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The Low-Carbon Diet Initiative:
Reducing Energy Use and Greenhouse Gas Emissions in the Food System using Life Cycle Assessment

Summary of a Symposium on Critical Issues and Research Methods

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Note: This summary is an edited compilation of topics discussed during the symposium. It should not be construed to represent any individual author's full range of opinions on any given topic.

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I. Introduction

A. Background

Amid growing concerns about climate change and long-term petroleum reserves, the food system looms large as a major user of fossil fuels and producer of greenhouse gases (GHG). The most recent studies suggest that the food system is responsible for up to 29 percent of global warming emissions generated by the consumer economy in industrialized nations (European Commission 2006). Individual foods, however, vary tremendously in how they are produced, processed, packaged, and transported, and therefore vary greatly in their carbon footprints. For this reason, changes in consumer and institutional food choices hold the potential to make a substantial impact on the overall energy audit and GHG emissions of our food system.

In order to make informed choices, however, food service providers and consumers require guidelines that are based on a systematic analysis of the detailed differences in energy use and GHG emissions of individual foods or categories of foods, taking into account variables such as differences in production systems (e.g. organic versus conventional), location of production, processing type and product form, transport mode, and distances from farm to processor to retail, and so on. Guidelines of this type are not currently available in the U.S., nor, in many cases, are the comprehensive data sets needed to inform them.

Product life cycle assessment represents a robust and effective methodology for comparing energy and environmental impacts throughout the food chain. Life cycle assessment (LCA) employs a standardized, integrated accounting framework for “cradle-to-grave” assessments of environmental impacts associated with the production, distribution, consumption, and disposal of goods or services. By compiling and analyzing the material and energetic inputs and outputs associated with each life cycle stage of a product or service system, an LCA makes transparent the environmental burdens that accrue through the system as a result of production, distribution, and consumption processes.

B. Program Goals

In 2006, the Agricultural Sustainability Institute (ASI) of the University of California, Davis (UC Davis), in collaboration with the UC Davis Institute of Transportation Studies, the UC Davis Energy Efficiency Center, and Bon Appetit Management Company Foundation, launched the “Low Carbon Diet Initiative” to stimulate research and outreach, with the ultimate goal of reducing energy intensity and the global warming potential of the food system. The research will use a life cycle assessment framework to identify factors affecting fossil fuel use and GHG emissions throughout the food system, from the farm to the consumer, including production, processing, distribution, storage, preparation, consumption, and waste handling. The program will then construct general guidelines where feasible, and explore opportunities for implementation. The research results and guidelines will also facilitate the understanding needed to implement broader energy- and climate change-related policy and planning.

After preparing a general plan of action for this initiative, the ASI convened a group of national and international experts on life cycle assessment and climate change issues in the food system in a three-day symposium in October, 2007 to comment on the ASI plan and to provide guidance on key issues relating to research and outreach in this area. The 25 invited participants included academic researchers, LCA consultants, agriculture and climate change staff in state and national governments, a food service industry representative, and non-profit staff (see Appendix 1 for the symposium agenda and the list of contributing authors on the cover page).

C. Purpose of this Summary and Intended Audience

This paper summarizes the key observations, conclusions, and recommendations reached during this symposium with respect to critical issues in LCA research on food products and potential avenues for stimulating change in the food system. This summary is intended as a guide to important considerations in these areas for researchers, students, industry, and policy makers interested in addressing global warming issues in the food system. It embodies important insights as well as unresolved questions that will frame the research and outreach agenda of the ASI and its collaborators as they move forward in implementing the Low-Carbon Diet Initiative. Readers should be aware, however, that the points discussed in this paper were generated by a particular group of individuals in focused, small group discussions on pre-assigned topics, as well as in more general large-group discussions. Although these individuals were selected for their diversity as well as for a broad scope of expert representation, the contents of this paper should not be interpreted as a comprehensive overview of all the work done or of all the possible viewpoints in the field, nor does it necessarily represent full consensus among the participants on each topic discussed.

II. Critical Issues in Food LCA Research

Prior to the symposium, ASI staff had identified five key issue areas that shape an agenda of research on LCA in food systems. Framed as questions, they embody typical dilemmas that currently characterize the thinking of concerned members of the consumer public and food-related industries. These dilemmas are all based on uncertainties in comparing energy use and GHG emissions across multiple sectors of the food system, and therefore fundamentally require LCA in order to be adequately addressed.

Each of these questions was given to a different subgroup of symposium participants, which was assigned to identify important issues and subtopics that need to be considered when researching the question and the relative importance of the question to different stakeholder groups. In some cases, the groups also revised the wording of the questions themselves. The results of each group’s discussions are summarized below. Each section begins with a statement of the key question, then defines the subtopics relevant to addressing that question, identifying some critical issues as well as insights already established in the literature. Each section then ends with some overall comments about additional important issues, a description of the stakeholder groups most likely interested in this key question, and the workgroup’s recommendations on how to research this topic.

A. Production Systems and Transportation

Key question:

> ***Under what conditions, and for which commodities, are perishable foods grown under conventional methods and sourced regionally or locally more energy- and GHG-efficient than the same perishable foods grown using alternative production methods***

(such as organic farming, conservation tillage, or other low-input approaches) but sourced globally?

The following sub-topics were identified as important pieces of the larger question, which will need to be addressed through further research.

a. *Food Miles*: Food miles can have differing impacts on fuel use and GHG emissions, depending on the modes of transport chosen. Some long-distance modes, such as ship and rail, are much more fuel efficient per unit of distance traveled compared to some short-distance modes such as light trucks and cars. Air transport, on the other hand, is so inefficient that its fuel use per ton-mile dwarfs that of any other mode of transport. Different fuel efficiencies of specific vehicles chosen within any particular transport category can also make a large impact.

b. *Organic versus Conventional*: Organic farming generally uses less energy per unit area than conventional industrial farming, but relative energy use per unit of food produced depends critically on comparative crop yields in organic versus conventional systems. Results for monocropped organic systems might be very different from those for polycropped organic systems; these may require separate analysis. More diverse systems have greater potential for carbon sequestration through use of green manure crops, catch crops, or grassed border areas.

c. *Infrastructure for Production:* Clustering of local production may lead to some efficiencies of scale, but urbanized areas may no longer have the necessary infrastructure in place. Participants were unsure about the feasibility and impact of reclaiming urban land for agriculture and building the necessary infrastructure to support local production.

d. *Renewable Energy Sources:* The introduction of renewable energy sources such as wind or solar or the use of hydrogen or electric vehicles relying on renewable energy sources may change the relative GHG and fossil fuel use impacts of transportation as opposed to production.

e. *Regional Comparative Advantage*: Agriculture in some regions requires substantially larger fossil fuel inputs than in other regions, due to biophysical and infrastructure variables such as climate conditions, irrigation systems and availability of water resources, sources of electricity, soil conditions which affect tillage, etc.
The group considered this sub-topic relatively well-researched, but not widely understood by the public.

This key question was considered important for food industries, producers, and government, especially at the federal level. Certain large institutional players (such as Wal-Mart and others) are showing increasing interest in reducing their carbon and energy footprints, and they have the potential to make large changes upstream in their supply chains. Among consumers, however, it appears that currently a few are very interested in this question while a large number have no overt interest in it at all. In order for research to be useful, consumers will need more generalized information, to avoid being overwhelmed. Producers and industry, on the other hand, will require more specific, actionable recommendations to result from research. The issue of how to define regions will also have to be considered carefully when designing case studies for research. Most likely, a bioregional approach will be most appropriate, as opposed to using political boundaries. Finally, an important area needing further work is to convert existing European emissions coefficients for different transport modes (as embodied in software such as SimaPro) into U.S.-relevant coefficients.

B. Scale of Production, Processing, and Distribution Systems

Key question:

> ***Do larger-scale food systems (comprising large farms, large processing facilities, and/or long-range distribution networks) exhibit economies of scale in terms of energy use and GHG emissions compared to smaller local- or regional-scale food systems? If so, at what size range does the rate of increase in economies of scale begin to slow, or exhibit diminishing returns?***

The following sub-topics were identified as important pieces of the larger question, which will need to be addressed through further research.

a. *Efficiencies of Distribution Networks:* Regional-scale distribution networks may use less fuel overall and have lower GHG emissions than long-distance, highly centralized distribution networks (and possibly also less than very localized, small-scale distribution networks).
The group considered the issue of "food miles" and its full implications as not yet well-understood, requiring more research in order to identify areas for improvement. Some studies have shown that local food systems in some cases require more fuel use in transport per unit of food, due to the relative inefficiencies of small trucks versus large trucks, rail, and ships used in larger-scale food systems. However, it is possible that the local food systems are in a better position to increase their overall efficiencies through measures such as renewable fuel sources, better engines, and optimized distribution routes. In addition, the potential GHG impact of using more biofuels within the food system overall, at multiple scales, is not yet well-understood.

b. *Efficiencies of Energy Sources:* Research is needed on the thresholds for economies of scale for different energy sources, for example biogas.

c. *Machine versus Human Labor:* Global-scale food chains often include farms in non-industrialized countries where more farming operations are performed by hand labor instead of machines, with potential savings in fossil fuel use and GHG emissions.

d. *Efficiencies of Farm Size:* Farms within a certain size range (small to midsized) generally produce higher yields per unit land area than very large farms. The implications of land use efficiency for energy efficiency are unclear.

e. *Processing and Scale of Distribution Networks:* Food characteristics such as perishability or water content can influence what scale is most appropriate for a type of food or level of processing. For example, highly perishable foods and water-heavy foods may be most efficiently distributed through small-scale local supply chains, while more processed, more dense, and less water-heavy foods might be more efficiently distributed through larger-scale systems.

   Many aspects of processing and transportation issues (including, for example, cold chain technology) have already been well-studied within the industry, and this information just needs to be integrated into more comprehensive LCA studies.

f. *Economies of Scale in Processing Plants:* Economies of scale may achieve significant fuel efficiency gains for certain processing methods more than for others (such as tomato paste production and canning versus sun-drying).

For more information on considering mode of transport in concert with distance, see section (C), below.

This key question was considered particularly important for producers, especially as they make decisions on whether or not to expand or invest in strategies to differentiate themselves in the marketplace. The sustainable agriculture community should become more engaged with these questions than it is. For consumers, getting reliable answers to these questions is very important to avoid the development of skepticism and misinterpretation of issues such as “food miles.”

The research strategy to address this question should begin with a general overview to identify those areas (particular industries, food categories, etc.) that exhibit the largest disparities in scale. Once these “hotspots” are identified, more detailed research on specific factors that affect them can ensue. For example, it may be prudent to start with one industry, such as dairy, a large portion of which plays out on a regional scale already, but which also encompasses long-range feed supply chains. Researchers may find it useful to focus on the top 20 or so commodities, or choose the top 10 ingredients found in a complex food item, instead of trying to cover every detail.

Other considerations when designing specific case studies include the issue of differences in packaging among the different scales of food systems. For example, a large portion of lettuce sold in large retail stores is in the form of pre-packaged lettuce rather than head lettuce. While the packaging itself creates more GHG emissions, it is possible that the packaging prevents some consumer-level waste that may otherwise occur with head lettuce. The comparative impacts of different ways of utilizing or disposing of waste in each food system should also be included in such studies.

C. Seasonality of Production, Processing and Distribution

Key question:

> ***Under what conditions and for which commodities are processed foods more energy- and GHG-efficient than fresh foods?***

The following subtopics were identified as important pieces of the larger question, which will need to be addressed through further research.

a. *Energy Efficiency in Processing:* Some forms of processing use less fossil fuel than others, and management factors can make a large difference in energy efficiency of processing plants.

b. *Processing Method and Transportation:* Processing methods that reduce weight (drying or paste production) and/or eliminate refrigeration requirements (canning) may substantially decrease fuel consumption during transport compared with fresh foods.

c. *Packaging Material:* The added weight of some packaging materials, such as glass, can add significantly to the energy required for transport of a unit of product.

d. *Packaging and Food Waste:* More extensive packaging may reduce food waste further down in the life cycle, offsetting the larger impacts of producing the packaging.

e. *Distance to Markets:* For example, Caribbean and Central American production areas are closer to eastern U.S. markets than is California.

f. *Efficiencies of Modes of Transport:* Distance must be weighted for mode of transport (energy use/tonne-km), since modes such as sea and rail shipment use much less energy per tonne-km than modes such as trucks, cars, and air freight. Air-freighted foods will almost always use more fuel and emit more GHGs than local foods.

g. *Greenhouse Production:* Out-of-season greenhouse production can substantially increase energy use and GHG emissions of fresh commodity production systems.

Transport issues are fairly well understood and documented already. Rather, it may be more important to define what is considered “local,” in terms of distance. However, while processing issues are generally understood, we are still lacking aggregated data to demonstrate the range of energy intensity within processing industries. In some cases, different processing facilities producing the same types of products can exhibit a five- to six- fold range of differences in energy intensity per unit of product due to differences in management. Economies of scale can also play a large role in processing efficiencies. Finally, many European studies have documented key patterns and relationships between variables in production, processing, and distribution. However, there is still a need to verify whether these trends hold in North America, perhaps by studying a few of the major commodities. In the final analysis, an urgent question is whether consumers will be willing to “buy into” the necessary dietary changes that would lead to a better energy and GHG profile.

Identification of general trends or guidelines across broad categories of food is more important for both consumers and policy makers than multiple case studies on individual foods. The caveat for this recommendation, however, is that impacts of eating out-of-season foods are very context-specific and difficult to generalize. For food industries, on the other hand, a few well-chosen, specific case studies among key large players might be an effective vehicle for driving change within particular industries.

When designing case studies, it will be important not only to compare the same foods in and out of season, but also to consider reasonable substitutions of commodities, according to seasonal availability. For example, instead of tomato slices during the winter, consumers in northern regions might choose slices of cooked root crops or winter squash to fill the same niche in a meal as fresh tomato slices fill in the summer time.

D. Livestock Production

Key question:

> ***Under what conditions are animal-derived foods relatively more energy- and GHG-efficient, and how does this efficiency compare to plant-derived protein foods?***

The following sub-topics comprise important pieces of the larger question, which will need to be addressed through further research.

a. *Ruminant versus Non-ruminant Species:* Ruminant species (cattle, sheep) produce more methane than other species (chickens, pigs), but can better utilize less concentrated feed with lower embodied energy.
   This particular topic is the most relevant aspect of the livestock issue for consumers and industry. Getting information to the retail sector is also important, as retail managers are the ones to make decisions about what products will be made available to consumers and promoted in sales campaigns.

b. *Free-Range versus Confinement-Raised Systems:* Extensive production systems (range-fed) may contribute to more methane production but lower fossil fuel-related GHG emissions than intensive, confinement-based production systems.
   Comparing different production systems has highest priority for policymakers and retailers. Information from such research will be more relevant in business-to-business communications than directly for consumers. A system for tracing products back to producers, as is now being used to address food safety concerns, might also be relevant for helping retailers identify where to source livestock products for the least GHG impact. Research needs to identify what information is needed to institute a transparent accountability program regarding environmental impacts.

c. *Nutrient Use Efficiency:* Improving efficiency of nutrient use can make a big impact in most production systems, since nitrous oxide emissions from fertilizer use and feed utilization by animals are known to comprise a dominant source of GHG emissions in many production systems. These emissions are highly variable and highly dependent on context-specific details such as climate and specific management practices, making generalizable research in this area very challenging.

d. *Plant versus Animal Proteins:* Most animal-derived protein foods are more energy- and GHG-intensive than plant-derived foods, per unit of food item.

The issue of plant protein versus animal protein is not a high priority for new research, as existing research has already overwhelmingly demonstrated that plant proteins are almost always environmentally superior to protein from livestock, from the perspective of energy intensity and GHG emissions. However, consumers will want to know about relevant nutritional differences, in order to make informed dietary choices. Overall, nutritional and environmental concerns could be allies in shifting consumer choices (except in the case of GHG-intensive vegetables, such as greenhouse-grown products). For example, nutrition-driven campaigns that aim to shift consumers to eating more fruits and vegetables and less red meat could also highlight the lower carbon footprints of such diets.

Only a very small percentage of U.S. consumers are currently interested in these issues, a trend mirrored among policymakers. Producers are currently somewhat more interested in GHG emissions as a group, but they also exhibit a high degree of variability. Even if most consumers are not yet concerned about this question, food industries need to be prepared in advance, as it is possible that more consumers will become interested in these issues in the future. Moreover, some food industries themselves are already taking the lead in educating consumers about the impacts of their dietary choices.

Case studies to investigate this question should include comparisons of different methods of raising livestock (range-fed versus confinement-fed, etc.).

E. Pre-Retail Versus Post-Retail Impacts

Key question:

> ***Under what conditions do post-retail decisions made by consumers and institutional food services overshadow efforts to increase energy- and greenhouse gas-efficiencies within any pre-retail sectors of the food system?***

The following sub-topics comprise important pieces of the larger question, which will need to be addressed through further research.

a. *Transportation of food post-retail:* Relatively small purchases from large, centralized supermarkets and use of fuel-inefficient vehicles can subtract substantially from the energy- and GHG-efficiency of food on a per unit basis. On the other hand, purchasing directly from farms at farmers markets, considered to be more sustainable by some consumers, could imply more energy use per kg food item consumed because of the relatively small amounts transported per person per car mile.

b. *Cooking:* Choice of home appliances (toaster, oven, microwave of different brands) and efficiency of those appliances affect the energy- and GHG-efficiency of food cooked at home.

c. *Storage:* Choice of preferred storage mode (refrigeration, freezing), size of storage facilities, and efficiency of appliances used will affect the relative energy- and GHG-efficiency of food items. Longer total duration of storage time can also add significantly to energy use and GHG emissions associated with individual food items.

d. *Food waste and packaging:* The amount of food discarded, the type of packaging, and the choice of disposal method (landfill, incineration, biogass production, or composting) will affect the overall energy- and GHG-efficiency of food items. In some cases, more packaging may help to reduce the amount of food wasted. Reducing the proportion of food waste has a double impact in that it reduces emissions from the waste stream and also reduces emissions from food production further upstream in the supply chain.

e. *Scale of Retail Space:* Energy- and GHG-efficiency per square foot of retail space can vary greatly between large supermarkets versus smaller outlets or farmers markets.

f. *Types of Institutional Food Service:* Different categories of institutional food service (business catering, restaurants, fast food outlets) vary greatly in their energy- and GHG-efficiencies, and may exhibit high levels of food waste at different stages of their operations.

g. *Scale of Food Preparation and Delivery:* More research is needed on the following topics: (1) whether ready-made meals cooked at a large scale result in lower GHG emissions than individual home cooking; (2) whether home delivery of food is preferable to individual shoppers logging mileage to retail shops; and (3) whether the changing geography of the retail landscape affects overall energy and GHG-efficiency of the system (i.e. centralized, large-scale supermarkets vs. smaller, conveniently located shops).

There was little consensus on how to prioritize these sub-topics for research, but one approach could be to begin by tackling those subjects that are already in the public awareness. For example, many people may already see waste reduction as an economic and moral issue. Or, existing research on topics such as home cooking efficiency and transport efficiency could be expanded to extend existing knowledge into a full LCA approach.

Overall, group members thought that U.S. consumers and producers are not currently very concerned about these issues. Retailers are slightly more interested, in terms of reducing transport distance and enhancing convenience in order to attract consumers. Government is currently most interested in these issues. The importance of a more in-depth analysis of this topic is underscored by existing research that indicates that post-retail activities account for a very high percentage of energy use and emissions in the total food chain, from 15% according to an internal study by the U.K. Department for Environment, Food, and Rural Affairs, and 23% for consumer-level storage and cooking according to a Netherlands study (Kramer 2000).

Symposium participants suggested that we need to identify “the hotspots”, or areas of highest energy use and/or emissions, first in a more generalized approach, and to follow up with specific studies to answer more focused questions.

III. Methodological Issues for LCA Research

Since the application of LCA to food products is a more recent phenomenon than its application to industrial products, and because food products encompass some uniquely challenging issues for LCA, many important methodological problems remain to be fully resolved. During the symposium, many of these issues were addressed in focused, small-group discussions on assigned topics. After an initial introduction to LCA methodology and its advantages and constraints, the remainder of this section summarizes the results of those small group discussions, organized by topic. Further details on several of these topics can also be found on the ASI website (www.asi.ucdavis.edu) in the slide presentations provided by several symposium participants.

A. Life Cycle Assessment Methodology: An Introduction

LCA methodology has been standardized by the International Organization for Standardization (ISO 14040 series). The first step of an LCA involves goal and scope definition, which includes clearly defining the purpose of the study, the research expectations, the system boundaries, as well as any key assumptions made (including allocation procedures). The system boundaries should include all system operations that contribute significantly to the life cycle, detail spatial and temporal limits, and correspond to a clearly articulated rationale. This step also includes delineating the functional unit, which is the unit of product or service that will comprise the reference unit for calculating impacts throughout all stages of the life cycle.

The next step is the life cycle inventory (LCI) analysis, which entails identifying and quantifying all relevant material and energy inputs and outputs (including waste and co-product streams) for each stage of the life cycle, and expressing these per functional unit of product or service delivered.

The environmental impacts (or impact potentials) associated with specific life cycle stages are derived during the impact assessment phase, which involves translating life cycle inventory data into quantitative contributions to a pre-defined selection of environmental impact categories. Impact categories represent specific environmental issues of concern, such as global warming, acid precipitation, eutrophication, and ozone depletion. Contributions to impact categories are calculated by using category indicators (reference types used to represent all emissions relevant to a given impact category) and characterization models (typically peer-reviewed methodologies such as the IPCC guidelines for calculating greenhouse gas emissions in CO_2 equivalents, or the World Meteorological Organization's guidelines for calculating ozone depleting emissions in CFC-11 equivalents) to assign life cycle inventory data to the relevant impact categories (see Appendix 4).

The final step, the life cycle interpretation phase, involves evaluating and interpreting the relative contributions of life cycle stages to each environmental impact category. This step facilitates the identification of life cycle stages that contribute disproportionately to specific areas of environmental concern.

B. Advantages and Constraints of Life Cycle Assessment Methodology

Quantitative life cycle assessment is among the most powerful tools for evaluating the discrete and cumulative contributions of specific industrial processes to those issues of environmental concern in which a clear causal relationship can be established at the industrial/environmental interface. One advantage of LCA, compared to other environmental impact assessment methodologies such as input-output analysis, is that it examines environmental impacts accruing at each stage of the life cycle, rather than aggregating data across life cycle stages. The resolution afforded provides opportunities for more nuanced examination of the relative importance of specific life cycle stages, as well as comparisons of product/service systems that deliver similar outputs – for example, comparing crops grown in a conservation tillage system versus the same crops grown in a conventional tillage system, or changing a beverage's packaging from glass to plastic. LCA is therefore well-suited to projects that have a goal of developing criteria for "best practices" or identifying specific ways of improving the production and provisioning of a given set of food products.

On the other hand, LCA is very data intensive and time consuming. Moreover, results are often highly sensitive to changes in the delineation of system boundaries and allocation procedures, thus confounding opportunities to make meaningful comparisons of product/service systems across LCA studies. Another common criticism of the LCA framework is the limited suite of environmental issues that it can realistically address. Quantitative life cycle assessment requires a mathematically definable relationship between the functional unit of a product/service system and a known or potential environmental interaction. For this reason, the majority of commonly used life cycle assessment impact categories are based upon the relatively well-known pathways associated with specific chemical emissions. Although much research effort has been invested in expanding the scope of life cycle impact assessment categories and methodologies in order to address a broader range of environmental concerns, the success of such initiatives is inevitably limited by the nature of the LCA framework (see Pelletier et al. 2006). In particular, life cycle assessment is not well suited to evaluating the contributions of product/service systems to environmental issues that manifest as a result of multiple, interacting factors, such as biodiversity loss or localized environmental degradation. However, in all such cases qualitative life cycle impact descriptions can contribute equally rich and informative perspectives on the role of industrial processes in environmental change.

C. Systems Boundaries

1. Some Guiding Principles for What to Include and Exclude

Defining the commodity chain and its system boundaries for a specific product is a critical part of LCA methodology and inconsistent system definitions may make comparisons between products impossible. The definition of the system boundary will ultimately depend on the specific purpose of the study, or the particular question it is intended to answer. Conducting a very comprehensive LCA with very expansive systems boundaries is not practical for most studies that wish to address specific issues. Instead, a recommended strategy is to narrow in on the parts of the system most relevant to the issue under study and obtain high-quality, detailed data for those parts, while keeping other parts of the system more generalized to standardized sectors with estimates of overall inputs and outputs. Some of the accepted sectors for food LCAs include the following:

- Production
- Processing
- Packaging
- Transport

- Retail
- Post-retail
- Waste

As a general rule, the variable resource costs, such as process energy used, will be more important to include than the fixed costs (the cost of building capital goods such as the factory or the stable), depending, however, on the purpose of the study. For example, the inclusion of employee processes, such as transportation to their jobs at a processing plant, will be unlikely to make a significant impact on the results of a study comparing different types of vegetable processing. Some studies (e.g. Ayer 2007) have also suggested that the impact of capital goods on energy intensity and GHG emissions of food production systems being studied were quite small. This small magnitude of impact suggests that detailed inclusion of capital goods in LCAs focusing on energy and GHG emissions of some types of production systems may not be crucial. Instead, they could be accounted for satisfactorily by using rough assumptions as opposed to detailed analysis.

Despite the example just noted, experts still disagree on the importance of including embodied energy of buildings, roads, and other capital goods. Some researchers argue that it is an over-generalization to suggest that capital goods never have to be included in a food LCA. Recent work has shown that they can make significant impacts (Frischknecht et al. 2007), especially in agriculture where certain equipment and buildings may only be used seasonally for relatively small amounts of time, and therefore the impacts of producing and constructing these items in the first place are not amortized over as many units of output (see also US EPA 2006, which shows that total GHG emissions from transportation can increase by a factor of up to 1.5, compared to only the direct emissions, when the indirect emissions from manufacturing the vehicles are included.) One strategy to deal with capital goods is to prioritize more detailed, context-specific data collection for items having a shorter lifespan, or that are used only intermittently. For other items, one can use generalized data modules available in LCA datasets. For example, the ecoinvent inventory datasets already include the resource use and emissions related to the capital goods needed for providing processes and services. For example, the environmental cost of using a truck includes both the actual diesel use and oil consumed by the truck as well as a certain percentage of the burdens associated with producing and maintaining the truck and the road systems. Using this generalized information would be preferable to simply excluding all capital investment from the outset of the study, which could lead to unwarranted neglect of potentially important issues in the long run.

2. Systems Expansion Method for Handling Co-Production and for Comparing Multiple Cropping Systems

A single process often produces more than one product, necessitating decisions of how to allocate environmental impacts of the process to each product. For example, dairy operations produce both milk and meat, and soybeans yield both oil and soybean cake used in concentrated feed. In such cases of co-production, environmental impacts can be allocated to each product according to relative economic value of the product (with a proportionally greater percentage of the environmental impacts being attributed to the product with the greater economic value). Relative weights, or mass, of the co-products can also be used to make allocation decisions.

However, because such allocation decisions are based on more or less arbitrary factors which do not necessarily reflect environmental reality, the ISO 14040 series recommend the use of ***system expansion*** instead, whenever feasible. Using systems expansion, the environmental burden of the whole production system is allocated to the main product in focus, and the saved environmental impact from the avoided production of a product similar to the co-product is subtracted from the total burden. For example, when milk production also produces an amount of beef, this saves an equivalent amount of meat production in another system, which would have created some environmental emissions. These emissions are subtracted from the milk calculation as avoided emissions. In the case of soybeans, if we consider the main product to be soybean cake, then the saved emissions, both from cultivating and pressing, of another oil crop (which is replaced by the soybean oil co-product) are subtracted from the total environmental burden of soybean cake.

In a more complicated case, consider that a swine operation produces manure in addition to meat, and that this manure may be applied to crop fields as a soil amendment and source of nitrogen (and it might even be used for biogas production).. In this case, one would expand the system boundaries of pork to include the storage and application of the manure to the fields, as well as the infrastructure and processes needed to capture the methane biogas. One would also include the systems required to make the products that might feasibly be replaced by the manure and biogas in the marketplace, in this case perhaps synthetic nitrogen fertilizer and natural gas. In the final analysis, one would then subtract the GHG emissions associated with the production of a functionally equivalent amount of (saved) fertilizer and an equivalent amount of natural gas from the pork emissions.

A more challenging case is presented by the comparison of conventional, monoculture cropping systems with alternative cropping systems that rely on multi-year crop rotations for soil fertility and pest control. In this case, the question becomes how to account for the rotation crops that are different from the primary crop under study, and which do not even appear in the conventional system. One approach is to estimate quantitatively, if possible, the benefits accruing to the main crop from the rotation crop, for example residual soil nitrogen or avoided yield losses from pests. Environmental impacts can then be allocated to each crop accordingly. In many cases, however, each crop in a rotation produces benefits for each other crop in that rotation, so that all crops could be considered as “co-products” of each other. In such cases estimating distinct benefits to each individual crop is difficult. Instead, one might attempt to estimate inputs and environmental impacts of each rotation crop as if it was a separate monocrop. With this approach, one would then be comparing an organic system over one rotation period to a conventional system with multiple monocrops producing the same types and amounts of products (or several individual conventional enterprises corresponding to the same products as the organic mixed system).

In the case of comparing organic systems with other systems, it is also important to use data from mature organic systems, since these systems often require several years to build up soil fertility, and it is unrealistic to compare immature systems with long-term conventional systems. Moreover, it is important to use a consistent method for allocation of livestock manure related emissions in comparisons where one system used animal manure and the other only chemical fertilizer.

3. Additional System Boundary Considerations

Some additional issues to consider when deciding on system boundaries:

- Agricultural products compete on a global market and inputs of feed, fodder and fertilizer to an agricultural system can be procured from many places, causing confusion or bias in the inventory. However, by defining the question precisely one may often focus on those marginal input suppliers on the world market who are in a position to increase production.
- When assessing alternative production forms and food chains, care should be taken to include any possible changes in land use, including associated soil carbon content and sequestration, when assuming a large-scale shift toward an alternative system.
- The timeframe under consideration may affect the system boundaries. For example, if the goal of a study is to compare the impacts of small, localized farm production with larger-scale production systems in the present or over the next few years, then including details on transportation infrastructure would not be necessary. However, if the purpose of the study is to illuminate policy considerations about whether to promote a shift in the system to more of one type of farm or another, then the resultant impacts on the transportation infrastructure, as well as the energy inputs required for long-term infrastructure investments that may be necessary to facilitate this shift, are inputs that should be included within the system boundary.

D. Functional Units

Functional units in food studies are most often chosen to be a unit of a particular food item, such as a kilogram of tomatoes or a liter of milk. There have been only a few studies in Europe that have attempted to redefine the functional unit to be a typical “basket of food.” A consumer “food basket” might be analogous to the consumer price index, in identifying a mix of typical food items and quantities purchased by consumers over a time span (either in one meal, or over a week or a month). We will need more studies with this type of functional unit if we are to conduct realistic comparisons of local- or regional-scale food systems with global scale systems, since such studies will typically require comparing entirely different food or meal options, and entail more than simply comparing asparagus grown locally to asparagus flown in from overseas. This approach could also be helpful in dealing with the difficulties of comparing organic and conventional systems, as described above, especially when the two systems entail entirely different crop combinations. Instead of attempting a crop-by-crop comparison, one might compare the two systems according to the overall food basket that each provides.

Information on typical food consumption is already available in many countries from consumer surveys. A food basket could also be devised that incorporates published nutritional guidelines, so that an LCA could compare the environmental impacts of what people are actually eating currently with what they *should* be eating from a nutritional standpoint (see Granstedt et al. 2005 and Kramer 2000 for examples of this work).

E. Databases and Data Needs

Several database initiatives exist to provide basic data for building life cycle inventories. Most of these efforts have been centered in Europe, with the exception of the U.S. Life Cycle Inventory (US LCI) Database, coordinated by the National Renewable Energy Laboratory. This database, however, is not necessarily consistent in terms of how different modules are created, how data is collected, and how boundaries are defined. It is also, at present, limited in terms of data relevant specifically to agriculture.

1. Strengths of existing databases

a) ecoinvent data v2.0 (based in Switzerland):

This database is:

- Transparently documented
- Quality-controlled
- Presented at the unit process level (which allows, for example, for selecting different mixtures of sources for electricity according to the specific context)
- Harmonized (consistent guidelines for developing data are followed throughout the database)
- Updated often (especially key data sets)
- Capable of providing estimates of uncertainty in the data, and allows LCA software tools (e.g. SimaPro) to calculate and compare uncertainties with a Monte-Carlo simulation
- Inclusive of data in the US LCI database (beginning with v2.0)

b) GABI and some other European databases:

These databases are parameterized – some numbers are not fixed, but instead are calculated based on user inputs (e.g. N_2O emissions are calculated based on amount of fertilizer input specified by the user).

2. Limitations of existing databases

- All databases are somewhat different and are not harmonized with each other, posing difficulties when users try to mix data derived from different databases in one LCA.
- European databases use different data formats (although format exchange tools do exist).
- Many existing databases do not represent uncertainty or inherent variability in the data – capturing variability is especially important when analyzing natural systems, including agriculture.
- Primarily European-based data is included.

3. Additional database challenges and shortcomings

- Updating the data is costly – ensuring that updates will occur requires long-term funding and a dedicated, overarching organization to oversee the work, and the ability to garner peer review.
- Some datasets lack regionally specific data, and regional differences are quite important in LCAs involving agriculture (thus the need to develop key LCI data for the U.S. context).

4. Additional data resources

- MOBILE 6.2: US-EPA modeling software that calculates vehicle emissions. These models can be adjusted to reflect the fleet of vehicles (or piece of farm equipment) of concern and they also change dynamically over time based on predicted policy changes for tailpipe/engine emissions. Combustion emissions data from these models could be combined with pre-combustion data from diesel and gasoline production to characterize the LCI of diesel or gasoline combustion.

- US-EPA has produced several reports and documents about the direct and indirect greenhouse gas emissions of transportation (including freight transportation). Data in these reports can be used to derive U.S.-relevant transportation coefficients (US-EPA, 2006). International Panel on Climate Change (IPCC) can provide the best global warming coefficients for general processes like energy use. However, since they are very general and standardized globally, they should be used only with care and forethought for specific LCA studies. For example, when considering N_2O emissions in agriculture, one must keep in mind that such emissions can vary tremendously from one year to the next, even in a single field.
- For globally produced products that do not vary significantly from one place to another, such as fertilizer, pesticides, and packaging material, one could substitute impact data from European databases when building a life cycle inventory for a U.S.-based LCA.
- The Web site Earthster.org is developing an open-source tool for companies to perform LCA for their products and processes.
- The Carnegie Mellon Green Design Institute has developed an Economic Input-Output Life Cycle Assessment Model that can be used to calculate environmental impacts of each of about 500 commodity sectors. It is based on an industry by industry economic input-output matrix for the U.S. Greenhouse gas emissions are calculated using US-EPA emissions factors for fuel use.
- LCAFood.dk (www.lcafood.dk) is a free access database with LCAs on most food products produced in relatively intensive systems corresponding to northern Europe.

5. Increasing data quality and accessibility

There is a trade-off between data quality and accessibility. Market forces can help to ensure quality and continual updating of databases that are developed for commercial sale, but affordability issues can limit access to such databases. However, in the European context, at least, availability of essential data is no longer a problem. The present need is to focus on quality control and harmonizing data across datasets so that it can be used more effectively, and for these processes, market forces can help. In the U.S. context, the lack of a comprehensive, coherent U.S.-specific database provides the opportunity for government funding to create a good quality, coherent database that is developed as a public good. Whether the quantity of funding necessary is politically feasible, however, remains in question. To date, the US LCI database effort has not received enough funding to become an effective resource, especially for food-related LCA, and is very dependent on private industry funding to start up new, industry-specific datasets.

One model for database development that has worked effectively in Switzerland is the requirement that any data-gathering study that is publicly funded must be incorporated into the ecoinvent database. This requirement ensures that private consultants or companies cannot keep information in their own private databases alone, without enriching the more national-scale ecoinvent database effort.

F. Managing Time and Data Requirements in LCA Implementation

Given the significant time and resource requirements needed to conduct comprehensive LCAs from scratch, various techniques can be used to streamline the process.

1. Purposeful delineation of system boundaries

As already noted in section (C) on systems boundaries, effort can be streamlined by careful delineation of the system boundary to focus the most detailed effort on those stages of the life cycle and those inputs that are the most variable and will have the most impact on the particular question or issue under study.

2. Modular approach

This approach is related to (1) above, in that generalized data modules obtained from standard databases (or from previous LCA studies) can be used to fill in information for those parts of the system that are not the specific, critical aspects under study. For example, if the main goal of one's study is to compare organic with conventionally grown produce items, one might find impacts already calculated for "typical" packaging materials used for these types of items. Such a packaging module might then be inserted into the complete LCA without additional, primary research being devoted to assess the precise numbers for those exact products under study.

3. Hybrid LCA

A hybrid approach combines the strengths of economic input-output (EIO) models with those of LCA models. EIO models trace essentially all the economic transactions between sectors of the economy. When linked with sector-wide material and energy inputs, and waste and pollution outputs, an industry-average LCI can be generated. The two advantages of EIO-LCA hybrid methods are ease of implementation and comprehensiveness from a systems boundary perspective. Drawbacks include highly aggregated results and a financial basis for environmental impacts, which may or may not reflect the true emissions or burdens associated with a sector. In a hybrid approach, EIO models are used to generate LCI data for stages of the life cycle that are not the main focus of the study, and that may be unaffected by a high level of aggregation and non-specificity. EIO data can also be used to fill gaps where process LCA data are unavailable. As in the modular approach discussed above, the more critical life cycle stages (depending on the study objectives) are then examined through a more detailed, process-based LCA.

4. Standardizing reporting formats

Many LCA studies that investigate a range of different food-related issues have already been completed, but the publications that report on their results do not always clearly indicate the system boundaries, functional unit, data sources, and variability or degree of uncertainty in the data. Standardization of reporting requirements could help make LCA studies more transparent and their results more usable in subsequent LCA work, avoiding the necessity of "reinventing the wheel" for each calculation in each new study.

G. Data Aggregation

In many sectors, and most especially in agriculture, the large number of individual firms (farms) and the high degree of variability among them necessitates some decision rules for aggregating data for inclusion in LCA studies. The method and degree of data aggregation that is appropriate for a given study will depend on the nature of the study and the specific questions pursued. For studies to establish baseline conditions (i.e., broadly representative activities), data should be aggregated to the extent possible across the full range of variability, and weighted for share of production. In such cases, the extent to which the data are representative should be clearly communicated (for example, “this study is based on 12 farms representing 60% of production in a given region”). For studies aimed at defining best practices, data should be aggregrated over a smaller range of representative activities and the high/low values should be articulated.

These two different approaches to aggregating data may be complementary in the case of studies aiming to demonstrate the impact of potential changes in the system – the broadly representative aggregation would provide the baseline values against which results from a more selective aggregation, or even a hypothetical model, could be compared. Guinee et al. (2001) provide some guidance regarding data quality, which should be considered in evaluating the appropriateness of particular data sets. In all cases, decisions regarding data inclusion/exclusion should be made with reference to the goals of the particular study.

The use of a representative modular approach is recommended for specific cases involving complex distribution systems, for example, the flow of canned goods from cannery to multiple nationally distributed warehouse centers and then to individual retail outlets. Rather than attempt to trace the exact route of any given can, which can vary considerably from week to week, it is more appropriate to use a systems-level approach that assumes system-wide average values. Such values can be obtained from modules in existing databases, and from other data sources, such as the commodity flow surveys available from the U.S. Bureau of Transportation Statistics. We hypothesize that the use of average data for these systems, as opposed to very specific data, is not likely to result in major differences in the outcomes. We are unaware, however, of whether this hypothesis has ever been empirically tested. Many LCAs dealing with agricultural production and distribution have shown that transportation generally only contributes a relatively small portion of life cycle impacts, depending on the degree of processing of the food product (see for example Carlsson-Kanyama et al. 2003).

While we can generate aggregate data fairly well at the pre-farm level (inputs and transportation), and also at the distribution level, taking care to capture the variability of farm production should be a high priority in food LCA studies, since there are substantial differences and also uncertainties in energy use and emissions (especially N_2O emissions) between production systems, locations, commodities, and other variables.

H. Geographic considerations

Data on agricultural production practices (such as pesticide and fertilizer inputs, seeds, machinery use, and field labor) in developing countries are very limited (Wargo 1998). Variables that change greatly by geographic location, such as wage rates, national policies, climate and soils, will be the primary source of variation in impacts of production in different countries. In theory, the rapid expansion of food exports from developing countries to industrialized nations is based on lower costs of production that must offset higher transportation costs. These lower costs could be in the form of labor from considerably lower wages, lower land prices and rents, and/or lower costs of purchased inputs. It is impossible to predict whether inputs, especially agrochemicals and fossil fuel use in mechanization, are greater in developing countries than in industrialized countries, and their use is likely to vary considerably by sector and region. In tropical regions, savings from lower wages and land prices could be invested in higher use of inputs, especially synthetic pesticides used to address greater pest problems. It is also likely that reliance on mechanization in developing countries is much lower because of lower wages.

Farmer and export firm surveys on production practices can provide important data for direct comparisons between different countries, but can be expensive and time-consuming. Simulation models and tools from geographic information science could be coupled with consultations with farmers in order to obtain a range of variation, which reflects on-the-ground realities.

I. Collaborating with Industry for Data Needs

Just as engagement with farmers is important, so is engagement with industry for any LCA research that extends beyond the farm gate, in order to fill data needs regarding industrial processes and practices. Such engagements need to be established with great care, in order to ensure industry buy-in, both for the purpose of accessing data as well as for generating greater impact with the research results. Single companies are often reluctant to supply information; they are typically more likely to cooperate if multiple companies within the industry get involved. Sharing of data can then be done in such a way as to ensure a level of confidentiality (by only sharing data aggregated for all companies) while also allowing companies to benchmark their own performance against others. Engaging industry in this way can also act as a means of awakening greater awareness of these issues within industry, and helping individual companies get ahead of the curve on energy use and GHG emissions.

Another approach is to merge data gathering functions with catalyzing change in an industry through an iterative approach. At the beginning, researchers may engage at least one or two companies; results are then published, stimulating more companies to become engaged in further efforts, and so on. Such an approach can help generate data on second-generation practices over time.

IV. Catalyzing Change: Communication and Outreach Strategies

While the symposium was primarily focused on appropriate topics of study and methodology for life cycle assessment, what to do with the results once you have them, and how to catalyze change in food-related industries and consumers, were topics that continually surfaced throughout the discussions. Many participants noted the difficulty in moving consumers to change their purchasing decisions, and called for novel ways to bring attention to the issue of greenhouse gas emissions in the food system. For example, if research was designed to include analysis of other benefits, such as nutritional benefits, flowing from lower GHG food options, then these other benefits might provide a different vehicle for promoting diets that lower energy use and GHG emissions. Certain food-related issues, such as food safety, have also received a great deal of public attention recently, offering possibilities for linking issues of high consumer concern with GHG emissions in our food system. Consumer research has demonstrated that people typically make purchase choices based on direct benefits to themselves. Moreover, different segments of the consuming public might respond better to some incentives than others (nutritional benefits, food safety, community benefits, environmental protection, etc.), necessitating a diversified approach. Collaborating with colleagues in colleges of business and marketing in this type of work will help make outreach efforts more effective. It was also noted that the Swedish food LCA researcher Annika Carlsson-Kanyama and colleagues had introduced the idea of a “climate watchers’ group”, akin to the concept behind “Weight Watchers”, in which individuals gather in groups to discuss and help each other to achieve consumption patterns with lower carbon footprints (Carlsson-Kanyama et al. 2003). On-line carbon calculators, even if they are not based on the most “perfect” data and the “best” calculations, can still be useful in communicating to consumers that their individual food choices can make a difference in GHG emissions. However, we are still lacking a consensus about the most important factors to include in such calculators. For example, a very simple “food miles” calculator could offer precise information, but would also be misleading to consumers.

Anticipating that such promotion efforts might only succeed in changing the behaviors of a portion of consumers, participants also noted that the food system offers many other possible points of intervention. Working with large retailers is one way to influences choices, not only downstream, among consumers, but also upstream, among industry suppliers. Industry-dominating retailers who are willing to implement new sustainability standards for their suppliers have the potential to catalyze change in large segments of the food industry. The growing movement among large retailers to begin to develop such standards offers an opportunity for producers further upstream, such as farmers, to voice their perspectives on what is truly needed to enhance sustainability as well as viability of their operations. Now, while this trend is still in its beginning phases, might be the best time to catalyze more discussion between upstream and downstream entities in the food system.

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Appendix 1
Agenda
Symposium on Energy LCA in Food Systems

Agricultural Sustainability Institute
University of California, Davis
October 8-10, 2007

Anticipated Outcomes:

- Identify and prioritize the key issues that address industry's, consumers', and policy makers' needs regarding energy use and global warming potential of food systems.
- Gather input for a white paper to frame key LCA issues, data needs and methodology standards that will guide research and make it relevant to the food services industry, consumers, and policy makers.
- Agree on a "roadmap" for launching a collaborative research and outreach program on energy and greenhouse gas LCA of food commodities.

MONDAY, OCTOBER 8

8:00 - 8:30am	**Continental breakfast**
8:30 - 8:50am	**Welcome and Introductions** by **Tom Tomich**, Director of the Agricultural Sustainability Institute, and **Daniel Sperling**, Director of the Institute of Transportation Studies, Energy Efficiency Center
8:50 - 9:15am	**Introduction to ASI's research and outreach plan** by **Sonja Brodt**
9:15 - 10:15am	**Presentation**: Energy in the Food System: Society and Policy *Chair: Gail Feenstra, ASI/SAREP* - Helene York, Bon Appétit Management Company Foundation - Guy Shrubsole, DEFRA, UK *Recorder: Colleen Hiner*
10:15 - 10:30am	**Break**
10:30 – 12:00am	**Presentation**: Energy Use in Specific Food System Sectors (Production, Transportation, Marketing) *Chair: Shermain Hardesty, UCD Dept of Ag and Resource Economics* - Niels Halberg, Danish Inst. of Agricultural Sciences, Ministry of Food, Agriculture and Fisheries, Denmark - Rich Pirog, Leopold Center, Iowa State University - Andrew Haden, Food and Farms Program, Ecotrust *Recorder: David Dunmire*
12:00 - 1:00pm	**Lunch**

1:00 - 1:15pm	**Introduction to Workgroup Sessions** *Tom Tomich*
1:15 - 2:15pm	**Workgroup Session 1:** Critical Issues in Food LCA Research *Chair: Tom Tomich, ASI/SAREP* - Production system v. transportation (group 1) - Scale of production/ distribution system (group 2) - Seasonality and processing (group 3) - Livestock production (group 4) - Pre-retail v. post-retail (group 5)
2:15 - 3:15pm	**Sharing Outcomes and Products from Workgroup Session 1** *Chair: Tom Tomich, ASI/SAREP* Group summaries of key research issues and info gaps (10 min each) Comments, questions, revisions to summary, and paragraph assignments (20 min each) *Recorder: Amber Ma*
3:15 – 3:30pm	**Break**
3:30 – 5:15pm (cont)	**Sharing Outcomes and Products from Workgroup Session 1** *Chair: Tom Tomich, ASI/SAREP* *Recorder: Amber Ma*
5:15 - 5:30pm	**Wrap up and feedback from the day** *Tom Tomich*
7:00pm	**Dinner at Mustard Seed**

<u>TUESDAY, OCTOBER 9</u>

8:00 - 8:25am	**Continental breakfast**
8:25 - 8:30am	**Gather; Turn in assignments from previous day**
8:30 - 9:30am	**Presentation:** LCA Methodology Issues *Chair: Jim Thompson, UCD Dept of Biological and Ag Engineering* - Niels Jungbluth, ESU-services Ltd., Switzerland - Klaas Jan Kramer, The Netherlands *Recorder: Colleen Hiner*

9:30 - 10:45am **Workgroup Session 2:** LCA Methodology/ Data Needs/ Research Frames

Chair: Gail Feenstra, ASI/SAREP
- Systems boundaries & Functional units (group 1)
- Databases & Streamlining methodologies (group 2)
- Data aggregation and geography issues (group 3)
- Strategic opportunities for case studies (group 4)

10:45 - 11:00am **Break**

11:00 - 12:00pm **Sharing Outcomes and Products from Workgroup Session 2**
Chair: Gail Feenstra, ASI/SAREP
Group summaries of key research issues and info gaps (10 min each)
Comments, questions, revisions to summary (20 min each)
Recorder: Colleen Hiner

12:00 - 12:45pm **Lunch**

12:45 - 1:45pm **Sharing Outcomes and Products from Workgroup Session 2 (cont.)**
Chair: Gail Feenstra, ASI/SAREP
Recorder: Colleen Hiner

2:00 - 5:30pm **Tours to Energy-Related Projects at UC Davis**
- Long-term Research on Agriculture Systems
- Hydrogen Fueling Station (UC Davis)
- Biogas Digester (UC Davis)

5:30 – 6:45pm **Village Homes – tour and appetizers**

7:00pm **Dinner at Osteria Fasulo (Village Homes)**

WEDNESDAY, OCTOBER 10

8:00 - 8:30am **Continental breakfast**

8:30 - 9:30am **Incorporating other environmental, social, and economic indicators into energy and GHG results** *Chair: Gail Feenstra*
Recorder: David Dunmire

9:30 - 10:15am **Review of white paper; discuss next steps** *Chair: Tom Tomich*
Recorder: David Dunmire

10:15 - 10:30am **Break**

10:30 - 12:00pm	**Final Discussion Session** *Chair: Gail Feenstra* Identify opportunities for future collaboration, roles of various institutions, additional stakeholders and potential collaborators, funding opportunities *Recorder: David Dunmire*
12:00 - 1:30pm	**Lunch and Adjourn**

Appendix 2

Who is Responsible for Environmental Impacts? The Role of Stakeholder Accountability in Framing a Research and Education Agenda

By Rich Pirog

Understanding the level of responsibility that consumers, farmers, food processors, retailers, and distributors will accept for food-related GHG emissions is critical in framing a research and education agenda on GHG emissions in food supply chains. In a July 2007 survey of more than 2000 British consumer by LEK Consulting (Wheatland 2007), 37 percent of respondents said they were responsible for their carbon footprint, closely followed by manufacturers and producers with 36 percent. Only 7 percent of respondents felt that retailers, supermarkets, and government were responsible. When asked who should play the biggest role in minimizing the carbon footprint of the country looking toward the future, the response changed significantly. More than 40 percent indicated that manufacturers and producers should have the biggest role, while only 20 percent felt that that they (consumers) should have this role; those who perceived government should have the biggest role increased to 22 percent.

As a research and education agenda is developed for GHG emissions in food supply chains, the following questions relating to "who is responsible" should be posed:

- Should LCA calculations include post-retail considerations, considering that consumers perceive they have a smaller role compared to providers and manufacturers in reducing GHG emissions in food supply chains?

- Should government set policies that reduce GHG emissions in each food supply chain sector? Should government be certifying the methodologies used in calculating GHGs so that all private businesses use the same approved methodologies?

- What are the associated costs in reducing GHG emissions in each food supply sector? Where can changes be made to balance cost with maximizing reductions in GHGs? What is the most fair and just way to assign these costs to players across the food supply chain?

- Should education programs be targeted at each sector of the food supply chain, or would better results be obtained by bringing all players in the chain (including consumers) together so they could become more knowledgeable about the GHG contributions each makes and the challenges each faces in reducing these emissions?

Appendix 3

Business Interests in LCA

By Todd English, Pablo Päster, and Helene York

Uncertainty in both federal and state regulations on greenhouse gas emissions represents one of the largest concerns businesses face. At the same time, consumer demand for environmentally responsible foods represents a significant upside opportunity, but with its own risks, as demand is growing while energy costs are rising.

The food industry can benefit from LCA analysis because it provides the necessary information on production methods and resource use that organizations can use to mitigate risks and costs. Increasingly, businesses require more detailed life cycle assessments information to communicate with their stakeholders as well as federal and state regulatory bodies. Lastly, food producers and processors will need to communicate the environmental impacts associated with providing food to consumers in an effort to develop support for sound food production techniques.

Business stakeholders that can benefit from LCA information:

- **Shareholders -** Shareholders are demanding detailed information from food producers in an effort to mitigate investment risks in light of potential climate change regulation as well as environmental concerns.

- **Customers -** Organic sales are rising in response to consumer concerns about the ill effects associated with mass food production. LCA information is important to support the public’s demand for more responsibly produced food.

- **Employees -** Companies that make sound decisions for the environment can gain support from their employee base. LCA information will allow organizations to make claims that are backed with data from sound methodologies.

- **Environment –** LCA analysis will provide the food industry with the information necessary to make sound environmental decisions.

Appendix 4
Established Environmental Impact Assessment Methodologies

By Nathan Pelletier

A wide variety of environmental impact assessment methodologies and impact categories are available for traditional, quantitative life cycle analyses. Each methodology offers a variety of impact categories for inclusion in an analysis. The choice of methodology and categories should reflect considerations of the goals of a given study.

The following is a list of methods and categories available through the SimaPro 7.0 software package. It should be noted that not all methods and impact categories are compatible with existing database processes.

CML BASELINE METHODOLOGY (Centre for Environmental Studies, Univ. of Leiden)

(most commonly employed impact categories in bold)

global warming (20, 100 and 500 year time horizons)
ozone layer depletion
acidification
eutrophication
abiotic depletion
fresh water aquatic ecotoxicity
marine aquatic ecotoxicity
terrestrial ecotoxicity
human toxicity
photochemical oxidation

CUMULATIVE ENERGY DEMAND

- cumulative energy demand
    - non renewable fossil
    - non renewable nuclear
    - renewable biomass
    - renewable wind, solar, geothermal
    - renewable water

ECO-INDICATOR

greenhouse
ozone layer
acidification
eutrophication
heavy metals
carcinogens
winter smog
summer smog

pesticides
energy resources
solid wastes

ECO-POINTS

numerous single pollutant indicators

EDIP (Environmental Design of Industrial Products)

global warming
acidification
europhication
photochemical smog
ecotoxicity water, chronic
ecotoxicity water, acute
ecotoxicity soil, chronic
human toxicity air
human toxicity water
human toxicity soil
land use

EPS (Environmental Priority Strategies)

severe morbidity
morbidity
severe nuisance
nuisance
crop growth capacity
wood growth capacity
fish and meat production
soil acidification
prod. cap. irrigation water
prod. cap. drinking water
depletion of reserves
extinction of species

IMPACT 2000

carcinogens
non-carcinogens
respiratory inorganics
ionizing radiation
ozone layer depletion
respiratory organics
aquatic ecotoxicity

terrestrial ecotoxicity
terrestrial acid/nutria
land occupation
aquatic acidification
aquatic eutrophication
global warming
non-renewable energy
mineral extraction

GWP (Global Warming Potential from the Intergovernmental Panel on Climate Change)

global warming potential – 20, 100, and 500 year time horizons

TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts)

global warming
acidification
HH cancer
HH cancer ground-surface
HH cancer root zone
HH non cancer
HH non cancer ground-surface
HH non cancer root zone
HH criteria air point source
HH criteria air mobile
eutrophication
ozone depletion
ecotoxicity
smog

Other impact categories are possible, and may be calculated independently of existing software packages (for example, biotic resource use).

Appendix 5
Socioeconomic Indicators in LCA

By Sonja Brodt and Klaas Jan Kramer

LCA was initially developed to assess environmental impacts of products, and, to date, the majority of LCA applications have focused strictly on measuring environmental indicators (see Appendix 3). Many symposium participants, however, expressed the concern that, by focusing solely on environmental variables, we may lose sight of other important impacts relevant to human life. This situation could hypothetically lead to non-optimal food systems designs that minimize energy and GHG impacts while potentially maximizing social and economic costs to people.

Many economic and social indicators, however, may not be well-suited to the LCA framework, which is specifically designed to trace impacts that accumulate through many different stages in the life cycle of a product. Many social and economic indicators that are typically used in other types of analysis are only measurable at one or two stages of the product chain, rendering a full LCA unnecessary. For example, specific labor conditions or income distributions often only apply to one industry, which may comprise just one step in the entire life cycle of a food product. Therefore, some participants recommended that, for these types of indicators, it may be more appropriate to focus on one sector at a time, using other tools, rather than perform a full LCA. An exception to this caveat is the methodology of value chain analysis, which examines economic value added to a product at different steps of the supply chain.

Participants identified several additional challenges to the use of socioeconomic indicators. For many such indicators, it is difficult to describe sound causal links between specific product system activities and the ultimate end effect, because complex socio-economic indicators (such as quality of life indicators) often result from a synergy of multiple processes. Social indicators are not always quantifiable, and can therefore be difficult to define clearly, and in a goal-oriented way that is clear on how they should be interpreted (i.e., which direction corresponds with improvement and which signals that something is a worse choice). Often, their interpretation is a matter of normative values and politics, beyond the pale of straightforward science. Finding meaningful units of measurement is also a challenge. Monetary cost is the most universal and commonly used unit, and although it presents significant challenges in value judgments (e.g., how do you value a human life?), it also allows for a way to compare relative values. In fact, several participants suggested that monetary costs *should* be used in precisely this way – not as an absolute value that carries specific meaning outside of a study, but more as a means for comparison and a way to capture relative differences between two products. Finally, several participants pointed out that performing a full LCA is difficult enough with only a few indicators, and we need to exercise caution in selecting an appropriate number and type of indicators that will render the project feasible within the limits of resources available. With every addition of another indicator, project costs, time, and complexity increase.

One suggestion for avoiding these difficulties is first to perform an LCA for desired environmental indicators, and then to assess the implications of those results for socioeconomic dimensions. Such a two-step process avoids trying to compile multiple, possibly contradictory indicators into one LCA outcome. It would also be very useful to use standard environmental

LCA results to identify benefits that cross over between different dimensions of sustainability. For example, a standard LCA might identify that maximizing feed efficiency in a livestock operation lowers the carbon footprint of the resulting meat product, while a further analysis might be able to show how this same technology also enhances the operator's financial standing and allows more operators to stay in business over time. Or, eating lower on the food chain may provide measurable health benefits in addition to lowering the carbon footprint of a person's diet.

Several organizations that have already worked to define socioeconomic indicators could serve as useful resources. For example, many corporations now produce corporate social responsibility reports. Ecotrust (www.ecotrust.org) and the Swedish Institute for Food and Biotechnology (http://engwww.sik.se/) have been working on developing socioeconomic indicators for a full LCA of salmon. The Vivid Picture project report from Ecotrust has several pages of socioeconomic indicators. The Global Reporting Initiative has developed sustainability reporting guidelines for organizations (http://www.globalreporting.org/ReportingFramework/G3Guidelines/) that could provide ideas for indicators. Several schools of management that offer sustainability-related MBAs (Bainbridge Management Institute, Presidio School of Management, University of Michigan, and UC Davis School of Management, and others) may also offer tools for socioeconomic analysis. The World Bank and other international development organizations have developed a social accounting framework that could provide useful ideas for socioeconomic indicators.

In selecting appropriate indicators, one must consider the goals of the study and which aspects of sustainability need to be addressed. Other factors important for indicator selection include data availability, reproducibility, validity, and ease of communication.

Below is a listing of social and economic aspects of sustainability that could be examined by choosing particular indicators. Most of these items were derived from a report on the Dutch horticulture sector (LTO-Nederland 2002; Boone and ten Pierick 2005).

Labor-related themes

- Employee satisfaction
- Relations (between colleagues and employers-employees)
- Possibilities for participation (e.g. work council)
- Possibilities for registering complaints (e.g. arguments with leaders, sexual harassment, etc)
- Labor safety
- Sick days (related to work)
- Satisfactory salary
- Possibilities for further education
- Facilities to combine work and private life (e.g. kindergartens, parental leave)
- Facilities to help employees with their careers (e.g. employability courses, outplacement)

Social themes

1) Emancipation and human rights:

  - Contribution to integration of minority groups
  - Gender equity
  - Maintenance of universal human rights (including banning of forced labor, child labor)

2) Economic and social welfare:
- Income distribution
- Family wellbeing
- Opportunities for recreation and enjoyment of life
- Freedom from unusually troublesome environmental factors like noise and smell

3) Animal welfare:
- Animal health
- Possibilities for natural behavior of animals
- Animal housing
- Care for animals
- Use of laboratory animals

4) Genetic modification:
- Producing and/or processing of genetically modified organisms

5) Food safety:
- Safety of the final products
- Measures to guarantee the safety of products, such as HACCP and systems for tracing products

6) Food and health:
- Production of “functional food” (also products aimed at certain needs in developing countries)
- Measures to prevent obesity
- Affordability of essentials, including food

Business-related themes

1) Business competitive advantage:
- Keeping up with technological, socio-cultural, and economic developments
- Keeping up with market developments
- Ability to translate technological and socio-cultural developments into new products and processes
- Ability to use market and consumer developments to develop new products and processes
- Consumer satisfaction
- Flexibility
- Capacity for innovation and a forward-looking orientation
- Ability to absorb new knowledge

2) Marketing/supply chains:
- The number and quality of communications between actors in a chain
- Informal and formal cooperation between actors in a chain
- Added value
- Profit margins
- Cost reductions

3) Business ethics:
- Predatory competition, or monopoly power
- Distribution of costs and benefits across the supply chain
- The influence of shareholders on companies

- Participation of members in a cooperative venture

4) Stimulation of local economy:

- Investments in underserved areas
- Local purchases
- Employment

Appendix 6
Life Cycle Costing
By Alissa Kendall

Life cycle assessment (LCA) is an accounting method for the material and energy inputs and waste outputs from a system. Through impact assessment this inventory is then translated into impacts categories. Life cycle costing (LCC), like LCA, is an accounting method but it captures the monetary costs at each stage of a product's or an activity's life cycle. As such, it complements the material, energy, and waste flow accounting performed in LCA. In its most conventional application, LCC accounts for purchase of capital, operations and maintenance, and end-of-life costs. In its most holistic application, LCC also captures external costs at each life cycle stage. External costs, or externalities, are costs (or benefits) not born by those involved in the economic transaction considered. Including externalities in cost analyses is occasionally referred to as "true cost accounting" since it attempts to characterize costs that are not reflected in the market price of a transaction.

Most environmental pollution from human activities is not captured in the cost of the products and energy we consume that cause pollution, an example of a negative externality. Applying LCC along with LCA is one method of translating environmental impact results from LCA into a single metric, dollars, that is tangible and compelling to the public, government, and business.

While LCC is conceptually straightforward, its implementation can be difficult. Expressing socio-environmental indicators in monetary terms brings with it ethical and moral considerations. Many externalities in our economy affect human health, mortality, or environmental systems. Assigning monetary values to these emotional and often complex problems can be highly contentious. Though we often look to tacit indicators of the monetary value of health, such as health care costs or lost productivity, it is difficult to assign explicit valuations to the externalities.

A second important factor in LCC is uncertainty. Two of the most important sources of uncertainty are external cost valuation and time. An external cost is a cost the market fails to price. This means an estimated cost is assigned based on one of many possible valuation methods, some methods rely on proxy costs that are priced by the market, such as health care costs or productivity loss, and others look to more subjective methods such as willingness to pay.

Time is especially important for long-lived systems, pollution with long term impacts or any other factors that are sensitive to time. For example, while greenhouse gas (GHG) emissions indisputably cause climate change, the actual effects of climate change are unknown, and will also vary based on a 20, 40, or 100 year time horizon. A damage cost estimate for GHG emissions will be different if damages are examined over a 20 year period rather than 100 year period. Or, the electricity grid may change over time, changing the impacts associated with any product that consumed electricity.

Discount rates are also necessary in LCC. A discount rate reflects the time value of money, or how much more a dollar is worth to someone now, rather than at a later day. Discount rate selection affects financial costs (e.g. operations & maintenance, disposal, and salvage value), but also external cost estimation of pollution or other environmental degradation with long lasting effects such as chronic illness or declining productivity from agricultural lands over time. Some economists have argued for a variable, and declining, discount rate for environmental costs (Weitzman 1999), while a constant rate for conventional costs. Certainly, discount rate selection is important and should be considered carefully in LCC.

LCC is a powerful tool for characterizing the true cost of an activity or system, accounting not only for short term and financial costs, but also external costs resulting from socio-environmental damages from pollution, resource depletion, or other externalities associated with a system or activity. LCC is a complementary tool to LCA since it requires the results from LCA in order to perform a true cost accounting. An important step in LCC, which is sometimes overlooked, is to explicitly characterize and, where possible, quantify uncertainty in results. Using scenario analysis or stochastic methods such as Monte-Carlo simulation can enhance and strengthen LCC results.