investor Network on Climate Risk, and the Global Framework for Climate Risk Disclosure

- Consumer-facing initiatives, e.g. the Climate Conservancy (TCC) Climate Conscious Assessment, the Carbon Trust Carbon Reduction Label, Carbonfund.org Carbonfree Certification, and the Climate Neutral Network Climate Cool Certification

I. GHG Accounting and Reporting Principles

The *GHG Protocol Corporate Standard* espoused a set of guiding principles as a foundation for GHG accounting and reporting at the entity-level. These principles are no less important in product-level GHG accounting, and mesh very well with the goals of traditional life cycle assessment (LCA):

Relevance	Ensure that the product-level inventory reflects GHG emissions associated with an assessed product or service so as to be useful to decision makers
Completeness	Account for all GHG emissions within the designated system boundaries
Consistency	Use a consistent methodology and reporting metrics so that results are readily comparable to other product-level inventories and meaningful in the context that they will be used
Transparency	Maintain a verifiable audit trail of all data used, disclose any relevant assumptions, and report on the specificity and quality of data used
Accuracy	Quantify GHG emissions associated with an assessed product or service in a systematic manner, striving to minimize uncertainties as far as practicable

II. System Boundaries

Prior to conducting any GHG inventory, boundaries must be set as to what emissions will be included. At the entity-level, these boundaries are organizational and operational (scope). Product-level inventories differ in that they track GHG releases across a product's life cycle; the field of life cycle assessment (LCA) regards a production "system" that is indifferent to organizational or operational boundaries. However, the system boundaries and scope thereof must be defined at the outset of any product-level inventory. Moreover, a standard for product-level inventories must weigh the many implications of such boundaries in terms of the availability of data, the intended use of an inventory, the exclusion of activities emitting significant GHGs, and costs.

A. STAGES

A product's life cycle is most readily divided into four stages:

1. Raw Materials Acquisition	Raw materials and natural resources are extracted from the earth and transported to a processing point
2. Manufacturing	Raw materials are converted to intermediate materials ready for product fabrication, products are fabricated, packaged, and distributed, all transportation and storage activities are included
3. Use/Reuse/Maintenance	Use, reuse, and maintenance of the product by the consumer, including storage, service and consumption
4. Waste Management	Disposal and/or recycling of the product at the end of its useful life, including transportation and storage activities

Life Cycle (Cradle to Grave)

A complete LCA defines system boundaries that include all of these stages, from so-called "cradle to grave." In the context of product-level GHG inventories, cradle to grave boundaries encompass GHG emissions during all the stages between the extraction of raw materials and the final disposal of the product to a condition in which GHGs are no longer emitted. The completeness of cradle to grave boundaries leads to the most accurate possible inventory of impacts on global climate and capitalizes on the ability of LCA to preempt shifting of GHG emissions from one stage to another within a product's life cycle. However, lack of high quality data and the analytical costs given the broad boundaries may present practical problems.

Upstream and Direct (Cradle to Gate)

In some cases, LCA system boundaries have been limited to the first two stages of Raw Materials Acquisition and Manufacturing only. Product-level GHG inventories conducted within such "cradle to gate" boundaries would account for all GHGs emitted beginning with the extraction of raw materials and ending with the delivery of the finished product to the end consumer. Such limited system boundaries may alleviate some concerns over data quality and analytical costs, but risk excluding downstream activities entailing significant GHG emissions.

Downstream (Gate to Grave)

In other cases, businesses are interested in isolating the GHG emissions entailed with the stages of Use/Reuse/Maintenance and Waste Management only. By limiting the LCA in this way, it becomes possible to inform consumers of energy savings associated with a given product while it is in their immediate control. Product-level GHG inventories conducted within such "gate to grave" system boundaries would account for all GHGs emitted beginning with the delivery of the finished product to the end consumer and ending with the final disposal of the product to a condition in which GHGs are no longer emitted. Again, limiting system boundaries in this way may alleviate some concerns over data quality and analytical costs, but risk excluding upstream activities entailing significant GHG emissions.

Intended Use

In considering which of the stages should be incorporated in product-level inventory, questions naturally arise regarding the intended use of the results. For example, objectives might include: (1) informing decision-makers whether or not to consume a product or class of product, (2) informing consumers as to the best choices within a class of product, (3) informing investors as to the risks or opportunities posed by sectors or businesses according to their GHG intensity, or (4) supporting the voluntary or mandatory regulatory schemes of policy-makers.

It is conceivable that separate product-level standards could be tailored to each of these different purposes, as the stages assessed and specificity of data required may vary among them. However, it seems preferable and possible to craft a product-level standard that is sufficiently rigorous to serve any of these uses, and then to provide guidance permitting users with less demanding objectives to either limit the boundaries of their inventory or use less specific data (e.g. academic publications or industry averages).

B. Scope and Subsystems

In addition to which stages will be included within the system boundaries of a product-level inventory, the scope of the system itself must also be established. While "scope" in the context of the *GHG Protocol Corporate Standard* refers to operational boundaries (e.g., Scopes 1, 2 and 3 are defined as Direct, Indirect from Energy Production and Indirect GHG emissions of the entity, respectively), the scope of a product-level inventory is concerned with "subsystems" and their material requirements. In LCA, subsystems are the many individual processes that together make up the entire production system.

By way of example, subsystems within a production system for stationery might include (1) harvesting of pulpwood, (2) bleaching of the pulp, (3) manufacturing of the machinery that cuts the stationery and folds the envelopes, (4) transporting employees at the stationery factory to and from work, and (5) disposal of trash from the factory lunchroom. Though all of these subsystems are related to the production of stationery, they are progressively less immediate to the product life cycle being assessed, and in some cases may demand an unapproachable level of complexity. It therefore seems likely that—at least initially—a practicable standard for product-level GHG inventories will limit the scope of the system being assessed. A reasonable scope must balance the principles of relevance, completeness and consistency, and must avoid systematic errors such as exclusion of consequential subsystems and double counting of emissions.

Options for Limiting System Scope

The field of LCA has generally dealt with the issue of scope in one or more of four ways:

1. All Material Inputs

Based on an assumption that no material input can be excluded from an assessment a priori, some LCAs set boundaries that theoretically include all subsystems (and thus all material requirements) of the system. Such boundaries have advantages of completeness and objective consistency. There is no possibility that consequential subsystems will be excluded from the assessment, and no value judgments have been made regarding what subsystems to include or exclude. However, some subsystems thus included in the assessment may be irrelevant in light of the business goals of the inventory, and the complexity and analytical costs of such an inclusive analysis may prove intractable.

2. De Minimis Exception

By designating a threshold for excluding subsystems on the basis of mass, energy or environmental releases, boundaries may be set to include substantially all of the system. Although consistently limiting system boundaries in this way should reduce the analytical burden, some analysis is necessary to demonstrate that excluded subsystems fall below the de minimis threshold. The advantages of a de minimis exception depend upon the basis of the designated threshold. An appropriate threshold will ensure that all relevant subsystems are included. However, an arbitrary threshold risks exclusion of consequential subsystems.

Commonly, the de minimis threshold is set according to the mass of material inputs. For instance, the methodology used by the Carbon Trust in its Carbon Reduction Label program requires that all GHG emissions associated with at least 95% of the mass of the product be included. Assuming there is some demonstrable relationship between GHG emissions and mass, this may be a legitimate basis for the threshold. Another basis for testing the significance of inputs might be the cost of the material relative to the value of the finished product, because cost is often a reasonable proxy for embodied energy (i.e. GHG emissions). More directly, the basis might be the embodied energy of material inputs relative to the embodied energy of the finished product where that information is available, or—most ideal—a percentage of the total GHG emissions that may be excluded as negligible. Regardless, a product-level standard adopting a de minimis rule based on any physical characteristics should present the rationale for its choice.

3. Sensitivity Analysis

Over and above the rough calculations that might be conducted to conclude a subsystem is de minimis, it may be possible to mathematically model a production system and exclude subsystems that do not contribute significantly to output variability using sensitivity analysis. Such analysis represents an objective basis for excluding subsystems, ensuring the relevance and completeness of the assessment. However, sensitivity analysis itself may be quite demanding, especially in the absence of a large existing database, so that the complexity and cost of analysis may remain high.

4. Exceptions by Type

By designating certain types of material inputs to be excluded, consistent system boundaries may be set which allow exclusion of subsystems regarded as remote or overly complex. (e.g., capital equipment manufacture or transport of personnel to work). Where the choice to except certain types of input is arbitrary, completeness is undermined and there is again a risk of excluding consequential subsystems. However, if the decision to exclude certain types of input can be made based upon past and/or preliminary analyses, the exceptions may be justified and the relevancy of the analytical scope ensured.

Capital Equipment

LCA studies have often excluded subsystems of capital equipment manufacture because they have been shown to contribute minimally to inventories of a system's environmental releases. While GHG emissions associated with construction of buildings and manufacture of process equipment should probably not be disregarded a priori, the allocation of such GHGs among the large number of products produced over the lifetime of such equipment may prove negligible. Further, inclusion of capital equipment subsystems would in most cases drastically alter the complexity of the inventory.

If capital equipment subsystems are excluded by type, as they are under the Carbon Trust/Defra/BSI draft standard, one possible justification might be that the significance of the GHGs emitted during a given stage is small relative to emissions in the other production stages. Because fuel and energy required to operate process equipment will be included in a product-level analysis, minor emissions during a single stage of the product's life cycle compared to the other stages may indicate that the capital equipment involved in that stage is not substantial. Another rationale for excluding capital equipment subsystems without undertaking de minimis calculations or full-blown sensitivity analysis might be that the ratio of capital and current expenditures during stage in question is low. Such a low ratio, if sustained over several production cycles, would suggest long lifetimes of necessary capital equipment, and thus a relatively small contribution to each product produced. Finally, the problem of double counting arises were the emissions associated with capital equipment to be included; the equipment is the product of some other system, and given widespread adoption of a product-level standard, those emissions would have been accounted for and reported as part of that other production system.

Personnel
Throughout a production system, there will be GHG emissions attributable to the personal transportation, and workplace activities of personnel. Despite an argument that these emissions might occur regardless of the existence of the assessed production system, these subsystems are highlighted by some businesses which encourage and/or incentivize their employees to reduce their individual impacts by carpooling, using mass transit, recycling, etc. For this reason, there may be pressure to include personnel subsystems in product-level inventories so that manufacturers will be credited for such progressive programs. To the extent that some production systems are much more labor intensive than others, and personnel-related contributions can be significant where large work forces commute long distances, for instance, there may be good reasons to include personnel subsystems in a standard product-level protocol. If, however, personnel subsystems are excluded by type, justifications of consistency and irrelevance should be provided. The Carbon Trust/Defra/BSI draft standard also excludes transportation of personnel to and from the workplace.

An Evolving Standard
As noted at the outset of this paper, the product-level GHG inventories performed to date have demanded that businesses assessing their own products actively pursue data regarding emissions upstream and downstream of their own operations. In most if not all cases, this entails using data from secondary sources, as discussed in more detail in the following Section III. While resort to more general sources undoubtedly undermines the accuracy of the inventory results, ongoing efforts to conduct product-level inventories (such as those of The Carbon Trust in the U.K. and The Climate Conservancy in the U.S.) are critical steps in the evolution of a widely adopted standard. Indeed, as more and more companies undertake product-level inventories according to an accepted standard, inventories will be able to progressively concentrate on accounting for the GHGs emitted during their Manufacturing stage only, as their material inputs arrive having already had their GHG emissions inventoried. In this scenario, only those businesses marketing their products to the end-consumer would also need to concern themselves with downstream emissions stemming from the Use/Reuse/Maintenance and Waste Management of the product.

III. IDENTIFYING AND CALCULATING GHG EMISSIONS

Once system boundaries have been set, all of the GHGs emitted within the circumscribed system must be identified and inventoried. Standardizing this process will entail laying out a hierarchy of data sources, establishing procedures for evaluating and reporting data quality, and providing general guidance for data collection. Here, these functions are discussed in the course of the four main steps of data collection:
(1) create a flow diagram, (2) develop a collection plan, (3) collect data, (4) evaluate data quality.

While there is significant overlap between product- and entity-level inventories, it is important to simplify the process of identifying and calculating GHG emissions for a particular product where possible by ignoring emissions not related to the production system being assessed. Only where emissions result from administrative or "overhead" activities or the production of several products are inextricably mixed should these GHGs require allocation among the different products involved (See Chapter IV).

Attributional versus Consequential
Prior to addressing data collection, it is worthwhile to briefly recognize the two main types of LCA and the practical implications of each. "Attributional" LCA analyzes the environmental flows that exist within a system., while "consequential" LCA analyzes how environmental flows beyond the system will be affected in response to the choices made within the system. In the context of a product-level GHG inventory, an attributional assessment would consider the GHGs emitted as a result of biodiesel fuel combusted during the distribution of a finished product. Consequential assessment would carry this a step further, considering not only how GHG emissions would differ if another fuel had been used instead

of biodiesel, but also how use of biodiesel, a fuel of limited supply, might impact its availability to other consumers outside the system.

While theoretical arguments have been made that consequential LCA grants decision makers insights to the consequences of their decisions, the completeness and accuracy of consequential assessments are limited in reality by reliance on imperfect economic models, incomplete data and the uncertain future. For these reasons, as well as concerns of feasibility, a standard for product-level GHG inventories should concentrate on attributing GHGs emissions to the assessed production system.

A. CREATING A FLOW DIAGRAM

A diagram illustrating the various subsystems and material flows of the production system being assessed is a useful tool to understanding the scope of a product-level GHG inventory and ensuring all of the inputs and outputs to the production system are accounted for. The more detailed the flow diagram, the more useful a tool it will be in the collection of data and evaluation of its quality. Figure 1 is a fairly detailed flow diagram depicting the production system of beer.

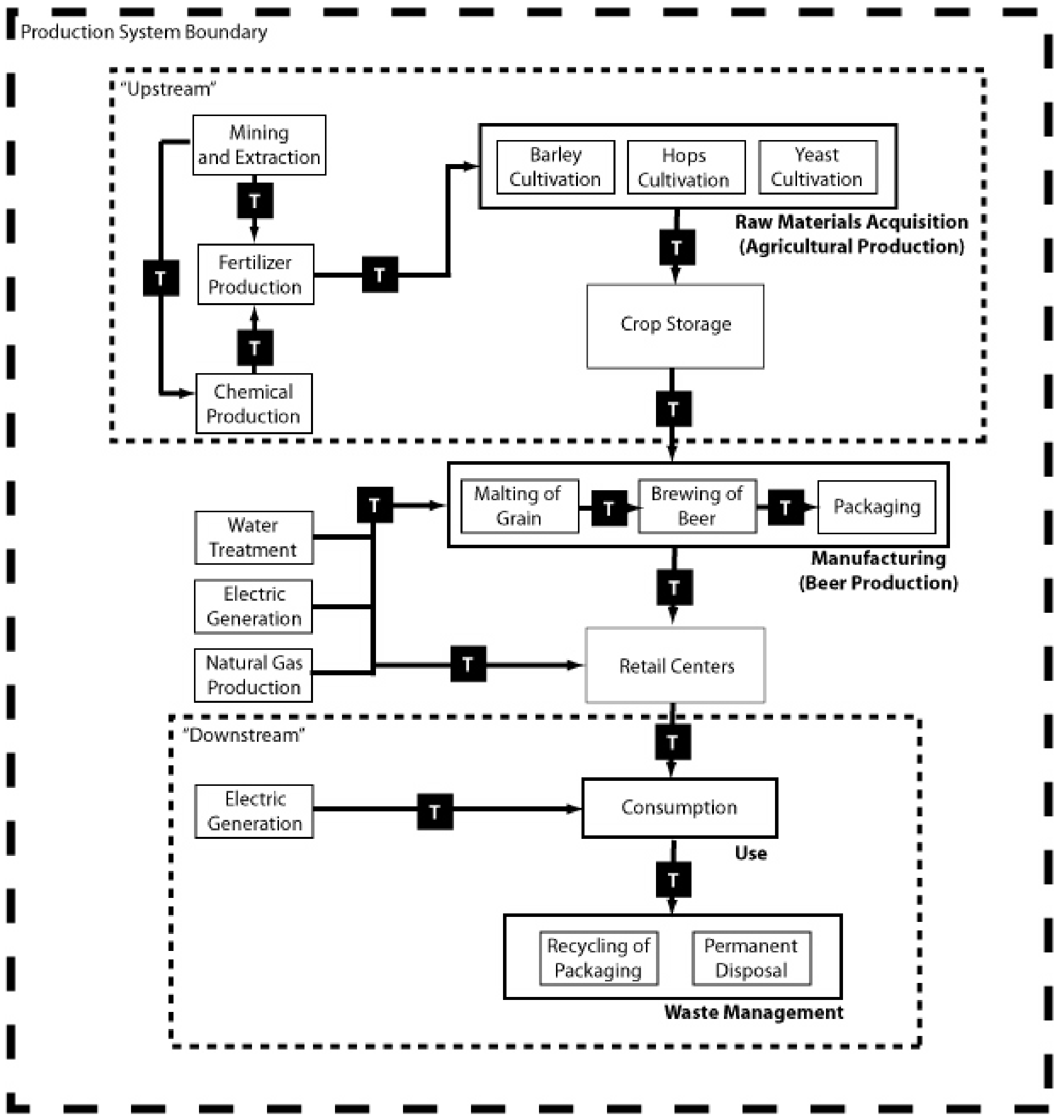

Figure 1. Example of Flow Diagram for the life cycle of beer. Black squares indicate transportation subsystems. Adapted from Figure 1 of Narayanaswamy et al. (2004).

B. DEVELOPING AND EXECUTING A COLLECTION PLAN

Building on the framework of a completed flow diagram, it will often be helpful to compose a comprehensive list of the data to be collected. The list should further identify the preferred data sources and types and consider verifiable documentation and data quality indicators (see section on evaluating data quality below). A robust standard for product-level GHG inventories will require data for emissions of all six "Kyoto" gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride).

In both developing and executing the data collection plan, valuable guidance may be found in the existing *GHG Protocol Corporate Standard*. For example, it will be useful to organize GHG emissions among the familiar categories of that standard: Direct emissions are those produced during the Manufacturing stage, and can be further categorized as stationary combustion, mobile combustion, process emissions, or fugitive emissions. Indirect emissions may be divided into those from off-site electricity generation and those from other upstream or downstream sources (namely the subsystems in the other stages of Raw Material Acquisition, Use/Reuse/Maintenance, and Waste Management). Direct emissions and Indirect emissions from off-site electricity generation can generally be accounted for following the procedures of the *GHG Protocol Corporate Standard*. But again, only those emissions directly attributable to the assessed production system should be counted in the inventory. The flow diagram should help to maintain focus on the production system being assessed.

Currently, the *GHG Protocol Corporate Standard* does not require accounting of indirect emissions from sources other than the generation of consumed power. Data on such indirect emissions is necessary to a complete, accurate and relevant product-level inventory, but presents challenges in its collection.

Indirect from Other Sources - Upstream

The most accurate product-level inventory would work upstream from the primary Manufacturing stage, iteratively treating each subsystem as an independent Manufacturing stage. The main hurdles to this sort of iterative analysis are the availability of high quality data and, relatedly, cost. Even apart from the aforementioned proprietary nature of upstream data, accurate tracking of material inputs may be difficult or impossible where these materials are commodity goods. Given widespread adoption of a standard for product-level analysis, a modular assessment is the ultimate goal; product-level inventories will focus on the careful tabulation of the GHGs produced during the Manufacturing stage where the best data is available and pass the result downstream where products become intermediate materials for other products.

However, in the near term, inquiries to suppliers may not bear useable data, and a product-level standard must allow for the use of secondary sources of data such as peer-reviewed scientific research and published industry averages. Data from these secondary sources is inarguably of lower quality than verifiable, primary data, and so will diminish the accuracy of the assessment. Thus, in order to maintain consistency and transparency, it will be important to characterize and report the quality of data used in a product-level inventory.

Indirect from Other Sources - Downstream

There is disagreement whether or not downstream emissions should be included in a product-level GHG inventory, because the Use/Reuse/Maintenance and Waste Management stages of a product's life are not within the direct control of the entity that manufactures and markets the product. Moreover, assessment of downstream emissions will almost always demand use of secondary sources of data such as averages. However, GHG emissions in the downstream stages can be quite consequential (e.g. automobiles), and proactive, responsible manufacturers can influence these emissions through product design and economically neutral incentives. Separate disclosure of upstream/direct and downstream emissions may allay many of these worries by isolating the emissions that may be both out of a manufacturer's direct control and also less accurate.

In calculating downstream emissions, secondary sources from parties outside of the production system should be preferred. For example, data on the required maintenance and average useful life of a television is better obtained from disinterested consumer groups than from the manufacturer. Where durable goods are concerned, amortization schedules of financial accounting may represent a reasonable expectation of a product's lifespan. In assessing how a product is likely to ultimately be disposed, national or regional average recycling rates for the product in question may be applied. Another means of evaluating the likelihood that a product will be recycled might be with reference to the percentage of post-consumer waste entering the production system as material input. In this way, a manufacturer could "control" the Waste Management stage and benefit while creating demand for recycled materials.

C. Evaluating Data Quality

As implied in the previous section, many assumptions may be required of early product-level GHG inventories, particularly with respect to indirect emissions up and downstream of the Manufacturing stage. A standard for conducting these assessments could safeguard the accuracy, relevance, completeness, and ensure the consistency and transparency of its results by including a mechanism for evaluating and reporting the quality of data involved. Because determination of system boundaries and allocation rules will be standardized, the data quality mechanism need not be overly complex to be effective. That said, more formal and quantitative Data Quality Indicators (DQIs) such as accuracy, completeness, precision, representativeness, bias, and comparability could be incorporated into later versions of the standard.

For example, each datapoint in a product-level inventory could be associated with a numerical indicator of its quality, assigned by whether the data resulted from: (1) direct measurement, (2) assumption based on peer-reviewed scientific research or other verified GHG inventories, (3) assumption based on a publicly available reference, or (4) assumption based on records or research of entities within the production system. In this way, a numerical average of data quality could be simply calculated and reported for any subsystem or stage in the product's life cycle. This numerical average would represent a qualitative indication of confidence and margin of error to all those interpreting the inventory results.

It is important to note that such a means of communicating data quality would not obviate a process of third-party verification of inventory results, nor would it free analysts from the obligation to disclose extraordinary assumptions that were required in the course of the product assessment.

As an interesting alternative to such a quantitative system, the draft product-level standard of the Carbon Trust/Defra/BSI proposes setting a threshold for the percentage of emissions attributable to primary sources. For example, over 50% of the total GHG emissions must be documented by primary data. This seems a worthwhile suggestion, as it would lend some amount of credibility to the results of any inventory conducted accordingly. However, it serves to fatally undermine product-level inventories undertaken in the absence of sufficient primary data regardless of their good intentions, and at the same time fails to distinguish between an inventory resulting from 99% primary data and one with only 51%.

IV. Functional Units and Allocation Rules

In order to arrive at a product-level inventory, the quantity of products produced by the system, or "functional units" in LCA terminology, must be analyzed just as closely as the GHGs emitted. Fortunately, most entities closely monitor their production output as well as any valuable byproducts, or "co-products." However, commonly available information may be limited to the quantity or mass of outputs, as more robust systems of activity based costing are not yet ubiquitous. Using available data, a standard for product-level GHG inventories must define rules for how overhead GHG "expenses" are allocated among various product lines, as well as whether and how GHG emissions will be attributed to any co-products whose production is inextricably bound up in the life cycle of the primary product being assessed. These allocation rules must attribute GHG emissions consistently and objectively, but also be defensible as to the relevance and accuracy of their results.

A. Allocation Keys

Attributional LCA allocates material and energy requirements among multiple outputs on the basis of an "allocation key" such as mass, volume, energy content or economic value. The application of appropriate allocation keys is dependent upon the nature and purpose of both the resource consumed and the products produced. As an extreme but illustrative example, where a manufacturer produces both feather pillows and bricks, fuel consumed by a warehouse forklift might best be allocated according to the mass of the products it transports. On the other hand, energy consumed to light and heat the warehouse might be better allocated on the basis of the volume of the products stored there. Continuing with this example, energy consumed in the company's administrative offices might be allocated most appropriately based on the percentages of the revenue realized from the sale of the company's different products. A standard for product-level GHG inventories should define which circumstances require which allocation keys, justifying its definitions by logic and science.

B. Co-Product Accounting

Once allocated, there remains a question of how co-products should be accounted for in the inventory of the primary product. Three options dominate: (1) Debit the GHG emissions associated with the co-product from the primary product inventory; (2) Credit the primary product with the economic value of the co-product; or (3) Ignore co-products and attribute all GHG emissions to the primary product.

LCA defines co-products as "process outputs that have value" to another production system, and considers them only while they are related to the primary product. Transport and refining of co-products are properly part of the Raw Materials Acquisition stage of another production system. The accounting options surrounding co-products are best explored in light of an example: During the production of beer, a residual mash of malted barley ("spent grain") is often dried and sold as cattle feed. It is impossible to separate the process of brewing beer (the primary product in the system) from the generation of this co-product, and so the energy used to malt the barley, for instance, might be allocated between the beer and the cattle feed. In this example, as for most co-products, the appropriate allocation key is probably economic value; if for every $1 worth of beer produced there is 1¢ of cattle feed produced, 1% of the energy used (and GHGs emitted) to malt the barley might be allocated to the cattle feed.

Debit GHG Emissions from the Primary Product

In the final inventory of GHGs emitted per functional unit of beer, traditional LCA debits 1% of the GHGs emitted during the malting of barley from what would otherwise represent the total GHG emissions from the production of the beer. The rationale for doing so is that this portion of emissions belongs to the animal feed and may be considered separately by an assessment of that feed. Corollary to this rationale is that animal feed produced as a co-product of beer displaces feed that would have otherwise been produced by some other means (which other means would also have entailed GHG emissions).

By excluding some percentage of emissions from the final inventory, this accounting approach has been criticized as undermining the accuracy and perhaps even the relevance of inventory results insofar as they purport to represent all GHGs associated with the production system. That is, some argue that the system is in place to manufacture beer, and the manufacturing company should not be able to effectively offset emissions from the production system by selling off byproducts that would exist whether or not a market for them did.

Credit the Economic Value of the Primary Product

Where functional units of beer will be considered in economic terms (see the section on GHG intensity metrics below), we might also credit the $1 worth of beer with the 1¢ of revenue gained through sale of the cattle feed. By this option, instead of $1 worth of beer having been produced for every x amount of GHGs emitted, we would conclude that $1.01 of beer was produced for that same x amount. This accounting acknowledges both the full mass of GHGs emitted as well as the full economic value created from the production of the beer. However, it may be susceptible to the same criticisms as GHG intensity metrics (see below).

Ignore the Co-Product
In response to the problems of debiting emissions from the primary product, an LCA concept argues that all GHG emissions should be imputed to the product in demand, regardless of whether the production system has found valuable uses for its byproducts. A potential problem for this approach is how to assess GHG emissions associated with the acquisition of a material that was a co-product in some other production system. In this case, even if some portion of GHGs were allocated to the intermediate material a posteriori, these emissions would be doubly counted as part of both production systems.

V. ACCOUNTING FOR GHG REDUCTIONS

The concept of being "carbon neutral" is ever more popular, as evidenced by a proliferation of private enterprises marketing offsets and consulting services, and the distinction of the term itself as the New Oxford American Dictionary's Word of the Year for 2006. The attraction of the idea lies in the ready opportunity for businesses to demonstrate their commitment to addressing the climate implications of their actions while sometimes capitalizing on efficiency gains or newly available clean technologies at a profit. In most if not all cases, however, even if significant measures are taken to reduce carbon emissions internally, it is necessary to counteract some GHG emissions through carbon offset projects in order to achieve a "carbon neutral" or "carbon free" product or service. These offset projects may take the form of land-based projects (e.g., tree planting), renewable energy developments (e.g., investments in wind power), or carbon sequestration efforts (i.e., capture and storage of GHGs out of the atmosphere).

Accounting for GHG reductions through offset projects in a product-level assessment is also attractive because it encourages businesses to take immediate action to mitigate GHG emissions while they work to achieve true emissions reductions through means such as energy efficiency and conservation, process reengineering, green building, or other practices. The dangers of accounting for GHG reductions in the form of offsets are twofold: (1) Risk of Reversibility - emissions reductions from these projects may not be permanent, e.g. a forest of trees that was planted to offset emissions burns, releasing GHGs back to the atmosphere, and (2) Additionality – emissions reductions may have occurred even in the absence of the "project." Therefore, it is imperative to ensure that offset projects represent true GHG reductions if they are to be included in a product-level GHG inventory, and this represents an undertaking beyond the scope of such an inventory.

It should be noted that the draft product-level standard currently under development by The Carbon Trust, Defra, and BSI excludes offsets from consideration, arguing that the standard aims to report the emissions associated with the production system itself, and not the purchase of offsets outside of that system.

Standards and Certifications
Markets for GHG offsets are still in their infancy and there is no widely accepted standard that covers all types of offset projects. Perhaps the most prominent existing standard is that of the Clean Development Mechanism (CDM) of the Kyoto Protocol. Whether due to flaws perceived in the CDM, its mandatory nature, or because of the U.S.'s nonparticipation in the treaty, myriad third-party organizations have sprung up to review and certify voluntary offset projects and providers according to different standards, often of their own devising. The more successful of these certifications include the Gold Standard label for carbon credits, the Green-e certification of the Center for Resource Solutions for renewable energy and energy efficiency projects, and the CCB Standards from the Climate, Community, and Biodiversity Alliance for land-based carbon mitigation projects. More recently, the International Emissions Trading

Association (IETA) and the Climate Group have promoted the Voluntary Carbon Standard as an all-encompassing standard for voluntary markets. Additionally, the *GHG Protocol for Project Accounting*, developed jointly by the WRI and the WBCSD, represents a tool for the critical assessment of GHG offset projects. A standard for product-level GHG inventories will ensure that GHG reductions are properly quantified, permanent and additional by deferring to one or more of these existing standards or certifications.

Accounting for Purchased Offsets

Even where the mitigation value of reduction projects is demonstrable, there remains a question of how, for the purpose of a product-level inventory, purchased reductions in the voluntary GHG market should offset GHGs emitted from the production system. Accepting that reduction projects and GHG markets can play an important role in a comprehensive strategy of mitigating climate change and should be built into a product-level standard, three possibilities exist: (1) Purchased reductions could counteract GHG emissions 1:1 in the product-level accounting, (2) Purchased reductions could counteract GHG emissions at something less than 1:1, (3) GHGs emitted from the assessed production system could be disclosed alongside information about reductions purchased to offset those emissions.

Accounting of offsets on par with emissions from the production system faces criticism that a product which is responsible for significant emissions can "buy its way out of trouble." However, there is a counterargument that reduction projects are marginal and finite, and that an operating GHG market will mean that production systems will opt to make reductions in their own processes where such reductions are more cost effective. Instead accounting for reductions at anything less than their full credit seems arbitrary, and the exact basis for such accounting would need justification. The reporting of both emissions and offsets may be the most even-handed approach, but may undermine the value of purchased reductions and the GHG market itself as a product-level standard becomes dominant.

VI. REPORTING PRODUCT-LEVEL EMISSIONS

A product-level GHG inventory completed according to the envisioned standard would result in a mass of GHG (CO_2e) emissions attributable to the assessed product over a set period of time or single production cycle, a quantity of functional units of the product produced over the same interval, and possibly related data quality indicators. These results could be communicated to decision-makers in any number of ways depending on the expected use and audience. For example, the Carbon Trust's consumer-facing Carbon Reduction Label reports the mass of GHG emissions of the entire production system per functional unit of product, as a product-level carbon footprint. Other options might be to communicate the results according to emissions produced during each of the life cycle stages, or according to the category of activities that caused the emissions (e.g. power generation, transportation, product use, etc.).

A. A GHG INTENSITY METRIC

Here we propose a more complex metric, based on the concept of GHG intensity, to be used in reporting the results of product-level inventories, one that we believe can maximize the comparability of results over time and among different products as well as convey the meaning of results to most potential users.

U.S. national GHG intensity is roughly 543 grams of CO_2e gas for every $1 of U.S. gross domestic product (GDP).[1] Using this as a baseline, the economic retail value of an assessed product can be compared to the mass of GHG emissions attributed to the product in order to determine the product's GHG intensity relative

[1] Calculated using 2006 GDP of 13,194.7 trillion dollars (adjusted to current dollars and reported by the Bureau of Economic Analysis of the U.S. Department of Commerce) and total GHG emissions in 2005 of 7,147.2 million metric tons CO_2e (reported by the Energy Information Administration of the U.S. Department of Energy).

to the national mean. To demonstrate, if a product-level inventory attributes 1.3 kilograms of CO_2e emissions to an assessed product, and that product's retail value is $5.00, its GHG intensity would be 260 grams of CO_2e gas for every $1 of product value. Thus, in this example, the assessed product's GHG intensity is about 52% less than the U.S. national GHG intensity, which could be construed as a sort of economy-wide mean. This percentage or some normalized version of it represents a ready basis of comparison for different products produced in the U.S. economy, and the metric has the advantage of evolving over time so that if the national mean GHG intensity decreases, product intensity must also decrease in order to maintain a comparable rating. Value judgments enter into any metric, but by factoring in the economic value created with a product, there is not only an acknowledgement of the market forces in play, but also the fact that most if not all stakeholders would prefer strategies that mitigate climate change without sacrificing socio-economic well-being.

The proposed intensity metric assumes that the retail value of products is optimized based on supply of and demand for the product and cannot be subjectively altered by a manufacturer so as to manipulate its GHG intensity. Further, in support of a GHG intensity metric, we favor an accounting of GHGs that are allocated to co-products by crediting the primary product so that the GHG intensity of the product is effectively reduced.

Relative versus Absolute

Criticisms of GHG intensity typically focus on the fact that economic trends can allow apparent reductions in GHG intensity while absolute GHG emissions nonetheless increase. However, the metric proposed here is focused at the product-level. A simple reporting of the mass of GHGs emitted per functional unit of product does not mean that GHG emissions will necessarily decrease on a national or global scale, either. Nonetheless, concerns about the relative nature of GHG intensity might be addressed by assuming some amount of economic growth in the calculations such that—were the national GHG intensity to match that of the product—absolute reductions in national emissions would be a necessary result.

National GHG Intensity

Other potential criticisms might relate to the utility of comparisons to national GHG intensity where the national figure is a very broad baseline and does not accurately reflect the GHG intensity of foreign imports. Ideally, a GHG intensity metric would be founded on sector-specific GHG intensity adjusted to include foreign imports. However, dependable calculations of sector-specific intensity do not yet exist. Given the economic maturity of the developed world, inclusion of foreign imports in the calculation of a product's GHG intensity would likely have the effect of disadvantaging the product in comparison to the national average where the product is ultimately sold. Given widespread adoption of such a metric, market forces would encourage decrease in GHG intensity in foreign countries in order that products whose supply chains originate in those countries can be competitive on the basis of GHG emissions.

Case studies are underway that will demonstrate whether national GHG intensity is too broad a baseline. Surely, there are sectors that are inherently more carbon- or energy-intensive, but it may be that the products of these sectors are infrequently finished products, and more often represent materials that are balanced with less carbon-intensive materials in the manufacture of finished products. If this is the case, national GHG intensity may do a fair job of representing this balance.

B. CARBON ADDED REPORTING

Another idea for reporting is modeled on the value added tax (VAT), whereby providers of raw materials, manufacturers and retailers all pay a fixed percentage of their profit (the value added) in tax. A similar scheme could apply to GHG emissions at the product level, so that each subsystem in a product's life cycle would report on the "carbon added" to an assessed product during that production process. Reporting on this basis would necessarily avoid double counting, and could mesh quite naturally with a future carbon tax, as well as the sort of GHG intensity metric proposed above.

VII. MAINTENANCE OF A PRODUCT-LEVEL STANDARD

Given the fast pace of developments in GHG reporting and the ever-growing availability of good data, a standard for conducting product-level GHG inventories will require oversight allowing for its maintenance over time. For example, WRI and WBCSD first published the *GHG Protocol Corporate Standard* in 2001, and together revised and updated the protocol in 2004. As part of their ongoing maintenance, these organizations established a "Structured Feedback Process" to ensure companies using the standard understood the requirements of the protocol and had opportunity to provide feedback regarding their experience in using the standard. Similarly, the many standards promulgated by the International Organization of Standardization (ISO) are reviewed and updated by that body, if necessary, at intervals of not more than five years.

If the draft product-level standard currently being developed by the Carbon Trust, Defra and BSI (the last of which is a member body of ISO) becomes the de facto standard for product-level GHG inventories, it seems likely that BSI will undertake any necessary maintenance of that standard, hopefully under ongoing advisement of the Carbon Trust, Defra, and other stakeholders.

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