DRAFT PROPOSAL

The Future of Drop-In Fuels:
Life-Cycle Cost and Environmental Impacts of Bio-Based Hydrocarbon Fuel Pathways

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Check if applicable:
Animal subjects ______
Human subjects ______

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1. Abstract

We propose to fulfill in this research all the stated objectives of the ARB: (1) Review the literature to gather existing information related to renewable drop-in fuels. Establish if data are available for life cycle analysis of various technology pathways and their related costs and environmental impacts. (2) Analyze the technology, feasibility, costs, and environmental impacts at both demonstration and commercial scale. Estimate where facilities could potentially be located in order to maximize production while minimizing environmental impacts. (3) Identify additional areas of research to facilitate the growing need for data related to technological advancement, costs, and environmental impacts. (4) Identify barriers to the success of these technologies, and where applicable, strategies to overcome these barriers. (5) Develop a strategy to monitor and track progress of these technologies as well as supplies and costs.

Potential drop-in fuel technology pathways include, but are not limited to: (1) upgrading alcohols to hydrocarbons, (2) catalytic conversion of sugars to hydrocarbons, (3) fermentation of sugars to hydrocarbons, (4) hydrotreating algal oils, (5) upgrading of syngas (CO and H_2) from gasification, and (6) pyrolysis or liquefaction of biomass to bio-oil with hydro-processing. Drop-in fuels are used in place of fossil-fuel derived gasoline, diesel, jet fuel, and marine fuel. We will establish the final drop-in fuel list for this research with ARB's input.

As we understand, the objectives of this research call for comprehensive life-cycle environmental and economic assessment of biofuels, including biomass production and transportation, biorefining, biofuels transportation and storage, and biofuel combustion. The supply chains behind these life-cycle stages should also be included in this research. They include industries in California, the rest of the United States, as well as abroad. The analysis will follow the principles of LCA, as described by the International Organization for Standardization (ISO) in the 14044 guidelines, and the best international academic and industrial practices, focusing on relevant environmental inventory metrics (GHG, criteria air, and toxic emissions, water withdrawal and consumption) and environmental impact categories (global warming potential, human and ecological health damage potential, resource depletion, water quality and quantity). We have selected and evaluated this broad set of sustainability metrics to cover the most relevant aspects needed for a comprehensive study of biofuels.

The project results will provide data that will influence LCFS policy in California or other jurisdictions worldwide that are developing their own LCFS-like programs. If this research leads to the development of lower-carbon fuels, it will be to the benefit of regulated parties under the LCFS and to the California consumers. In the longer term, the data will inform many other initiatives of ARB that might support the need for drop-in fuels.

2. Introduction

Although ethanol currently dominates the U.S. biofuel market, cost effective drop-in fuels are the key to rapid scale-up of biofuel production. Drop-in fuels hold this promise because, unlike ethanol, they can be transported, blended, and distributed using existing petroleum infrastructure, and they can be combusted in existing vehicles without modifications to the engine and fuel system. They also have the potential to achieve more favorable greenhouse gas (GHG) footprints than biofuels that are not infrastructure compatible, such as ethanol or biodiesel, because truck and rail transportation could be partially eliminated in favor of energy efficient pipelines (Strogen et al., 2011).

However, technologies to convert bio-based feedstocks to drop-in fuels are less mature than ethanol production processes. Drop-in fuel pathways begin with sugars/starches, lignocellulosic biomass, or algae, and through various permutations of gasification, pyrolysis, enzymatic hydrolysis, fermentation, catalytic conversion, and hydrotreatment, fuels that meet specifications for gasoline, diesel, jet fuel, and marine fuel can be produced. Tracking the range of appropriate feedstocks, relative maturity, and economic viability of this rapidly changing array of fuel production technologies is a challenge in itself.

We have assembled a multidisciplinary team with high levels of skill and experience in the scientific areas relevant to this project: life-cycle (environmental) assessment (LCA), including life-cycle impact assessment, environmental, energy, chemical, mechanical engineering, civil infrastructure systems analysis, and public health risk assessment. Professors Horvath and McKone have approximately 50 years of collective experience with comprehensive environmental analysis, specifically LCA, life-cycle impact assessment, and life-cycle cost analysis (LCCA). They have published over 220 articles in the areas of air and water quality, human and ecological impact assessment, product and service LCA, transportation and industrial energy analysis, and product life-cycle optimization. They have finished several recent analyses focused on product- and sector-related energy efficiency and GHG reduction opportunities. They teach LCA (and cover biofuels), sustainable technologies and infrastructure (Horvath), and risk assessment (McKone) courses at UC Berkeley.

Both Horvath and McKone derive valuable working experience related to relevant environmental problems from their (current and past) memberships of the U.S. Environmental Protection Agency's Science Advisory Board, other governmental, international, and academic organizations, and from experiences with several past ARB and other State of California agency projects.

Our research team has significant experience with biofuels environmental and policy assessment, especially LCA, and all four team members have already worked together on biofuels research. Horvath and McKone have been co-leading the Energy Biosciences Institute's (www.energybiosciencesinstitute.org) biofuels life-cycle assessment program at UC Berkeley since its inception in 2008. Dr. Scown was first a graduate student and then a postdoc and principal researcher in our EBI project from day one. Alexei Bordas has been doing research on biofuels issues with the rest of this team for a year now, and he is a Ph.D. student on Horvath's lab.

The project team has been the core of the biofuels LCA team at the EBI, which has served as the quantitative environmental assessment team for selected aspects of biofuels production and infrastructure with the goal of assessing the life-cycle energy, water, GHG, and human health impacts of second-generation biofuel pathways, with a primary focus on cellulosic ethanol pathways (McKone et al., 2011; Scown et al., 2011; Scown et al., 2012; Strogen et al., 2011, 2012). Horvath, McKone and Scown are currently continuing this work in the EBI, with a focus on technoeconomic modeling to support biorefinery-level decision-making, such as lignin utilization and pretreatment process choices. The ongoing EBI research provides a unique experience and insight that will benefit this ARB project. We care also building cooperation with the U.S. Department of Energy-funded Joint Bioenergy Institute (JBEI), located in Emeryville, CA. However, the proposed ARB project does not overlap with our current EBI biofuel LCA project or any planned projects with the JBEI.

3. Objectives

We adopted the stated objectives of the ARB for this research:

• Review the literature to gather existing information related to renewable drop-in fuels. Establish if data are available for life cycle analysis of various technology pathways and their related costs and environmental impacts.
• Analyze the technology, feasibility, costs, and environmental impacts at both demonstration and commercial scale. Estimate where facilities could potentially be located in order to maximize production while minimizing environmental impacts.
• Identify additional areas of research to facilitate the growing need for data related to technological advancement, costs, and environmental impacts.
• Identify barriers to the success of these technologies, and where applicable, strategies to overcome these barriers.
• Develop a strategy to monitor and track progress of these technologies as well as supplies and costs.

Potential drop-in fuel technology pathways include, but are not limited to: (1) upgrading alcohols to hydrocarbons, (2) catalytic conversion of sugars to hydrocarbons, (3) fermentation of sugars to hydrocarbons, (4) hydrotreating algal oils, (5) upgrading of syngas (CO and H_2) from gasification, and (6) pyrolysis or liquefaction of biomass to bio-oil with hydro-processing. Drop-in fuels are used in place of fossil-fuel derived gasoline, diesel, jet fuel, and marine fuel. We will establish the final drop-in fuel list for this research with ARB's input.

The project results will provide data that will influence LCFS policy in California or other jurisdictions worldwide that are developing their own LCFS-like programs. If this research leads to the development of lower-carbon fuels, it will be to the benefit of regulated parties under the LCFS and to the California consumers. In the longer term, the data will inform many other initiatives of ARB that might support the need for drop-in fuels.

As we understand, the objectives of this research call for comprehensive life-cycle environmental and economic assessment of biofuels, including biomass production and transportation, biorefining, biofuels transportation and storage, and biofuel combustion. The supply chains behind these life-cycle stages should also be included in this research.

4. Technical Plan

Methods

We have designed a research plan that will allow the ARB to understand the state of drop-in biofuel research and development, the potential feedstocks and fuel products, and data gaps that must be filled in order to complete life-cycle cost and environmental assessments for each pathway. Our approach consists of six major tasks, beginning with a detailed literature search and communications with researchers at the EBI and the JBEI, where the research team of Scown, McKone, and Horvath has ongoing (EBI) and emerging (JBEI) collaboration.

The literature/research review is followed by a life-cycle cost and environmental assessment data gap analysis, scale-up scenario analysis, identification of research needs, and identification of potential barriers to development and scale-up of drop-in biofuels.

The analysis of drop-in fuels will follow the principles of LCA, as described by the International Organization for Standardization (ISO) in the 14044 guidelines, and the best international academic and industrial practices, focusing on all life-cycle phases of fuels (biomass production, feedstock transportation, biorefining, fuel storage and distribution, fuel combustion), relevant environmental inventory metrics (GHG, criteria air, and toxic emissions, water withdrawal and consumption) and environmental impact categories (global warming potential, human and ecological health damage potential, resource depletion, water quality and quantity). We have selected and evaluated this broad set of sustainability metrics to cover the most relevant aspects needed for a comprehensive study of biofuels. We will include not just the direct impacts of production, transportation or use, but the extensive supply chains behind all life-cycle stages as well.

Our approach begins with an assessment of drop-in fuel production pathways by tracking technological progress through literature reviews and direct contact with laboratory researchers and technoeconomic modelers at the EBI, JBEI, and the National Renewable Energy Laboratory (NREL). Using literature values and technoeconomic model results, we will assemble energy and mass flows for each pathway and identify data that are missing or are highly uncertain. These energy and mass flows will be incorporated into Excel-based process summary sheets that allow users to alter operating conditions and feedstock types within a set of reasonable ranges to customize their outputs or conduct sensitivity analyses. The Excel sheets will also be posted on a wiki-style site to allow for expert feedback on the chosen set of fuel pathways and built-in assumptions, ensuring that our simplified biorefinery tools are grounded in the best available research (Klein-Marcuschamer et al., 2010). These publicly available tools will serve as useful frameworks and data sources for incorporation of drop-in fuel production pathways into the LCFS.

Using the mass and energy flow data collected along with expert feedback, we will establish a set of the most promising pathways from a technical and economic standpoint. These pathways will be selected for California scale-up scenario modeling in ArcGIS. Using current and projected feedstock availability data alongside marginal/low-value land conversion strategies for dedicated feedstock production (Perlack and Stokes, 2011; Perlack et al., 2005; Scown et al., 2012), we will develop a scale-up scenario for each selected pathway to determine the total volume of fuel that could be produced in California, and the resulting biomass and fuel logistics. These scale-up scenarios will also include site selection criteria that account for natural resource constraints, such as water availability, and potential benefits of co-location with existing industrial facilities or power plants. The result of the scenario analysis will be a set of strategies for scale-up of drop-in fuel production pathways in California that minimize costs and regulatory barriers, maximize available feedstock utilization, and minimize environmental burdens.

<u>Tasks</u>

The following are the tasks as we understand at this point. Naturally, we would be pleased to revise the tasks as the ARB sees fit.

1. *Review of literature and ongoing laboratory research*
   The purpose of this task is to develop an inventory of drop-in fuel production pathways, including possible feedstocks, pretreatment, conversion, the composition of fuel products, and any potential co-products. Our group is uniquely qualified to conduct this review because of our existing collaborations with the EBI and the JBEI, where we have developed internal tools for assessing the life-cycle energy, greenhouse gas (GHG) emissions, water use, and human health implications of cellulosic ethanol production. We propose to conduct a thorough review of existing literature and current research about pathways still in development at institutions around the world, e.g., at NREL. Information about each potential drop-in fuel production pathway will be organized into five categories: potential feedstocks, feedstock pretreatment requirements, conversion process, fuel products, and co-products:

   - Potential feedstocks
     The range of feedstocks that a conversion process can handle will be a determining factor in its success. Even in biorefineries that convert low-value lignocellulosic biomass, the feedstock is expected to be the largest single contributor to the total cost of production (Klein-Marcuschamer et al., 2011). Processes requiring feedstocks such as starches, sugars, and oil crops are less technologically challenging in many cases, but are less desirable because of the resulting competition with food production (Searchinger et al., 2008; Sexton et al., 2009). We will evaluate pathways based on two important metrics: the type of feedstock(s) that can be converted, and the flexibility to handle multiple types at one time or quickly switch from one feedstock type to another. Together, these will determine the potential scale of production, both in and outside California, and the ability of biorefineries to mitigate feedstock-related risks through diversification.
   - Pretreatment requirements
     Second only to feedstock costs for some pathways, biomass pretreatment can be one of the most costly and important biorefinery stages, requiring significant heat, acid, ammonia, or other solvents (Klein-Marcuschamer et al., 2011). Pretreatment is necessary for some biomass conversion processes in order to break up the crystalline structure of

the cell walls, liberating cellulose and hemicellulose for further deconstruction. Some pretreatment methods, for example ionic liquids, can offer greater feedstock flexibility because of their ability to treat a wide variety of biomass types (Shi et al., 2013). For different drop-in fuel production pathways, we will gather information on whether pretreatment is required, which specific processes are most appropriate, and how overall yield can vary depending on pretreatment choices. Mass and energy balances for pretreatment processes are readily available (Alizadeh et al., 2005; Humbird et al., 2011; Klein-Marcuschamer et al., 2011).

- Conversion process
  The conversion process is at the heart of drop-in fuel production technology. We will gather detailed cost, energy, and mass flow data for each conversion process to provide the ARB with a clearer understanding of both the current state of these technologies as well as the potential for future improvements. In some cases, a conversion technology may be prepared to handle simple feedstocks such as sugars and starches, but successfully processing lignocellulosic biomass will be a longer-term goal. Thus, pathways must be assessed on the basis of each feedstock type. Table 1 provides a summary of potential pathways, potential feedstocks, pretreatment requirements, fuel products, and co-products.
- Fuel products
  The composition of fuel products will determine their total demand, ease of distribution, and potential impact on ecological and human health. Any variation between new drop-in fuels and their traditional petroleum counterparts can have implications for infrastructure compatibility and their behavior in the environment (Bunting et al., 2010). We will carefully track the chemical composition and properties of fuel products from each pathway, as established by the ARB Multimedia Working Group, and note any potential areas for additional study.
- Co-products
  Fuel production processes often result in co-products: cellulosic ethanol production yields lignin that can be combusted to produce heat and excess electricity, biodiesel production yields glycerol that can be used in personal care and food products, and corn ethanol production results in dried distillers grain with solubles (DDGS) for use in animal feed. A high-value co-product can help a fuel pathway become economically viable and, in some cases, result in significant carbon offset credits (Scown et al., 2011). Conversely, a co-product that reaches market saturation can quickly become a waste product. We will track co-products that may result from each drop-in fuel pathway and assess the life-cycle economic and environmental impacts they may have.

Pathway	Potential feedstocks	Pretreatment required?	Lead company	Primary fuel products	Co-products	Source
Upgrading alcohols to hydrocarbons	Sugars, starches, biomass	Yes	N/A	Gasoline, diesel, jet fuel	Lignin	(Anbarasan et al., 2012)
Catalytic conversion of sugars to hydrocarbons	Sugars, starches, biomass	Yes	Virent	Gasoline, diesel, jet fuel	Lignin	(NABC 2011)
Fermentation of sugars to hydrocarbons	Sugars, starches, biomass	Yes	Amyris	Diesel	Chemicals	(NABC 2012)
Hydrotreating algal oils	Algal oil	No	N/A	Diesel	Naphtha	(Davis et al., 2011)
Upgrading of syngas from gasification	Biomass	Yes	N/A	Diesel, gasoline	Chemicals	(Spath and Dayton, 2003)
Pyrolysis or liquefaction of biomass to bio-oil with hydroprocessing	Biomass	Yes	N/A	Gasoline, diesel	None	(Jones et al., 2009)

Table 1: Pathway summary and sample literature sources

2. *Life-cycle cost and environmental assessment data gap analysis*
The purpose of this task is to conduct a preliminary life-cycle cost and environmental assessment of promising drop-in fuel production pathways identified in Task 1 and identify data gaps and significant sources of uncertainty. We will approach this task using LCA and LCCA methods by separating the biofuel life cycle into four phases:

- Biomass/algae cultivation
- Pretreatment and conversion
- Distribution and storage
- Fuel combustion

Because the pretreatment and conversion processes will be unique to the drop-in fuel pathways analyzed for this project, many of which have not yet been studied on the basis of cost and environmental impacts, this stage will be our primary focus. Biorefinery mass and energy flows will be calculated based on technoeconomic model results and literature values, and compiled in Excel-based tools. These tools will be posted on a wiki-style site to be further vetted by experts in EBI, JBEI, NREL, and other research institutions.

The preliminary pretreatment and conversion results will be integrated into a full LCA framework to determine how sensitive total cost, GHG emissions, and human health results are to existing data gaps and uncertainties. Our framework will utilize multiple baselines for comparison, including conventional petroleum-based transportation fuels and, where appropriate, non-drop-in biofuels such as ethanol derived from corn, sugar, and biomass.

To populate these LCAs, we will draw on previous work by our group on life-cycle water impacts of biofuel production, life-cycle greenhouse gas and criteria air pollutant emissions from biofuel distribution and storage, and full life-cycle GHG emissions resulting from cellulosic ethanol production (McKone et al., 2011; Scown et al., 2011; Scown et al., 2012; Strogen et al., 2011, 2012). Additionally, we expect to utilize a variety of ISO 14044-compliant LCA tools and databases, including GaBi (www.pe-international.com), SimaPro (www.pre.nl), ecoinvent (www.ecoinvent.ch), as well as the Economic Input-Output Life-Cycle Assessment (EIO-LCA, www.eiolca.net) tool, EPA's eGRID, and the National Renewable Energy Laboratory Life Cycle Inventory Database, and Argonne National Laboratory's GREET (http://greet.es.anl.gov) model.

In addition, we have access to a unique tool, the MRIO LCA tool (Multiregional Input-Ouput LCA), which Arpad Horvath finished co-authoring in 2012 as part of the ARB project "Retail Climate Change Mitigation: Life-Cycle Emission and Energy Efficiency Labels and Standards" and another project through CalRecycle. The MRIO LCA is the only LCA tool customized to California conditions and practices.

3. *Scale-up scenario modeling*

Understanding drop-in fuel production pathways at a process level is a crucial first step. However, to understand the potential of drop-in fuels both in California and nation-wide, scale-up scenarios must be developed. We propose an approach in ArcGIS that brings together data on feedstock availability, site suitability, fuel distribution and blending infrastructure, and potential facility co-location opportunities. Depending on the needs of the ARB, these scenarios can be California-specific or expanded beyond the state.

Each scenario will begin with an estimate of current and future feedstock availability, including residues and dedicated crops (US DOE 2008; Perlack and Stokes, 2011). A set of appropriate biorefinery sites will be developed based on water availability, proximity to highway, rail, and pipeline infrastructure, and proximity to other industrial facilities or power plants for which co-location would be beneficial. Co-location benefits include waste heat utilization, co-product utilization, and shared regulatory burden. These potential locations will then be narrowed down based on a minimization of biomass transportation costs. The results will provide insight into what fraction of available feedstocks can be utilized and the volume of fuel that can ultimately be produced. This scenario analysis will also provide guidance for future site selection, and strategies for minimizing environmental and regulatory burdens.

4. *Identification of research needs*

In this task, we will identify additional areas of research to facilitate the growing need for data related to technological advancement, costs, and environmental impacts. We will accomplish this based on the accumulated expertise and up-to-date knowledge of biofuels, specifically drop-in fuels, as a result of having completed tasks 1-3 and having progressed with our research in the EBI and potentially the JBEI. In particular, we will identify environmental impacts and cost components in all life-cycle stages that emerge as the most important, and perform uncertainty and quality assessment of how precise, accurate, and robust the technological and environmental models and the associated resource use and environmental emission factors are for these most important contributors to the sustainability of drop-in fuels. As an example, biorefinery components that will contribute significantly to capital costs and environmental impacts include catalysts. Relatively little is known about them. Based on our findings, we will put forward recommendations for areas in which economic cost-cutting and environmental improvements are necessary.

5. *Identification of potential barriers*

   Based on our findings in tasks 1-4 and other biofuels research we are doing, we will be in a good position to identify the extant and emerging technological, economic, environmental, and possibly other societal barriers to the success of drop-in fuels in our society. Based on our findings, we will make recommendations as to how these barriers could be overcome.

6. *Developing a strategy to monitor and track progress with drop-in fuels*

   We will develop a strategy for lasting monitoring of progress in drop-in fuel technologies, environmental and economic performance, and societal acceptance throughout the industry and associated supply chains (in California, or outside). The strategy will include a written analysis and guidelines, but also a user guide to the Excel and ArcGIS-based tools we will use and develop in this research. We believe that it is a winning strategy to create computer-based decision-support tools in biofuels research as the tools provide a lasting yet flexible framework that can be updated and further refined by the researchers who created it, but also by the users. We have much experience with biofuels research tools, but also have many years of experience in creating other decision-support tools (e.g., CalTOX, TRACI, EIO-LCA, PaLATE, MRIO LCA).

5. Deliverables

Our understanding is that the ARB will need quarterly progress reports (dates are shown in the Project Schedule), a draft final report at the end of month 30 of the project, and a final report by the end of the project in month 36. Additional deliverables may also be determined in consultation with the ARB staff.

6. Management of Research

The project team will consist of:

Principal Investigator:
Arpad Horvath, Ph.D.
  Professor, Department of Civil and Environmental Engineering
  University of California, Berkeley

Senior personnel:
Thomas E. McKone, Ph.D.
  Adjunct Professor of Environmental Health Sciences, School of Public Health, UC Berkeley;

Senior Scientist and Deputy for Research, Energy Analysis and Environmental Impacts Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory

Graduate Student Researcher:
Alexei Bordas, Ph.D. student, Civil and Environmental Engineering, UC Berkeley

If the project is funded, we will appoint at UC Berkeley (through a Multilocation Appointment, MLA):
Corinne Scown, Ph.D., Principal Scientific Engineering Associate, Energy Analysis and Environmental Impacts Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory

Brief biographical summaries of Arpad Horvath and Thomas McKone are attached.

Arpad Horvath is a professor in the Department of Civil and Environmental Engineering (http://www.ce.berkeley.edu/~horvath), head of the Energy, Civil Infrastructure and Climate Graduate Program, Director of the Consortium on Green Design and Manufacturing, and Director of the Engineering and Business for Sustainability certificate program (http://sustainable-engineering.berkeley.edu). His research focuses on life-cycle environmental and economic assessment of products, processes, and services. He has advised 15 Ph.D. dissertations thus far, all in LCA and LCCA, and two on biofuels. He was Conference Chair of the 6th International Conference on Industrial Ecology in 2011. Arpad Horvath is an Associate Editor of the *Journal of Infrastructure Systems*, and is on the editorial advisory boards of *Environmental Science & Technology*, *Journal of Industrial Ecology*, and *Environmental Research Letters*. He is a member of the Environmental Engineering Committee of the U.S. Environmental Protection Agency's Science Advisory Board.

Thomas McKone is an Adjunct Professor of Environmental Health Sciences in the School of Public Health at UC Berkeley, and a Senior Scientist and Deputy for Research Programs in the Energy Analysis and Environmental Impacts Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory. His research focuses on the development, use, and evaluation of models and data for human-health and ecological risk assessments and the health and environmental impacts of energy, industrial, and agricultural systems. McKone has served on the US EPA Science Advisory Board and has been a member numerous National Academy of Sciences committees, including the recent committee on "The Hidden Costs of Energy". During the last five years he has worked with the ARB and the Multimedia Working group both to prepare the guidance documents to define the process for conducting California multimedia evaluations for new fuel formulations and to prepare the California multimedia evaluations for biodiesel, renewable diesel, and E85. He will participate in this research through his current MLA appointment at UC Berkeley.

Corinne Scown will be appointed through an MLA arrangement to work at UC Berkeley on this project. She is an LBNL scientist working on emerging technology assessment, including next-generation biofuels, energy storage technologies for transportation, and carbon capture and sequestration. Her previous research related to biofuels has included quantification of the life-cycle water impacts and greenhouse gas footprint of biofuel production, as well as development of U.S. national scenarios for strategic scale-up of cellulosic ethanol production. Her current research focuses on technoeconomic and environmental modeling of biomass conversion processes, including cellulosic ethanol and drop-in fuel pathways. Dr. Scown has ongoing collaborations with researchers in both the Energy Biosciences Institute (EBI) and the Joint Bioenergy Institute (JBEI).

Alexei Bordas is a second-year Ph.D. student with background in civil and environmental engineering, energy science, and mechanical engineering. He is dedicated to working on this project for his dissertation research.

Professors Horvath and McKone will be responsible for all programmatic and strategic aspects of the project. Horvath, as the PI, will be in charge of project administration and reporting, and will advise all project tasks. Dr. Scown will be the core technical researcher on all tasks, and will write the draft final report and the final report. Alexei Bordas will mostly work on tasks 1-3, but will help out Dr. Scown on the other tasks as well as the draft final report. The project results will become part of his doctoral dissertation.

The program will be managed and coordinated through regular communication of the entire team via weekly meetings and email. Three team members have worked together for more than five years now specifically on biofuels (detailed below), thus regular communication is already established. Horvath is Bordas' academic and dissertation advisor, so student-faculty communication is institutionalized.

7. Prior Knowledge of Biofuels and Related Research of Applicants

Just to repeat what we have already stated in the Introduction, our project team has a wealth of experience with LCA and LCCA, biofuels, and infrastructure, and the other scientific areas relevant to this project. Professors Horvath and McKone have approximately 50 collective years of relevant experience. They have published over 220 articles and reports in the areas of air and water quality, human and ecological impact assessment, product and service LCA, transportation and industrial energy analysis, and product life-cycle optimization. Several recent analyses we have finished have specifically focused on product- and sector-related energy efficiency and GHG reduction opportunities. They teach LCA, infrastructure (Horvath) and risk assessment (McKone) courses at UC Berkeley. Both professors derive valuable experience, guaranteeing the success of this project, from their (current and past) memberships on the U.S. Environmental Protection Agency's Science Advisory Board, and from experience with several past ARB projects.

All four team members have already worked together on biofuels research. Professors Horvath and McKone have been co-leading the EBI's (www.energybiosciencesinstitute.org) biofuels life-cycle assessment program at UC Berkeley since its inception in 2008. Dr. Scown was first a graduate student and then a postdoc and principal researcher in our EBI project from day one. Alexei Bordas has been doing research on biofuels issues for a year now.

The current project team has been the core of the biofuels LCA team at the EBI, which has served as the quantitative environmental assessment team for selected aspects of biofuels production and infrastructure. Our focus has been (1) to develop environmental metrics and methods for analyzing the life-cycle stages, resources, and processes associated with biofuels, (2) to develop and apply methods to study the life-cycle environmental effects of the various pathways from biomass to fuels using state-of-the-art LCA methods, metrics, and tools, and (3) to enable the appropriate use of biofuels primarily in the United States, but also globally, by developing scientific insights, metrics, and state-of-the-art methods and tools to understand when and under what conditions biofuels are sustainable in the short and the long term. We have developed the *EBI LCA tool* (for now available only to the EBI) to operationalize biofuel environmental scenario analyses and increase confidence in biofuels decision-making for technical and policy evaluation. The *EBI LCA tool* makes possible geographically-specific U.S. scenario analysis based on county-level assessments of air emissions, water resource impacts, and the impacts of soil alterations (pesticide and fertilizer use). Figure 1 shows the structure and scope of the *EBI LCA tool*. County-level assessment can then be aggregated to track multi-county, state, regional, and national level impacts. We have already completed a Miscanthus-to-ethanol environmental assessment for the United States, thus we have demonstrated that we can analyze biofuels at unit as well as regional or national scales.

The *EBI LCA tool* allows decision-makers to predict and evaluate life-cycle environmental inventories of the broadest set of sustainability metrics for all stages of a transportation fuel's life-cycle: feedstock production and logistics, fuel production processes, transportation and production/delivery infrastructure.

The following list describes the environmental assessment items that have guided our biofuels LCA:

Agricultural systems (including biomass preprocessing)

- Materials inputs and energy use in farm logistics and biomass transportation to biorefineries
- Greenhouse gas (GHG), criteria air pollutant and toxic emissions
- Use and impacts of biocides and fertilizers
- Use of water for irrigation and energy production, and GHG emissions from water use
- Soil carbon and nitrogen emissions
- New and modified infrastructure, and the upstream impacts of providing this infrastructure

Biorefining

- Materials inputs and energy use in biorefining
- Greenhouse gas, criteria-air-pollutant and toxic emissions
- Water demand and embedded greenhouse gas emissions from water use
- Waste production
- Energy use
- Environmental costs and savings from the use of combined heat and power technologies at biorefineries
- New and modified infrastructure, and the upstream (supply chain) impacts of providing this infrastructure

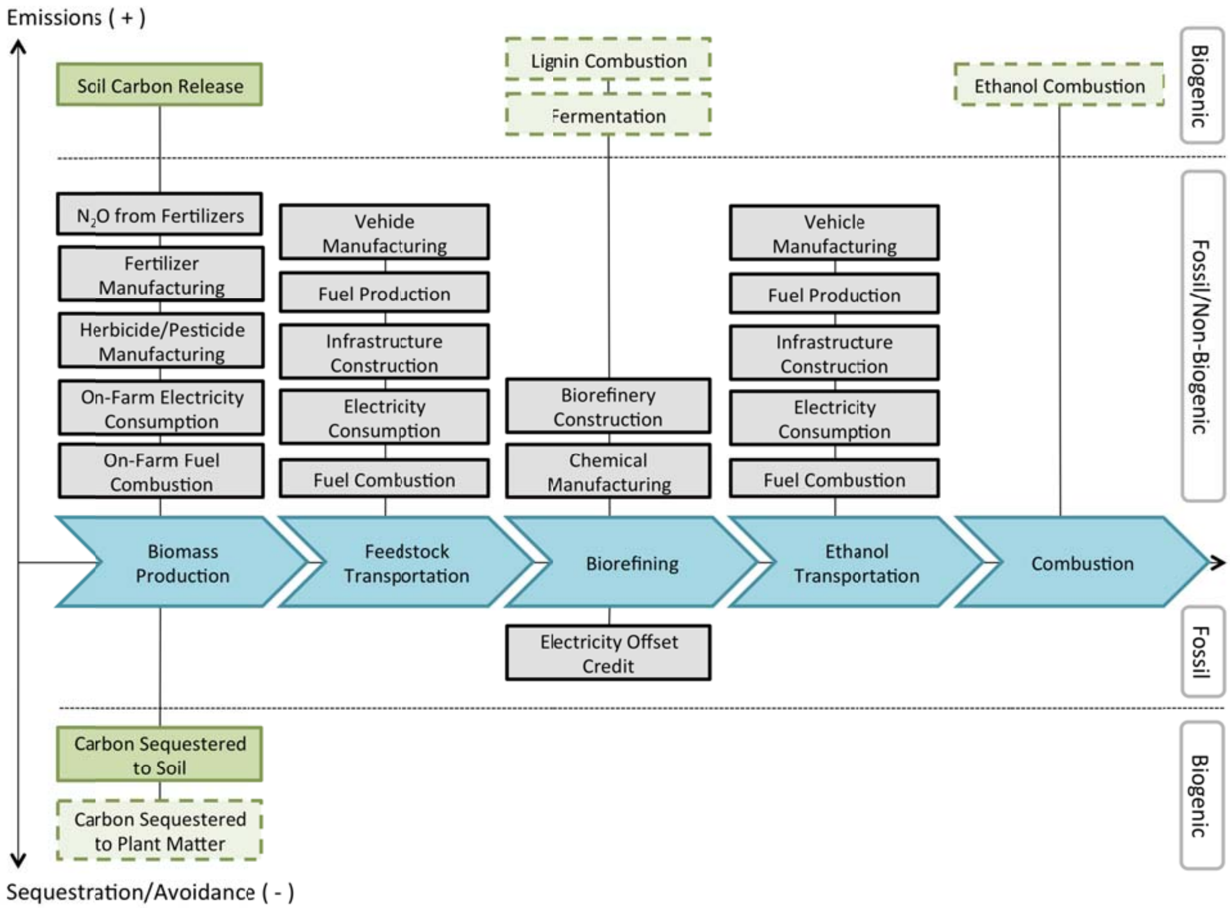

Figure 1: *EBI LCA tool* structure as applied to greenhouse gas emissions in a *Miscanthus* to ethanol scenario (source: Scown et al. 2012)

Fuel Transportation and Storage
- Energy use
- Greenhouse gas, criteria-air-pollutant and toxic emissions
- Evaporative emissions
- Soil and groundwater contamination (from leaks)
- New and modified infrastructure, and the upstream impacts of providing this infrastructure

The *EBI LCA tool* makes possible geographically-specific scenarios based on county-level assessments of air emissions, water resource impacts, and the impacts of soil alterations (pesticide and fertilizer use). County-level assessments can then be aggregated to provide multi-county, state, regional, and national level impacts assessments. The county-level results are indexed by FIPS code and can be displayed and integrated into further analysis using GIS. A version of the *EBI LCA tool* also provides county-level choropleth mapping of the results within Excel itself.

Summary of Our EBI Results to Date

After having built a formidable research and analysis capacity needed to evaluate current and emerging biofuels scenarios from a life-cycle environmental perspective, we have published 7 peer-reviewed papers and advised the completion of two Ph.D. dissertations:

Peer-reviewed Publications:

- McKone, T.E., Nazaroff, W.W, Berck, P., Auffhammer, M., Lipman, T., Torn, M., Masanet, E., Lobscheid, A.B., Santero, N.J., Mishra, U., Barrett, A., Bomberg, M., Fingerman, K., Scown, C., Strogen, B., Horvath, A., (2011), "Grand Challenges for Life-Cycle Assessment of Biofuels," *Environmental Science & Technology*, 45(5), 1751-1756. **This paper was voted the 2nd runner-up to the Best Feature Paper in ES&T in 2011.**
- Scown, C.D., Horvath, A., McKone, T.E. (2011), "Water Footprint of U.S. Transportation Fuels." *Environmental Science & Technology*, 45 (7), 2541-2553
- Scown, C.D., Nazaroff, W.W, Mishra, U., Strogen, B., Lobscheid, A.B., Masanet, E., Santero, N.J., Horvath, A., McKone, T.E. (2012), "Lifecycle Greenhouse Gas Implications of U.S. National Scenarios for Cellulosic Ethanol Production." *Environmental Research Letters*, 7(1), January.
- Apte, J.S., Bombrun, E., Marshall, J.D., Nazaroff, W.W (2012), "Global Intraurban Intake Fractions for Primary Air Pollutants from Vehicles and Other Distributed Sources." *Environmental Science &Technology*, 46(6), 3415-3423
- Strogen, B., Horvath, A., McKone, T.E. (2012), "Fuel Miles and the Blend Wall: Costs and Emissions from Ethanol Distribution in the United States." *Environmental Science & Technology*, 46(10), pp. 5285-5293, DOI: 10.1021/es204547s
- Lobscheid, A., Nazaroff, W. W, Spears, M. S., Horvath, A. and McKone, T. E. (2012), "Intake Fractions of Primary Conserved Air Pollutants Emitted from On-road Vehicles in the United States." Atmospheric Environment, 63, pp. 298-305
- Strogen, B., Horvath, A. (2013), "Greenhouse Gas Emissions from Construction, Manufacturing and Operation of U.S. Liquid Fuel Distribution Infrastructure." *J. of Infrastructure Systems* (in print)

Seminars, Conference Presentations, and Other Outreach Activities in the last two years:

June 2011: "Life-cycle Environmental and Economic Decision-Making for Alternative Biofuels," Presentation at the 6th Conference of the International Society for Industrial Ecology, Berkeley

May 2012: "Life-cycle Assessment," Seminar in the EBI's Bioenergy 101 series, Berkeley

May 2012: "Life-cycle Assessment of Biofuels for Transportation: Understanding the Effects of Scale," Presentation at the SETAC Europe Conference, Berlin, Germany

June 2012: "Life-cycle Assessment of Biofuels," EBI Seminar, Berkeley

November 2012: Special Symposium organized by T. McKone and A. Horvath: "Life-Cycle Assessment of Emerging Technologies," SETAC North America 33rd Annual Meeting, Long Beach, CA (with 16 platform presentations)

Doctoral Dissertations Completed:

Scown, C. "Water Footprint of U.S. Transportation Fuels," Department of Civil and Environmental Engineering, UC Berkeley, December 2010

Strogen, B. "The Role of Distribution Infrastructure and Equipment in the Life-cycle Air Emissions of Liquid Transportation Fuels," Dept. of Civil and Environmental Engineering, UCB, May 2012

Our research and capacity building for LCA of biofuels has taken several forms. We have explored, evaluated, and advanced the state-of-the-art LCA modeling of transportation fuels and synthesized information across the different components of the life cycles of fuels. The product of this effort was a comprehensive framework for addressing life-cycle impacts and a formalized process for addressing information gaps. Our modeling has been fully compliant with the ISO 14040 LCA guidelines and the best academic and industrial practices, and has included not just the direct impacts of production, but the extensive supply chains as well. We have selected and evaluated a broad set of sustainability metrics covering all aspects needed for a comprehensive study of transportation fuels.

We wrote a synthesis and position paper in 2011, "Grand Challenges for Life-cycle Assessment of Biofuels," which was published in *Environmental Science & Technology*. It provides a research roadmap for the field, and has been received with great interest by researchers. For several months, it was one of the most read papers of the journal. It was voted the 2nd runner-up to *The Best Feature Article in ES&T* for 2011.

Corinne Scown's dissertation research has developed a water footprint assessment of transportation fuels in the United States, including ethanol from corn stover and Miscanthus, electricity, and gasoline, based on the research by one of our two GSRs, Corinne Scown. We wrote up this research in an *ES&T* paper, "Water Footprint of Transportation Fuels." For several months, it was one of the most read papers of the journal.

We have published a paper ("Lifecycle Greenhouse Gas Implications of U.S. National Scenarios for Cellulosic Ethanol Production") outlining six U.S. land-use scenarios for growing Miscanthus in order to meet the second-generation biofuel mandate of the U.S. government by 2020. We were informed in this effort by the EBI scenario on Miscanthus-derived ethanol. We generated additional insights, and turned the scenarios into environmental emissions and a plan forward for Miscanthus-derived ethanol in the United States. With this work, we have established ourselves as a team that can work not only on unit analyses (e.g., quantifying the environmental footprint of one liter of ethanol), but on national-scale analyses as well.

Another student has worked on synthesizing current knowledge on liquid fuel transportation modes and storage options, and on developing emission factors for these options. These metrics have been incorporated into the *EBI LCA tool* and documented in the *J. of Infrastructure Systems* papers "Greenhouse Gas Emissions from Construction, Manufacturing and Operation of U.S. Liquid Fuel Distribution Infrastructure," and the *ES&T* paper "Fuel Miles and the Blend Wall: Costs and Emissions from Ethanol Distribution in the United States," in which we showed that the E10 clean air mandate and blend wall has resulted in millions of tons of unnecessary CO_2 emissions and billions of dollars of avoidable costs because Midwestern corn ethanol was sent to the coastal states before the local Midwestern markets have become saturated with ethanol.

An important and widely-used metric for assessing health impacts of air emissions and combustion products in LCA is the intake fraction (iF)—the ratio of pollutant uptake by a target population divided by the emission rate. The *EBI LCA tool* includes county level iF values for the United States with county-level spatial resolution. But until 2011, there were very limited assessments of iF for regions outside of the US. We have published the first assessment of intra-urban iF values for distributed ground-level emissions in all 3,646 global cities with more than 100,000 inhabitants. This encompasses a total population of 2.0 billion. They found that, for conserved primary pollutants, population-weighted median, mean, and interquartile range iF values in this population are 26, 39, and 14−52 ppm, respectively, where 1 ppm signifies 1 g inhaled/t emitted. Their global mean urban iF r is roughly twice as large as previous estimates for cities in the United States and Europe. This work was published in the journal *Environmental Science and Technology* in early 2012.

8. Data Management Plan

We will be using published data from scientific reports, peer-reviewed and conference papers, and public or commercial LCA and cost databases, so we will not have challenges associated with data measurement, equipment, and instrumentation. If multiple data are available from sources, we will average the data, but also show the range of recorded data, i.e., the lowest as well as the highest values.

9. Project Schedule

Task 1. Review of literature and ongoing laboratory research
Task 2. Life-cycle cost and environmental assessment data gap analysis
Task 3. Scale-up scenario modeling
Task 4. Identification of research needs
Task 5. Identification of potential barriers
Task 6. Developing a strategy to monitor and track progress of drop-in fuel technologies

MONTHS	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36
TASK												
1	■	■	■	■								
2					■	■						
3							■					
4								■				
5									■			
6										■		
		p	p	p	p	p	p	p	p	d		f

p = Deliver quarterly progress report
d = Deliver draft final report (to be submitted 6 months prior to contract expiration)
f = Deliver final report

10. Estimated Cost by Task

Table 2 shows the estimated cost by task. Note that the salaries of Thomas McKone and Corinne Scown (as planned) will be paid through multilocation appoitments (MLA), and as such, they are treated as purchase orders by UC Berkeley and categorized in the budget as "Materials and Supplies."

Task	Labor	Employee Fringe Benefits	Sub cons ult	Equi pme nt	Travel, Subsist ence	E D P	Copy /Print	Mail Phone Fax	Mater and Suppl	Anal yses	Misc.	Over head	Total
1	12,956	1,741							30,997			4,569	50,264
2	13,590	5,689							51,028			6,571	76,880
3	6,795	2,844							25,514			3,286	38,440
4	6,795	2,844							25,514			3,286	38,440
5	15,586	7,225							41,754			5,951	70,516
6	15,586	7,225							41,754			5,951	70,516
	$71,309	$27,569	$0	$0	$0	$0	$0	$0	$216,562	$0	$0	$29,616	$345,056

Table 2. Estimated cost by task.

11. References Cited

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Anbarasan, P., Baer, Z.C., Sreekumar, S., Gross, E., Binder, J.B., Blanch, H.W., Clark, D.S., Toste, F.D., 2012. Integration of chemical catalysis with extractive fermentation to produce fuels. Nature 491, 235-239.

Bunting, B., Bunce, M., Barone, T., Storey, J., 2010. Fungible and compatible biofuels: literature search, summary, amd recommendations. Oak Ridge National Laboratory, Oak Ridge, TN.

Davis, R., Aden, A., Pienkos, P.T., 2011. Techno-economic analysis of autotrophic microalgae for fuel production. Applied Energy 88, 3524-3531.

Humbird, D., Davis, R., Tao, L., Kinchin, C., Hsu, D., Aden, A., Schoen, P., Lukas, J., Olthof, B., Worley, M., Sexton, D., Dudgeon, D., 2011. Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol. National Renewable Energy Laboratory, Golden, CO.

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Klein-Marcuschamer, D., Oleskowicz-Popiel, P., Simmons, B.A., Blanch, H.W., 2010. Technoeconomic analysis of biofuels: A wiki-based platform for lignocellulosic biorefineries. Biomass and Bioenergy 34, 1914-1921.

Klein-Marcuschamer, D., Simmons, B.A., Blanch, H.W., 2011. Techno-economic analysis of a lignocellulosic ethanol biorefinery with ionic liquid pre-treatment. Biofuels, Bioproducts and Biorefining 5, 562-569.

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Perlack, R.D., Wright, L.L., Turhollow, A.F., Graham, R.L., Stokes, B.J., Erbach, D.C., 2005. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. Oak Rige National Laboratory, Oak Ridge, TN.
Scown, C.D., Horvath, A., McKone, T.E., 2011. Water Footprint of U.S. Transportation Fuels. Environmental Science & Technology 45, 2541–2553.
Scown, C.D., Nazaroff, W.W., Mishra, U., Strogen, B., Lobscheid, A.B., Masanet, E., Santero, N.J., Horvath, A., McKone, T.E., 2012. Lifecycle Greenhouse Gas Implications of US National Scenarios for Cellulosic Ethanol Production. Environmental Research Letters 7, 014011.
Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., Yu, T.-H., 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. Science 319, 1238-1240.
Sexton, S.E., Rajagapol, D., Hochman, G., Zilberman, D.D., Roland-Holdst, D., 2009. Biofuel Policy Must Evaluate Environmental, Food Security and Energy Goals to Maximize Net Benefits. California Agriculture 63.
Shi, J., Thompson, V.S., Yancey, N.A., Stavila, V., Simmons, B.A., Singh, S., 2013. Impact of mixed feedstocks and feedstock densification on ionic liquid pretreatment efficiency. Biofuels 4, 63-72.
Spath, P.L., Dayton, D.C., 2003. Preliminary Screening - Technical and Economic Assessment of Synthesis Gas to Fuels and Chemicals with Emphasis on the Potential for Biomass-Derived Syngas. National Renewable Energy Laboratory, Golden, CO.
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Strogen, B., Horvath, A., McKone, T.E., 2012. Fuel Miles and the Blend Wall: Costs and Emissions from Ethanol Distribution in the United States. Environmental Science & Technology 46, 5285-5293.
U.S. DOE, 2008. Strategic Development of Bioenergy in the Western States: Development of Supply Scenarios Linked to Policy Recommendations. U.S. Department of Energy and U.S. Department of Agriculture, Washington, DC.

12. Brief Curriculum Vitae and Relevant Publications Lists

Arpad Horvath
Professor
Department of Civil and Environmental Engineering, 215 McLaughlin Hall
Leader, Energy, Civil Infrastructure and Climate Graduate Program
Director, "Engineering and Business for Sustainability" Certificate Program
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EDUCATION
Technical University of Budapest (Hungary), Civil Engineering, M.S., 1993
Carnegie Mellon University, Pittsburgh, PA, Civil and Environmental Engineering, M.S., 1995
Carnegie Mellon University, Pittsburgh, PA, Civil and Environmental Engineering, Ph.D., 1997

APPOINTMENTS
- Courses taught: CE268E Civil Systems and the Environment, CE292A Technologies for Sustainable Societies, CE 11 Engineered Systems and Sustainability, CE 166 Construction Engineering, CE 167 Project Management
- Chair, *2011 Conference of the International Society for Industrial Ecology* (Berkeley, June 2011)
- January 2010 – present: **Member**, Editorial Advisory Board, *Environmental Science and Technology*, an ACS journal
- October 2009 – present: **Member**, Science Advisory Board (Environmental Engineering Committee), U.S. Environmental Protection Agency
- November 2005 – May 2012: **Chair**, Technology and Sustainability Committee, College of Engineering, UC Berkeley
- August 2005 – May 2007: **Member**, Committee on Environmental Impacts of Wind Energy Projects, National Research Council, The National Academies
- July 2010 – present: **Professor**, UC Berkeley
- July 2005 – June 2010: **Associate Professor**, UC Berkeley
- May 2005 – present: **Editorial Board Member**, *J. of Industrial Ecology*
- May 2002 – present: **Associate Editor**, ASCE *J. of Infrastructure Systems*
- May 2000 – present: **Director**, Consortium on Green Design and Manufacturing (CGDM), UC Berkeley
- July 1999 – June 2005: **Assistant Professor**, UC Berkeley
- January 1998 – June 1999: **Research Faculty**, Carnegie Mellon University
- July 1997 – December 1997: **Postdoctoral Researcher**, Carnegie Mellon University

HONORS AND AWARDS
- Best Paper of 2011 – Feature, Second Runner-up, *Environmental Science & Technology*, "Grand Challenges of Life-cycle Assessment of Biofuels"
- Best Paper of 2008 – Policy Analysis, Second Runner-up, *Environmental Science & Technology*, "Assessing the End-of-Life Impacts of Buildings"
- Walter L. Huber Civil Engineering Research Prize "for original and outstanding contributions to the life-cycle environmental modeling and assessment of infrastructure systems," American Society of Civil Engineers (2008)

- Laudise Prize "for outstanding achievements in industrial ecology by a young scientist or engineer," International Society for Industrial Ecology (2005)
- AT&T Foundation Industrial Ecology Faculty Fellowship (1998, 2000, 2001, 2004)
- National Science Foundation CAREER award (2001-2006)

SYNERGISTIC ACTIVITIES

- 2010-11: Co-development of a new graduate program in Civil and Environmental Engineering: "Energy, Civil Infrastructure and Climate," which has as one of its main foci the sustainability of transportation fuels
- 2007: Co-development of the "Engineering and Business for Sustainability" certificate program at UC Berkeley (http://sustainable-engineering.berkeley.edu), which has several courses on energy
- 2002-2012: Co-development of the course *CE 292A Technologies for Sustainable Societies*, which discusses, among others, energy, fuels, and transportation issues
- 2000 – present: Director of the Consortium on Green Design and Manufacturing, one of the oldest and most productive green engineering and management groups in the United States.
- 2000-2012: Development and regular updating of the course *CE 268E Civil Systems and the Environment*, which is the first and only course on campus dedicated to life-cycle environmental and economic analysis.
- 1995 – present: Co-development of the life-cycle assessment (LCA) model based on economic input-output analysis (EIO-LCA) and the first free web-based LCA software (www.eiolca.net)
- 1995: Development of a toxicity-based emissions metric, CMU-Equivalent Toxicity, based on occupational health values

REPRESENTATIVE RECENT PUBLICATIONS (from a total of more than 60 peer-reviewed papers)

- Strogen, B., Horvath, A. (2013), "Greenhouse Gas Emissions from Construction, Manufacturing and Operation of U.S. Liquid Fuel Distribution Infrastructure." *J. of Infrastructure Systems* (in print)
- Lobscheid, A., Nazaroff, W. W, Spears, M. S., Horvath, A. and McKone, T. E. (2012), "Intake Fractions of Primary Conserved Air Pollutants Emitted from On-road Vehicles in the United States." *Atmospheric Environment*, 63, pp. 298-305
- Strogen, B., Horvath, A. and McKone, T. (2012), "Fuel Miles and the Blend Wall: Costs and Emissions from Ethanol Distribution in the United States." *Environmental Science & Technology,* 46(10), pp. 5285-5293, http://dx.doi.org/10.1021/es204547s
- Chester, M. and Horvath, A. (2012), "Life-cycle Greenhouse Gas, Health, and Environmental Impacts of Future Long-Distance Transportation." *Environmental Research Letters,* 7(2)
- Scown, C. D., Nazaroff, W. W, Mishra, U., Strogen, B., Lobscheid, A. B., Masanet, E., Santero, N. J., Horvath, A. and McKone, T. E. (2012), "Lifecycle Greenhouse Gas Implications of U.S. National Scenarios for Cellulosic Ethanol Production." *Environmental Research Letters*, 7(1)
- Humbert, S., Marshall, J., Shaked, S., Spadaro, J., Nishioka, Y., Preiss, P., McKone, T., Horvath, A. and Jolliet, O. (2011), "Intake Fractions for Particulate Matter: Recommendations for Life Cycle Impact Assessment." *Environmental Science & Technology*, 45(11), pp. 4808-4816
- Scown, C., Horvath, A., and McKone, T. (2011), "Water Footprint of U.S. Transportation Fuels." *Environmental Science & Technology*, 45(7), pp. 2541-2553, http://dx.doi.org/10.1021/es102633h
- McKone, T., Nazaroff, W. W, Berck, P., Auffhammer, M., Lipman, T., Torn, M., Masanet, E., Mishra, U., Lobscheid, A., Santero, N., Barrett, A., Bomberg, M., Fingerman, K., Scown, C., Strogen, B. and Horvath, A. (2011), "Grand Challenges for Life-cycle Assessment of Biofuels." *Environmental Science & Technology*, 45(5), pp. 1751-1756, http://dx.doi.org/10.1021/es103579c "The Best ES&T Feature Paper of 2011 – Second Runner-up "
- Chester, M. and Horvath, A. (2009), "Environmental Assessment of Passenger Transportation Should Include Infrastructure and Supply Chains." *Environmental Research Letters*, 4(2), "The most downloaded ERL paper of 2009."

Thomas E. McKone

Education and Training

University of St. Thomas, Chemistry, B.A., 1974
University of California, Nuclear Engineering, MS, 1977, PhD, 1981

Research and Professional Experience

2000-present	Lawrence Berkeley National Laboratory: Senior Scientist; Deputy for Research Programs, Energy Analysis and Environmental Impacts Department; and Group Leader, Sustainable Energy Systems Group,
1996–present	Adjunct Professor and Researcher, School of Public Health, UC Berkeley; Course taught: PH220C Health Risk Assessment, Regulation, and Policy
2002–present	Member, United Nations Environment Program, International Life Cycle Board
2007–present	Member, Scientific Guidance Panel of the California Environmental Contaminant Biomonitoring Program.
2010–present	Member, Board on Environmental Studies and Toxicology, National Research Council, National Academy of Sciences.
2010–present	Member, National Institute for Environmental Health Sciences National Advisory Environmental Health Sciences Council.
2010–present	Member, Committee on Human and Environmental Exposure Science in the 21st Century, National Research Council, Scientific National Academy of Sciences,
2008–2010	Member, Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption, National Research Council, National Academy of Sciences.
2006–2008	Member, Committee on Improving Risk Analysis Approaches Used by the US EPA, National Research Council, National Academy of Sciences.

Research Interests

- The use and interpretation of large data sets and complex mass-balance models in life-cycle assessments
- Assessing model uncertainty and reliability
- Public health and ecological impacts of energy, industrial, and agricultural systems.

Publications (selected out of more than 160)

1. B. Strogen, A. Horvath, T.E. McKone “Fuel Miles and the Blend Wall: Costs and Emissions from Ethanol Distribution in the United States,” Environ. Sci. Technol. 46 (10):5285–5293, 2012.
2. C.J. Mattingly, T.E. McKone, M.A. Callahan, J.A. Blake, E.A. Cohen-Hubal “Providing the Missing Link: The Exposure Ontology ExO,” Environ. Sci. Technol. 46:3046-3053, 2012.
3. C.D.Scown, W.W. Nazaroff, U. Mishra, B. Strogen, A.B. Lobscheid, E Masanet, N.J. Santero, A. Horvath, T.E. McKone “Life cycle greenhouse gas implications of US national scenarios for cellulosic ethanol production” Environ. Res. Lett. 7:014011, 9 pages, 2012.
4. Scown CD, Horvath A, McKone TE. Water footprint of U.S. transportation fuels. Environ. Sci. Technol 2011, 45: 2541–2553,.

5 McKone TE, Nazaroff WW, Berck P, Auffhammer M, Lipman T, Torn MS, Masanet E, Lobscheid A, Santero N, Mishra U, Barrett A, Bomberg M, Fingerman K, Scown C, Strogen B, Horvath A. Grand Challenges for Life-Cycle Assessment of Biofuels. Environ Sci Technol 2011, 45(5): 1751–1756.

6 Hauschild MZ, Huijbregts M, Jolliet O, MacLeod M, Margni M, van de Meent D, Rosenbaum RK, McKone TE. Building a model based on scientific consensus for Life Cycle Impact Assessment of Chemicals: the Search for harmony and parsimony. Environ Sci Technol 2008 42: 7032–7037.

7 Bennett DH, Margni MD, McKone TE Jolliet O. Intake fraction for multimedia pollutants: A tool for life cycle analysis and comparative risk assessment. Risk Analysis 2002 22(5): 903-916.

8 Bare JC, Norris G, Pennington DW, McKone TE (2002) "TRACI – The tool for the reduction and assessment of chemical and other environmental impacts," J Industrial Ecol 2002 6(3-4): 49-78.

9 McKone TE, Castorina R, Kuwabara Y, Harnly ME, Eskenazi B, Bradman A. Merging models and biomonitoring data to characterize sources and pathways of human exposure to organophosphorous pesticides in the Salinas Valley of California. Environ Sci Technol. 2007. 41: 3233-3240.

10 McKone TE, Small MJ. Integrated environmental assessment, part III: Exposure assessment. Journal of Industrial Ecology. 2007 11(1):4-7.

11 McKone TE, MacLeod M. Tracking multiple pathways of human exposure to persistent multimedia pollutants: Regional, continental, and global scale models. Annual Reviews of Environment and Resources, 2004 28: 463-492.

12 MacLeod MJ, McKone TE. Overall multi-media persistence as an indicator of potential for population-level intake of environmental contaminants. Environ. Toxicol. Chem, 2004 23: 2465-72.

13 Eisenberg JN, McKone TE. Decision tree method for the classification of chemical pollutants: incorporation of across chemical variability and within chemical uncertainty. Environ Sci Technol. 1998 32: 3396-3404.

d. Synergistic activities.

1. 2002-2008: Developed the course PH 220c Risk Assessment Regulation and Policy at UC Berkeley
2. 2001-present: Organized workshops and peer review meetings for the United Nations Environment Program Life Cycle Task Force on Toxic Impacts. These efforts form recommended practice and guidance for use in ecotoxicity, human toxicity and related categories.
3. 1998-2008: Director, EPA-funded Exposure Modeling Research Center at LBNL/UC Berkeley
4, 1996-2004: Collaborated with the US EPA to develop the TRACI model—the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts in life-cycle assessments.
5. 1993-present: Development of the CalTOX multimedia model with applications to comparative risk assessment, sustainability and life-cycle impact assessment.