DRAFT PROPOSAL

SUPPORT FOR ADVANCED CLEAN CARS

UNDERSTANDING THE AFFORDABILITY, SOCIAL BENEFITS, AND LIFETIME COST OF ADVANCED ELECTRIC VEHICLES:

Expanding and enhancing the Advanced Vehicle Cost and Energy Use Model (AVCEM) to quantify amortized initial costs versus operating cost, and to value the social costs and benefits of battery-electric, plug-in hybrid electric, and fuel-cell vehicles (including integration with a renewable energy system) compared with advanced conventional petroleum vehicles.

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ABSTRACT

Concerns about climate change, urban air pollution, and dependence on unstable and expensive supplies of foreign oil have lead policy makers and researchers to investigate alternatives to conventional petroleum-fueled internal-combustion-engine vehicles (ICEVs) in transportation, including battery-electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hydrogen fuel-cell electric vehicles (HFCVs). However, although there are no technical barriers to developing electric vehicles (EVs) that perform as well as do petroleum ICEVs, it is not yet clear whether advanced EVs can be developed economically. There have been many studies of the lifetime cost of advanced EVs, including some recent detailed Regulatory Impact Analyses (RIAs), but no existing analysis or model is comprehensive and detailed enough to provide reliable and useful estimates of the full social lifetime cost of advanced vehicles. Our preliminary review of the literature indicates the following research needs in the social lifetime cost of advanced vehicles (these correspond to tasks in our project):

Task 1. Comprehensive, detailed iterature review
Task 2. Analysis of discounting
Task 3. Battery lifetime model
Task 4. Battery cost model
Task 5. Fuel-cell cost and performance model
Task 6. Analysis of retail cost vs. manufacturing cost
Task 7. Energy use of internal-combustion engines (ICEs)
Task 8. Validation of EV energy-use model
Task 9. External costs of air-pollution and climate change
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Task 11. Costs and benefits of vehicle-to-grid (V2G)
Task 12. Renewable-hydrogen refueling station cost
Task 13. Amenity benefits of home recharging
Task 14. Analyses of consumer and social lifetime cost
Task 15. Develop user-friendly social-lifetime cost model
Task 16. Publish model documentation and peer-reviewed journal articles

To address these issues, we propose to expand and enhance the existing Institute of Transportation Studies (ITS)-Davis Advanced Vehicle Cost and Energy Use Model (AVCEM) into a user-friendly model to provide comprehensive, detailed, original estimates of the full social lifetime cost of BEVs, PHEVs, and HFCVs. AVCEM is an electric, gasoline, and alternative-fuel vehicle energy-use and lifetime-cost model that designs a motor vehicle to meet range and performance requirements specified by the modeler, and then calculates the initial retail cost and total private and social lifetime cost of the designed vehicle. For this project, we will provide a comprehensive range of results from the expanded and enhanced AVCEM, which will answer important questions regarding the affordability, initial cost, social benefits, and lifetime cost of advanced electric vehicles (including integration with a renewable energy system) (see

Task 14 for a list of questions we will answer). We will document our efforts in at least 14 peer-reviewed academic journal articles that will define the state of knowledge concerning the social lifetime cost of advanced vehicles.

Our proposal explicitly addresses several research interests expressed in the "Support for Advanced Clean Cars" (SACC) section of the *2013-2014 Solicitation of Draft Research Proposals.* Section I of the SACC states "ARB seeks innovative approaches to understanding issues related to consumer acceptance, technological progress, as well as consumer, societal or economic impacts of the regulatory programs" (p. 19). Section II of the SACC states "Trends of particular interest include the types, costs, and effectiveness of pure- or near-zero emissions technologies that emerge in the marketplace as well as consumers' willingness and ability to purchase these technologies". Section III of the SACC presents a research area called "Affordability of new vehicles," which discusses tradeoffs between higher initial costs and lower fuel savings, focusing mainly on ways of quantifying and presenting these tradeoffs to consumers. Finally, Section III of the SACC presents a research area called "Valuation of co-benefits," which discusses valuing non-market aspects of advanced vehicles, including home recharging convenience, water pollution impacts, oil-use impacts, and vehicle-to-grid charging.

Our core research team, which includes Dr. Mark Delucchi, Dr. Marshall Miller, Dr. Andy Burke, and Dr. Tim Lipman, along with several graduate students and post-doctoral students in several departments, and participating faculty including Prof. Joan Ogden and Dr. Ken Kurani has extensive expertise in all aspects of the proposed project, including cost-benefit analysis, engineering cost analysis, life-cycle emissions analysis, renewable energy systems, air-pollution damage-cost analysis, vehicle energy-use modeling, battery and fuel-cell cost and performance simulation, hydrogen production and delivery modeling, and more.

Over the next couple of years we have approximately $100,000 of funding available, and are seeking another $100,00 of co-funding (not counting this proposal).

BACKGROUND

Concerns about climate change, urban air pollution, and dependence on unstable and expensive supplies of foreign oil have lead policy makers and researchers to investigate alternatives to conventional petroleum-fueled internal-combustion-engine vehicles (ICEVs) in transportation. Because vehicles that get some or all of their power from an electric drivetrain can have low or even zero emissions of greenhouse-gases (GHGs) and urban air pollutants and can consume little or no petroleum, there is considerable interest in developing and evaluating advanced electric vehicles, including battery-electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hydrogen fuel-cell electric vehicles (HFCVs). However, although there are no technical barriers to developing electric vehicles (EVs) that perform as well as do petroleum ICEVs, it is not yet clear whether advanced EVs can be developed economically.

No manufacturer is producing advanced EVs in large quantities, and the prices quoted for demonstration vehicles produced in small quantities tell us nothing about long-run manufacturing costs at high production volumes. Moreover, the manufacturing cost is not the only relevant cost metric: vehicles that have higher initial costs might have lower operating and maintenance costs and as a result might have lower total costs over their lifetime. And even if advanced EVs have higher lifetime consumer costs than do comparable ICEVs, they still might have lower lifetime social costs, on account of having lower “external” costs, or “co-benefits”. The total social lifetime cost is a broad indication of the total costs and benefits to society of EV policies – arguably the metric of most interest to policy makers and analysts.

Although there have been many studies of the lifetime cost of advanced EVs, including some recent detailed Regulatory Impact Analyses (RIAs) (U. S. Environmental Protection Agency [EPA], 2012a; EPA and National Highway Traffic Safety Administration [NHTSA], 2012), our preliminary review and analysis of the literature (including the recent RIAs) indicates that no existing analysis or model is comprehensive and detailed enough to provide reliable and useful estimates of the full social lifetime cost of advanced electric vehicles. Moreover, given the rapidly growing interest in developing renewable energy for all sectors of the economy (Jacobson and Delucchi, 2011; Delucchi and Jacobson, 2011), it is especially interesting to examine the social lifetime cost of EVs as an integral part of both supply and demand in a high-renewable-energy economy – an area that has received relatively little attention. In the section “Overview of objectives and proposal” we list the research and modeling needs indicated by our preliminary but broad literature review. (Note that each need corresponds to a task discussed in detail in our “Technical Plan” section.)

To address these issues, we propose to greatly expand and update the Institute of Transportation Studies (ITS)-Davis Advanced Vehicle Cost and Energy Use Model (AVCEM) into a user-friendly model to provide comprehensive, detailed, original estimates of the full social lifetime cost of BEVs, PHEVs, and HFCVs, for the US and for California. We will provide a comprehensive range of results from AVCEM, to answer important questions regarding the affordability, initial cost, social benefits, and lifetime cost of advanced electric vehicles, integrated with a renewable energy system (see Task 14). We will document our efforts in at least 14 peer-reviewed academic journal articles that will define the state of knowledge concerning the social lifetime cost of advanced vehicles. The next section provides an overview and a discussion of the objectives of our proposal.

OVERVIEW AND OBJECTIVES OF PROPOSAL

Introduction

Our overall objective is to expand and enhance AVCEM to address a wide range of research needs in the broad field of cost-benefit analysis of advanced EVs (including integration with a renewable energy system). We have some co-funding for this large effort, and hope to get support from CARB to complete the project, tailor the model and results to California, and publish extensively in the peer-reviewed academic literature.

The original version of AVCEM was developed with CARB support in the year 2000 (Delucchi, 2000a). Since then we have used it in a wide range of analyses, and have published at least five peer-reviewed articles based on it (Sun et al., 2010a, 2010b; Delucchi and Lipman, 2010, 2001; Lipman and Delucchi, 2006). Over past decade it has remained one of the most detailed, well-documented tools developed. Only recently have comprehensive Regulatory Impact Analyses (RIAs) employed methods and levels of detail similar to those used in AVCEM (EPA, 2012a; EPA and NHTSA, 2012).

Of course, the state of knowledge regarding the costs and benefits of advanced vehicles is always expanding, and so over the past several years we have begun to update and enhance AVCEM to incorporate newer information and more detailed formal representations. This effort has been partially supported by various sources (see section "Preliminary cost proposal,"), but we are seeking additional funding to complete the entire project and have an appropriately documented, user-friendly, publicly available user-friendly model with analysis and results published extensively in the peer-reviewed academic literature.

Overview of AVCEM

AVCEM is an electric, gasoline, and alternative-fuel vehicle energy-use and lifetime-cost model. AVCEM designs a motor vehicle to meet range and performance requirements specified by the modeler, and then calculates the initial retail cost and total private and social lifetime cost of the designed vehicle. It can be used to investigate the relationship between the lifetime cost -- the total cost of vehicle ownership and operation over the life of the vehicle -- and important parameters in the design and use of the vehicle.

There are four submodels within AVCEM:

The **model of vehicle cost and weight** consists of a model of manufacturing cost and weight, and a model of all of the other costs -- division costs, corporate costs, and dealer costs -- that compose the total retail cost. The manufacturing cost is the materials and labor cost of making the vehicle. In our analysis, material and labor cost is estimated for all of the more than 40 subsystems that make up a complete vehicle. We also perform detailed analyses of the manufacturing cost of the key unique components of electric vehicles: batteries, fuel cells, fuel-storage systems, and electric drivetrains.

The **model of vehicle energy use and performance** is a second-by-second simulation of all of the forces acting on a vehicle over a specified drive cycle. The purpose of this model is to accurately determine the amount of energy required to move a vehicle of particular characteristics over a specified drivecycle, with the ultimate objective of calculating the size of the engine, battery, fuel-cell system, fuel-storage system, and electric-drivetrain necessary to satisfy the user-specified range and performance requirements.

Periodic ownership, operating, and lifetime costs include insurance, maintenance and repair, and energy costs; factors affecting the lifetime cost of major components such as batteries and fuel cells; and financial parameters and methods for amortization and present-value calculations. The lifetime costs of batteries, fuel cells and other components are a function of component lifetime, salvage or re-use value, and replacement costs, which are modeled explicitly in AVCEM.

External costs and transfers include the external cost-per-mile of air pollution, climate change, noise, and oil use (macro-economic adjustment costs, wealth transfers, military costs, and oil-use environmental damages). AVCEM also includes adjustments for three cost items – fuel taxes, oil-industry producer surplus, and auto-manufacturer true corporate profit (i.e., producer surplus) – that are costs to the private consumer but are transfers and hence not costs from the standpoint of society.

AVCEM includes several combinations of fuels (electricity, hydrogen, methanol, ethanol, CNG, LNG, LPG, and methanol), fuel feedstocks (petroleum, wood, corn, natural gas, and a full range of primary energy sources for electricity generation), and vehicle technologies (HFCVs, BEVs, HEVs, PHEVs, and ICEVs). HFCVs may be hybridized with a peak power device, such as a high-power battery.

AVCEM allows users to specify up to seven different kinds of vehicles for detailed analysis. There also are five different drive cycles, characterized by beginning and ending velocity, grade, and wind speed by time interval. The user selects one vehicle type and drivecycle from among the five.

AVCEM produces a range of useful outputs, including: vehicle performance characteristics, cost and performance characteristics for major components such as batteries and fuel cells; a complete detailed breakdown of lifetime costs per mile of travel; break-even gasoline prices; and the total present value of all cost streams over the life of the vehicle. Presently, inputs and outputs for AVCEM are for the United States.

ITS-Davis work on AVCEM

The orginal version of AVCEM was prepared with funding from CARB and several grants from University of California (UC)-wide programs. The main investigators were Mark Delucchi (ITS-Davis), Tim Lipman (then at ITS-Davis, now at ITS-Berkeley), Andy Burke (ITS-Davis) and Marshall Miller (ITS-Davis). Since then all four of the original investigators have continued to work on AVCEM, with funding from a range of sources. We also have worked with about 10 graduate students in several departments UC Davis and UC Berkeley, post-docs at ITS-Davis, and other ITS-Davis researchers and faculty, including Joan Ogden, Ken Kurani, and Cynthia Lin.

Today, the core AVCEM team remains Delucchi, Miller, Burke, and Lipman, with occasional participation by Ogden and Kurani, and a team of 2-4 graduate students. This team has extensive expertise in all aspects of the proposed project, including cost-benefit analysis, engineering cost analysis, life-cycle emissions analysis, air-pollution damage-cost analysis, vehicle energy-use modeling, battery and fuel-cell cost and performance simulation, hydrogen production and delivery modeling, and more.

Over the next couple of years we have approximately $100,000 of funding available, and are seeking another $100,00 of co-funding (not counting this proposal). In order to complete all of the necessary expansions and enhancements to AVCEM, we are seeking approximately $200,000/year for three years from all sources, including this request to CARB.

In the next section of this proposal, we summarize the proposed expansions and enhancements. Note that AVCEM already is a functioning model containing rudimentary versions of the proposed new modeling tasks. If there is a modest shortfall in funds, then we will complete the model structure and parameter documentation but put off work on making the model user-friendly.If there is a more serious shortfall, we will complete the model structure, with placeholder data, and put off more extensive data gathering for later.

Summary of our proposed tasks
As mentioned above, our broad, preliminary review indicates the following research and modeling needs, each of which correspond to a task in our proposal.

1. <u>Comprehensive, detailed literature review</u>. There is an enormous literature on all aspects of the social lifetime cost of advanced vehicles, but to our knowledge there has been no systematic review and analysis of this literature with an eye towards identifying the areas where further research is needed.

2. <u>Analysis of discounting</u>. The assumed discount rate is a powerful determinant of the lifetime cost, but although there is a large literature on discounting, some important considerations concerning social versus private discount rates and other issues have not been resolved.

3. <u>Battery lifetime model</u>. The lifetime cost of the battery is determined by the battery lifetime as well as the battery manufacturing cost, but no published model has a detailed representation of battery lifetime as a function of battery chemistry, charging conditions, temperature, discharge patterns, and other factors.

4. Battery cost model. Detailed battery-cost models have been developed recently, but these need to be integrated into complete vehicle lifetime cost models to allow the appropriate optimization of vehicle lifetime cost given formal representations of tradeoffs and interactions between vehicle design, vehicle range, vehicle performance, driving patterns, battery cost, vehicle weight, battery lifetime, and so on.

5. Fuel-cell cost and performance model. Detailed fuel-cell cost and performance models also have been developed recently, but these need to be integrated into vehicle lifetime cost models, along with fuel-cell lifetime models, to allow the appropriate optimization of vehicle lifetime-cost given formal representations of tradeoffs and interactions between vehicle design, vehicle range, vehicle performance, driving patterns, fuel-cell cost, vehicle weight, fuel-cell lifetime, hybridization of fuel-cells and batteries, and so on.

6. Analysis of retail cost vs. manufacturing cost. Recent work has advanced our understanding of the relationship between vehicle retail-level cost and variable manufacturing cost, for conventional ICEV components, but more work needs to be done to extend this understanding to the estimation of the retail-level costs of expensive new components (such as batteries) for advanced vehicles.

7. Energy use of ICEs. No lifetime cost model that we are aware of has an integral model of the energy-use of ICEs as a function of easily specifiable engine characteristics.

8. Validation of EV energy-use model. The energy-use of EVs is an important determinant of lifetime cost and GHG emissions, but to our knowledge the existing detailed EV energy-use models have not been validated against component-level second-by-second energy-use measurements from actual in-use vehicles.

9. External costs of air-pollution and climate change. Two important components of the social lifetime cost of advanced vehicles are the cost of air pollution and the cost of climate change. Although many studies have included estimates of these external costs, only a handful have used detailed, conceptually sound models, and none cover all of the important components of the total cost.

10. External costs of oil use. There are at least five different external costs of oil use (macroeconomic costs of price shocks, wealth transfers, Strategic Petroleum Reserve, military costs of defending oil, and water pollution costs), and while all of these have been estimated in various articles in the literature, no lifetime-cost model or overall analysis contains a detailed analysis of all of the components.

11. Costs and benefits of vehicle-to-grid (V2G). There has been considerable recent interest on the use of V2G to help match supply and demand in renewable energy

systems, but there has been no systematic analysis of the costs and benefits of an integrated EV/V2G/renewable-energy system.

12. Renewable-hydrogen refueling-station cost. Hydrogen storage tanks at HFCV-refueling stations also can serve as decentralized storage in an electricity system with a high percentage of variable renewable power supply, but to our knowledge there has been no analysis of the costs and benefits of integrated HFCV/refueling-station/renewable-electricity system.

13. Amenity benefits of home recharging. Compared to ICEVs, EVs can offer enhanced and new values, such as those related to regenerative braking or home recharging, but no cost-benefit analysis of EVs includes estimates of all of these.

14. Analyses of consumer and social lifetime cost. Because of the research needs discussed above, there are no published, comprehensive, detailed estimates of the total consumer and social lifetime costs of advanced vehicles.

15. User-friendly model. There is no publicly available, user-friendly comprehensive model of the consumer and social lifetime costs of advanced vehicles with all of the features proposed here.

16. Publish model documentation and peer-reviewed journal articles. Our preliminary literature review indicates that there are no comprehensive, detailed, peer-reviewed articles addressing all of the research needs discussed above.

The “Technical plan” presented below elaborates on each of these as research tasks. With the completion of the tasks described below, we will have the first model capable of detailed, original analysis of all aspects of the consumer and social lifetime cost of advanced electric vehicles, for California and the US. We will use the model to answer a wide range of questions of interest to researchers, analysts, technologists, regulators, and policy makers (see Task #14 for details).

HOW THE PROPOSAL RESPONDS TO CARB'S OBJECTIVES AND *SOLICITATION OF DRAFT RESEARCH PROPOSALS*

Our proposal explicitly addresses the following research interests expressed in the "Support for Advanced Clean Cars" section of the *2013-2014 Solicitation of Draft Research Proposals* (relevant information from the Solicitation are shown in italics):

Section I, Objective: "ARB seeks innovative approaches to understanding issues related to consumer acceptance, technological progress, as well as consumer, societal or economic impacts of the regulatory programs" (p. 19). We propose to develop a model that will allow CARB and other regulators to rigorously and formally evaluate consumer affordability and the consumer and societal impacts of regulatory programs for advanced vehicles.

Section II, Background: "Trends of particular interest include the types, costs, and effectiveness of pure- or near-zero emissions technologies that emerge in the marketplace as well as consumers' willingness and ability to purchase these technologies" (p. 19) The model we propose will provide the most advanced, conceptually correct estimation possible of the costs and effectiveness of zero-emission vehicles, and will provide metrics that inform our understanding of consumer willingness and ability to purchase these vehicles.

Section III, Research Areas, Affordability of new vehicles: This section discusses tradeoffs between higher initial costs and lower fuel savings, focusing mainly on ways of quantifying and presenting these tradeoffs to consumers. Our model will quantify and present these tradeoffs clearly, in as much detail as is desired. Also, because any such consumer-based analysis first requires a correct estimate of the actual lifetime cost streams that consumers will face – amortized battery costs, battery replacement or salvage costs, amortized drivetrain costs, maintenance and repair costs, insurance costs, energy costs, and so on – we first will build the lifetime-cost model necessary to analyze the affordability of new vehicles.

Section III, Research Areas, Valuation of co-benefits: This section discusses valuing non-market aspects of advanced vehicles, including home recharging convenience, water pollution impacts, oil-use impacts, and vehicle-to-grid charging. We will perform rigorous, original analyses and quantify all of these as well as other oil-use and energy-security "co-benefits," and air-pollution and climate-change co-benefits.

TECHNICAL PLAN

Our technical plan presents all of the tasks necessary to properly build and validate the model we have described generally above. However, we understand that not all of these tasks are relevant or of equal interest to CARB. In the following, we propose to ask for CARB support for the tasks marked with a double asterisk by the title; the other, un-marked tasks are shown so that the CARB tasks can be seen in the context of a coherent total project. Of course, CARB is free to select any of tasks for funding, or request modifications to any of them before funding them.

1. Comprehensive and detailed review of the literature on the private and social lifetime cost of advanced vehicles, to identify areas where further original research is needed.

In order to avoid unnecessarily duplicating prior efforts, and to ensure a focus on the areas of research that have received the least attention, we will perform a comprehensive review and analysis of the entire recent literature on the costs and performance of BEVs, PHEVs, and HFCVs. We will review journal articles and research reports that have been published in the last 10 years and present credible, original research on any aspect relevant to the total lifetime cost of advanced EVs, including: manufacturing costs of batteries, fuel cells, and drivetrains; manufacturing costs of baseline vehicles; periodic costs such as energy costs, insurance costs, and maintenance and repair costs; external costs such as air-pollution damages, climate-change-damages, and oil-use costs; total private and social lifetime costs; and performance and energy-use modeling. We will rate the originality and detail of every aspect of each study, with an eye towards summarizing where the best research has been done, and where work remains to be done.

We already have gathered over 100 articles and reports, and have performed a preliminary review of them. Based on our knowledge of the literature and the people and institutions who work in these areas, we believe that we have all of the leading papers and reports done in the last 10 years. Our preliminary review of these articles and reports has indicated the research and modeling needs that we have expanded upon as research tasks in this Technical Plan.

This task is 40% complete.

2. Analysis of the appropriate use of social versus private-consumer discount rates.

The rate at which capital costs are amortized over the life of the vehicle – or, alternatively, the rate used to calculate the present value of the stream of costs over the vehicle lifetime – is an important determinant of the total lifetime cost of the vehicle. But although there is a large literature on discounting, some important considerations concerning social versus private discount rates and other issues have not been resolved.

First, some analyses use a relatively high private discount rate – above (and sometimes well above) 10% – on the grounds that vehicle choice studies and other studies of apparent consumer tradeoffs between higher initial costs and lower operating costs indicate that consumers demand very fast "paybacks" of their initial investment. However, this generally is not valid because the arguments in the consumer's decision calculus are not the same as the factors in the estimation of the true resource-opportunity costs of investments over time. This means that it is a conceptual mistake to use the former as a proxy for the latter. (See Delucchi [2007a] for a preliminary discussion of related issues.)

Second, and more importantly, analyses that do focus on a social discount rate typically use a relatively high rate, usually at least 3% (e.g., the U.S. Office of Management and Budget [2003] stipulates that RIAs use 3% and 7% range; and see Johnson and Hope [2012] for a discussion of discounting in estimates of the social cost of carbon). Many academic analyses derive an estimate based on the Ramsey optimal growth model (see Johnson and Hope, 2012). In any case, there are theoretical reasons to believe that the resulting estimates of the discount rate overestimate the true resource or welfare opportunity cost to society over time.

In this task, we will present the conceptual underpinnings of the appropriate treatment of the discount rate in analyses of the lifetime cost of advanced vehicles, and then present theoretical and empirical considerations involved in estimating the rate. Our preliminary work indicates that the a theoretically correct estimate of the social discount rate for the purpose of evaluating the costs and benefits of advanced clean vehicles is in the range of 1% or less. This of course will have a significant impact on the estimates of lifetime costs.

This task is 20% complete.

3. Detailed models of battery lifetime and performance.
The lifetime cost of a battery is a function of the manufacturing cost, performance, and the life of the battery. The life of the battery is a function of the battery chemistry, the charging algorithm, the power and depth of discharge per cycle, the number of cycles of different characteristics, the ambient temperature, and the length of time the battery is standing. Although the lifetime of the battery is just as important of determinant of the lifetime as is the initial manufacturing cost, there has been comparatively little formal modeling of battery lifetime, and to our knowledge no modeling of the battery lifetime, as a function of the factors given above, in the context of estimating the lifetime cost of batteries. Because of this deficiency alone, most published estimates of the lifetime cost of electric vehicles are too uncertain to serve as useful guides to policymakers.

In this task, we will incorporate into AVCEM a model of battery lifetime as a function of the parameters mentioned above. We will use test data for lithium-ion batteries from our own UC Davis Battery and Fuel Cell Laboratory, along with other published and proprietary industry results (e.g., Lunz et al., 2012), to determine and parameterize the functional forms that best fit the available data. With this detailed and validated battery lifetime model, we will be able to determine how different ambient conditions and driving and charging patterns, including the use of V2G services, affect battery lifetime and ultimately EV lifetime cost.

The input or control variables for this analysis will include: battery chemistry; vehicle range and performance requirements, which determine the total energy and power requirements of the battery; ambient temperature; the frequency, power, and depth of charging; the daily driving profile, which determines the relevant battery characteristics such as state of charge and discharge power second-by-second; and the frequency, power, and depth of cycling for V2G. With this level of detail, we will be able to understand battery life for any driving and charging scenario in any ambient conditions. We will establish reasonable base-case data sets for California and the U. S.

This task is 35% complete.

****4. Reduced-form model of battery manufacturing cost, based on Argonne National Laboratory's detailed cost model.**

Recently, Argonne National Laboratory (ANL) has completed the most detailed publicly available analysis of the manufacturing cost of lithium-ion batteries. The ANL model is available in a spreadsheet, with written documentation (Nelson et al., 2011). In this task we will make a reduced-form version of the ANL model that can be incorporated into AVCEM, and also will make two enhancements to the ANL model.

The ANL model is too large, and has too many finely detailed input parameters, to be usefully incorporated whole into AVCEM. Therefore, we will reduce the model to 15-20 equations in which the mass of each major battery material (e.g., lithium, or aluminum), along with labor time, are a function of basic battery-design parameters, such as ah/cell, cell voltage, and number of cells. We will develop these equations so that they cover the entire ANL model battery design space with close to 100% accuracy, thus providing a truly universal reduced-form equation set. We then will multiply these calculated component masses by unit material or component costs, and will multiply the labor time by the unit labor rate. This will result in a reduced-form model that has nearly all of the power of the original ANL model, but can be specified in terms of simple battery design parameters.

We also will enhance the ANL model in two ways. First, our review of the model structure, and of the external peer-review commissioned by ANL, indicates that the model does not fully represent real tradeoffs between battery specific power and battery specific energy in battery design. Specifically, in the ANL model the cell or module mass is determined by the specified energy only; the power of the battery has no effect on the mass. In reality, however, the design and mass of a cell are affected by the power requirements as well as energy requirements. To correct this, we will create simple but realistic functions to trade off energy and power and determine the mass of the various cell components (the anode, cathode, the current collectors and the electrolyte). These trade-off functions will be based on our extensive experience with battery design, testing, and operation. We will incorporate these tradeoff functions into the ANL model prior to deriving reduced-form representations to be incorporated into AVCEM.

Second, ANL's default unit-cost values for key materials (e.g., $/kg-lithium) are fixed, but in reality, the cost of key materials will change over time. Where appropriate, we will replace the fixed unit-cost values with cost functions that relate the unit cost to global demand for the material. We previously have done this for the cost of platinum, and have published the analysis in the peer-reviewed literature (Sun et al., 2011); here, for lithium, we will use the approach used in the platinum analysis. For the lithium analysis we also will involve Paul Gruber, a staff member at ITS-Davis who has extensive experience on lithium supply issues and has published in the peer-reviewed literature an analysis of the impact of EV development on lithium supply (Gruber et al., 2012).

This task is 25% complete.

****5. Detailed models of the cost, performance, and lifetime of fuel cells.**
The lifetime cost of the fuel cell, like the lifetime cost of the battery, is a function of the manufacturing cost, performance, and lifetime of the fuel cell. The US Department of Energy has sponsored detailed analyses of fuel-cell manufacturing costs (Marcinkoski et al., 2011), and several researchers have published detailed models of fuel-cell performance as a function of the characteristics of the membrane, the air pressure, the stoichiometry, the catalyst loading, and other factors (e.g., Spiegel, 2008). There also are a number of studies of the factors contributing to the life of fuel cells, such as membrane thickness, catalyst loading, and others (e.g., Mathias et al., 2005). However, there is no lifetime cost model that properly integrates state-of-the-knowledge representations of manufacturing cost, performance, and life. Because of this, there is no reliable model or published estimate of the lifetime cost of fuel cells.

We will draw on the best available work to build into AVCEM an integrated fuel-cell cost, performance, and life model, as a function of key fuel-cell design parameters, including membrane type, membrane thickness, catalyst loading at the anode and cathode, air pressure, and stoichiometry. We then will be able to perform optimization studies to determine the combinations of membrane thickness, catalyst loading, pressure, and stoichiometry that result in the lowest lifetime cost, accounting for the actual tradeoffs in fuel cell design and operation (e.g., a higher catalyst loading improves performance and lifetime but also increases initial cost; higher pressure improves performance but again increases initial cost). For parameters not part of the optimization, we will provide the most appropriate base-case values.

This task is 25% complete.

****6. Analysis of the difference between retail costs and manufacturing cost, as a function of the cost and characteristics of new technologies.**
Detailed analyses of the total cost of a vehicle build from an estimate of the variable manufacturing cost, which is a function of material and labor cost, to the retail-level cost. The difference between the retail cost and the manufacturing cost comprises sales taxes, dealer costs, shipping costs, corporate costs, and division costs (different accounting systems use different terms). The ratio of the retail cost to the manufacturing cost can be quite large – in the range of 1.3 to 2.5 – depending on the accounting system, the definition of "manufacturing cost," and the component or vehicle subsystem being analyzed. This factor-of-two uncertainty in the ratio translates into enormous uncertainty in the retail-level cost of expensive components, like batteries: it makes a considerable difference to the total lifetime cost of an EV if a battery with a $4000 manufacturing cost is multiplied by 1.3 or 2.5 to obtain the retail-level cost.

To address this uncertainty, the EPA, which performs cost analyses as part of its Regulatory Impact Analyses, sponsored a team to perform an original analysis of this ratio (Rogozhin et al., 2009a); their work was published in the *International Journal of*

Production Economics (Rogozhin et al., 2009b). We will start with this work, and improve on it in several ways. First, we will treat separately costs that can be estimated on the basis of microeconomic theory; these include inventory-holding costs and corporate profit. Second, instead of estimating a constant ratio between retail-level and manufacturing costs – which effectively assumes that all of the costs incurred above the manufacturing level are proportional to the manufacturing cost – we will assume that some of these “overhead” costs are fixed, and *independent* of the magnitude of the manufacturing cost. This is important because there is a large difference between assuming a fixed cost of $1000 allocated to a battery of *any* manufacturing cost, and multiplying any manufacturing cost by, say, 2.0. Third, we will develop a precisely defined, comprehensive accounting system, so that our estimates of variable manufacturing cost as we define it plus our estimates of all of the other costs up to the retail level result in an exhaustive and mutually exclusive set of cost categories. Fourth, we will develop multiplier estimates specifically for expensive, novel components of EVs, such as batteries and hydrogen-storage systems. To do this, we will start with the detailed information on overhead costs estimated by Rogozhin et al. (2009a, 2009b), and then consult with industry experts to determine, specifically for components like batteries and fuel cells (which we were not analyzed by Rogozhin et al.), which cost categories are likely to remain fixed and which are likely to be a function of the manufacturing cost.

This task is 0% complete.

7. Comprehensive re-analysis of the equations for the energy use of ICEs

The energy use of advanced electric vehicles and of the counterpart ICEVs they are compared with is an important determinant of lifetime cost and lifecycle GHG emissions. Some of the comparisons of the lifetime cost of EVs with the lifetime cost of ICEVs are based on detailed models of vehicle energy; for ICEVs, these models generally use engine maps to determine the energy losses (or energy efficiency) of the ICE itself. However, engine maps are valid only for a particular engine, and hence models that use this approach can compare only those vehicles for which engine maps are available.

In order to be able to compare a wider range of vehicles, AVCEM estimates the energy use of ICEs on the basis of analytical equations fit to the actual test data used to create maps. These equations are a function of widely available engine characteristics such as compression ratio, displacement, number of cylinders, and air-fuel ratio. However, the current AVCEM equations are fit to a limited set of relatively old data (Delucchi, 2000a). Therefore, in this task, we will create a more recent and more comprehensive set of test data, and then derive new equations that fit the expanded data set. This will produce accurate estimates of ICE energy use for engines of any size, number of cylinders, and so on. The test data come from published engine maps and from our analysis of the data in EPA’s Mobile Source Observation Database (MSOD) (EPA, 2012b).

This task is 40% complete.

8. Validation of the electric-vehicle drive-cycle and energy use model against real driving and drivetrain data.

Most detailed analyses of the lifetime cost of EVs use models of EV energy use. Most of these models, including the one in AVCEM, are validated by comparing published test data with modeled results. However, these bulk comparisons cannot provide any information on why model predictions deviate from actual data. It is more diagnostically useful to compare model predictions with measured data at specific points in the drivetrain, for each second of the drivecycle.

The UC Davis PHEV Center has a BEV (a Toyota Scion xB converted by AC propulsion to an eBox, with a 35-kWh lithium-ion battery [http://en.m.wikipedia.org/wiki/AC_Propulsion_eBox#section_3]) fitted with a data box that measure voltage and current at the battery terminals, and other vehicle data, over narrow time slices of the driving cycle. For this task, we will compare the second-by-second predictions of our model with the actual data from the eBox, when AVCEM is specified to match the eBox and the driving characteristics of the test drives. With this comparison, we will be able to diagnose any discrepancies between model predictions and actual data.

This task is 50% complete. (We have gathered and input the test data).

****9. Expanded treatment of external costs of pollution, including incorporation of upstream air pollutant emissions and damages, and a more disaggregated treatment of climate-change emissions.**

Two important components of the social lifetime cost of advanced vehicles are the cost of air pollution and the cost of climate change. Although many studies have included estimates of these external costs, only a handful have used detailed, conceptually sound models. And among this handful, there is to our knowledge no single model that has the nine features that we propose here and discuss below.

In general, we will build on our prior seminal work on the external costs of motor-vehicle use (Delucchi, 2000b; Delucchi and McCubbin, 2010) to incorporate a detailed treatment of the external costs of air pollution and climate change into AVCEM, with the nine features discussed next.

i) We will estimate air-pollution and climate-change damages from end use, the complete lifecycle of fuels, and the complete lifecycle of vehicles (including the lifecycle of materials for vehicles).

ii) We will estimate damages from the lifecycle of electricity for EVs and the lifecycle of advanced non-petroleum fuels, such as ethanol derived from cellulosic biomass.

iii) We will create a complete, detailed, original inventory of emissions of all air pollutants and GHGs from all stages of the lifecycles of fuels, vehicles, and materials. These inventories will be built by extracting output from special runs of the Lifecycle Emissions Model (LEM) (Delucchi et al., 2003). The LEM, a forerunner of the GREET and Canadian GHGenius LCA models, produces detailed, complete inventories for all urban air pollutants and greenhouse gases for all stages of the lifecycle of energy and material commodities. Presently the LEM has national-level data. If we have sufficient funding, we also will develop inventories specifically for California, using the expertise and knowledge of CARB staff and embodied in the CA-GREET model.

iv) We will account for the effects on exposure of differences in the location of major source categories, such as power plants and vehicles. We will estimate the effects of different locations by using normalized dispersion factors, which estimate the dispersion of pollution from source *s* relative to the dispersion from a reference source, in our case motor vehicles. In our earlier work (McCubbin and Delucchi, 1999; Delucchi, 2000b) we used a Gaussian dispersion model to estimate these normalized dispersion factors. For this project, we will review other estimates of normalized dispersion factors, and where appropriate use other dispersion and air-quality models to update our original estimates.

v) We will make detailed estimates of air-pollution damages to human health (mortality and morbidity), agriculture, forests, visibility, and materials. We will update our earlier, comprehensive, state-of-the art estimates of the health-damage cost of motor-vehicle air pollution (McCubbin and Delucchi, 1999), the cost of crop damage caused by motor-vehicle ozone pollution (Murphy et al., 1999), and the visibility cost of air pollution (Delucchi et al., 2002). These analyses remain comparable in detail and methodological soundness to the recent analyses performed by the National Research Council (NRC) (2010). Delucchi and McCubbin (2010) compare our earlier work with the NRC work and other studies.

vi) We will have a comprehensive accounting of all plausible morbidity and mortality consequences of air pollution. The review of Delucchi and McCubbin (2010) indicates that our prior work covers more plausible health damage relationships than most other major studies. For this study, we will review the recent epidemiology literature and extend and update our dose-response functions as appropriate.

vii) Our climate-change-damage analysis will account for all direct and indirect climate effects of all pollutants (rather than only CO_2, N_2O, and CH_4). Appendix D of Delucchi et al. (2003) outlines the method we will use. In general, climate-change damages are the present value of the impacts of temperature change due to radiative forcing, estimated on the basis of a declining non-zero discount rate over a long period of time. More technically, we will estimate the present value of damages from a one-gram year-zero (target-year) emission of a gas or aerosol. The present value of damages is the product of damages and a discount factor for each discrete time interval, summed over all time intervals up to a time horizon. Damages in each time interval ΔN are estimated as a simple function of the temperature change over *ΔN* (nominally in degree-years). The temperature change, in turn, is estimated as a function of the gas or aerosol remaining in the atmosphere (in gram-years), the radiative forcing per unit of remaining gas or aerosol, and the climate sensitivity (which specifies the relationship between radiative forcing and temperature). For some species, the amount remaining and the radiative forcing per unit are estimated as a function of the concentration of the species. To account for the lag between radiative forcing and the ultimate associated equilibrium temperature change, due to the thermal inertia of the oceans, we estimate temperature change in each interval *ΔN* as a function of radiative forcing gas or aerosol remaining and radiative forcing in all prior intervals.

viii) We will do a detailed review and analysis of the literature on climate-change damages in dollars of damages per gram of GHG emitted, including the major climate-change-damage models FUND (Anthoff et al., 2011a, 2011b), PAGE (Wahba and Hope, 2006), and RICE (Nordhaus, 2007).

ix) We will ensure internally consistent use of the same morbidity and mortality values in the calculation of climate-change damages and the calculation of air-pollution damages.

This task is 35% complete.

****10. Original analysis of the external costs of oil use.**

Alternatives that displace oil use in transportation will have at least five general kinds of social benefits not included in the cost of the foregone petroleum: i) reduced susceptibility to the negative macroeconomic consequences of oil-price shocks; ii) reduced transfer of producer surplus to foreign oil producers; iii) reduced need for the Strategic Petroleum Reserve (SPR); iv) reduced need to devote military resources to defending foreign oil supplies; and v) reduced water pollution from spills and leaks of petroleum. No detailed analysis has included all of these benefits. For this task, we will perform original, detailed analyses of all of these except water-pollution costs, for which we will do a literature review and analysis.

For all five of the costs described above, the oil-externality cost per mile for any vehicle is equal to gallons of oil used over the fuel lifecycle, per mile of travel, multiplied by the externality cost per gallon of oil. The externality cost per gallon of oil is described below. Fuelcycle oil use for all vehicle types is estimated using the LEM (Delucchi et al., 2003).

In order to estimate per-gallon externality costs i) and ii) above, we need a model of the world oil market. This model will have three primary components: a model of the long-run marginal costs (LRMC) of oil production and gasoline refining for OPEC, US, and rest-of-world producers; a model of OPEC decision making in the face of expectations about future supply and demand; and methods for estimating the macro-economic adjustment costs given models of supply and demand.

To estimate oil LRMC, we will begin with a construction of the U.S. oil cost curve based on publicly available from American Petroleum Institute (2004). We then will derive the gasoline cost curve assuming that oil and gasoline costs have the same correlation as their prices. We will use three energy-projection scenarios from the Energy Information Administration *Annual Energy outlook* to project future oil and gasoline cost curves. To estimate supply curves for OPEC and the rest of the world (ROW), we will use unpublished World Bank data on crude oil annual average world price and production in years 2003 and 2004.

As regards OPEC decision making, we are interested in examining OPEC's behavior within the global oil market, accounting for both supply-side factors and demand-side factors. In particular, we aim to explore the effect of OPEC's contemporary supply decisions on the future demand for oil in order to incorporate a feedback effect and to estimate OPEC's optimal price path. We will model OPEC's objective function using discrete time periods, where OPEC maximizes the present discounted value of profits by selecting the optimal extraction path, subject to constraints on per-period extraction capacity, total available reserves, and the quantity supplied by the competitive fringe.

To estimate the macroeconomic adjustment costs given our models of LRMC and OPEC behavior, we need additional formal relationships between price trajectories, shock probabilities, and macro-economic adjustment costs. We will estimate relatively simple relationships on the basis of work by Leiby (2007), Jones et al. (2004), and Greene and Tishchishyna (2000).

The costs of the SPR include operating and maintenance costs, amortized capital costs, and oil-holding costs, which can be positive or negative depending on the difference between the costs of acquisition and the value of releases. Delucchi (2007b) presents the results of a detailed analysis of all of these components; here, we will use the methods from that study with updated parameter values.

To estimate military costs, we will update our earlier peer-reviewed estimates (Delucchi and Murphy, 2008) with the results of recent analyses of the allocation of military effort to regions with large oil reserves (Stern, 2010). Our widely cited 2008 paper remains the only published peer-reviewed estimate that carefully estimates the military-expenditure costs of using oil in transportation. That paper reviews the relevant literature, develops the conceptual and theoretical basis for estimating and attributing military-expenditure costs, and presents estimates of the costs. Subsequently, Stern (2010) examined one of the key parameters in our analysis – the military cost related to the Middle East in general – and, using a different method of allocating military resources than we did, estimated a much higher value for this parameter. We will critically appraise Stern's work and as appropriate use it to update our analysis.

To estimate water-pollution costs we will perform a literature review and analysis, updating the analysis summarized in Delucchi (2000).

Although we are building from scratch original estimates of oil supply and demand, our team, which includes faculty and Ph.D. students in the Agricultural and Resource Economics Department at UC Davis, has extensive research experience with all of the underlying data-gathering and modeling requirements.

This task is 25% complete. (Initial literature reviews and model-development complete.)

****11. Estimate costs of V2G recharging in a high-renewables electricity system.** Electric-vehicle batteries can be used as decentralized storage in an electricity system with a high percentage of variable renewable power sources (Delucchi and Jacobson, 2011; Harris and Webber, 2012). This system, in which vehicles store electricity and then return it to the grid, is known as "vehicle-to-grid," or V2G. Regulators and analysts are becoming increasingly interested in V2G as an important link between programs that expand the use of EVs and programs that expand the use of renewable energy. In this task, we will expand on the growing body of V2G work in three critical ways.

First, we will perform a careful analysis of the full resource cost of V2G, including an original analysis of the effect of V2G cycling on battery life. We will focus on the *cost* of V2G, which is the appropriate metric in a social lifetime cost analysis, rather than on the *value* of V2G, which is of interest to regulators and utilities concerned with pricing and incentives. (Discussions of V2G sometimes confuse *value* and *cost*.) Our work will expand upon the detailed analysis presented in Delucchi and Jacobson (2011), which estimated three main components of the cost of V2G cycling: accelerated loss of battery capacity, extra electronics for managing V2G operations, and loss of energy during charge/discharge cycling. We will deepen and update the Delucchi and Jacobson (2011) analysis of these cost components by literature review and, to the extent possible, acquisition of test data from the UC Davis Battery Laboratory.

Second, we will develop a formal representation of utility "demand" for V2G services as a function of supply and operational characteristics of a renewable electricity grid.

Third, we will estimate the battery-cycling cost of V2G by combining our detailed model of battery lifetime and cost (tasks #3 and #4) with a detailed representation of charging and driving patterns and the formal representation of utility "demand" for V2G services discussed in the preceding paragraph.

The result of this will be the first documented, detailed, original model of the full cost of an integrated EV-V2G-renewable energy system, in which the cost of powering EVs from a reliable, high-renewables electricity mix is estimated as a function of the interaction between the electricity supply, electricity demand, driving patterns, charging patterns, battery characteristics, and battery second life.

This task is 30% complete.

12. Estimate costs and benefits of hydrogen refueling stations with extra storage capacity in a high-renewables electricity system.

Hydrogen storage tanks at HFCV-refueling stations also can serve as decentralized storage in an electricity system with a high percentage of variable renewable power supply (Delucchi and Jacobson, 2011; Martin and Grasman, 2009). In any energy-system scenario, regardless of the nature of the primary energy supply, HFCV-refueling stations need substantial on-site hydrogen storage capacity in order to be able to quickly satisfy peak vehicle demand for fuel without having to install on-site hydrogen production capacity with a peak hydrogen power output equal to the peak power hydrogen demand by vehicles. And in any system, the tradeoff between the capacity of the storage system and the peak output of the hydrogen production system is a cost optimization problem that depends on the costs of the equipment as a function of the capacity and the anticipated demand profiles. A number of models with representations of HFCV refueling stations, including AVCEM, have sufficient detail to be able to analyze this tradeoff and perform this optimization.

Integration with a high-renewable electricity system presents additional considerations. In an electricity system with a high percentage of variable primary power supply, one way to address the mismatch between the variable power supply profile and the power demand profile is to increase the power of the supply to match the peak demand more closely, and then, rather than curtail the system output when the generation exceeds the demand, use the excess instantaneous generation to generate hydrogen at HFCV refueling stations (Delucchi and Jacobson, 2011).

For this task, we will model the optimal configuration of HFCV-refueling stations as a function of the electricity-system benefits of using distributed hydrogen tanks to effectively store renewable electricity supply, as well as a function of the demand for hydrogen and the cost functions for on-site hydrogen storage and production. The result of this will be the first documented, detailed, original model of the full cost of an integrated HFCV-refueling-station/renewable-electricity system, in which the cost of using HFCVs with hydrogen derived from a reliable, high-renewables electricity mix is estimated as a function of the interaction between the electricity supply, electricity demand, driving patterns, hydrogen refueling patterns, hydrogen storage costs, and hydrogen refueling station costs.

This task is 15% complete.

****13. Quantify value of amenity benefits of advanced vehicles, such as home recharging.**

Compared to ICEVs, EVs have three sources of enhanced and new values: i) the electric drivetrain, ii) the charging and energy system, and iii) new identity expressions (Axsen and Kurani, 2013; Turrentine et al., 2011; Turrentine and Kurani, 2007; Heffner et al., 2007).

i) The values to be derived from the electric drivetrain are the most immediate and the most within the control of the vehicle designer and manufacturer. For example, electric motors reach maximum torque almost instantaneously, which results in more rapid low-speed acceleration compared with ICEVs. Another positive attribute of electric (and hybrid) drivetrains not available in conventional drivetrains is regenerative braking, which provides functional, symbolic, and emotional values, such as higher efficiency and lower operating cost, the satisfaction of contributing to important social goals to conserve energy, and high-tech cachet.

ii) Sources of new values to be derived from charging a car from the electrical grid rather than refueling at a station dispensing petroleum-based fuels include a sense of independence from oil, the satisfaction of using a relatively clean source of energy, avoiding inconvenient trips to refueling stations, avoiding exposure to toxic gasoline vapors, being assured of always having fuel readily available, and stable electricity prices compared to fluctuating gasoline prices.

iii) In-depth, long-term research reveals that after weeks of experimentation, learning, and adaptation, households with EVs not only have evolved new transportation- and household-activity patterns, but also have begun to create new personal and social identities (Axsen and Kurani, 2013; Turrentine et al., 2011). Because EVs have markedly different functional and emotional attributes than do conventional vehicles, household do not merely substitute new EVs into their pre-existing, unmodified transportation and activity patterns, but rather recreate their living and travel patterns to take advantage of the new possibilities offered by electric transportation.

For this task, we will draw on the extensive household-interview experience of the lead survey researcher at the UC Davis Plug-in and Hybrid EV Center (Dr. Ken Kurani), in collaboration with Prof. David Bunch of the UC Davis Graduate School of Management, to collect survey data for use with standard non-market valuation techniques to quantify the dollar value of the amenity benefits of advanced electric vehicles. The sample size, construction, and administration of the survey will depend on the availability of co-funding for this task. If we are unable to secure co-funding, we will limit the activity of this task to inserting into ongoing survey projects questions related to the amenity benefits of electric vehicles.

This task is 0% complete.

**14. Perform analyses of consumer and social lifetime costs of advanced vehicles.

With the completion of tasks #1 through #13, we will have the first model capable of detailed, original analysis of all aspects of the consumer and lifetime cost of advanced electric vehicles. We will use the model (an expanded and updated version of AVCEM) to answer a wide range of questions of interest to researchers, analysts, technologists, regulators, and policy makers:

- How does the lifetime cost of advanced EVs, expressed as either an amortized cost stream or a net-present value of all costs, compare with the lifetime cost of petroleum-fueled ICEVs?

- What full retail price of gasoline is required for the lifetime cost of EVs to be equal to the lifetime cost of gasoline ICEVs, and how does this "breakeven" retail price compare with official projections of energy agencies?

- What are the most important and uncertain determinants of the lifetime cost, and how does the lifetime cost vary with plausible variation in these factors?

- How do lifetime costs vary with levels of production of vehicles and components?

- How do different vehicle designs and driving patterns affect the total lifetime cost?

- How important are tradeoffs between driving range, vehicle performance, and total lifetime cost?

- How large are the external costs compared with consumer (private) costs? How does consideration of external costs affect social lifetime-cost comparisons, qualitatively and quantitatively?

- What are the total resource costs and system benefits to utilities and vehicle owners of V2G as part of a renewable energy system?

- What are the total resource costs and system benefits to utilities, fuel suppliers, and vehicle owners of having decentralized storage at HFCV-refueling stations, as part of a renewable energy system?

- How and why do our results differ from those of previous, less detailed studies?

- What do our findings suggest about the cost and development goals and targets of regulatory agencies, national laboratories, and others?

- What are the implications of our findings for further research?

- What are the implications of our findings for policy making?

- Overall, what are the implications of our findings for the future development of and prospects for advanced vehicles?

This task is 0% complete.

****15. Development of user-friendly version of the model for ARB staff and ultimately the public.**

For this task, we will re-organize and reformat the model and develop appropriate user interfaces in order to ensure that it can be used easily by regulatory analysts and other researches. The first step will be to appropriately organize the functional areas of AVCEM into separate tabs in a sensible way. The second step will be to reformat the model using appropriate color coding, labeling, outlining, and commenting, to make the operation of AVCEM and the distinction between inputs and outputs as clear as possible. The third step will be to develop macros, pop-ups, and other user interfaces to automate the operation of AVCEM.

This task is 0% complete.

****16. Document model development and results, publication of journal articles.**

We will publish complete documentation of the model, a comprehensive sampling of results, and at least 14 peer-reviewed journal articles:

-- Literature review and analysis
-- Battery cost and performance
-- Fuel-cell cost and performance
-- Engine energy-use modeling
-- Validation of electric-vehicle energy use
-- Original analysis of OPEC oil pricing behavior, and impacts on energy-security and oil-use costs (possibly two papers)
-- Combined air-pollution and climate-change damage cost model estimates
-- Costs and benefits of vehicle-to-grid charging in high-renewable electricity systems
-- Costs and benefits of HFCV refueling stations in high-renewable electricity systems
-- several articles on private and social lifetime cost of advanced vehicles

This task is 10% complete. (We update the documentation as we complete tasks.)

Products

-- User-friendly fully operational model.

-- Complete model documentation.

-- At least 14 peer-reviewed journal articles (see task #16 above).

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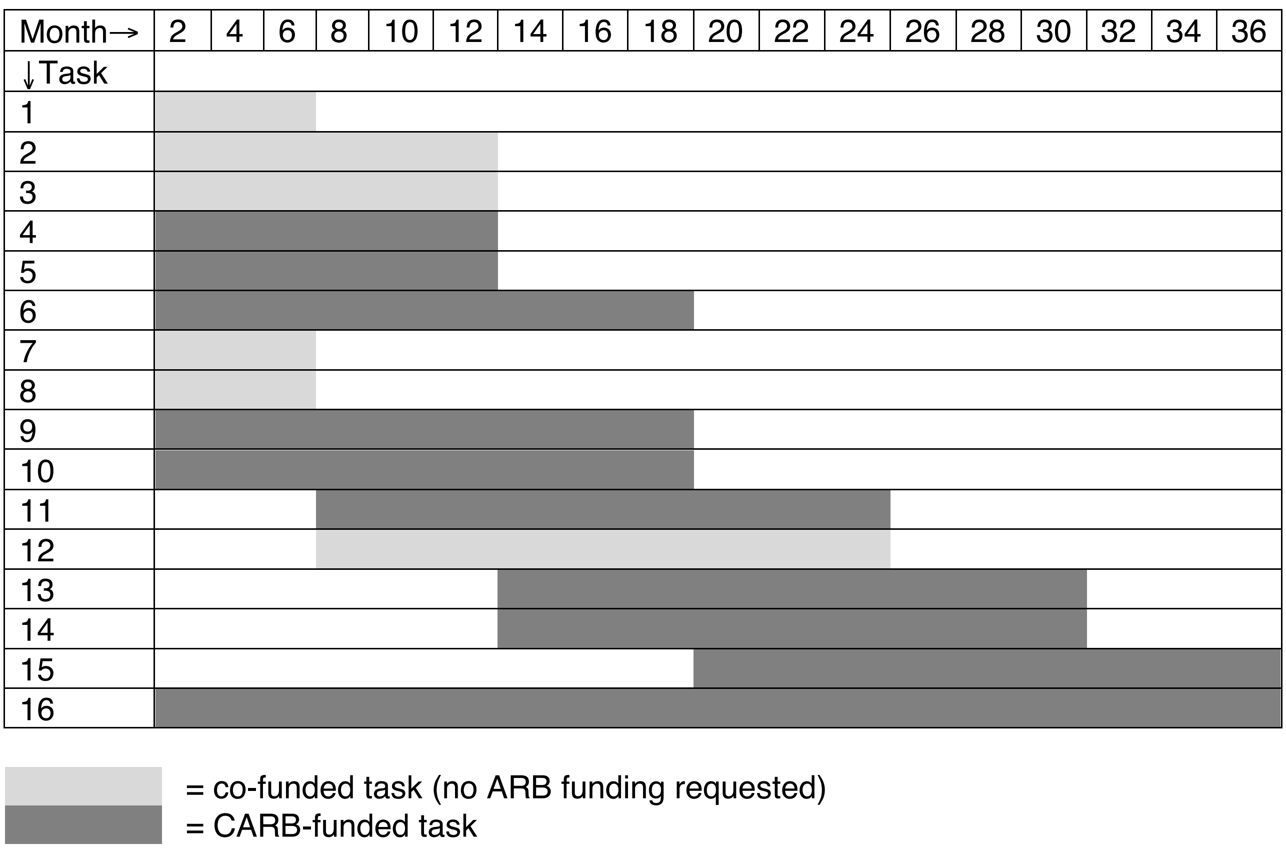
PROJECT SCHEDULE

Task 1. Comprehensive, detailed iterature review
Task 2. Analysis of discounting
Task 3. Battery lifetime model
Task 4. Battery cost model
Task 5. Fuel-cell cost and performance model
Task 6. Analysis of retail cost vs. manufacturing cost
Task 7. Energy use of ICEs
Task 8. Validation of EV energy-use model
Task 9. External costs of air-pollution and climate change
Task 10. External costs of oil use
Task 11. Costs and benefits of V2G in renewable energy system
Task 12. Renewable-hydrogen refueling-station cost
Task 13. Amenity benefits of home recharging
Task 14. Analyses of consumer and social lifetime cost
Task 15. Develop user-friendly model
Task 16. Publish model documentation and peer-reviewed journal articles



PRELIMINARY COST PROPOSAL

The total budget request is shown in the “Preliminary budget with co-funding” table below. Requested CARB funding is shown in the main body of the table, and expected co-funding is shown in a separate column at the right hand side. We expect substantial co-funding from several sources, including ITS discretionary funds, the NextSTEPS program, the University of California ITS Multi-Campus Research Program and Initiative on Sustainable Transportation, and the California Energy Commission. At present we have secured approximately 50% of the expected co-funding. Note that the co-funding does not include the research commitment by Academic Senate faculty.

The next table shows the approximate cost burden by task.

Preliminary budget with co-funding

A. Direct Costs	CARB Funding	Co-funding
1. Labor and Employee Fringe Benefits	**$301,111**	**$158,597**
Researcher		
Mark Delucchi, PI	$235,724	$93,210
Graduate student researchers	$65,388	$65,388
2. Subcontrator(s) / Consultants(s)	$0	$0
3. Equipment	$0	$0
4. Travel & Subsistence	**$4,711**	**$7,711**
Trips to CARB, Sacramento	$211	$211
Domestic conferences and meetings	$4,500	$4,500
International conferences	$0	$3,000
5. Computer programs and related	$0	$0
6. Photocopying & Printing	$150	$150
7. Mail, Telephone, Fax	$30	$30
8. Materials & Supplies	$0	$0
9. Analyses, reports, databases	$0	$0
10. Student tuition and fees	$31,678	$31,678
Total Direct Cost	**$337,680**	**$198,167**
B. Indirect Costs		
1. Overhead		
Total minus tuition and fees	$306,002	$166,489
Overhead rate for state agencies	$30,600	$16,649
TOTAL PROJECT COST	**$368,281**	**$214,816**

Estimated cost by task

Task	CARB	Co-funds
Task 1. Comprehensive, detailed iterature review	$0	$10,741
Task 2. Analysis of discounting	$0	$21,482
Task 3. Battery lifetime model	$0	$21,482
Task 4. Battery cost model	$29,462	$17,185
Task 5. Fuel-cell cost and performance model	$25,780	$21,482
Task 6. Analysis of retail cost vs. manufacturing cost	$14,731	$4,296
Task 7. Energy use of ICEs	$0	$10,741
Task 8. Validation of EV energy-use model	$0	$10,741
Task 9. External costs of air-pollution and climate change	$73,656	$21,482
Task 10. External costs of oil use	$55,242	$10,741
Task 11. Costs and benefits of V2G	$36,828	$10,741
Task 12. Hydrogen refueling station cost	$0	$12,889
Task 13. Amenity benefits of home recharging	$22,097	$8,593
Task 14. Analyses of consumer and social lifetime cost	$36,828	$10,741
Task 15. Develop user-friendly model	$36,828	$10,741
Task 16. Publish model documentation and journal articles	$36,828	$10,741
TOTAL PROJECT COST	**$368,281**	**$214,816**

CARB

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I. PROFESSIONAL EXPERIENCE

Research Scientist

University of California, Davis, Institute of Transportation Studies, 1993- present.

Private consultant

World Bank, Global Environmental Facility, International Energy Agency, Organization for Economic Cooperation and Development, U. S. Department of Energy, Argonne National Laboratory, Oak Ridge National Laboratory, U. S. Environmental Protection Agency, U. S. Department of Transportation, California Air Resources Board, California Energy Commission, and others; 1989-present (see section VIII).

Post-Graduate Researcher

University of California, Davis, Institute of Transportation Studies, 1991-93.
Princeton University, Center for Energy and Environmental Studies, 1990-91.

Research Assistant

University of California, Davis, 1985-88
University of California, Berkeley, 1979-81.

II. EDUCATION

Ph. D., Ecology (emissions of greenhouse gases from transportation fuels and electricity; alternative fuels for transportation), University of California, Davis, 1990.

M. Arch. (planning; energy use in buildings), University of California, Berkeley, 1982 .

B. A. (architecture), University of California, Berkeley, 1979.

Physics and civil engineering major, University of California, Los Angeles, 1976-78.

III. HONORS AND AWARDS

University of California Transportation Center Post-graduate Fellowship, 1991-92.
Transportation Student of the Year, Region IX University Transportation Center (California), 1991.
Chevron Graduate Student Fellowship, 1990.
U. C. Regents Fellowship, 1988-89.
U. C. Regents Fellowship, 1987-88.
U. C. Regents Fellowship, 1986-87.
Twice nominated as outstanding teaching assistant.
National Collegiate Natural Resource Management Award, 1987.
Honorable Mention, National Science Foundation Fellowship Competition, 1986.

PROFESSIONAL SOCIETIES AND ACTIVITIES

Member, Energy Committee of the Transportation Research Board of the National Research Council of the U. S. National Academy of Sciences, 1990 to present

Member, Alternative Fuels Committee of the Transportation Research Board of the National Research Council of the U. S. National Academy of Sciences, 1990 to present

Editorial Board of the *Journal of Transportation and Statistics,* 1998-2002.

Peer reviewer for a wide range of engineering, economic, environmental, and transportation journals

IV. TEACHING EXPERIENCE

Instructor, Transportation Technology and Policy 299, Research, U. C. Davis, Fall 2011
Instructor, Transportation Technology and Policy 290C, Grad Research Conference, U. C. Davis, Fall 2011
Instructor, Transportation Technology and Policy 299, Research, U. C. Davis, Spring 2010
Instructor, Transportation Technology and Policy 290C, Grad Research Conference, U. C. Davis, Spring 2010
Instructor, Transportation Technology and Policy 299, Research, U. C. Davis, Winter 2010
Instructor, Transportation Technology and Policy 290C, Grad Research Conference, U. C. Davis, Winter 2010

Instructor, Transportation Technology and Policy 299, Research, U. C. Davis, Spring 2009
Instructor, Transportation Technology and Policy 290C, Grad Research Conference, U. C. Davis, Spring 2009
Instructor, Transportation Technology and Policy 290C, Grad Research Conference, U. C. Davis, Winter 2009
Instructor, Transportation Technology and Policy 299, Research, U. C. Davis, Fall 2008
Instructor, Transportation Technology and Policy 290C, Grad Research Conference, U. C. Davis, Fall 2008
Instructor, Transportation Technology and Policy 290C, Grad Research Conference, U. C. Davis, Spring 2008
Instructor, Transportation Technology and Policy 290C, Grad Research Conference, U. C. Davis, Winter 2008
Instructor, Transportation Technology and Policy 289A, *Energy and Environmental Modeling,* U. C. Davis, Spring 2007
Instructor, Transportation Technology and Policy 298, *Investigation of a New Town Plan with a Dual Transportation Infrastructure,* U. C. Davis, Spring 2004
Instructor, Transportation Technology and Policy 298, *The Social Cost of Motor-Vehicle Use*, U. C. Davis, Winter 1999
Instructor, Ecology 290, *The Social Cost of Motor-Vehicle Use*, U. C. Davis, Spring 1996.
Teaching Assistant, Environmental Studies 1, *Environmental Analysis*, U. C. Davis, Spring 1988
Teaching Assistant, Environmental Studies 168A, *Methods of Environmental Policy Evaluation*, U. C Davis, 1987
Teaching Assistant, Environmental Studies 10, *Introduction to Environmental Studies*, U. C. Davis, 1985
Teaching Assistant, Environmental Design 1, *Introduction to Environmental Design*, U. C. Berkeley, 1980

V. PUBLICATIONS

A. Journal articles and book chapters

84. M. Z. Jacobson and M. A. Delucchi, “Response to Trainer's Second Commentary on a Plan to Power the World With Wind, Water, and Solar Power,” *Energy Policy*, in press (2012).

83. M. Z. Jacobson, R. W. Howarth, M.. A. Delucchi, S. R. Scobies, I. M. Barth, M. J. Dvorak, M. Klevze, H. Katkhuda, B. Miranda, N. A. Chowdhury, R. Jones, L. Plano, and A. R. Ingraffe, “Examining the Feasibility of Converting New York State’s All-

Purpose Energy Infrastructure to One Using Wind, Water, and Sunlight," submitted to *Energy Policy*, September 12 (2012).

82. M. A. Delucchi, "Beyond Lifecycle Analysis: Developing a Better Tool for Simulating Policy Impacts," submitted to *The Journal of the Washington Academy of Sciences* (2012).

81. M. A. Delucchi and M. Z. Jacobson, "Response to 'A Critique of Jacobson and Delucchi's Proposals for a World Renewable Energy Supply' by Ted Trainer," *Energy Policy* **44**: 482-484 (2012).

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79. R. Plevin, M. A. Delucchi, et al., "Review of Recent Findings of the Climate Effects of Bioenergy," manuscript in preparation (2012).

78. Y. Sun, C.-Y. Lin, M. A. Delucchi, and J. M. Ogden, "The Producer Surplus Associated with Gasoline Fuel Use in the United States," manuscript in preparation (2012).

77. M. O'Hare, M. Delucchi, R. Edwards, U. Fritsche, H. Gibbs, T. Hertel, J. Hill, D. Kammen, D. Laborde, L. Marelli, D. Mulligan, R. Plevin, and W. Tyner, "Comment on 'Indirect Land Use Change for Biofuels: Testing Predictions and Improving Analytical Methodologies' by Kim And Dale: Statistical Reliability and the Definition of The Indirect Land Use Change (ILUC) Issue," *Biomass and Bioenergy* **35**: 4485-4487 (2011).

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75. M. A. Delucchi and M. Z. Jacobson, "Providing All Global Energy Needs with Wind, Water, and Solar Power, Part II: Reliability, System and Transmission Costs, and Policies," *Energy Policy* **39**: 1170-1190 (2011).

74. M. Z. Jacobson and M. A. Delucchi, "Providing All Global Energy Needs with Wind, Water, and Solar Power, Part I: Technologies, Energy Resources, Quantities and Areas of Infrastructure, and Materials," *Energy Policy* **39**: 1154-1169 (2011).

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66. T. E. Lipman and M. A. Delucchi, "Comparing Greenhouse Gas Emissions," Chapter 6 of *Sustainable Transportation Energy Pathways*, ed. by J. Ogden and L. Anderson, Institute of Transportation Studies, University of California, Davis, pp. 133-170 (2011).

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Environmentally Conscious Engineering, edited by M. Kutz, John Wiley and Sons, New Jersey, pp. 57-96 (2008).

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50. M. A. Delucchi, "The Cost of Protecting Oil in the Persian Gulf," *RFF Weekly Policy Commentary*, Resources for the Future, Washington, D. C., November 5 (2007). www.rff.org/Publications/WPC/Pages/11_05_07_Cost_ProtectingOil_PersianGulf_Delucchi.aspx. Published in *Issues of the Day*, ed. by I. W. H. Parry and F. Day, Resources for the Future, Washington, D. C., Chapter 23, pp. 48-49 (2010). www.rff.org/Documents/Publications/1004_Issues_of_the_Day/Issues_of_the_Day_Part_2_Energy_Policies.pdf.

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47. M. A. Delucchi, "Environmental Externalities of Motor Vehicle Use," chapter 23 in *Handbook of Transport and the Environment, Handbooks in Transport Volume 4*, edited by D. Hensher and K. Button, Elsevier Ltd., Oxford, England, pp. 429 – 449 (2003).

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38. M. A. Delucchi, "Transportation and Global Climate," *Journal of Urban Technology* **6** (1): 25-46 (1999).

37. J. J. Murphy, M. A. Delucchi, J. Kim, and D. R. McCubbin, "The Cost of Crop Damage Caused by Ozone Air Pollution from Motor Vehicles," *Journal of Environmental Management* **55:** 273-289 (1999).

36. M. A. Delucchi and S.-L. Hsu, "The External Damage Cost of Noise from Motor Vehicles," *Journal of Transportation and Statistics* **1** (3)**:** 1-24, October (1998).

35. J. J. Murphy and M. A. Delucchi, "A Review of the literature on the Social Cost of Motor-Vehicle Use in the United States," *Journal of Transportation and Statistics* **1** (1): 15-42, January (1998).

34. M. A. Delucchi, "The Social Cost of Motor-Vehicle Use," *The Annals of the American Academy of Political and Social Science* **553**: 130-142 (1997).

33. T. E. Lipman and M. A. Delucchi, "Hydrogen-Fueled Vehicles," *International Journal of Vehicle Design* **17**: 562-589 (1997).

32. M. A. Delucchi, "The Annualized Social Cost of Motor-Vehicle Use in the U. S., Based on 1990-1991 Data: Summary of Theory, Data, Methods, and Results," in

Full Costs and Benefits of Transportation, ed. by D. L. Greene, D. Jones, and M. A. Delucchi, Springer-Verlag, Berlin, Germany, pp. 27-68 (1997).

31. J. DeCicco and M. A. Delucchi, "Introduction and Overview," in *Transportation, Energy, and Environment: How Far Can Technology Take Us?,* ed. by J. DeCicco and M. A. Delucchi, American Council for an Energy-Efficient Economy, Washington, D. C., pp. 1-20 (1997).

30. M. A. Delucchi, "The Annualized Social Cost of Motor Vehicle Use in the U. S., Based on 1990-1991 Data: Summary of Theory, Data, Methods, and Results," in *Social Costs and Sustainability, Valuation and Implementation in the Energy and Transport Sector,* ed. by O. Hohmeyer, R. L. Ottinger and K. Rennings, Springer-Verlag, Berlin, Germany, pp. 380-417 (1996).

29. M. A. Delucchi, "Total Cost of Motor-Vehicle Use," *Access*, Number 8, University of California Transportation Center, Berkeley, pp. 7-13, Spring (1996).

28. M. A. DeLuchi, D. L. Greene, and Q. Wang, "Motor Vehicle Fuel Economy: The Forgotten NMHC Control Strategy?," *Transportation Research-A* **28A**: 223-244 (1994).

27. M. A. DeLuchi, "Emissions from the Production, Storage, and Transport of Crude Oil and Gasoline," *Journal of the Air and Waste Management Association* **43**: 1486-1495 (1993).

26. M. A. DeLuchi and J. M. Ogden, "Solar-Hydrogen Fuel-Cell Vehicles," *Transportation Research-A* **27A**: 255-275 (1993).

25. M. A. DeLuchi, "Greenhouse-Gas Emissions from the Use of Transportation Fuels and Electricity," *Transportation Research-A* **27A**: 187-191 (1993).

24. K. A. Nesbitt, K. S. Kurani, and M. A. DeLuchi, "Home Recharging and the Household Electric Vehicles Market: A Near-Term Constraints Analysis," *Transportation Research Record* **1366**: 11-19 (1993).

23. J. M. Ogden and M. A. DeLuchi, "Solar Hydrogen Transportation Fuels," Chapter 8 of *Transportation and Global Climate Change,* ed. by D. L. Greene and D. J. Santini, American Council for an Energy Efficient Economy, Washington, D. C., pp. 189-241 (1993).

22. M. A. DeLuchi and Q. Wang, "Electric Vehicle Impacts and Economics," Chapter 4 of *Electric Vehicles: Technology, Performance, and Potential*, International Energy Agency/Organization for Economic Cooperation and Development, Paris, France, pp. 139-166 (1993).

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14. M. A. DeLuchi, "Greenhouse Gas Emissions from Alternative Motor Fuels," in *Energy Matters*, Volume 1, Number 2, Transportation Research Board Committee on Energy Conservation and Travel Demand, pp. 3-4, December (1990)

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B. Research reports, technical reports, theses

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Part 1: Overview of AVCEM (M. Delucchi) (19 pp.).
Part 2: Model of Vehicle Cost and Weight (M. Delucchi) (~110 pp.) (in preparation).
Part 3: Model of Vehicle Energy Use (M. Delucchi) (~ 60 pp.)
Part 4: Periodic Ownership and Operating Costs (M. Delucchi) (~95 pp.)
Part 5: References and Parameter list (33 pp.) (M. Delucchi).
Part 6: Modeling Battery and Drivetrain Efficiency (M. Delucchi and M. Miller) (35 pp.).
Part 7: Results from AVCEM (M. Delucchi) (~50 pp.) (in preparation).

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Main report and 13 appendices. Approx. 1175 pp., as follows (page lengths refer to current working documentation, which in some cases differs from published 2003 documentation):

Main Report: A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Material*s* (~ 415 pp.) (M. A. Delucchi).
Appendix A: Energy use and emissions from the lifecycle of diesel-like fuels derived from biomass (20 pp.) (M.A. Delucchi).
Appendix B: Data for other countries (88 pp.) (M. A. Delucchi).
Appendix C: Emissions related to cultivation and fertilizer use (82 pp.) (M. A. Delucchi).
Appendix D: CO2-equivalency factors (124 pp.) (M. A. Delucchi).
Appendix E: Data on methane emissions from natural gas production, oil production, and coal mining (24 pp.) (M. A. Delucchi).
Appendix F: Emissions of nitrous oxide and methane from alternative fuels for motor vehicles and electricity-generating plants in the U. S. (76 pp.) (M. A. Delucchi and T. Lipman).
Appendix G: Parameters calculated with the Advanced Vehicle Cost and Energy Use Model (AVCEM) (8 pp.) (M. A. Delucchi).
Appendix H: The lifecycle of materials and motor vehicles (137 pp.) (M. A. Delucchi, with D. Salon).
Appendix J: Emission factors for heavy-duty diesel vehicles (~ 25 pp.) (in preparation) (M. A. Delucchi).
Appendix K: Input-output data for hydrogen from coal and hydrogen from biomass conversion processes (48 pp.) (G. Wang and M. A. Delucchi).
Appendix X: Pathways diagrams (26 pp.) (G. Wang and M. A. Delucchi).
Appendix Y: Some results from the LEM (~ 50 pp.) (in preparation) (M. A. Delucchi).
Appendix Z: References to the main report (53 pp.) (M. A. Delucchi).

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53. M. A. Delucchi, *Overview of the Lifecycle Emissions Model (LEM)*, UCD-ITS-RR-02-02, Institute of Transportation Studies, University of California, Davis, August (2002).

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51. M. A. Delucchi, *Incorporating the Effect of Price Changes on CO_2-Equivalent Emissions from Alternative-Fuel Lifecycles: Scoping the Issues,* for Oak Ridge National Laboratory, UCD-ITS-RR-05-19, Institute of Transportation Studies, University of California, Davis (2005). Originally published 2002, revised in September 2005.

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49. H. Zhou. D. Sperling, M. Delucchi, and D. Salon, *Transportation in Developing Countries: Greenhouse Gas Scenarios for Shanghai, China*, Pew Center for Global Climate Change, Arlington, Virginia, July (2001).). (Also UCD-ITS-RP-01-14, Institute of Transportation Studies, University of California, Davis.)

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19 to 39. M. A. Delucchi et al., *The Annualized Social Cost of Motor-Vehicle Use, Based on 1990-1991 Data*, UCD-ITS-RR-96-3, Institute of Transportation Studies, University of California, Davis, California, November 1996-October 2005. Approximately 2100 pp. in 21 reports:

Report 1: The Annualized Social Cost of Motor-Vehicle Use in the U.S., 1990-1991: Summary of Theory, Methods, Data, and Results (M. Delucchi).
Report 2: Some Conceptual and Methodological Issues in the Analysis of the Social Cost of Motor-Vehicle Use (M. Delucchi).
Report 3: Review of Some of the Literature on the Social Cost of Motor-Vehicle Use (J. Murphy and M. Delucchi).
Report 4: Personal Nonmonetary Costs of Motor-Vehicle Use (M. Delucchi).

Report 5: Motor-Vehicle Goods and Services Priced in the Private Sector (M. Delucchi).

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Report 8: Monetary Externalities of Motor-Vehicle Use (M. Delucchi) (under revision).

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Report 12: The Cost of Crop Losses Caused by Ozone Air Pollution from Motor Vehicles (J. Kim, J. Murphy, M. Delucchi, and D. McCubbin).

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Report 14: The External Cost of Noise from Motor Vehicles (M. Delucchi and S. Hsu) (with separate 250-page data Appendix).

Report 15: U.S. Military Expenditures to Protect the Use of Persian-Gulf Oil for Motor Vehicles (M. Delucchi and J. Murphy).

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C. Books and edited books

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D. Conference proceedings

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VI. PROFESSIONAL PRESENTATIONS AND OTHER MEDIA EVENTS

VI.1 INTERVIEWS AND OTHER MEDIA EVENTS (maintained starting January 2011)

4. Interviewed for "Post-Carbon Pathways" project, by John Wiseman, www.postcarbonpathways.net.au/2012/08/21/mark-delucchi/, April 25 (2012).

3. Participant in a panel on the future of nuclear power and the potential for renewable energy after the nuclear accident in Japan, "The Insighters," KPFK radio station, March 23 (2011).

2. Live presentation on the global potential for wind, water, and solar power, "The Morning Mix," KPFA radio station, March 23 (2011).

1. Interviewed and videotaped for documentary "Shape Shift: A Documentary about the Transition to Renewable Carbon-Free Energy Worldwide, with a Focus on North America," www.indiegogo.com/Shape-Shift, December (2010).

VI.2 PROFESSIONAL PRESENTATIONS

145. "Full Social Costs of Advanced Future Vehicles and Fuels," *NextSTEPS Fall 2012 Symposium,* Buehler Alumni Center, University of California, Davis, November 30 (2012).

144. "Renewable Intensive Futures," *NextSTEPS Fall 2012 Symposium,* Buehler Alumni Center, University of California, Davis, November 29 (2012).

143. "Transportation in a World Based 100% on Wind, Water, and Solar Power," *Shell Energy Scenarios Meeting,* Institute of Transportation Studies, University of California, Davis, Tuesday, October 30 (2012).

142. "Transportation in a World Based 100% on Wind, Water, and Solar Power," *Energy-Food-Water Dialogue,* UC Davis Conference Center, University of California, Davis, Tuesday, October 30 (2012).

141. "Advanced Vehicle Cost and Energy-Use Model," poster, *NextSTEPS Research Symposium,* Buehler Alumni Center, University of California, Davis, November 7-8 (2011).

140. "A Critique of LCA Models of GHG Emissions from Transportation Fuels," *NextSTEPS Research Symposium,* Buehler Alumni Center, University of California, Davis, November 7 (2011).

139. "Technical and Economic Feasibility of a World based 100% on Wind, Water, and Solar Power," STEPS Seminar Series, Institute of Transportation Studies, University of California, Davis, October 27 (2011).

138. "An Idea for a Sustainable Transportation System and New Town Plan: How We Can Have Safe, Clean, Convenient, Inexpensive, and Pleasant Transportation Without Making People Drive Less or Give Up Suburban Living," presented at UCLA Environmental Science Colloquium Series, Institute of the Environment, University of California, Los Angeles, April 13 (2011).

137. "Lifecycle Analysis of CO_2-Equivalent Greenhouse-Gas Emissions from Biofuels," seminar at Chevron Headquarters, San Ramon, California, April 6 (2011).

136. "Technical and Economic Feasibility of a World based 100% on Wind, Water, and Solar Power," seminar at Chevron Headquarters, San Ramon, California, April 6 (2011).

135. "Technical and Economic Feasibility of a World based 100% on Wind, Water, and Solar Power," *Cal-IRES Forum, UC Davis Energy Week 2011,* Buehler Alumni Center, University of California, Davis, April 4 (2011).

134. "Transportation in a World Based 100% on Wind, Water, and Solar Power," *2011 STEPS / NextSTEPS Symposium: Insights from STEPS & Introduction to NextSTEPS,* Buehler Alumni Center, University of California, Davis, January 19 (2011).

133. "Lifecycle Emissions of Greenhouse Gases and Air Pollutants from Advanced Vehicles," *2011 STEPS / NextSTEPS Symposium: Insights from STEPS & Introduction to NextSTEPS,* Buehler Alumni Center, University of California, Davis, January 18 (2011).

132. "Analyzing Long-Term Sustainable Transportation for the World," *Long Term Renewable Energy Futures – An International Perspective*, University College London, London, England, May 21 (2010).

131. "A Plan for Wind, Water, and Solar Power to Provide 100% of the World's New Energy Production by 2030," *Long Term Renewable Energy Futures – An International Perspective*, University College London, London, England, May 21 (2010).

130. "Air Quality and Greenhouse-Gas Life-Cycle and Social-Cost Analysis of New Propulsion Technologies," Keynote address, *18th international Symposium on Transport and Air Pollution*, Zurich, Switzerland, May 19 (2010).

129. "A Few Things We Know about Global Clean Energy Systems, Focusing on Transportation," *Political Economy Research Institute Conference on Clean-Energy Economics,* Surdna Foundation, New York, New York, March 22 (2010).

128. "Lifecycle Analysis of CO_2-Equivalent Greenhouse-Gas Emissions from Biofuels," *CRC Workshop on Lifecycle Analysis of Biofuels*, Argonne National Laboratory, Argonne, Illinois, October 20 (2009).

127. "A New Town Plan and Transportation System: How We Can Have Safe, Clean, Convenient, Inexpensive, and Pleasant Transportation Without Making People Drive Less or Give Up Suburban Living," presented at the ITS-UC Davis/China Energy and Transportation Collaboration Meeting, Institute of Transportation Studies, University of California, Davis, July (2009).

126. "Lifecycle and Social Lifetime Cost of Advanced Vehicles," *Sustainable Transportation Energy Pathways Annual Meeting*, Institute of Transportation Studies, University of California, Davis, July (2009).

125. “A New Town Plan and Transportation System: How We Can Have Safe, Clean, Convenient, Inexpensive, and Pleasant Transportation Without Making People Drive Less or Give Up Suburban Living,” presented at the U. C. Berkeley Goldman School of Public Policy Seminar Series*,* University of California, Berkeley, October 1 (2008).

124. “Important Issues in Lifecycle Analysis of CO_2-Equivalent Greenhouse-Gas Emissions from Biofuels,” *Measuring and Modeling the Lifecycle GHG Impacts of Transportation Fuels*, University of California, Berkeley, July 1 (2008).

123. “Lifecycle Analysis of GHG Emissions from Biofuels,” 2008 STEPS Symposium and Sponsor Workshop, University of California, Davis, May 14 (2008).

122. “Incorporating Price Effects into Lifecycle Analysis,” *Climate Change Seminar Series*, National Center for Environmental Economics, U. S. Environmental Protection Agency, Washington, D. C., March 5 (2008).

121. “Important Uncertainties in Lifecycle Analysis: Land Use Change, CO_2-Equivalency Factors, and the Nitrogen Cycle,” workshops for the U. S. Environmental Protection Agency, Washington, D. C., March 4 (2008).

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119. “Conceptual Issues in Lifecycle Analysis of Transportation Fuels,” presented at a workshop for the Coordinating Research Council, Las Vegas, Nevada, January 24 (2008).

118. “Lifecycle Analysis of CO_2-Equivalent Greenhouse-Gas Emissions from Biofuels,” *83rd Annual Meeting of the Transportation Research Board*, presentation of Mark Delucchi’s material by Dr. Robert Noland, Washington, D. C., January 15 (2008).

117. “Lifecycle Analysis of Greenhouse-Gas Emissions from Biofuels,” seminar at Chevron Headquarters, San Ramon, California, October 26 (2007).

116. “Lifecycle Analysis of Greenhouse-Gas Emissions from Biofuels,” joint seminar with Quanlu Wang of Argonne National Laboratory, Institute of Transportation Studies, University of California, Davis, July 24 (2007).

115. “Lifecycle Analysis of Greenhouse-Gas Emissions from Biofuels,” presented to California Air Resources Board, Sacramento, California, June 25 (2007).

114. "Lifecycle Analysis of Greenhouse-Gas Emissions from Biofuels," presented to the *Clean Air Task Force's State Climate Collaborative Annual Meeting*, Chicago, Illinois, June 15 (2007).

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112. "Social Cost of Transportation," *Energy Crossroads Workshop*, Stanford University, March 2 (2007).

111. "Lifecycle Analysis of Greenhouse-Gas Emissions from Biofuels," *ITS Seminar Series*, Institute of Transportation Studies, University of California, Davis, February 2 (2007).

110. "Lifecycle Analysis of Greenhouse-Gas Emissions from Biofuels," *Denmark-U. S. Clean-Technology Workshop*, SRI, Menlo Park, California, January 30 (2007).

109. "A Novel Town and Transportation Plan," presentation to the Committee on Sustainable Transportation, *83rd Annual Meeting of the Transportation Research Board*, Washington, D. C., January 24 (2007).

108. "Lifecycle Analysis of Greenhouse-Gas Emissions from Biofuels," *Workshop on the Environmental, Resource, and Trade Implications of Biofuels*, Stanford University, December 5-6 (2006).

107. "Overview of Track 4, Environmental Analysis," *H2P Advisory Board Meeting*, Davis, California, July 24 (2006).

106. "Social Cost and Lifecycle Greenhouse Gas Impacts of Transportation Fuels," *Haagen-Smit Symposium*, Aptos, California, May 8-May 11 (2006).

105. "Lifecycle Emissions Analysis of Fuel Options," *Hydrogen Societal Benefits and Costs Workshop*, University of California, Davis, October 4-5 (2005).

104. "Issues of Methods and Data in Social-Cost Analysis," *Hydrogen Societal Benefits and Costs Workshop*, University of California, Davis, October 4-5 (2005).

103. "Air Pollution Damage Costs for Motor Vehicles; Estimates, Applications, and Perspectives," presented at *Air Pollution as a Climate Forcing: A Second Workshop*, Honolulu, Hawaii, April 4-6 (2005).

102. "Lifecycle Analysis of Emissions of Greenhouse Gases from Transportation," presented at *Air Pollution as a Climate Forcing: A Second Workshop*, Honolulu, Hawaii, April 4-6 (2005).

101. "The Environmental and Social Costs of Transportation," presentation to the Bren School of Environmental Science and Management, University of California, Santa Barbara, April 23 (2004).

100. "A New Town Plan and Transportation System: How We Can Have Safe, Clean, Convenient, Inexpensive, and Pleasant Transportation Without Making People Drive Less or Give Up Suburban Living," presented at the U. C. Berkeley Transportation Seminar Series*,* University of California, Berkeley, January 23 (2004).

99. "Lifecycle Emissions from Alternative Transportation Fuels," presented at *Transforming Transportation: Hitting the Road*, EMBARQ/WRI, Washington, D. C., January 15 (2004).

98. "International Comparison of Lifecycle Emissions from Transportation," presented at Session 265 of the *83rd Annual Meeting of the Transportation Research Board*, Washington, D. C., January 12 (2004).

97. "Estimating the Size of Transportation Externalities," presented at Session 368 of the *83rd Annual Meeting of the Transportation Research Board*, Washington, D. C., January 12 (2004).

96. Tutorial on Lifecycle Emissions Analysis, presented at the World Bank, Mexico City, November 6 (2003).

95. "Lifecycle Environmental Impacts of Alternative Fuels," presented at the U. S./Mexico Conference on LPG in Transportation, Mexico City, November 6 (2003).

94. "Evaluation of Climate Change and Other Impacts of Transportation Projects," presented to the InterAmerican Development Bank, Washington D. C., July 18 (2003).

93. "A New Town Plan and Transportation System: How We Can Have Safe, Clean, Convenient, Inexpensive, and Pleasant Transportation Without Making People Drive Less or Give Up Suburban Living," presented at the *U. C. Merced Conference on Building Sustainable Universities,* University of California Merced, Modesto, California, April 29 (2003).

92. "A New Town Plan and Transportation System: How We Can Have Safe, Clean, Convenient, Inexpensive, and Pleasant Transportation Without Making People Drive

Less or Give Up Suburban Living," lecture in Landscape Architecture Urban Design class, University of California Davis, January 27 (2003).

91. "A New Town Plan and Transportation System: How We Can Have Safe, Clean, Convenient, Inexpensive, and Pleasant Transportation Without Making People Drive Less or Give Up Suburban Living," Institute of Transportation Studies Seminar Series, November 14 (2002).

91. "Social Cost of Transport: Marginal Social-Cost Pricing of Transport Modes, and Cost-Benefit Analysis of Transport Alternatives," presented to the Sacramento Air Quality Collaborative Forum, Alumni Center, California State University Sacramento, September 5 (2002).

90. "A New Town Plan and Transportation System: How We Can Have Safe, Clean, Convenient, Inexpensive, and Pleasant Transportation Without Making People Drive Less or Give Up Suburban Living," lecture in Landscape Architecture Urban Design class, University of California Davis, February 13 (2002).

89. "Social Cost Accounting of Cars versus Transit," presented at the Institute of Transportation Studies Weekly Seminar, University of California, Davis, January 31 (2002).

88. "Recent Well-to-Wheel Studies: Results and Analytical Issues," presented at the Workshop on Fuel-cycle Modeling to Assess Well-to-Wheel Energy and Emissions," 81st Annual Meeting of the Transportation Research Board, Washington, D. C., January 12 (2002).

87. "Lifecycle Analysis and External Costs in Transportation, presented at *Energy Policy and Externalities: the Life-Cycle Analysis Approach*, International Energy Agency, Paris, France, November 15 (2001).

86. "Comparing Full-Cost Accounting of Private Autos and Public Transit: Sorting Out Costs, Benefits, and Subsidies," presented at *Redefining, Reevaluating, and Reinventing Transit*, The Transportation/Land Use/Environmental Connection, Annual Policy and Research Symposium Series, UCLA Conference Center, Lake Arrowhead, California, October 14-16 (2001).

85. "Methodological Issues in Lifecycle Analyses," presented at *Managing Transitions in the Transportation Sector: How Fast and How Far?*, VIIIth Biennial Conference on Transportation, Energy, and Environmental Policy, Asilomar Conference Center, Monterey, California, September 11-14 (2001).

84. “The Social Cost of Transportation Air Pollution,” presented to the Sacramento Air Quality Collaborative Forum, Alumni Center, California State University Sacramento, June 25 (2001).

83. “An Analysis of the Cost and Performance of Battery and Hybrid Electric Vehicles,” presented at the *Zero-Emission Vehicle Conference*, Institute of Transportation Studies, University of California, Davis, May 16 (2001).

82. “An Analysis of the Private and Social Cost of Electric Vehicles,” presented at *Externalities in the Urban Transport: Assessing and Reducing the Impacts,”* San Donato Milanese, Italy, October 27 (2000).

81. “A Summary of the External Costs of Motor-Vehicle Use in the U. S.,” presented at *Externalities in the Urban Transport: Assessing and Reducing the Impacts,”* San Donato Milanese, Italy, October 27 (2000).

80. “Methodological Issues in Lifecycle Analysis,” presented at the *Air and Waste Management Association 93rd Conference and Exhibition*, Salt Lake City, Utah, June 20 (2000).

79. “The Social Cost of Motor-Vehicle Use,” presented at *the Crossroads of European Transport and Environmental Policy*, University of Lisbon, Portugal, May 26-27 (2000).

78. “Greenhouse Gas Impacts of Urban Transport Systems,” presented at UNDP/GEF workshop *Commercialization of Fuel Cell Buses: Potential Roles for the Global Environment Facility*, UN Headquarters, New York, April 27 (2000).

77. “Lifecycle Model of Energy use, Criteria-Pollutant Emissions, and Greenhouse-Gas Emissions for Transportation Fuels and Electricity,” presented at *The 11th Global Warming International Conference & Exposition*, Boston, Massachusetts, April 26 (2000).

76. “Uncertainties in full fuel cycle analysis,” presented at *Ultra-Clean Vehicles: Technology Advances, Relative Marketability and Policy Implications,* University of California, Davis, December 2 (1999).

75. “Cost study of electric vehicles,” presented at *Ultra-Clean Vehicles: Technology Advances, Relative Marketability and Policy Implications,* University of California, Davis, December 1 (1999).

74. “Lifecycle analysis of New and Existing Transportation Technologies,” presented at the *21st Symposium on Biotechnology for Fuels and Chemicals*, Fort Collins, Colorado, May 4 (1999).

73. “Fuel Lifecycle Emissions in Canada and the United States,” presented at the 9th Canadian Hydrogen Conference, Vancouver, British Columbia, Canada, February 7-10 (1999).

72. “Results on the Joint Control of GHG and Criteria Pollutants,” presented at the 78th annual meeting of the Transportation Research Board, Washington, D. C., January 10-14 (1999).

71. “Transportation Fuels, Global Warming Issues, and Recent Analysis Results,” presented at the 78th annual meeting of the Transportation Research Board, Washington, D. C., January 10-14 (1999).

70. “EDV Cost Model,” presented at the 78th annual meeting of the Transportation Research Board, Washington, D. C., January 10-14 (1999).

69. “The Social Cost of Gasoline versus Electric Vehicles,” presented *Externalities in Urban Transport: Assessing and Reducing the Impacts,* Milan, Italy, October 27-29 (1998).

68. “LPG for motor vehicles: a total fuelcycle analysis of emissions of urban air pollutants and greenhouse-gases,” presented at the *11th World LPG Forum*, Rome, Italy, October 21-23 (1998).

67. “The Annualized Social Cost of Motor-Vehicle Use in the U. S.: Estimates and Applications” presented at the *4th International Social Cost and Sustainability Conference*, New York, New York, October 1-3 (1998).

66. “Transportation Contributions to Greenhouse Gas Emissions,” presented at a seminar on the Tehran Transportation Emissions Reduction Project, the World Bank, Washington, D. C., September 15 (1998).

65. “Issues in the Estimation of the Impact of Alternative Fuels of Climate,” presented to the Energy Committee of the Transportation Research Board, at the 77th annual meeting of the Transportation Research Board Washington, D. C., January 11-15 (1998).

64. “The Annualized Cost of Motor-Vehicle Use: Summary of Theory, Methods, Data, and Results,” presented at the 77th annual meeting of the Transportation Research Board, Washington, D. C., January 11-15 (1998). Part of a special TRB session devoted to entirely to my social-cost analysis, items V.D.19 to V.D.39.

63. “The Uses of Social Cost Analysis,” opening address to the conference *Policies for Fostering Sustainable Transportation Technologies,* Asilomar, California, July 17

(1997).

62. “The Annualized Cost of Motor-Vehicle Use: Summary of Theory, Methods, Data, and Results,” presented at the U. C. Davis *Social-Cost Workshop*, Davis, California, May 29 (1997).

61. “The Annualized Cost of Motor-Vehicle Use,” presented at the *Workshop on Urban Passenger Transport and Environmental Statistics*, Washington, D. C., May 14 (1997).

60. “The Annualized Cost of Motor-Vehicle Use,” seminar given at the World Bank, Washington, D. C., May 13 (1997).

59. “The Social Cost of Motor-Vehicle Use: Summary of Results,” presented to the Federal Highway Administration, Washington, D. C. January 17 (1997).

58. “The Social Cost of Motor-Vehicle Use,” public briefing for Congressional staff, Rayburn House Office Building, U. S. Congress, Washington, D. C. January 16 (1997). Follow up private briefing for Congressional staff on May 13, Dickson Senate Office Building, Washington, D. C.

57. “The External Cost of Motor-Vehicle Use: Implications for Alternative Fuels,” presented to the Alternative Fuels Committee of the Transportation Research Board, Washington, D. C. January 15 (1997).

56. “The Social Cost of Motor-Vehicle Air Pollution,” presented to the Air Quality Committee of the Transportation Research Board, Washington, D. C. January 15 (1997).

55. “Preliminary Conceptual Synthesis: Putting the Pieces Together into an Integrated EV Design Energy-Use, Manufacturing Cost, and Lifecycle Cost model,” presented at *Electric Vehicle Cost Analysis: Concepts, Methods, and Data*, University of California, Davis, November 19 (1996).

54. “Emissions of Greenhouse Gases from the Use of Alternative Transportation Fuels,” and “The External Costs of Motor-Vehicle Air Pollution,” two-part presentation at *Technical Seminar on Air Pollution and Urban Transport*, Tehran, Iran, November 3 (1996).

53. “The Social-Cost of Motor-Vehicle Use,” seminar given at the Center for Transportation Analysis, Oak Ridge National Laboratory, Oak Ridge, Tennessee, January 12 (1996).

52. “External Costs of Alternative Fuels,” presented at *Is Technology Enough?*,

Asilomar, California, July 31-August 4 (1995).

51. “Social Overhead Costs,” presented at the *Full Social Costs and Benefits of Transportation*, Beckman Engineering Center, Irvine, California, July 7, 1995.

50. “Critical Issues in the Estimation of the Social Cost,” presented at the *Full Social Costs and Benefits of Transportation*, Beckman Engineering Center, Irvine, California, July 7, 1995.

49. “The Social Cost of Motor-Vehicle Use: Can We Get the Big Numbers Right?,” presented at the Third Externalities Workshop, Ladenburg, Germany, May 27-30, 1995.

48. “Lifecycle Cost of Alternative-Fuel Vehicles,” presented at the Green Fleets Project, Workshop #2, Vancouver, British Columbia, January 31, 1995.

47. “Emissions of Greenhouse Gases from the Use of Alternative-Fuel Vehicles,” presented at the Green Fleets Project, Workshop #2, Vancouver, British Columbia, January 31, 1995.

46. “Original Estimates of the Social Cost of Motor-Vehicle Use,” presented at the 74th Annual Meeting of the Transportation Research Board, Washington, D. C., January 26, 1995.

45. “The Social Cost of Motor-Vehicle Use,” presented to the Federal Highway Administration, Office of Policy Development, Washington, D. C., December 13, 1994.

44. “Uncertainty in Estimates of Emissions of Greenhouse Gases from Alternative-Fuel Vehicles” presented to the “CarTalk” Committee of the Office of the President of the United States, Washington, D. C., November 14, 1994.

43. “The Social Cost of Motor-Vehicle Use,” presented to the Transportation Research Board, Beckman Engineering Center, Irvine, California, October 4, 1994.

42. “The Social Cost of Petroleum and Alternative-Fuel Vehicles,” presented at Argonne National Laboratory, Center for Transportation Research, Argonne, Illinois, May 31, 1994.

41. “The Social Cost of Motor-Vehicle Use, Based on 1990-1991 Data: Preliminary Results,” presented at the meeting of the Alternative Fuels Committee of The Transportation Research Board, 73rd Annual Meeting of the Transportation Research Board, Washington, D. C., January 12, 1994.

40. "Which Fuel: Hydrogen or Methanol?," presented at *Toward a Fuel Cell Future, Planning for the Commercialization of Fuel Cells*, Holiday Inn Capitol Plaza, Sacramento, California, September 2-3, 1993.

39. "Full Social Costs and Benefits of Transportation," presented at *Transportation and Energy: Strategies for a Sustainable Transportation System*, Asilomar, California, August 22-25, 1993.

38. "The Social Cost of Motor-Vehicle Use: Concepts and Methods," invited testimony at the SB1214 Hearing at the California Energy Commission, Sacramento, California, April 22, 1993.

37. "Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity," presented at the International Conference on Global Warming, Portland, Oregon, March 9, 1993.

36. "Why Alternative Transportation Fuels: Global Warming and Air Quality," presented at the Alternative Fuels Conference, Portland, Oregon, March 9 (1993).

35. "The Social Cost of Motor-Vehicle Use in 1990: Preliminary Results," presented at the meeting of the Alternative Fuels Committee of the Transportation Research Board, 72nd Annual Meeting of the Transportation Research Board, Washington, D. C., January 13, 1993.

34. "The Social Cost of Motor-Vehicle Use in 1990: Preliminary Results," Institute of Transportation Studies Noon Seminar, University of California, Davis, November 16, 1992.

33. "Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, and Preliminary Estimates of the Social Costs of Motor Vehicle Use," presented at the meeting of the International Association of Energy Economics, New Orleans, October 25-28, 1992.

32. "Lifecycle Costs of Fuel-Cell Vehicles," presented at the Princeton Fuel Cell Seminar, Princeton, New Jersey, October 21-22, 1992.

31. "The Hydrogen Economy, Lifecycle Costs Of Zero-Emission Vehicles, and Zero-Emission And Low-Emission Vehicles Compared," presentation to the Transportation Group of Lawrence Livermore National Laboratory, September 18, 1992.

30. "Lifecycle Cost of Battery-Powered and Fuel-Cell Powered Vehicles" *Future of the Automobile in an Environmentally Constrained World,* Santa Cruz, California, September 9-11, 1992.

29. "The Energy and Environment Problem: How We Got Here, What It Is, Where We Are Going, and What Is Costing Us," *Future of the Automobile in an Environmentally Constrained World, Santa Cruz, California*, September 9-11, 1992.

28. "Zero-Emission Vehicles: Life-Cycle Costs and Environmental Impacts, And Comparison With Other Alternative-Fuel Vehicles," 25th ISATA Silver Jubilee International Symposium on Automotive Technology and Automation, Conference on Zero Emission Vehicles -- The Electric/Hybrid and Alternative Fuel Challenge, Florence, Italy, June 1-5, 1992.

27. "Comparative Fuel-Cycle Evaluation of Energy Use and Environmental Emissions for EVs and Other Low-Emission Vehicles," International Conference on the Urban Electric Vehicle, Stockholm, Sweden, May 25th-27th, 1992.

26. "Hydrogen Fuel Cell Vehicles: Lifecycle Cost Analysis," seminar, Chevron Corporation, San Francisco, California, December 12, 1991.

25. "Hydrogen and Methanol fuel Cell Vehicles: A Solution to Transportation Greenhouse Gas Emissions?," Energy Division Seminar, Oak Ridge National Laboratory, Oak Ridge, Tennessee, November 25, 1991.

24. "Can Fuel Cells Replace the Internal Combustion Engine?," Center for Energy and Environmental Studies Seminar Series, Princeton University, Princeton, New Jersey, November 19, 1991.

23. Participant, Round Table meeting of the organization *Energy, Technology, and the Environment -- an Agenda for Action for the 21st Century,* McLean, Virginia, October 30-31, 1991.

22. "Emissions of Greenhouse Gases From Linked Trips Involving Buses, Trains, and Cars," *Transportation and Global Climate Change: Long-Run Options*, Asilomar, California, August 25-28, 1991.

21. "Transportation and Greenhouse Gas Emissions," *Transportation and Global Climate Change: Long-Run Options*, Asilomar, California, August 25-28, 1991.

20. "Global Warming Effects of the Motor Vehicle: The Total Fuel/Vehicle Pathway," *1991 SAE Government/Industry Meeting*, Washington, D. C., May 15-17, 1991.

19. "Environmental Impacts of Advanced Transportation Fuels and Technologies, "Global *Pollution Prevention '91*, International Conference and Exposition, Washington, D. C., April 4, 1991.

18. "Hydrogen vs. Other Alternative Fuels for Vehicles," New York City Department of Transportation symposium on hydrogen as a vehicular fuel, New York, March 12, 1991.

17. "Emissions of Greenhouse Gases from Alternative Transportation Fuels: State of Knowledge," meeting of the U. S. Alternative Fuels Council, Denver, Colorado, February 15, 1991.

16. "A Strategy for a Transition to Long-Term Alternative Transportation Fuels," *Automobiles and Their Alternatives: An Agenda for the 1990s*, sponsored by the Conservation Law Foundation and the Energy Foundation, Boston, January 23-25, 1991.

15. "Evaluation of Hydrogen and Other Alternative Transportation Fuels," seminar, Sandia National Laboratory, December 18, 1990.

14. "Technical, Economic, and Environmental Uncertainty in the Evaluation of Methanol, Ethanol, CNG, LNG, Hydrogen, and Battery-powered Vehicles," *Roads to Alternative Fuels*, the second biennial U. C. Davis conference on alternative transportation fuels, Asilomar, California, July 11-13, 1990.

13. "Modeling Emissions of Greenhouse Gases from Fossil and Nonfossil Transportation Fuels," seminar, International Energy Agency and the Environment Directorate of the Organization for Economic Cooperation and Development, Paris, June 8, 1990.

12. "Alternative Transportation Fuels," Center for Energy and Environmental Studies Seminar Series, Princeton University, Princeton, New Jersey, January 11, 1990.

11. Discussant, session on Global Warming and Transportation Energy Use, *68th annual meeting of the Transportation Research Board*, Washington, D. C., January 8, 1990.

10. "Emissions of Greenhouse Gases from the Use of Methanol As a Transportation Fuel," *Methanol as an Alternative Fuel Choice: An Assessment*, conference sponsored by John Hopkins International Energy Program, The American Petroleum Institute, and the World Resources Institute, Washington, D. C., December 4, 1989.

9. "Nuclear-Electrolytic Hydrogen as a Transportation Fuel," *American Nuclear Society's Winter Meeting*, San Francisco, California, November 29, 1989.

8. "Alternative Vehicular Fuels: Effects on Emissions of Regulated Pollutants and Greenhouse Gases," Natural Resources Policy Seminar, University of California at

Davis, November 1, 1989.

7. "Technology, Environmental Impacts, and Costs of Alternative-Fuel Vehicles," *International Workshop on Global Climate Change: Long-Term Energy Scenarios and Policy Options for the Developing World*, Berkeley, California, June 15, 1989.

6. "Natural Gas versus Methanol Vehicles: A Comparison of Resource Supply, Performance, Fuel Storage, Emissions, Cost, Safety, and Transitions," *Society of Automotive Engineers International Fuels and Lubricants Exposition and Meeting*, Portland, Oregon, October 10-13, 1988.

5. "Transportation Fuels and the Greenhouse Effect," Hearing on Climate Change and the Greenhouse Effect, California State Senate Special Committee on Solid and Hazardous Waste, Sacramento, California, September 27, 1988.

4. "Hydrogen Fuel Use," California Air Resources Board public meeting to consider the potential of various alternative fuels for improving air quality, Sacramento, California, September 9, 1988.

3. "Hydrogen and Electric Vehicles," *Transportation Fuels in the 1990s and Beyond*, Monterey, California, July 17-19, 1988.

2. "Air Quality Impacts of Electric, Natural Gas, Methanol, and Hydrogen Vehicles," *Transportation and Air Quality: Common Ground*, summer meeting of Committee A1F03 of the Transportation Research Board, Sacramento, California, June 25-26, 1988.

1. "Transportation Fuels and the Greenhouse Effect," *67th annual meeting of the Transportation Research Board*, Washington, D. C., January 14, 1988.

VII. GRANTS FUNDED THROUGH THE UNIVERSITY OF CALIFORNIA

VII.1 AS PRINCIPAL INVESTIGATOR

28. "Final Development of the Advanced Vehicle Cost and Energy-Use Model (AVCEM), Year 3" proposal to ITS Multi-campus Research Program and Initiative (MRPI) on Sustainable Transportation. Funded for $20,000, January 1, 2012 to December 31, 2012.

27. "Modeling the Climate Impact of Biofuels," proposal to U. C. Davis-Chevron Biofuels Cooperative Research Program, year 4 extension funding. Funded for $144,000, January 1, 2012 to December 31, 2012.

26. "Final Development of the Advanced Vehicle Cost and Energy-Use Model (AVCEM)," proposal to ITS Multi-campus Research Program and Initiative (MRPI) on Sustainable Transportation. Funded for $35,000, January 1, 2011 to December 31, 2012.

25. "Modeling the Climate Impact of Biofuels," proposal to U. C. Davis-Chevron Biofuels Cooperative Research Program. Funded for $540,293, January 1, 2009 to December 31, 2011.

24. "Modeling the Nitrogen Cycle and its Impacts in the Lifecycle Emissions Model," proposal to The David and Lucile Packard Foundation. Funded for $115,128, September 2008 to October 2009.

23. "Lifecycle Analysis of Biofuels, Part 3." Gift from Chevron of $80,000, November 2007.

22. "Using Simulations to Investigate Travel, Lifestyle, and Economic Issues in New Towns Designed with a Dual Transportation Infrastructure," proposal to the University of California, Davis, Sustainable Transportation Center. Funded for $54,818, October 2007 to September 2009.

21. "Implications of Next Generation GHG Policies on Material Flows – A Life Cycle Approach Integrating Engineering, Public Policy, and Market Behavior," proposal to National Science Foundation, sub awarded through Rochester Institute of Technology and UC Berkeley. Funded for $29,302.00, September 2006-August 2008.

20. "Review of White Paper on Land-Use Change Issues in Life-Cycle Analysis of Biofuels." Gift from the Clean Air Task Force, $9,870, March 2007.

19. "Analysis Of Lifecycle Environmental Impacts And Lifetime Social Cost of Plug-in Hybrid Electric Vehicles," proposal to the University of California, Davis, Plug-in Hybrid Electric Vehicle Research Center. Funded for $95,504, January 2007.

18. "Lifecycle Analysis of the California Air Resources Board's Climate Change Reduction Strategies," proposal to the California Air Resources Board. Funded for $199,560, June 2007 to September 2009.

17. "Lifecycle Analysis of Biofuels, Part 2." Gift from Chevron of $60,000, November 2006 to July 2007.

16. "Analysis of Biomass Supply and Conversion, and Lifecycle Analysis of Greenhouse-Gas Emissions from Biofuels" proposal to Nissan Motor Company. Funded for $86,550, November 2006 to April 2007.

15. “Lifecycle Analysis of Biofuels, Part 1.” Gift from Chevron of $40,000, November 2005 to May 2006.

14. “Costs and Environmental Impacts of Biofuels for Vehicles,” proposal to Nissan Motor Company. Funded for $86,256, November 2005 to March 2006.

13. “Lifecycle Analysis of Emissions of Greenhouse Gases from the Use of Alternative Transportation Fuels in Japan, China, the U. S., and Europe,” proposal to Nissan Motor Company. Funded for $73,700, October 2004 to April 2005. (Report V.D.72 and parts of report series V.D.57 to V.D.70.)

12. “Cost and Performance of Hybrid-Electric and Fuel-Cell Vehicles,” proposal to the University of California Energy Institute. Funded for $24,000, July 2002 to June 2003. (Report V.D.56.)

11. “Electric-Vehicle Cost Analysis,” proposal to the California Air Resources Board. Funded for $120,000, July 1995 through April 1997. (Report V.D.46.)

10. “Social-Cost Analysis of Alternative Transportation Systems and Fuels,” proposal to the University of California Transportation Center. Funded for $37,000, August 1995 through July 1997. (Report series V.D.19 to V.D.39.)

9. “Social-Cost Analysis of Alternative Transportation Systems and Fuels,” proposal to the University of California Transportation Center. Funded for $66,000, August 1993 through July 1994. (Report series V.D.19 to V.D.39.)

8. “Social-Cost Analysis of Alternative Transportation Systems and Fuels,” proposal to the University of Energy Research Group. Funded for $17,700, July 1993 through June 1994. (Report series V.D.19 to V.D.39.)

7. “The Social Cost of Transportation: Motor Vehicles (Including Alternative-Fuel Vehicles), Public Transit, Telecommuting, and Bicycling,” proposal to the California Energy Commission. Approved for $250,000, but declined by me.

6. “Social Cost Analysis of Alternative Transportation Systems and Fuels,” proposal to the Energy Foundation. Funded by Pew Charitable Trusts, $89,000, December 1991 through January 1994. (Report series V.D.19 to V.D.39.)

5. “Emissions of Criteria Air Pollutants, Toxic Air Pollutants, and Greenhouse Gases from Linked Trips Involving Automobiles, Buses, and Trains,” proposal to the California Energy Commission. Funded for $25,000, August 1992 to December 1993. (Report V.D.17.)

4. “Social Cost Analysis of Alternative Transportation Systems and Fuels,” proposal to the University of California Transportation Center. Funded for $33,000, August 1992 through July 1993. (Report series V.D.19 to V.D.39.)

3. “Social Cost Analysis of Alternative Transportation Systems and Fuels,” proposal to the University of Energy Research Group. Funded for $17,000, July 1992 through June 1993. (Report series V.D.19 to V.D.39.)

2. “The Social Costs of Alternative Transportation Fuels,” proposal to the Region Nine University Transportation Center, May 1989. Funded for $10,000.

1. “Electric Vehicles in California: Life-Cycle Costs, Emissions, Performance and Effect on Petroleum Dependency,” proposal to the Universitywide Energy Research Group California Energy Studies Program, February 1988. Funded for $17,000.

VII.2 AS CO-PRINCIPAL INVESTIGATOR OR SENIOR RESEARCHER

5. Research on sustainability, water impacts, and lifecycle analysis of transportation fuels, funded by the Energy Foundation and The David and Lucile Packard Foundation, Principal Investigator Sonia Yeh, 2009-2010. Senior Researcher Mark Delucchi budgeted for $24,858.

4. University of California analytical support for the development of the State of California Low Carbon Fuel Standard, funded by the Energy Foundation, The David and Lucile Packard Foundation, and the California Air Resources Board, Principal Investigator Sonia Yeh, 2007-2009. Senior Researcher Mark Delucchi budgeted for $38,249.

3. “Identifying Appropriate System Boundaries and Capturing Land Use Change Effects for Life Cycle Carbon Calculations of Biofuels,” proposal to U. C. Davis-Chevron Biofuels Cooperative Research Program, Principal Investigator Alissa Kendall, funded January 1, 2008 to December 31, 2008. Project Advisor Mark Delucchi budgeted for $9,999.

2. “Sustainable, Environmentally Friendly, and Cost-Effective Production of Biomass for Energy Efficient Biofuels in California,” proposal to U. C. Davis-Chevron Biofuels Cooperative Research Program, Principal Investigator Johan Six, funded March 1 2007 to February 28, 2010. Co-Principal Investigator Mark Delucchi budgeted for $46,135.

1. “An E10 Ethanol-Blend National Policy: Implications for California’s Environment Economy,” proposal to U. C. Davis-Chevron Biofuels Cooperative Research

Program, Principal Investigator Cynthia Lin, funded March 1 2007 to February 28, 2009. Co-Principal Investigator Mark Delucchi budgeted for $15,616.

VIII. PRIVATE CONSULTING

53. Sierra Research, April 2006. Use of the LEM and GHGenius to estimate lifecycle emissions from transportation fuels.

52. Center for Transportation Research, Argonne National Laboratory, June 2005 to December 2005. Analysis of lifecycle emissions from the use of biofuels for transportation. (Part of report series V.D.57 to V.D.70.)

51. International Energy Agency, June 2005. Review of MOVES model and documentation.

50. Northeast States for Coordinated Air Use Management, August 2004 to November 2005. Development of the Social-Cost Calculator (SCC): A Model for Calculating the Social Cost of Changes in Motor-Vehicle Use in the U.S. (Report V.D.73.)

49. U. S. Environmental Protection Agency, October 2004. Review of integration of GREET model with MOVES model.

48. International Energy Agency and World Business Council for Sustainable Development, October 2003 – October 2004. Analysis of lifecycle emissions from transportation systems in 15 countries, Part 2. (Part of report series V.D.57 to V.D.70.)

47. California Energy Commission, August 2003. White paper on conceptual and methodological issues in the lifecycle analyses of transportation fuels. (Report V.D.71.)

46. World Bank/GEF, February 2003. Expert review of GEF project “Project Concept Development: Peru: Public Transport Improvement for Lima”.

45. International Energy Agency and World Business Council for Sustainable Development, September 2002 – February 2003. Analysis of lifecycle emissions from transportation systems in 15 countries. (Part of report series V.D.57 to V.D.70.)

44. Oak Ridge National Laboratory, January 2003 – January 2004. Analysis of greenhouse-gas emissions related to the development of biofuels. (Part of report series V.D.57 to V.D.70.)

43. Energy Foundation, September 2002 – January 2003. Analysis of the lifecycle costs of hybrid electric vehicles. (Report V.D.56.)

42. World Bank/GEF, December 2002. Expert review of GEF project “Project Concept Development: Chile: Sustainable Transport and Air Quality for Santiago”.

41. ICF Inc., June 2002-Novmber 2002. Review of lifecycle analyses of greenhouse-gas (GHG) emissions from transportation, for U. S. EPA’s GHG emissions inventory.

40. U. S. Environmental Protection Agency, September 2002. Review of EPA model of fuelcycle CO_2 emissions from conventional and alternative transportation fuels.

39. California Air Resources Board, March 2002 – October 2002. Review of CARB/CEC response to California Assembly Bill 2076, Strategies to Reduce Petroleum Dependence in California.

38. Sacramento Area Council of Governments, December 2000-June 2004. Analysis of the social cost of Study Alternatives in the 2025 Metropolitan Transportation Plan. (Report V.D.73.)

37. Sacramento Area Council of Governments, June 2001-June 2002. Analysis of the social cost of noise in the 2025 Metropolitan Transportation Plan.

36. World Bank/GEF, February 2002. Expert review of GEF project “Project Brief: Mexico: Introduction of Climate Friendly Transport Policies and Measures in the Mexico City Metropolitan Area (MCMA)”.

35. Ryerson, Master, and Associates, Inc. (for the U. S. Postal Service), July 2001-November 2001. Lifecycle cost analysis of battery-powered electric vehicles for the U. S. Postal Service. (Part of Report Series V.D.74 to V.D.80.)

34. Levelton Engineering Ltd. (for Natural Resources Canada), May 2001-September 2001. Development and update of Lifecycle Emissions Model.

33. Tellus Institute, Inc., July 2001-September 2001. Analysis of emissions from the lifecycle of petroleum used in the South Coast Air Basin.

32. Sierra Research, Inc., July 2000 – December 2001. Manufacturing and lifecycle costs of battery and fuel-cell-powered electric vehicles. (Part of report series V.D.74 to V.D.80.)

31. Oak Ridge National Laboratory, March 2000 - July 2002. Preliminary analysis of methods for expanding lifecycle analyses to incorporate economic effects of price changes.

30. Parsons Brinkerhoff, Inc., March 2000 – May 2000. Review of cost-benefit analysis in "Transit Guidebook" being prepared for FTA.

29. World Bank/GEF, March 2000. Expert review of GEF project "Marikina Bikeways Project" for the city of Marikina in the Philippines.

28. University of California Davis/Pew Charitable Trust, November 1999 - November 2001. Application of fuelcycle energy use and emissions model to the analysis of transportation plans in developing countries.

27. World Bank/GEF , August 1999. Expert Review of UNDP/GEF project "Brazil: Hydrogen Fuel Cell Buses for Urban Transport."

26. Propane Vehicle Council, June 1998 - February 1999. Estimation of emissions of lifecycle emissions of greenhouse gases and criteria pollutants from propane vehicles, propane forklifts, and propane water and space heaters, and comparison with alternatives. (Publications V.D.43 through V.D.45.)

25. Oak Ridge National Laboratory, June 1998 - September 1999. Continued refinement of model of lifecycle energy use and emissions for alternative fuels; development of Canadian version of model; analysis of Kyoto GHG emissions protocol.

24. Oak Ridge National Laboratory, July 1997 - December 1997. Analysis and model of lifecycle emissions and energy use for alternative transportation fuels.

23. U. S. Energy Information Administration, Washington, D. C., March 1996 - December 1997. Revised model of greenhouse-gases from transportation fuels and electricity. (Reports V.D.40 and 41.)

22. World Bank/GEF June 1996 - June 1997. Member of expert panel consulting on ways to reduce emissions from the transportation sector in Tehran, Iran (Tehran Transport Emissions Reduction Project). (Publication V.A.23.)

21. Energy and Environmental Analysis, Inc., Arlington, Virginia, January - February 1996. Estimated greenhouse-gas emissions from the use of transpiration fuels in Australia.

20. Argonne National Laboratory, Washington, D. C., April 1995 - December 1997. Revised model of greenhouse-gases from transportation fuels and electricity. (Reports V.D.40 and 41.)

19. Federal Highway Administration and Battelle Columbus Laboratory, January 1995 - June 1996. Continued work on the analysis of the social-cost of motor-vehicle use. (Report series V.D.19 to V.D.39.)

18. Oak Ridge National Laboratory, November 1995 - February 1996. Contributed to development of the 1996 *Transportation Statistics Annual Report*, by the Bureau of Transportation Statistics.

17. Union of Concerned Scientists, Berkeley, California, May - June 1995. Wrote report on tax subsidies related to oil use. (Incorporated into report series V.D.19. to V.D.39.)

16. Southern California Edison, May 1994 - October 1994. Wrote report on lifecycle costs of battery-powered electric vehicles. (This was developed into Report V.D.18.)

15. U.S. Government Accounting Office, Washington, D. C., August 1994. Reviewed GAO report on electric vehicles.

14. World Bank, April 1994. Member of expert panel consulting on ways to reduce emissions from the transportation sector in Tehran, Iran (Tehran Transport Emissions Reduction Project).

13. U. S. Department of Energy, March 1994. Developed a model of greenhouse-gas emissions from the use of reformulated gasoline.

12. Southern California Edison, March 1994. Critiqued DRI/McGraw-Hill study "Economic Consequences of Adopting California Programs for Alternative Fuels and Vehicles."

11. Oak Ridge National Laboratory, March 1994. Provided greenhouse-gas emission coefficients for section 602 Voluntary Reductions in Emissions of Greenhouse Gases.

10. U. S. Congress, Office of Technology Assessment, October 1993 - March 1994. Wrote a report on the lifecycle costs of conventional, battery, and fuel-cell powered vehicles using renewable fuels. (Contribution to report V.D.16.)

9. U. S. Congress, Office of Technology Assessment, August 1992 - October 1993. Wrote report on the annualized social cost of motor-vehicle use, based on 1990-1991 data. (This report developed into report V.D.18.)

8. World Resources Institute, Washington, D. C., April - September 1991. Analyzed the cost of mortality and morbidity caused by emissions from motor vehicles. (Incorporated into report V.D.19.)

7. Oak Ridge National Laboratory, Oak Ridge, Tennessee, May 1990 - February 1991. Wrote a report on the relationship between fuel economy and hydrocarbon emissions. (Report V.D.13.)

6. R. F. Webb Corporation, Ontario, Canada, October 1990, and February, 1992. Wrote a report on greenhouse gas emissions from LPG, diesel, gasoline, methanol, CNG, and electric vehicles.

5. International Energy Agency, Paris, May - October 1990, and April, 1991. Modeled emissions of greenhouse gases from fossil and nonfossil transportation fuels.

4. Organization for Economic Cooperation and Development, Environment Directorate, Paris, March 1990. Assessed the technology, cost, and environmental impacts of alternative transportation fuels. (Developed into report V.D.15.)

3. Environmental Protection Agency, Raleigh, North Carolina, December 6-8, 1989. Member of panel of experts that reviewed the Agency's draft report *Alternative Fuels Research Strategy*.

2. Argonne National Laboratory, Argonne, Illinois, 1989 and 1993. Developed a model of emissions of greenhouse gases from alternative transportation fuels. (Reports V.D.11 and V.D.12.)

1. California Energy Commission, Sacramento, California, September - December 1987. Wrote a report on alternative transportation fuels (report V.D.3).