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Sponsoring Agency: California Air Resources Board
Project Title: A Comprehensive Total Cost of Ownership Model for EV/PHEV Based Clean Vehicles Across the Full Product Lifecycle Including Battery Manufacturing, Vehicle Use, Second Life Battery Utilization, and End of Life Material Recovery

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PROPOSAL: ADVANCED CLEAN CARS TOPIC

A Comprehensive Total Cost of Ownership Model for EV/PHEV Based Clean Vehicles Across the Full Product Lifecycle Including Battery Manufacturing, Vehicle Use, Second Life Battery Utilization, and End of Life Material Recovery

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January 31, 2013

Check if applicable:

Animal subjects _______ Human subjects _______

Contents

1. Abstract

In this work, we propose to build on ongoing efforts at UC Berkeley and the Lawrence Berkeley National Laboratory to develop a comprehensive total cost of ownership assessment of plug-in electric vehicle (PEV) operation focused on the state of California. The model developed for the project will include vehicle costs, policy incentives such as PEV-specific charging tariffs, operating costs, grid integration benefits (e.g., demand response, spinning reserve, regulation, etc), secondary life battery valuation, end of life battery dispositioning and material recovery, and quantification of climate and air quality impact and benefits across the product life cycle. This integrated PEV assessment model -- covering both battery EVs and plug-in hybrid EVs -- would provide a valuable tool to policy makers who are assessing the relative merit of various policy options and/or regulatory frameworks. Obtaining a better understanding of the full costs of operation of various state-of-the-art vehicle types is of major importance for key policy and planning objectives,

Along with cost reductions from technological improvements and volume manufacturing, benefits from grid integration are often cited as providing an untapped value to PEV customers via grid storage and services to help improve the economic attractiveness of PEV ownership. While this is certainly feasible and pilots are underway in several locations collecting data and testing communications and control protocols, existing battery degradation models contain simplifications in the rate and modeling of battery degradation and thus leave potentially large error margins in determining the value of battery second life. In concert with the integrated total cost of ownership modeling above we also propose to develop an improved model for battery degradation along with integration of driving-cycle modeling and vehicle to grid (V2G) service operational cycles to provide a better estimate of battery lifetimes and thus more accurate overall costs and benefit estimates for grid services and secondary uses of PEV batteries

The work plan is split into four primary parts and is described in detail in the Technical Plan Section below.

- Drive train and Battery requirements and Manufacturing Cost Model: Key outputs will be system parameters and other supporting components for "small" and "large" PEV designs including both battery and plug-in hybrid vehicles. Since the battery is the critical cost piece, the cost model will focus heavily on Li-Ion based battery manufacturing costs.
- Battery Degradation Model: This will integrate vehicle powertrain and grid services cycling into existing battery degradation models being developed at LBNL and will be discussed more in the Introduction and in Task 3 in the Technical Plan below.
- Life-Cycle Cost Assessment: This will include vehicle operating costs, V2G interaction (demand shifting and additional grid ancillary services), secondary uses for the battery as grid storage, and the development of an improved battery degradation model.
- Ancillary Benefits and EOL: The final part of the TCO model will include end of life (EOL) recycling and material recovery and additional ancillary benefits associated with the PEV value proposition (incentives, credits for displaced carbon, and health and environmental impacts).

The team will perform scenario analysis based on different market adoption scenarios and sensitivity analysis for the integrated TCO impacts of various policy options and to price assumptions for fuel and electricity. A task flow for the proposed work is shown in Figure 1.

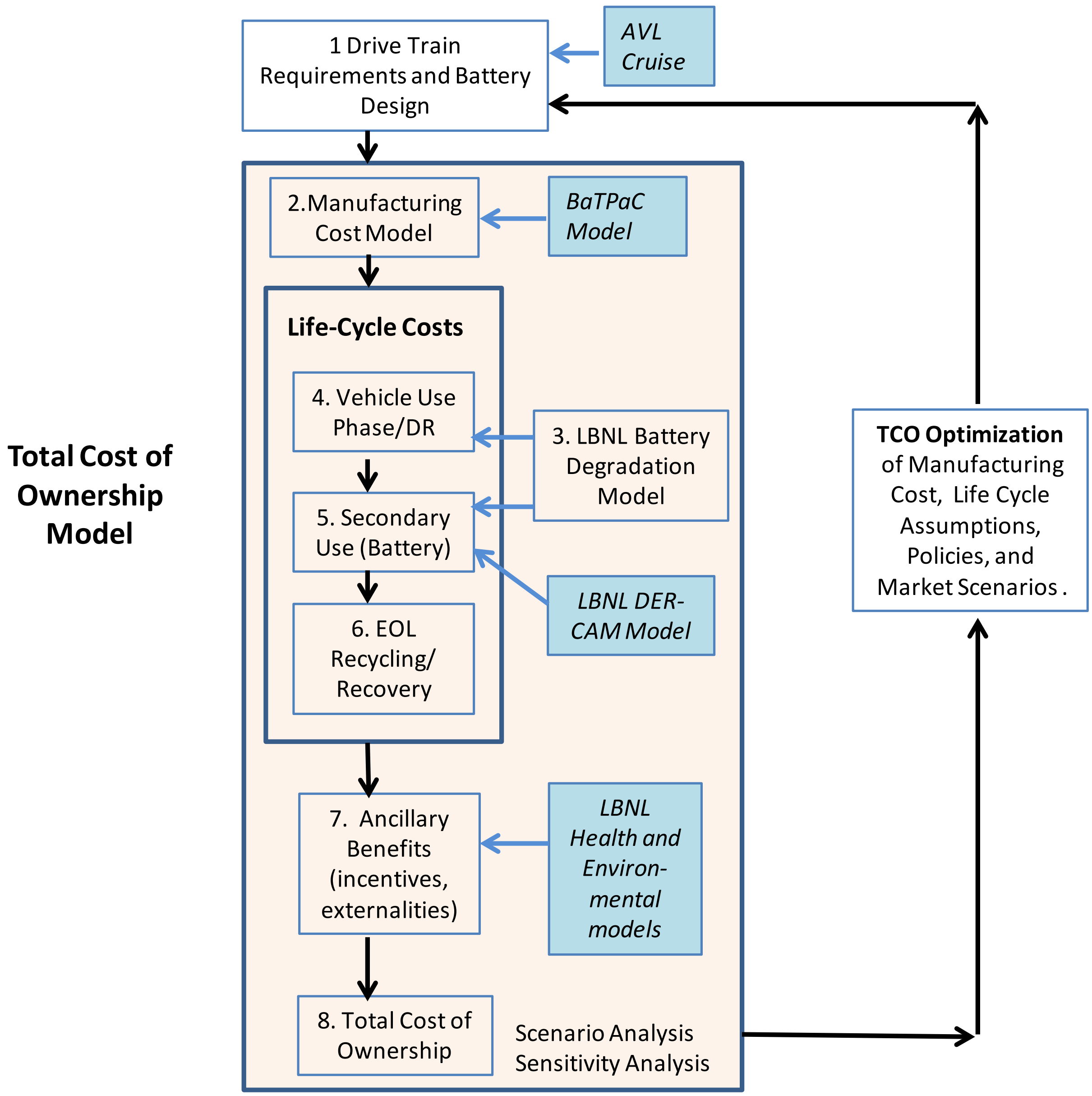

Figure 1. Total Cost of Ownership task flow. The TCO model will consist of manufacturing costs, use-cycle costs including vehicle use, secondary use of battery and ancillary benefits such as carbon credits and criteria pollutant reduction. Existing models shown in blue will be utilized for the TCO model.

2. Introduction

Accounting for approximately 33% of U.S. national and 40% of California's GHG emissions, the transportation sector remains a critical one for both medium and long-term carbon reduction targets for the state (CCST 2011, Wei 2012a). Even under "best case" scenarios of aggressive energy efficiency, clean electricity, partial vehicle, building and process heating electrification, and partial replacement of petroleum based liquid fuels with low carbon biofuels, the transportation sector is projected to account for a greater fraction of emissions in 2050 than today's 38% fraction (Wei 2012a). Reducing reliance on petroleum-based fossil fuel is thus an increasing challenge especially if the state population continues to grow in inland areas as projected and if overall vehicle miles travelled continue to grow.

Governor Edmund G. Brown II has developed an aggressive zero-emission vehicle action plan detailed a roadmap to 1.5 million zero emission and low emissions vehicles in California by 2025 and the State has developed a package of regulations in support of this initiative (ARB 2012). To achieve these goals requires a consistent policy message to consumers, vehicle producers and related businesses.

Recent aggressive plans to increase the market share of plug-in electric vehicles (PEVs) at the state and federal levels place stringent requirements on PEV batteries. Batteries must be safe to operate, have high energy density, recharge quickly, avoid prohibitively high upfront costs, and ideally be reused and recycled in a safe, sustainable, and cost-effective manner (Brown 2012a, Brown 2012b, CEC 2011, DOE 2012a, DOE 2012b).

Limited vehicle driving ranges (related to battery energy density), slow recharge times, and high battery first cost are currently the primary barriers to increased market penetration of plug-in electric vehicles (Giffi 2011, Tran 2012, EIA2012). These issues have led to a national effort to lower the cost and increase the capacity of electric batteries. For example, Energy Secretary Steven Chu recently announced a "Manhattan Project" style initiative that includes Lawrence Berkeley National Laboratory (LBNL) as a leading partner in an effort to reduce the cost of batteries five-fold, and increase the energy density of batteries five-fold in five years (DOE 2012a). Affordable, reliable, safe, and long-lived batteries are a key technology linchpin to enable market penetration of electrified vehicles, and are thus a key focus area for this work.

Total cost of ownership: a critical perspective

Total cost of ownership (TCO) can be defined as the total costs associated with a technology's purchase, installation, operation, maintenance, and disposal. For complex energy supply technologies like PEVs, however, TCO analysis provides an enhanced framework for design and manufacturing optimization because battery operations and in particular non-vehicle applications can have a significant impact on operational costs, battery degradation, and second life valuation. A rigorous TCO—the approach proposed in this project—also includes possible ancillary financial benefits that can lower the effective TCO of a given technology. Examples of potential ancillary benefits for the PEVs considered in this project include: (1) grid support benefits in the form of demand response (DR) battery secondary-use concepts; (2) possible "green energy" rebates from utilities and governments, which may be offered if a given technology has a lower life-cycle environmental or GHG emissions "footprint" than standard technologies and/or if it's use will reduce societal health impacts and costs through avoided emissions; (3) end of life resale or recycling revenues; and (4) avoidance of other capital cost or infrastructure investments e.g., large enough aggregation of electric vehicle batteries could reduce the investment requirements for grid storage capacity under higher fractions of intermittent renewable generation. Examination of both direct manufactured cost and TCO is employed in this project to allow for optimization or reduction of both factors in the context of multiple battery usage applications.

Current TCO studies for PEVs are of limited scope, typically including some portion of the following: vehicle cost characterization, operating costs such as maintenance and electricity charges, grid services such as peak demand shifting, frequency regulation, and spinning reserves, and estimated valuation after vehicle use-life of battery secondary usage. For example, some models include estimates of V2G valuation from spinning and non-spinning reserves (Sioshansi 2010) and/or frequency regulation service (Dallinger 2010). There are existing manufacturing cost model for batteries (Nelson 2009) and operating cost studies (Lidicker 2010).

Wide scale adoption of clean vehicles in California would also provide health and environmental benefits that are sometimes estimated in these analyses but not necessarily for California and not with geospatial resolution (Delucchi 2001). It is thus challenging for policy makers to assess the total cost of PEV ownership" for the state since the various studies utilize different vehicle design assumptions, different policy regimes for electricity or grid service markets, different operating conditions (climates, etc.).

We propose a TCO analysis approach that brings together University of California, Berkeley experts on PEVs, technology manufacturing, and transportation sustainability with Lawrence Berkeley National Laboratory researchers in battery technology, grid integration, and life cycle impact assessment and industry advisors.

The TCO modeling framework provides insight into critical questions that can inform the state as it sets forth to meet its transportation targets, and sets the stage for further extension and study. Key points include that:

- the TCO model provides a more comprehensive picture of the overall cost impacts and benefits of clean cars;
- the TCO model informs policy sensitivity: the impact of DR incentives, financing incentives e.g. tax deductions, rate structure, carbon pricing, some incentive based on health and environmental externalities;
- the framework allows direct comparison between power train technologies provides insight on cost trajectories and total integrated costs -- this would set the stage to include other power train technologies such as FCV/battery vehicles running on hydrogen or plug-in hydrogen + battery vehicles;
- the ancillary impacts aspect of the TCO model will include geospatial analysis that can address social equity issues as "all emissions in urban areas are expected to improve because of the shifting of the emission sources from millions of individual vehicles in population centers" (Kintner-Meyer2007) to cleaner distributed or renewable electricity generation; and
- furthermore, modeling of spatial and temporal market adoption of PEV sets the stage for more detailed spatial/temporal modeling of the electricity grid as a possible extension of this project work.

The assessment of grid services in the TCO framework will consider the following two cases:

1. Consideration of DR in the form of demand shifting and peak load shaving (no discharging to grid) during vehicle use phase.
2. Consideration of second life battery storage for grid or residential/PV service.

A third case, that of grid services in the form of frequency regulation or storage arbitrage in the form charging and discharging to the grid during the vehicle use phase will not be considered in detail due to less predictability, potentially greater advance commitment requirements, and the as yet un-quantified risk to battery lifetime and performance, but is a potentially important case for more detailed work in the future.

The proposed work would meet several of the issues for investigation laid out in the Advanced Clean Cars topic as shown in Table 1 below and would build upon work that several members of the research team have done in PEV modeling, fuel cell system TCO analysis, battery technology and degradation, and distributed generation resource optimization.

Battery Degradation Modeling

Extensive literature review of lithium-ion battery aging studies shows that the majority of prior research has been performed in highly controlled laboratory environments. In real world applications, vehicle batteries are exposed to highly transient charging rates, state-of-charge swings, and interchanged combinations of battery use and idling, all over a wide range of operating temperatures. The models developed under controlled conditions will be used to study battery degradation in real world conditions. Despite the pressing need for understanding battery degradation in these real world conditions, literature review has shown only one group has conducted limited studies under these real-world conditions (Peterson 2010a, Peterson 2010b, Peterson 2012). These studies only captured cycling-induced aging under a very constrained temperature range and using highly simplified vehicle physics models. Moreover, existing studies do not capture degradation from battery aging (in an idle condition). Thus, there is still a pressing need to understand battery degradation in real world conditions through the proposed method of coupling detailed vehicle powertrain models with battery degradation models.

Advisory Board

For this work, an Industry Advisory board for expert consultation will be drawn from among Ford, GM, Daimler, Toyota, Tesla, and major battery companies, as members of the research team have high level contacts at these companies.. Other advisors include the Bay Area Climate Collaborative (Rafael Reyes, Executive Director), the California PEV Collaborative, and EV-related companies in the newly formed Cal Charge Consortium (Doug Davenport, LBNL, lead contact).

Other LBNL Resources

For PEV-grid interactions, the Demand Response Research Center (DRRC) at LBNL is an excellent resource for providing technical assistance in understanding historical values for all services, AS/CAISO market structure, coordination and planning issues, as well as technical barriers in both policy and technology. The Consortium for Electric Reliability Technology Solutions (CERTS) at LBNL will also be available for consultation regarding grid reliability issues and renewable integration requirements. In addition, the DRRC, Battery Technology, CERTs, and Micro-grid groups at LBNL are pursuing a major research initiative in grid integration and thus the team should be well positioned to leverage ongoing and future related research activities in this area.

Item from ARB Call for Proposals in Clean Cars	Plan	Relevance	Ongoing related work at UC-Berkeley or LBNL
1. Impacts on vehicle manufacturing	The work will track manufacturing cost trends and pathways.	Vehicle cost reduction potential over time with higher manufacturing volumes and more advanced process integration such as automated webline processing.	(+) LBNL/UCB Fuel Cell Total Cost of Ownership Project: Design for Manufacturing and Assembly work (Lipman, Wei, McKone, Scown)
2. Valuation of co-benefits	The team will consider the following co-benefits and ancillary financial benefits: carbon credits, health & environmentally significant criteria pollutants	Provide quantification of co-benefits under various market adoption scenarios.	(+) This is the focus of LBNL Sustainable Systems Group is Life Cycle Impact Assessment of Emerging technologies (Scown, McKone, Wei)
3. Advances in vehicle technology	Specific focus on manufacturing cost reduction pathways and quantification in Li-Ion batteries will be pursued.	Project battery cost reduction expectation from advanced battery technology improvements over next 10-15 years.	(+) World renowned battery expertise at LBNL. Vince Battaglia of Battery Group will be part of the technical team.
4. New car market trends	Adopt county-based vehicle adoption scenarios adopted from LBNL vehicle modeling for biofuel production	Estimate spatially resolved health and environmental impacts and valuation as function of market adoption scenario.	(+) LBNL work in geospatial national vehicle adoption modeling Biofuel production modeling (Scown, McKone)
5. Affordability of new vehicles	Analysis of the affordability/1st cost reduction with innovative financing approaches and leasing models as in photovoltaics (PV) and energy efficiency (EE) retrofits; Study of charging cost reduction policies.	Quantify policies in innovative financing that can reduce first costs of EV/HEV or charging costs	(+) LBNL Energy Analysis and Impact Assessment Department is a national leader in policy and impact assessment of innovative clean energy financing policies in EE and PV.
6. Other – Grid services impact quantification	Develop battery degradation model together with grid services cycles and drive cycle modeling	Provide better quantification of 2nd use battery valuation	(+) LBNL Microgrid Group, Battery Technology Group, and Demand Response Research Center is actively pursuing V-G pilots (LA Air Force Base) and collection of battery storage cycling data.

Table 1. Relevance of proposed work items to ARB Clean Cars proposal request.

3. Objectives

The total cost of ownership modeling provides a comprehensive modeling framework for achieving the following objectives:

- Estimation of total cost of ownership (TCO) for clean vehicles and extension of the TCO analysis to include other monetized benefits:
  - carbon credits
  - valuation of DR benefits during vehicle use and second-life use of batteries
  - health benefits from reduced criteria pollutant emissions

- Determination of vehicle design/manufacturing conditions to reduce or minimize TCO:
  - Drive-train and vehicle design assumptions
  - Manufacturing cost scenarios (volume, battery cost and performance)

- Identification of other important factors and opportunities for TCO reduction through exercise of the model across a range of scenarios and through sensitivity analysis. Scenario analysis will consider different fuel and electricity prices, various market adoption scenarios, a range of cost assumptions, and various policy assumptions.

The value thus gained by ARB is a better understanding of the overall value proposition of zero emission electric and plug in–hybrid vehicles through inclusions of co-benefits and externalities, valuation estimation of secondary life usage of electric batteries and/or battery material recycling or material recovery. This will provide insight to CARB for the evolution of projected manufacturing costs for EV/PHEV vehicles. The proposed work will provide quantitative guidance for policy impacts, particularly for the 2018 and beyond model years as well as providing guidance and context for which policies have the greatest impact to TCO.

Furthermore, the project will also provide a staging ground for future important follow up studies and interactions:

- Improved battery degradation modeling could lead to better vehicle control strategies or battery configurations that could improve overall EV efficiency.
- Spatially resolved scenarios of HEV market adoption could lead to studies on the impact of highly localized HEV market penetration on local load balancing areas.
- The development of seconadary-use battery valuation models in various building/grid configurations could lead to greater interest in the requirements and potential for battery asset management business models.
- The work will provide insight into the role and importance for standardization in battery configurations and testing.
- The work on EOL recycling and reuse valuation can be a starting point for developing new recycling and material recovery strategies and processes.
- The work could be extended to include Fuel-cell vehicles and plug-in FCV-hybrid vehicles.

4. Technical plan

Task 1 - Drive train Requirements and Battery Design (Q1-Q2, UCB[1])

The goal of this task is to characterize the drive train requirements for two PEV body types and two different design strategies, conventional and lightweight body-in-white. The approximately power ratings (to be refined during this project task) are 75/100kW (sedan) and 125/150kW (SUV) using lightweight aluminum composite (or high strength steel) compared with conventional steel construction. The body and drivetrains selected are proxies for compact/mid-size passenger vehicles and the SUV/minivan market, collectively comprising the majority of vehicles sold in the California market.

Total Drivetrain Power Rating (approx.)	**EV**		**PHEV**	
	Battery (Li-ion)	BIW and Interior	Battery (Li-ion)	BIW and Interior
Mid-size sedan				
75 kW	B1 (25 kW)	Lightweight	B5 (75 kW)	Lightweight
100 kW	B2 (33 kW)	Conventional	B6 (100 kW)	Conventional
SUV/Minivan				
120 kW	B3 (40 kW)	Lightweight	B7 (120 kW)	Lightweight
140 kW	B4 (47 kW)	Conventional	B8 (140 kW)	Conventional

Table 2. Four drivetrain levels and body types are proposed for cost analysis for EV and PHEV (with eight battery designs considered with varying W/kg and Wh/kg)

The team will consult with battery technologists at LBNL and with the industry advisory group for inputs on battery design and configurations specifically for the Li-ion based system. From a candidate list of technologies shown in Table 3, the team will down select 2- 3 lithium-ion based chemistries based on tradeoffs in power, energy and other performance attributes relative to the drivetrain requirements above.

Vehicle modeling of drivetrain and "rest of plant" will utilize AVL Cruise software, to be licensed for use in the project under the AVL AST University Partnership Program. This program makes the full suite of AVL software products available to university-base research teams, including AVL Boost, AVL Cruise, AVL Excite and AVL Fire, where AVL Cruise as the drivetrain simulation package is of most direct use for this project. Key outputs will be a set of drive train and vehicle component requirements and battery designs for each of the eight design cases. In conjunction with examining the eight vehicle and battery designs, vehicle light-weighting strategies will mainly focus on body-in-white and key interior components.

[1] All quarters are referenced to the start of project, Task Lead is indicated by either UCB or LBNL.

Cell chemistry	Positive electrode active	Negative electrode	Examples	Capacity	Battery life	C-rate	Safety	Cost	Specific properties / characteristics
NCA/C	Nickel, Cobalt and Aluminium oxide(NiCoAl)	Graphite	• Panasonic 18650 in Tesla Model-S • JCS in Ford Transic Connect Electric	++	=	=	=	+	• Operates at lower voltage than Co/C, which results in improved safety
LMO/C	Lithiated manganese oxide ($LiMn_2O_4$)	Graphite	•LG Chem in GM Chevy Volt and Ford Focus Electric •AESC in Nissan Leaf • SB LiMotive BMW Cooper Mini-e and Fiat 500EV • EnerDel in Th!nk City	+	-	=	+	+	• Poor aging properties due to high solubility of manganese • Lower cost •Ex: GP Batteries GP1850M80
LFP/C	Lithiated iron phosphate ($LiFePO_4$)	Graphite	• BYD in BYD F3DM/F6DM • EIG in FEV Caliber ReEV • A123 in Fisker Karma • Valence in Smith EV Edison Panel Van • LG Chem in Hyundai Sonota	+	=	+	+	=	• Very little energy released when overcharged (because phosphate bonds are much stronger than oxide ones)
NCM/C	Nickel cobalt manganese ($Li(NiCoMn)O_2$)	Graphite	•Dow Kokam	+	-	=	+	+	
LCO/LTO	Lithiated cobalt oxide ($LiCoO_2$)	Titanate	• Toshiba SCiB in Mitsubishi Minicab MiEV	=	+	++	+	-	• No SEI (Solid Electrolye Interface), and thus no overheating problems and faster charging
LMO/LTO	Lithiated manganese oxide ($LiMn_2O_4$)	Titanate	• EnerDel	=	+	++	++	-	• No SEI, and thus no overheating problems and faster charging • Operates at lower voltage than Co/C, which results in improved safety
LFP/LTO	Lithiated iron phosphate ($LiFePO_4$)	Titanate	• Altairnano LTO batteries	--	++	++	++	--	• No SEI, and thus no overheating problems and faster charging • Very little energy released when overcharged (because phosphate bonds are much stronger than oxide ones)

Table 3. Comparative table of some of the most common Li-ion battery chemistries. (Source: R. Habfast, B. Williams, **T. Lipman** of the University of California, Berkeley, Transportation Sustainability Research Center, 2011).

Task 2 - Manufacturing Cost Model (Q2-Q4, UCB)

The goal here is the development of a manufacturing cost model covering the vehicle types in Table 2. Existing battery cost models e.g. BaTPac from Argonne National Lab and other vehicle cost models will be utilized and enhanced based on analysis and consideration of advanced manufacturing processes and process integration.

The primary focus will be on Li-ion battery manufacturing cost reduction since that is the critical component that limits PHV cost and range. The team will investigate and quantify cost reduction potential from advanced manufacturing. An example of this analysis is the consideration of fully automated, large-scale "web-line" or roll-to- roll manufacturing with real-time process control. The team will utilize its extensive knowledge and process costing information gained from the LBNL Fuel Cell Total Cost of Ownership project (Wei 2012b), where anode and cathode deposition processes are similar for batteries and fuel cells.

Inputs on latest battery manufacturing trends, vendors, and technology development opportunities will be elicited from battery experts at LBNL and the industry advisory group. A patent search will also be conducted for manufacturing processes and assembly processes. Cost modeling for non-battery subsystems including electric motors, motor controllers, heating/cooling, and other auxiliary systems will utilize previous research by TSRC, additional literature resources, and industry feedback. Research staff at UC-Berkeley TSRC also has extensive experience in body-in-white material and costing analysis (Mayyas 2012).

The TCO model will be implemented in Analytica, a software tool that is designed for decision, uncertainty, and sensitivity analysis and offers a free publicly available player (input interface). The Task 1 deliverable will be a manufacturing cost model based on the battery and vehicle requirements specified in Task 1.

Task 3 - Battery Degradation Model (Q2-Q4, LBNL)

Background

Powertrain models are a collection of sub-models for components (i.e. engine, motors, batteries, power converters, vehicle dynamics, etc.), with overarching models for vehicle control strategies and driver demand. Existing powertrain-modeling tools (e.g. AVL Cruise supplemented with examination of Autonomie from Argonne National Lab) will be used as a key baseline to establish vehicle designs. These provide models of several hybrid, plug-in hybrid and electric vehicle configurations. The battery models will be modified to include degradation models and the vehicle power electronics system will be modified to simulate vehicle charging and discharging to interface with grid models.

Interfacing powertrain models with battery degradation models

Two different types of battery aging must be captured within the vehicle models: 1) aging during cycling, and 2) calendar aging during idling and battery storage. For this, test data and knowledge of chemical kinetic and physical processes are used to develop semi-empirical models of capacity fade.

The goal in this task is the development of an integrated modeling tool which combines detailed models of electrified vehicle powertrain operation, electricity grid and microgrid integration models. Efforts will also be made to incorporate temperature dependencies appropriate for California climates.

For this work a cycling aging model developed by Wang et. al. 2011 will be integrated within the powertrain models to capture the cycling portion of capacity fade aging. Similarly a representative model (Sankarasubramanian 2012) of capacity fade from calendar aging will be integrated with the vehicle powertrain models to capture the idling portion of aging.

Battery cycling data from grid services will be available from two existing projects co-led by research team member Michael Stadler of LBNL will be used to mimic battery-grid interactions.

(1) Los Angeles Air Force Base V-G and Building Storage pilot for grid services (DR and ancillary services) collected from the pilot fleet of 40 vehicles; (2) 2nd use battery modeling duty cycling in a residential or commercial building microgrid.

The LBNL battery group is a strong technical resource for battery performance characterization and degradation modeling and the micro-grid group (M. Stadler) will provide data and modeling support for duty cycle usage for battery 2nd use in residential PV + battery systems. Output for this task will be a refined battery degradation model including the cycling inputs described above.

Task 4 - Life cycle cost model - Vehicle Use phase and Grid interaction (Q3-Q5, LBNL)

This task will include literature review of vehicle use phase costs and modeling of electricity charges as a function of charging time and tariffs. We will utilize existing work (Lidicker 2010) on fuel and electricity costs, supplemented by latest information on PEV time-of-use rates offered by utilities. Vehicle driving behavior patterns will be derived from National Household Transportation Survey (NHTS) data and other sources. Maintenance costs will be approximated from data available to date in literature and reported data.

Battery-Grid Interactions

Significant value exists in providing grid ancillary services in California, including frequency regulation, spinning reserve, and fast-ramping capabilities. However, the overall market for regulation and spinning reserves in the California ISO is estimated to be only 0.7% and 2% of the overall electricity market, respectively and is thus rather modest in size, with total ancillary service costs of $139 million in 2011 (CAISO 2012). Market size and price trend data for frequency regulation and spinning reserves has been analyzed in a recent LBNL paper (Table 4 and Figure 2). However, this must be balanced against changes in FERC and CAISO regulations that can improve the business case for fast, accurate services – such as aggregated battery storage - that can provide ancillary services, like demand response (MacDonald 2012). There is also the prospect for greater demand for ancillary services (AS) from higher intermittent generation penetration from increasingly stringent RPS standards beyond the 33% target in 2020.

[M$/yr]		CAISO-S	CAISO-N	ERCOT	MISO	PJM
Regulation	2009	NA	NA	105	NA	160
	2010	12	12	118	43	126
	2011	18	12	152	38	123
Spinning Reserve	2009	NA	NA	119	NA	24
	2010	11	14	122	33	32
	2011	19	18	462	23	51

Table 4: Annual market size (M$/yr) of US ISO/RTO Regulation and Spinning Reserve Markets. Darker cell shades indicate real-time markets, lighter are day-ahead markets. (MacDonald 2012).

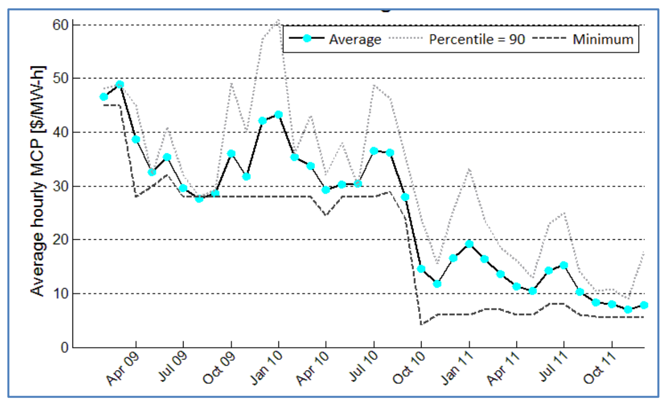

Figure 1: Monthly Market Clearing Price (MCP) statistics for NYISO regulation. (MacDonald 2012).

Participation in ancillary services markets such as frequency regulation and spinning reserves is limited by regulations, telemetry requirements, aggregation requirements and minimum bid sizes (typically 1MW minimum). The highest technical risk area is the degree to which the battery lifetime and capacity are degraded by interaction with grid services. Charge cycling in particular has not been well characterized across a full range of potential grid interactions.

For grid interaction in the vehicle use phase, a range of ancillary services will be considered, either exclusively (e.g. demand shifting for peak reduction) or in artful combination. A variety of technical experts will be consulted from CAISO, electric utilities and technical experts at LBNL in grid reliability and demand response. For example tariff reductions from participation in an interruptible load program are one potential value stream and simulating calls for load interruption by the utility can be compared to the degree of available resource from EVs vs other resources. For all grid interactions in Task 4 and 5, careful consideration and accounting will be made for key assumptions in terms of battery standardization and testing.

For other services, a minimum degree of aggregation will be needed (e.g. spinning reserves). The team will make an assessment of each type of grid service and with an effort to provide a range of potential valuation given the current set of logistical, technical and policy constraints and utilizing historical values for all services in the CAISO and electric utilities. The team will also estimate a "technical potential" for such services from electric vehicle grid integration in an ideal configuration of system stakeholders. For example, the team will consider the scenario where CAISO offers a more flexible, favorable environment to "limited energy storage resources" in terms of telemetry, aggregation and bidding requirements.

Initial focus will be on non V-G applications (e.g., battery not charging grid) such as frequency down regulation (e.g., controlled and dispatchable battery charging) and curtailable load in the day-ahead energy balancing market since these will be the least degrading to battery performance. Analysis will also take into account the daily and seasonal variation of CAISO ancillary services market clearing prices. Data will be also be utilized from the LA AFB V-G and Building Storage pilot (technical lead by LBNL) for grid services (DR and ancillary services) collected from the pilot fleet of 40 vehicles.

Task 5 - Life cycle cost model- Secondary battery use (Q4-Q6, LBNL)

The objective of this task is to estimate battery secondary use value. Assuming that there is a standard for energy loss and/or power loss for acceptance into the second use battery market e.g. no more than 80% energy fade, the team will make use of projections for grid storage cycling and from the microgrid group at LBNL on battery duty cycling profiles in building storage applications. This "2nd-use" date will be used to provide updated battery degradation projections from the modeling work in Task 2. This new integrated information will provide greater quantification on the potential for battery secondary use value.

Assessment of battery end-of-life options

For vehicle technologies that have not yet reached cost-competitiveness with their conventional counterparts, any opportunity to derive additional value can be important their success. The goal of this task is to determine how second life options and traditional recycling will impact the total cost of ownership for PEVs, as well as their environmental impacts. For example, PEV batteries are retired, a significant portion of their original capacity remains – approximately 70%. Building from the concept of V2G technology, these retired batteries can be collected and utilized for full-time energy storage on the electrical grid, which in turn enables more intermittent renewables, such as wind and solar, to be brought online.

Particular focus in this task will be on residential and small to medium commercial buildings deployment of batteries in a "micro-grid" configuration together with other distributed resources such as PV. The scale of this application appears better matched to the size and scale of vehicle battery storage units and thus this market should have lower requirements for aggregation services and lower repurposing costs (warranty, testing, re-assembly into appropriate modules, etc.) than large, utility scale storage installations or applications.

We will utilize battery/grid interaction modeling information using the DER-CAM modeling tool, an optimization tool for the deployment of distributed energy resources in micro-grid sites developed at LBNL. The tool provides an optimal mix of distributed resources such as PV, energy storage, or fuel cells by minimizing energy costs or CO_2 emissions and fully factors in utility tariff structures and demand charges for different utility regions across the state. Here, we will utilize DER-CAM to understand optimal charging times in residential and commercial building micro-grids, which combine storage with other distributed resource such as PV.

A key task here will be to understand battery duty cycling in residential and commercial micro grid applications through already funded DER-CAM modeling. The resultant characterization of battery duty cycling will be input into the battery degradation model developed in Task 3 and DER CAM will be updated to include the improved battery degradation model.

The annualized value to buildings from ancillary services will then be explored in DER-CAM, initially focused on the frequency regulation market (regulation capacity-up and down and regulation energy), where revenue streams are calculated by offering regulation reserve to the grid and accounting for regulation energy flows (Beer 2012). For example, Beer 2012 that annual electricity savings from a medium commercial building with peak electricity demand 373kW in Northern California can reach 15% from battery integration in a micro-grid energy management system, largely from regulation capacity payments. This result uses a simplified battery degradation model in that degradation is linearly proportional to energy throughput, regardless of actual cycling behavior.

A range of these valuations can then be discounted back to time of battery purchase to estimate a secondary life battery valuation for the vehicle owner. A range of different business models could support this. For example, business models based on battery asset management could develop in the next decade that aggregate second life batteries and that may also either lease new batteries or offer new battery discounts to vehicle purchasers.

For both Tasks 4 and 5, the Demand Response Research Center (DRRC) at LBNL is an excellent resource for providing technical assistance in understanding historical values for all services, AS/CAISO market structure, coordination and planning issues, as well as technical barriers in both policy and technology. The Consortium for Electric Reliability Technology Solutions (CERTS) at LBNL will also be available for consultation regarding grid reliability issues and renewable integration requirements. In addition, the DRRC, Battery Technology, CERTs, and Micro-grid groups at LBNL are pursuing a major research initiative in grid integration and thus the team should be well positioned to leverage ongoing and future related research activities in this area.

Task 6 – End of Life and Ancillary Financial Benefits (Q4-Q6, UCB)

After any second life options have been exhausted, physical and chemical recycling processes also play an important role. Both PEV batteries and fuel cells contain valuable material including cobalt and platinum that can be recovered at their end-of-life. Additional components can be reused in new batteries and fuel cells, or recycled for use in entirely different products. We will explore the impact of these material recovery options on overall PEV costs and environmental impacts, and make recommendations for prioritizing the recycling of specific components or materials.

Quantification of environmental co-benefits

Although greenhouse gas mitigation is often at the forefront of arguments for large-scale deployment of PEVs and FCVs, there are a number of environmental benefits that could result from significant PEV adoption. The goal of this task is to quantify, and where possible, monetize important environmental co-benefits so they may be factored into the total cost of ownership. We propose to examine three major categories: human health, water, and greenhouse gas (GHG) emissions.

Human health impacts

Unlike conventional petroleum vehicles, PEVs are clean at the point of use, emitting no pollutants that are harmful to human health. This is particularly important because automotive emissions tend to occur in densely populated areas. The fraction of emissions in densely populated areas that are inhaled by humans, known as the intake fraction (iF), is generally higher than for emissions that occur in more rural areas, as is often the case for power plants and other centralized facilities (Lobscheid 2012). The implication is that shifting emissions from vehicles to power plants is likely to reduce the overall disease burden, even if total emissions do not decrease. We will utilize geospatially-disaggregated iFs provided by Lobscheid 2012 along with conventional vehicle and power plant emissions data to quantify the expected change in human health impacts resulting from significant market adoption of PEVs.

Water use

Shifting from conventional vehicles running on petroleum fuels to vehicles that rely on electricity or hydrogen will impact the energy sector's reliance on freshwater resources. In terms of water consumption per km traveled PEVs are expected to offer a net reduction relative to conventional vehicles (Scown 2011). We will quantify the net changes in freshwater withdrawals and consumption based on the previously defined conservative, moderate, and aggressive PEV market adoptions scenarios.

Greenhouse gas emissions

Achieving a reduction in net GHG emissions is one of the major drivers of interest in alternative fuel vehicles such as PEVs. Using PEV charging scenarios, we propose to quantify a range of expected life-cycle GHG emissions based on the previously discussed PEV market adoption scenarios and potential future electrical grid mixes through 2050. We will also draw from existing tools such as the open-access GREET model for data relating to vehicle manufacturing, fuel production, as well as transmission, storage, and distribution infrastructure.

Task 7 - Total Cost of Ownership Scenarios and Sensitivity Analysis (Q5-Q7, UCB)

Market adoption scenario modeling

The economic and environmental impacts of PEVs are dependent on consumer adoption. Unlike centralized infrastructure such as power plants or fuel production facilities, passenger vehicles are consumer products and the market share of alternative vehicles is tied to fleet turnover rates and their cost-competitiveness relative to conventional vehicles. We propose a scenario modeling approach in ArcGIS to provide census tract-level conservative, moderate, and aggressive market adoption curves for California through 2050. Our market penetration model will be grounded in logistic curves commonly used to predict consumer adoption of new technologies (Bandivadekar 2008, Karplus 2010).

Using National Household Transportation Survey (NHTS) and Ventyx transportation energy use data, we will estimate potential charging/fueling scenarios and identify key locations for future supporting infrastructure, such as PEV charging stations and hydrogen fueling stations. These scenarios will also allow us to develop a better understanding of the overall infrastructure costs associated with scaling up PEVs and make recommendations for minimizing these costs.

Other scenarios will explore the impact of electricity and fuel costs and future policies or policy incentives on total cost of ownership, for example the potential impact of higher RPS standards post 2020 that could increase the need for electrical storage and overall market size for grid ancillary services, or the design of utility tariffs and/or regulation markets.

We will also include analysis of PEV affordability/first-cost reduction potential with innovative financing approaches and leasing models as in photovoltaics (PV) and energy efficiency (EE) retrofits, and quantify TCO impacts of innovative financing policies that can reduce first costs of EV/HEV or charging costs. The team will consult with LBNL's nationally-known experts on innovative clean energy financing policies in EE and PV (Electricity Policy and Markets Group) to help accomplish this task.

Our scenarios will provide valuable information regarding the range of electricity likely to be demanded by alternative vehicles through 2050, as well as the scale at which additional services such as vehicle-to-grid (V2G) and battery second life energy storage could be available to utilities.

Sensitivity analysis of total cost will also be performed. Output will include tornado charts for total cost of ownership versus important cost parameters as well as an overall valuation for total cost including all of the factors from Tasks 2-6 above. The overall model will be implemented in Analytica, a software tool that is designed for decision, uncertainty, and sensitivity analysis and offers a free publicly available player (input interface).

Task 8 - Draft Final Report (Q5-Q6, UCB)

- The draft final report will be delivered 6 months before the end of the project.

Task 9 - Amend Final Report (Q7-Q8, UCB)

- The final report will include documentation, discussion and results from all of the analyses described in tasks 1-7 above.

5. Facilities and Technical Team

Facilities, infrastructure and resources:

UCB-TSRC

The Transportation Sustainability Research Center was formed to study the economic, social, environmental, and technological aspects of sustainable transportation. It is housed at the Institute of Transportation Studies at the University of California, Berkeley. TSRC is managed by the Institute of Transportation Studies of the University of California at Berkeley, and it is headquartered at the University's Richmond Field Station.

Since TSRC was founded in 2006, it has been a leading center in conducting timely research on real-world solutions for a more sustainable transportation future. TSRC conducts research on a wide array of transportation-related issues, addressing the needs of individuals as well as the public. Research efforts include advanced vehicles and fuels, energy and infrastructure, goods movement, and energy systems analysis.

TSRC uses a wide range of analysis and evaluation tools, including questionnaires, interviews, focus groups, automated data collection systems, and simulation models to collect data and perform analysis and interpretation of the data to generate recommendations for key issues of interest to policymakers to aid in decision-making. TSRC has assisted in developing and implementing major California and federal regulations and initiatives regarding sustainable transportation. These include the California Global Warming Solutions Act (AB 32), the Low Emission Vehicle Program and Zero Emission Vehicle Mandate, the Pavley Law, Low Carbon Fuel Standards policies, California SB 375 (anti-sprawl legislation), and the federal Energy Independence and Security Act of 2007.

Lawrence Berkeley National Laboratory

LBNL is a member of the national laboratory system supported by the U.S. Department of Energy through its Office of Science. It is managed by the University of California (UC) and is charged with conducting unclassified research across a wide range of scientific disciplines employing approximately 4,200 scientists, engineers, support staff and students. The Environmental Energy Technologies Division (EETD) mission is to perform analysis, research, and development leading to better energy technologies and reduction of adverse energy-related environmental impacts.

The Batteries for Advanced Transportation Technologies (BATT) Program is the premier fundamental research program in the U.S. for developing high-performance, rechargeable batteries for electric vehicles (EVs) and hybrid-electric vehicles (HEVs). This program is supported by the U.S. Department of Energy Office of Vehicle Technologies and is managed by the Lawrence Berkeley National Laboratory. LBNL is also a major collaborator on the DOE Joint Center for Energy Storage Research (JCESR) with a five-year committed budget of $125 million.

Our project team has more than 50 years of combined experience in the fields of energy systems analysis, energy storage chemistry and physics, technoeconomic assessment, vehicle design, manufacturing processes and environmental and economic decision-support tool development. Combined, we have published over 150 articles and technical reports in these fields. Since the late 1970's, LBNL has had an active effort in energy systems analysis research. LBNL owns software licenses for the vehicle powertrain modeling tool, Autonomie, built on a highly customizable platform combining submodels to capture the dynamics of individual powertrain components (i.e. batteries, motors, generators, engine, transmission, differential, power electronics, etc.). LBNL researchers have developed the Distributed Energy Resources Customer Adoption Model (DER-CAM) as an optimization tool for deploying and scheduling distributed energy resources for minimizing energy costs and reducing CO2 emissions from micro-grid sites. Recently, LBNL researchers have expanded DER-CAM to estimate economic and environmental potential from deploying electric vehicles with commercial buildings as part of a micro-grid.

Relevant to the proposed work on PEV cost modeling, LBNL can offer a number of significant research and software resources. LBNL has a license for *Analytica,* which is a visual software package developed by Lumina Decision Systems for creating, analyzing and communicating quantitative decision models using hierarchical influence diagrams. LBNL---EETD has used *Analytica* to evaluate energy technologies and policies with regard to economics, environment, and energy security and translating these assessments into total cost of ownership. LBNL also has a license for *ArcGIS,* which is a powerful geospatial visualization and modeling software package that supports complex site selection criteria, logistics optimization using real---world road, rail, and other transportation network data, and detailed cost modeling. LBNL has also built significant data and modeling capacity to address the externalized costs of a broad range of energy systems. These data and models are incorporated in platforms such as *Analytica, Matlab, ArcGIS,* and *Excel.*

Project Team Description

The team is made up of highly qualified researchers in the areas of techno-economic assessment, PEV technology, markets, and policy, battery modeling, vehicle powertrain simulation, total cost of ownership modeling, and life-cycle assessment. The key team members' technical qualifications are as follows:

PI: Timothy Lipman, PhD is an energy and environmental technology, economics, and policy researcher with the University of California - Berkeley. He is serving as Co-Director for the campus' Transportation Sustainability Research Center (TSRC), based at the Institute of Transportation Studies, and as Director of the U.S. DOE Pacific Region Clean Energy Application Center (PCEAC). He also is a Lecturer in the UC Berkeley Department of Civil and Environmental Engineering. Dr. Lipman's research focuses on electric vehicles, advanced battery systems, fuel cell technology, combined heat and power systems, renewable energy, and electricity and hydrogen infrastructure. He completed a Ph.D. degree in Environmental Policy Analysis with the Graduate Group in Ecology at UC Davis (1999) and also holds an MS degree from UC Davis and an undergraduate degree from Stanford University. He is a member of the Alternative Transportation Fuels Committee of the National Academy of Science Transportation Research Board, the Hydrogen and Fuel Cell Technical Advisory Committee for the U.S. Department of Energy, and is on the editorial board of the International Journal of Sustainable Engineering.

LBNL PI: Thomas E. McKone, PhD is a Senior Staff Scientist and Deputy Department Head at the Lawrence Berkeley National Laboratory (LBNL) and an adjunct professor and researcher at the University of California, Berkeley School of Public Health. Over the last three decades, Dr. McKone's research has been directed at the use and interpretation of large data sets and complex mass-balance models in health-risk assessments and life-cycle impact assessments. At LBNL he leads a 50-person research group that addresses technology, sustainability, and impact assessment for emerging energy technologies and also serves as deputy department head for research in the Energy Analysis and Environmental Impacts Department. At UC Berkeley he supervises graduate-student research in exposure and impact measurements and teaches graduate-level courses in risk assessment. Outside of Berkeley, he has served six years on the EPA Science Advisory Board, has been a member of more than a dozen National Academy of Sciences (NAS) committees, and has been on consultant committees for the Organization for Economic Cooperation and Development (OECD), the World Health Organization, and the International Atomic Energy Agency. He is a fellow of the Society for Risk Analysis and a former president of the International Society of Exposure Science (ISES). He has a BS in chemistry and received his PhD in Nuclear Engineering from UCLA.

Project Manager: Max Wei, PhD is a Program Manager in the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory. His work is focused on total cost modeling for emerging clean energy technologies and modeling medium- and long-term greenhouse gas reduction scenarios for California. He is project manager for a total cost of ownership modeling project for stationary fuel cell systems for the Department of Energy which extends direct manufacturing cost modeling to include ancillary benefits such as carbon credits, reduced costs for building equipment operations, and health benefits from reduce criteria pollutant emissions. He was a key contributor to "California's Energy Future – The View to 2050," a recent report for the California Council on Science and Technology and was lead author for "California's Carbon Challenge: Scenarios for Achieving 80% Emissions Reduction in 2050," a recent report for the California Energy Commission (CEC). For the latter report, he developed energy system scenarios including deep energy efficiency, clean electricity, electrification of building heat, and aggressive electrification of passenger vehicles and industry process heating. Dr. Wei has eleven years industry experience in leading edge semiconductor technology development and was a process integration manager for five years at Intel. At Intel, he received two Intel Achievement Awards, the highest annual honor in the company, awarded for "significantly improving the business." He holds four patents in semiconductor manufacturing technology. Dr. Wei has a Ph.D. in Electrical Engineering and Computer Science and an M.B.A., both from the University of California, Berkeley.

Vince Battaglia has degrees in chemical engineering from The Johns Hopkins University, B.S.; and The University of California at Berkeley, M.S. and Ph.D. Upon graduating he spent 11 years with Argonne National Laboratory's Battery group, with 4 ½ of those years spent in Illinois studying $LiAl/FeS_2$ and Li/VOx rechargeable batteries for EV applications and the other 6 ½ years on assignment in Washington DC as a technical advisor to the Electrochemical Energy Storage Program of the Office of Energy Efficiency and Renewable Energy of the U.S.D.O.E. He has spent the last seven years at Lawrence Berkeley National Laboratory where he leads a research group studying the energy, power, and cycling limits of advanced battery materials designed for hybrid and electric vehicles. Vince also participates on the USABC Technical Advisory Committee where he provides, on a quarterly basis, technical expertise on the evaluation of battery developer programs sponsored by DOE.

Anand Gopal, PhD is a Senior Scientific Engineering Associate at Lawrence Berkeley National Laboratory (LBNL). His interdisciplinary research interests lie at the nexus of transportation technology development and policy analysis with the goal of reducing greenhouse gas emissions from that sector in developing countries. He is expert in the consequential life-cycle assessment of all energy systems, particularly in sugarcane biofuels from Brazil, Indonesia and India. Dr. Gopal has published several peer-reviewed articles on bioenergy including one specifically on the life-cycle analysis of sugarcane ethanol and its relevance to the California Low Carbon Fuel Standard. He recently completed his Ph.D. in Energy and Resources from the University of California, Berkeley. Dr. Gopal is the recipient of several scholarships and awards including the Transatlantic Renewable Energy Fellowship administered by the German Foreign Office and the top award for the design of a hydrogen power park in the H2U Design Contest funded by Chevron and the US Department of Energy. Dr. Gopal received his M.S. in Environmental Systems Engineering from Humboldt State University (2003) and a Bachelor of Technology in Civil Engineering from the Indian Institute of Technology Madras (1999). At LBNL, Dr. Gopal is developing, MoSTrans, a sensing platform using smart phones to procure high-fidelity transportation data from around the world. He is currently working on a project which uses MoSTrans, powertrain simulation, policy and economic analysis to design vehicle batteries for electrified vehicles in India.

Samveg Saxena, PhD is a post-doctoral researcher at LBNL and UC Berkeley. Dr. Saxena received his Masters and Ph.D in mechanical engineering from UC Berkeley, specializing in development of high efficiency combustion engines. At LBNL, Dr. Saxena has led efforts to use detailed vehicle powertrain models to understand how hybrid vehicles can be optimized for the cost-sensitive developing world markets. He has also led efforts to integrate battery degradation dynamics into detailed powertrain models, allowing battery and car manufacturers to understand the useful life of batteries in hybrids, plug-in hybrids and electric vehicles. Prior to joining LBNL and UC Berkeley, Dr. Saxena gained industry experience developing vehicle powertrain technologies at the Multimatic Technical Center, and Magna Powertrain's Engine Technologies Group (both located in Toronto, Canada). Dr. Saxena has received several awards for his research excellence, including the NSERC Canada Graduate Scholarship (NSERC is the Canadian equivalent of the National Science Foundation, NSF). As a recognized expert in powertrain technologies, Dr. Saxena serves as a session organizer for powertrain technology sections of the Society of Automotive Engineers (SAE) and American Society of Mechanical Engineers (ASME), and also as an editorial board member of a leading combustion and energy journal "Progress in Energy and Combustion Sciences".

Corinne Scown, PhD is a Principal Scientific Engineering Associate at Lawrence Berkeley National Laboratory (LBNL). Prior to joining LBNL, she received a PhD in Civil Engineering from the University of California Berkeley, and served as a postdoctoral scholar there. She is interested in different methodological approaches to life-cycle assessment and scenario analysis for emerging or evolving technologies. As a graduate student at Carnegie Mellon University, she worked on development of the economic input-output life-cycle assessment (EIO-LCA) tool, along with infrastructure interdependency modeling using both input-output methods and *ArcGIS* network analysis. During her PhD work at UC Berkeley, Dr. Scown studied the life cycle of advanced biofuels for transportation. Through scenario modeling and life-cycle assessment, she quantified the impact of various electricity, petroleum, and bio-based transportation fuels on water scarcity in the United States, and the potential for increases in water-related energy consumption. As a postdoctoral scholar at UC Berkeley, she continued this biofuels work, extending it to greenhouse gas emissions and developing a set of land conversion scenarios for dedicated feedstock through optimization, with varying economic and environmental constraints. At LBNL, Dr. Scown works on county-level plug-hybrid electric vehicle market penetration scenarios for the US and the resulting impact on liquid fuel demand, life-cycle costing of stationary fuel cells, and co-management of energy and water resources.

Michael Stadler is a Research Scientist at Lawrence Berkeley National Laboratory, California, USA. He studied at Vienna University of Technology, from which he holds a Master's degree in electrical engineering and a Ph.D. summa cum laude in energy economics. He is also the general manager and founder of the Center for Energy and innovative Technologies (CET) in Austria. Michael published more than 145 papers, journal papers, reports, as well as five software tools in his 12 year career so far. He published or contributed to 15 high-level international journal papers, e.g. contributions to IEEE, Energy Policy, Applied Energy, or Renewable Energy. He is also very active at American Council for an Energy-Efficient Economy (ACEEE) and European Council for an Energy Efficient Economy (ECEEE) conferences. In recent years, Michael has been focusing more and more on microgrids and smart grids as well as combined heat and power (CHP).

Note: A. Gopal currently holds a joint appointment with UC-Berkeley TSRC while M.Wei and C. Scown will have multi-locational appointments (MLA) at UC-Berkeley for this work. C. Scown currently has has an MLA appointment at the Energy Biosciences Institute at UCB. Gopal, Wei, and Scown will be covered under the UC-Berkeley campus budget and not the LBNL subcontract..

Advisory Board:

For this work, an Industry Advisory board for expert consultation will be drawn from among Ford, GM, Daimler, Toyota, Tesla, Umicore, and major battery companies, as members of the research team have high level contacts at these companies. Other advisors include the Bay Area Climate Collaborative (Rafael Reyes, Executive Director), the California PEV Collaborative, and EV-related companies in the newly formed Cal Charge Consortium (Doug Davenport, LBNL, lead contact).

Management approach:

As a multi-institutional project, every effort will be made to ensure clear communication to team members of overall timelines, key deliverables, deliverable need dates, and deliverable owners. Progress to goals and reporting of progress and any gaps in resourcing/technical plan/funding, etc. will be discussed at regular biweekly team meetings. Interactions among the participants will include exchanges of information as well as people (e.g., graduate students, postdocs, scientists) through site visitations and tele-conferences with industry advisors. Other meetings and trainings (especially at the beginning) at the various research sites will also occur as necessary. The subcontractor will be responsible for submitting to UC-Berkeley the necessary information for the various reporting requirements, e.g., monthly budget, and quarterly progress.

The Project Manager (PM) will have overall oversight of the project, ensure that the project is on track, and flag any issues to ARB in a timely manner. The PM will develop quarterly milestones for the full duration of the project in consultation with the project principal investigators (to be detailed in the final proposal) and to be ratified by ARB at the project outset. Monthly check-in meetings will be held with ARB project manager, project PIs and the PM to review progress to quarterly milestones and any gaps to achieving those milestones with additional meetings with ARB if needed. Project Manager Max Wei has over six years of experience in successfully leading multi-million dollar funded R&D teams at Intel and Lawrence Berkeley National Laboratory (see bio above and CV in Section 10).

Planned allocation of resources is shown in Table 5 below.

Task	Description	Task Lead	Labor %	Research Staff
1	Vehicle and Battery Requirements and Specifications	UCB	8%	Lipman, Gopal, Post-doc
2	Cost Modeling - Battery	UCB	15%	Lipman, Wei, Post-doc, GSRA
	Cost Modeling - Vehicle	UCB	9%	Lipman, Wei, Post-doc, GSRA
3	Battery Degradation Model	LBNL	10%	Saxena, Battaglia, Stadler
4	Life Cycle Use - Vehicle and Grid Interaction	LBNL	8%	Saxena, Battaglia, Stadler, McKone
5	Life Cycle Use - Second Use of Battery	LBNL	10%	Saxena, Battaglia, Stadler, McKone
6	End of Life and Ancillary Benefits	UCB	20%	Scown, Gopal, McKone
7	Scenario Modeling	UCB	12%	Wei, Scown, Post-doc
8,9	Draft and Final Report, Admin services	UCB	8%	Lipman, Wei, Scown, Saxena

Table 5. Planned allocation of resources by Task.

One tool that will be used for measuring project progress against plan is a "Project Dashboard" or one page summary of key tasks, status, owners, gaps and critical paths. An example management dashboard is shown in Table 6 below taken from the LBNL/UCB fuel cell total cost of ownership project. This management tool has been effective in the past for tracking of critical path items, highlighting need dates, status and key areas of focus in a concise one page format.

Technology/Application: Low Temp. PEM/ Cogeneration of Power, Heating **Date:12/10/12**

#	Priority	Item	Tools / Models	Owner	Status (Red/Yellow/ Green)	Gaps	Plans: Critical Path	ECD
1	High	Patent Review		Max	Core stack done			Done
2	High	Functional Requirements	ENG	Tim	1-250kW systems completed		Ballard, Altergy, Vendors	Done
3	High	Manuf. Flows	Patents, Ballard	Max	Stack focus; basic flows for stack components completed	Assembly process; Advanced flows for 2020	Ballard inputs, DOD Manhattan Project, AMR	1/15/2013; 1/30/2013
4	Med/Hi	Detailed Bill of Materials (BOM)	Arena Solutions SW	Shuk	BOM tool licenses procured. Base stack 80% done		Shuk to update BOM for all system sizes	1/15/2013
5	High	DFMA/ Cost of parts	Boothroyd-D SW, ENG	Josh	DFMA for GDL, CCM, and metal plates done	Addit. resourcing needed	CCM, Seal key focus area for Dec/Jan; New post doc 1/1/13	Complete CCM 1/30, Seals 2/15/13

Table 6. Sample Project Dashboard sheet for management tracking of key work deliverables.

6. Co-Funding:

- Research members on the team have working relationships or high level contacts with automakers and funding leverage and/or in-kind support are being pursued with Toyota and other companies. Industry co-funding will be finalized in the final proposal.

- In addition, the work will be able to utilize several ongoing projects at LBNL:
  - Modeling of secondary battery use duty cycling in building storage applications with PV (Michael Stadler, Vince Battaglia)
  - LBNL participation in a $4.78M V-G and Building Integration Pilot Project at the Los Angeles Air Force Base.
- For both examples, actual drive cycle and grid interaction (demand response and ancillary services) data will be made available to the research team. This "virtual" cofounding is not included in the anticipated co-funding amount above, but would amount to an estimated 10-15% additional co-funding.

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Sankarasubramanian, S., and Krishnamurthy, B., "A capacity fade model for lithium-ion batteries including diffusion and kinetics", Electrochimica Acta, 70: 248-254, 2012, doi: 10.1016/j.electacta.2012.03.063.

Scown, C.D., Horvath, A., McKone, T.E., 2011. Water footprint of U.S. transportation fuels. Environmental Science & Technology 45, 2541–2553.

Sioshansi, R., Denholm, P. "The Value of Plug-In Hybrid Electric Vehicles as Grid Resources," Energy Journal; 2010, Vol. 31 Issue 3, p1.

Tran, M. et al., 2012. "Realizing the electric-vehicle revolution," Nature Climate Change 2: 330.

Wang, J., Liu, P., Hicks-Garner, J., et. al., "Cycle-life model for graphite-$LiFePO_4$ cells", Journal of Power Sources, 196(8): 3942-3948, 2011, doi:10.1016/j.jpowsour.2010.11.134.

Wei, M. 2012b, Thomas McKone, "A Total Cost of Ownership Model for Design and Manufacturing Optimization of Fuel Cells in Stationary and Emerging Market Applications", Department of Energy Annual Merit Review for Fuel Cell Research, Arlington, Virginia May 17, 2012, available at: http://www.hydrogen.energy.gov/pdfs/review12/fc098_wei_2012_o.pdf

Wei, M. 2012a, J. H. Nelson, M. Ting, C. Yang, J. B. Greenblatt, J. E. McMahon, D. M. Kammen, C. Jones, A. Mileva, J. Johnston, and R. Bharvirkar, 2012. *California's Carbon Challenge,* Lawrence Berkeley National Laboratory, Report Number 5448E.

******** END OF TECHNICAL PROPOSAL SECTION (25 pages) *********

8. Timeline

Task	Description
1	Drive train Requirements and Battery Design
2	Manufacturing Cost Model
3	Battery Degradation Model
4	Life cycle cost model - Vehicle Use phase and Grid demand response
5	Life cycle cost model- Secondary use
6	EOL Recycling/Reuse and Ancillary Financial Benefits
7	Total cost of ownership Scenario and Sensitivity analysis
8	Draft Final Report
9	Amend Final Report

	QUARTER	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
TASK									
1									
2									
3									
4									
5									
6									
7									
8									
9									
		m, p	p	m, p	p	m, p	p, d	m, p	f

m = Meeting with ARB Staff
p = Quarterly progress report
d = Deliver draft final report (to be submitted 6 months prior to contract expiration)
f = Deliver final report

9. Budget

Task	Labor	Employee Fringe Beneftis	Sub-con	Org. Burden	Soft-ware	Travel	Misc. (Campus) for additional supplies, software, telephone and materials	Misc. (Subcon) including phone, TID, training, electricity, department burden	Rent, off-campus office space	Direct Total	Over-head	Total	OH rate
1	26.4	7.9			5.0	0.4	0.2		0.4	40.2	3.7	43.9	9%
2	79.1	23.6			5.0	1.3	0.5		1.1	110.5	11.1	121.7	10%
3	34.2	11.7	LBNL	7.8		1.1		2.9		57.7	33.3	91.0	58%
4	26.6	9.1	LBNL	6.1		0.7		2.3		44.7	25.9	70.6	58%
5	34.2	11.7	LBNL	7.8		0.4		2.9		57.0	33.3	90.3	58%
6	68.5	20.5					0.4		0.9	90.3	9.7	100.0	11%
7	39.5	11.8					0.2		0.5	52.1	5.6	57.7	11%
8,9	26.4	7.9					0.2		0.4	34.7	3.7	38.5	11%
	335	104	0	22	10	4	1	8	3	487	126	614	25.9%

10. Curricula Vitae of Key Scientific Personnel

TIMOTHY E. LIPMAN, PHD

CONTACT INFORMATION

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University of California
Berkeley, CA 94704 USA

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Email: telipman@berkeley.edu
Website: http://tsrc.berkeley.edu

EDUCATION

University of California, Davis
PhD, Graduate Group in Ecology / Environmental Policy AOE, 1999
Dissertation Topic: Zero Emission Vehicle Cost and Benefits Analysis
Minors: Transportation Technology; Atmospheric Science
Advisor: Daniel Sperling
University of California, Davis
MS, Transportation Technology and Policy, 1998
Stanford University
BA, Anthropology, 1990 - Self-Designed major in Environmental Studies

RESEARCH & TECHNICAL EXPERIENCE

University of California – Berkeley **January 2006 - Present**
Co-Director, Transportation Sustainability Research Center
- Lead for TSRC alternative fuels and vehicles program
- Principal investigator for campus fuel cell vehicle and plug-in hybrid vehicle research, including lead PI for Richmond Field Station hydrogen refueling system project
- Co-PI for California Clean Mobility Program with California Air Resources Board, Bay Area Air Quality Management District, and Toyota
- Track Leader: Energy Biosciences Institute – Life-Cycle Assessment of Future Biofuels (2008-2010)

University of California – Berkeley **January 2004 – December 2006**
Assistant Research Engineer, Institute of Transportation Studies
- Conducted sustainable transportation research projects and/or subawards for the National Science Foundation, California Energy Commission, California Air Resources Board, and Bay Area Air Quality Management District
- Established U.S. Department of Energy Pacific Region Clean Energy Application Center at UC Berkeley with UC Irvine and San Diego State University
- Assisted in launching UC Berkeley Transportation Sustainability Research Center

University of California – Berkeley **February 2000 – December 2003**
Post-Doctoral Fellow and Asst. Research Scientist, Energy and Resources Group
- Assisted in the development of the campus Renewable and Appropriate Energy Lab
- Led the development of the CETEEM model for analysis of fuel cell power systems
- Track Leader: UC Davis Hydrogen Pathways Program

University of California – Davis **January 2000 – August 2000**
Associate Director Fuel Cell Vehicle Center, Institute of Transportation Studies
- Assisted FCV Center director with program development and research oversight
- Performed analysis of regulatory and policy barriers to further fuel cell and hydrogen system development
- Performed economic analysis of fuel cell system and fuel cell vehicle commercialization

NASA-Ames Research Center **June 1990 – August 1992**
Environmental Scientist working under Boeing Aerospace Safety Contract
- Assisted NASA environmental scientists with groundwater remediation effort
- Prepared NEPA and CEQA compliance documents
- Prepared Emergency Response Plans
- Assisted with base-wide efforts for reduction in use of hazardous chemicals.

TIMOTHY E. LIPMAN, PHD

TEACHING EXPERIENCE

University of California, Berkeley - Lecturer **August 2009 – May 2012**

- Co-instructor for CEE 256: Sustainable Transportation Systems at UC Berkeley with Dr. Susan Shaheen (Fall 2009, Fall 2010, and Spring 2012)
- Fellow, UC Berkeley 2010-2011 Lecturer Fellows Program

University of California, Davis – Graduate Student Instructor **August 1998 – June 2002**

- Instructed "Key Principles of Environmental, Energy, and Transportation Systems" course (Fall 1998 and Spring 2002)

REGULATORY EXPERIENCE

United States Department of Energy - Member **November 2012 – Present**

- Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), Energy Efficiency and Renewable Energy (Special Government Employee)

SELECTED PUBLICATIONS

- Williams, Brett, Elliot Martin, Timothy Lipman, and Daniel Kammen (2011), "Plug-In-Hybrid Vehicle Use, Energy Consumption, and Greenhouse Emissions: An Analysis of California Clean Mobility Partnership Household Vehicle Placements In Northern California," Special Issue Energy-Friendly Transportation, *Energies* **4**(3): 435-457.
- McKone, T.E., W.W. Nazaroff, P. Berck, M. Auffhammer, T.E. Lipman, M.S. Torn, E. Masanet, A. Lobscheid, N. Santero, U. Mishra, A. Barrett, M. Bomberg, K. Fingerman,C. Scown, B. Strogen, and A. Horvath (2011), "Grand challenges for Life-Cycle Assessment of Biofuels," *Environmental Science and Technology* **45**: 1751-1756.
- Lidicker, Jeffrey R., Timothy E. Lipman and Susan A. Shaheen (2010), "Economic Assessment of Electric-Drive Vehicle Operation In California and the United States," TRB10-3667, *Transportation Research Record*, No. **2191**: 50-58.
- Williams, Brett D. and Timothy E. Lipman (2010), "A Strategy For Overcoming Plug-In-Hybrid Battery Cost Hurdles In California: Integrating Post-Vehicle Secondary Use Values," TRB10-3652, *Transportation Research Record*, No. **2191**: 59-66.
- Williams, Brett D. and Timothy E. Lipman (2010), "Strategies for Transportation Electric Fuel Implementation in California: Overcoming Battery First-Cost Hurdles," California Energy Commission Public Interest Energy Research Report, #CEC-500-2009-091, February.
- Martin, Elliot, Susan A. Shaheen, Timothy E. Lipman and Jeffrey R. Lidicker (2009), "Behavioral response to hydrogen fuel cell vehicles and refueling: Results of California drive clinics," *International Journal of Hydrogen Energy* **34** (20): 8670-8680.
- Shaheen, Susan A., Elliot Martin, and Timothy E. Lipman (2008), "Dynamics In Behavioral Response to a Fuel Cell Vehicle Fleet and Hydrogen Fueling Infrastructure: An Exploratory Study," *Transportation Research Record* **2058**: 155-162.
- Lutsey, Nicholas, Christie-Joy Brodrick, and Timothy Lipman (2007), "Analysis of potential fuel consumption and emissions reductions from fuel cell auxiliary power units (APUs) in long-haul trucks," *Energy Policy* **32**: 2428-2438.
- Shaheen, Susan A. and Timothy E. Lipman (2007), "Reducing Greenhouse Emissions and Fuel Consumption: Sustainable Approaches for Surface Transportation," Special Issue on Efforts to Reduce CO2 in Transportation, *International Association of Traffic and Safety Sciences* **31**(1): 6-20.
- Lipman, Timothy E. and Mark A. Delucchi (2006), "An Analysis of the Retail and Lifecycle Costs of Hybrid Electric Vehicles," *Transportation Research – D* **11**(2): 115-132.
- Lipman, Timothy E. (2004), "Integration of Motor Vehicle and Distributed Energy Systems," *Encyclopedia* of *Energy,* Academic Press/Elsevier Inc., ISBN 0-12-176480, March.

RESEARCH INTERESTS

Electric drive vehicles, renewable energy systems, hydrogen infrastructure, advanced electro-chemical batteries, fuel cell systems, vehicle-to-grid power, combined heat and power

Thomas E. McKone
Senior Scientist and Deputy for Research Programs
Energy Analysis and Environmental Impacts Department
Lawrence Berkeley National Laboratory
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temckone@LBL.gov

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

Research and Professional Experience

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

Research Interests

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

Publications (selected out of >160)

1. B. Strogen, A. Horvath, T.E. McKone "Fuel Miles and the Blend Wall: Costs and Emissions from Ethanol Distribution in the United States," Environ. Sci. Technol. 46 (10):5285–5293, 2012.
2. C.J. Mattingly, T.E. McKone, M.A. Callahan, J.A. Blake, E.A. Cohen-Hubal "Providing the Missing Link: The Exposure Ontology ExO," Environ. Sci. Technol. 46:3046-3053, 2012.

3. C.D.Scown, W.W. Nazaroff, U. Mishra, B. Strogen, A.B. Lobscheid, E Masanet, N.J. Santero, A. Horvath, T.E. McKone "Life cycle greenhouse gas implications of US national scenarios for cellulosic ethanol production" Environ. Res. Lett. 7:014011, 9 pages, 2012.
4. Scown CD, Horvath A, McKone TE. Water footprint of U.S. transportation fuels. Environ. Sci. Technol 2011, 45: 2541–2553,.

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

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

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

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

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

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

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

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

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

Synergistic Activities

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

Max Wei, Ph.D., M.B.A

CONTACT INFORMATION

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EDUCATION

M.B.A. University of California, Berkeley
Haas School of Business, 2009
Certificate in Engineering and Business for Sustainability
Class and project focus: Energy markets, energy policy and technology

Ph.D., University of California, Berkeley
Department of Electrical Engineering and Computer Sciences, 1995
Dissertation: Patterning Periodic Nanostructures Using Soft X-Ray Interference
Minors: Solid state physics and Device electronics
Advisors: David T. Attwood, T.K. Gustafson

SELECTED RESEARCH & TECHNICAL EXPERIENCE

Program Manager, Lawrence Berkeley National Lab 5/12-Present
Energy Analysis and Environmental Impacts Department, Environmental Energy Technologies Division, Berkeley, California

- Project leader for the development of a Total Cost of Ownership model for stationary fuel cell systems, a $1.9 million multi-year research project for the U.S. Department of Energy.
- Direct and conduct research and analysis on direct manufacturing costs, indirect factory costs, life-cycle costs, and valuation of externalities such as carbon credits and public health benefits for stationary fuel cell systems. The cost model is being developed for low-temperature proton exchange membrane (PEM) technology initially and will be extended to high-temperature PEM and solid oxide fuel cell technology in 2014-2016.

Senior Research Associate, Lawrence Berkeley National Laboratory 5/10- 5/12
Energy Analysis and Environmental Impacts Department, Environmental Energy Technologies Division, Berkeley, California

- Developed integrated energy system demand and supply scenarios toward meeting long term California greenhouse gas emission goals, including scenarios for aggressive vehicle electrification and electrification of building and process heating.
- Lead researcher for California Carbon Challenge project for the California Energy Commission. Constructed new version of a LEAP energy model for California, providing an integrated quantitative estimate of energy-related greenhouse gas emissions to 2050 utilizing existing databases and new estimates for major sectors (residential, commercial, industrial, transportation) and multiple energy sources. Modeled electricity demand to 2050 including building, vehicle, and industry electrification scenarios across the Western Electricity Coordination Council region.

Process Integration Manager, Intel Corporation 2005-2007
45-nanometer NOR Flash Technology Development California Technology and Manufacturing Division, Santa Clara, California

- Led process development team and owned cell architecture definition and integrated process flow of industry leading 45nm NOR flash memory.
- Initiated several technological innovations to overcome key technical challenges and filed three patents for NOR flash memory. Presented the novel flash technology at a leading international semiconductor conference in Japan (VLSI Technology Symposium).
- Key decision-maker in setting program technology direction. Built high level development plans, set milestones and summarized key recommendations, progress to

milestones and risk assessment. Chaired and directed large meetings with multiple stakeholders to ensure overall technology development effort on track.

RECENT PUBLICATIONS

M. Wei, J.H. Nelson, J.B. Greenblatt, A. Mileva, J. Johnston, M. Ting, C. Yang, C. Jones, J.E. McMahon, D.M. Kammen, "Deep Carbon Reductions in California Require Electrification and Integration Across Economic Sectors", submitted to Environmental Research Letters, October 30, 2012.

M. Wei, S. Patadia, D.M. Kammen, "Putting Renewables and Energy Efficiency to Work: How Many Jobs can the Clean Energy Industry Create in the U.S.?" Energy Policy 38 (2010) 919-931.

RECENT REPORTS

M. Wei, James Nelson, Michael Ting, Chris Yang, J.B. Greenblatt, J.E. McMahon, "California's Carbon Challenge: Scenarios for Meeting 80% Emissions Reduction in 2050," Lawrence Berkeley National Laboratory Report LBNL-5448E, November 2012.

J.B. Greenblatt, M. Wei, Chris Yang, Burton Richter, Bryan Hannegan, Heather Youngs, Jane C.S. Long, Miriam John, "California's Energy Future – The View to 2050 Summary Report," California Council on Science and Technology, May 2011.

M. Wei, D. Kammen, "Economic Benefits of a Comprehensive Feed-In Tariff: An Analysis of the REESA in California," Renewable and Appropriate Energy Laboratory (RAEL) report in cooperation with the Feed-in Tariff Coalition, Energy and Resources Group, University of California, Berkeley, California, July 2010.

INVITED TALKS

M. Wei, "Breaking Barriers to Achieving Deep Carbon Reduction in California by 2050," Aspen Global Climate Institute, Workshop on Climate Sensitivity on Decadal and to Century Timescales, Aspen Colorado, May 24, 2012.

M. Wei, "California's Carbon Challenge: Scenarios for Meeting 80% Emissions Reduction in 2050," The Road to a 100% Renewable Energy System Workshop. Sponsored by the Center for Sustainable Energy and Power Systems, University of California, Santa Cruz. Milpitas, California, August 1, 2011.

M. Wei, "Carbon Emissions and Cost impact of Converting to Heat Pump Based Water Heating," ACEEE Hot Water Forum, Berkeley, California, May 11, 2011.

M. Wei, Keynote Address, "Transitioning to a New Energy Economy," National Energy Technician Education Summit. Sponsored by the American Association of Community Colleges, National Science Foundation, and the Advanced Technology Environmental and Energy Center. Washington, D.C. December 8, 2010.

M. Wei, D. Kammen, S. Patadia, "Job Creation Potential of the Green Economy – A U.S. Perspective," presented at the Green Jobs in China Conference, International Labor Organization, Beijing, China, March 2009.

PATENTS

Semiconductor device with buried source rail # 20090001440 (submitted 2009)
Self-aligned contact formation utilizing sacrificial polysilicon # 7632736 (2009)
High Concentration Indium Fluorine Retrograde Wells #7129533 (2006)
High Concentration Indium Fluorine Retrograde Wells # 6838329 (2005)

Vincent S. Battaglia, Ph.D.

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Berkeley, California 94720
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45 Mountain View Dr.
San Anselmo, California
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Chemical engineer specializing in research and development, technical management, and program development of electrochemical energy storage and conversion programs.

PROFESSIONAL EXPERIENCE

LAWRENCE BERKELEY NATIONAL LABORATORY

Berkeley, CA *2004 to Present*

Program Manager 4

- **Deputy Department Head** Research Program development for Energy Storage and Distributed Resources
- **Principal Investigator** of the Battery Fabrication Laboratory of the BATT (Batteries for Advanced Transportation Technologies) program.
- **Co-Principal Investigator** of two ARPA-E projects.
- **Lead investigator** in the development of the Technology Life Verification Test Manual - a manual designed for accelerated life testing of batteries.
- **Technical expert** in the evaluation of battery developer programs as a participant of the USABC Technical Advisory Committee and Office of Vehicle Technologeos Electrochemical Energy Storage Tech Team.
- **Program manager** on future direction of both the Applied Battery Research (ABR) and BATT Programs – the two, DOE-supported battery-research programs.

ARGONNE NATIONAL LABORATORY

Washington, DC *1998 to 2004*

Technical Coordinator

DOE's Energy Storage Research for Automotive Applications

- 1998-2004: Provided **technical direction** of the ATD and BATT programs for the Office of FreedomCAR and Vehicle Technologies.
- 2000: **Restructured** the BATT fundamental battery research program to more directly address the needs of HEV, FCV, and EV applications.
- 1998: Helped conceive and spearhead the **development** and **organization** of the ATD applied battery research program for the DOE.

Technical Coordinator *1997 to 1998*

Partnership for a New Generation of Vehicles (PNGV)

- 1997: Participated in technical team meetings concerning all aspects of the PNGV, from systems analysis to fuel cell research.
- 1997-1999: **Directed** graduate research in direct methanol fuel cells.

ARGONNE NATIONAL LABORATORY

Argonne, Illinois *1993 to 1997*

Chemical Engineer

- Identified key mechanisms of capacity fade of the Li/Polymer technology.
- Created electrochemical cell models for the Li/Polymer technology.

- Developed a transport and thermodynamic model of the LiAl/FeS_2 system.
- Designed modules of both the lithium polymer and LiAl/FeS_2 systems for electric vehicle application.

UNIVERSITY OF CALIFORNIA
Berkeley, California
Doctor of Philosophy, Research Assistant *1989 to 1993*

- Calculated the inductance effects of high-power batteries.
- Investigated the feasibility of a novel electroless deposition process.
- Modeled the growth of iron oxide on iron under anodic conditions.
- Provided teaching assistance for Chemical Engineering Laboratory, and Heat and Mass Transfer.

Masters of Science, Research Assistant *1985 to 1988*

- Designed, built, and demonstrated a 60,000 cc coal gasification unit.
- Characterized the conversion of coal to hydrogen, carbon monoxide, and carbon dioxide as it relates to underground coal gasification.

EDUCATIONAL HISTORY

UNIVERSITY OF CALIFORNIA, *Berkeley* *1989 to 1993*
Ph.D., Chemical Engineering
Advisor: John Newman
Dissertation: Current-Potential Characteristics of Electrochemical Systems

UNIVERSITY OF CALIFORNIA, *Berkeley* *1985 to 1988*
M.S., Chemical Engineering
Advisor: Edward Grens, II
Dissertation: Gasification of Coal Cores Surrounded by Packed Beds

JOHNS HOPKINS UNIVERSITY, *Baltimore* *1981 to 1985*
B.S., Chemical Engineering
Advisor: Geoffrey Prentice
Course Work Minor: Economics

AWARDS

Pacesetter Award: from Argonne National Laboratory for work related to the phenomenological understanding of lithium insertion and impedance rise in a metal oxide cathode material.

PUBLICATIONS AND RECOMMENDATIONS

Upon request

PROFESSIONAL SOCIETIES AND MEMBERSHIPS

USABC Technical Advisory Committee
Electrochemical Society

Anand R Gopal, PhD

CONTACT INFORMATION

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Email: argopal@lbl.gov

EDUCATION

University of California, Berkeley
PhD, Energy and Resources Group, 2011
Dissertation: Lifecycle Assessment of Sugarcane Biofuels

Humboldt State University, Arcata, CA
M.S. Environmental Systems Engineering, 2003

Indian Institute of Technology, Madras
BTech, Civil Engineering, 1999

EXPERIENCE

Lawrence Berkeley National Laboratory, Sr. Scientific Engg. Associate **Aug 2011-present**
Conduct Scientific Research and Policy Analysis in Transportation Energy and Energy Efficiency in the US and several emerging economies. Manage and co-lead Projects.
Projects

- **Battery Design for Electric Cars in India**: Policy and Economic Analysis lead. This project is a systems design approach where LBNL battery research is directed with the objective of designing an EV or HEV specifically for the traffic, consumer preferences and policy environment of India.
- **Super-Efficient Appliance Deployment Initiative**: Co-lead of Financial Incentive Programs for Energy Efficiency among all SEAD member countries
- **Clean Energy Development in India**: Assessing the potential and developing policies for the deployment of clean transportation technology in India

Sugar Group Companies, Indonesia, LCA Engineer, J**ul 2010 - Present**
Lead LCA engineer for the company. Assess the life cycle carbon and energy footprint of Sugarcane ethanol using consequential and attributional methods.

Potsdam Institute for Climate Impact Research, Berlin, Guest Scientist**, 2009**
Research focused on assessing the potential of bioenergy for climate mitigation using Integrated Assessment Modeling

University of California, Berkeley, Graduate Researcher, **2006 – 2009**
Research work involved advanced thermodynamic modeling of biomass gasifiers, economic and policy analysis of bioenergy in transportation and life cycle assessment of biofuels

Schatz Energy Research Center, Arcata CA, Research Engineer, **2002 – 2006**

- Lead early developer of the partnership between Chevron Technology Ventures, the California Air Resources Board, the California Dept of Transportation and the center to fund and construct northern California's first hydrogen fueling station.
- Designer and builder of PEM Fuel cell test stations.
- Lead member of the center's fuel cell modeling team using MATLAB and COMSOL.

SELECTED JOURNAL PUBLICATIONS

S Saxena, A Phadke, A Gopal, V Srinivasan. Understanding Fuel Savings Mechanisms to Inform Optimal Battery Sizing for India. In review at *International Journal of Powertrains*
A Gopal, D Kammen, M O'Hare. Byproduct Biofuels Can Be Very Low Carbon in Some

Policy Environments: A Full CLCA of Indian Molasses Ethanol. In review at *International Journal of Life Cycle Assessment*

W Morrow, A Gopal, G Fitts, S Lewis, L Dale, E Masanet. Feedstock Loss from Drought is a Major Economic Risk for Biofuel Producers. In Review at *Biomass and Bioenergy*

A. R. Gopal & D. M. Kammen. Molasses for ethanol: The economic and environmental impacts of adding a new pathway to the lifecycle greenhouse gas emissions of sugarcane ethanol. *Environmental Research Letters, 2009 vol. 4 (4) pp. 044005*

A.E. Farrell & A.R. Gopal. Bioenergy research needs for heat, electricity and liquid fuels. *MRS Bulletin, Apr 2008, Vol 33*

T McNish, A Jacobson, D Kammen, A. R. Gopal, R Deshmukh. Sweet Carbon: An Analysis of Sugar Industry Carbon Market Opportunities Under the Clean Development Mechanism. *Energy Policy, 2009 vol. 37 (12) pp. 5459-5468*

TOOLS AND SKILLS

GREET, GTAP (computable general equilibrium model used for consequential LCAs), Crystal Ball, MATLAB, COMSOL Multiphysics, PowerSim, ArcGIS, Spatially explicit land use modeling and Integrated Assessment Modeling of Global Energy Systems

Samveg Saxena, Ph.D

Contact Information

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Lawrence Berkeley National Laboratory
Berkeley, CA 94720 USA

Phone: 510-269-7260
e-mail: ssaxena@lbl.gov

Education

University of California, Berkeley
Masters and Ph.D, Mechanical Engineering, December 2011
Dissertation: High efficiency, low emissions internal combustion engines
Minors: Control systems, Electrical engineering
Advisor: Prof. Robert Dibble

University of Ontario Institute of Technology
B. Engineering, Manufacturing Engineering, May 2007

- Graduated with highest honors

Research & Technical Experience

Lawrence Berkeley National Laboratory **January 2012 – Present**
Post-doctoral researcher

- Leading research efforts using detailed powertrain modeling to understand fuel savings potential of hybrid vehicles in the developing world
- Leading research efforts to integrate battery degradation dynamics with detailed vehicle powertrain modeling
- Developed simulation tools to use exergy analysis to understand loss mechanism in internal combustion engines and prioritize areas for further research

University of California, Berkeley **August 2007 – December 2011**
Graduate Student Researcher and Instructor

- Developed strategies for maximizing power output and enabling effective control of high efficiency, low emissions homogeneous charge compression ignition engines
- Taught thermodynamics and mechanical engineering laboratory courses

Multimatic Technical Center **April 2007 – August 2007**
Vehicle Systems Engineer

- Responsible for powertrain design of a concept car, and prototyping of new automotive technology concepts

Magna Powertrain Engine Technologies Group **April 2006 – April 2007**
New Technology Engineer

- Responsible for calculations, design, testing and validation of new engine technology concepts

Editorial and Professional Development Experience

Progress in Energy and Combustion Sciences **January 2012 - Present**
Journal editorial board member

Society of Automotive Engineers **February 2011 - Present**
Session organizer for two sessions at SAE World Congress

- Kinetically controlled compression ignition
- Fuel and additive effects on compression ignition

American Society of Mechanical Engineers **January 2011 – Present**
Session organizer for “Advanced Combustion” session at IC Engine meeting

Selected Publications

- S. Saxena, I.D. Bedoya, N. Shah, and A. Phadke, "Understanding Loss Mechanisms and Identifying Areas of Improvement for HCCI Engines using Detailed Exergy Analysis", ICEF2012-92052, and Report LBNL-5534E, 2012 – Recommended for fast-track publication in ASME Journal of Engineering for Gas Turbines & Power.
- S. Saxena, S. Schneider, S. Aceves, and R. Dibble, Wet ethanol in HCCI engines with exhaust heat recovery to improve the energy balance of ethanol fuels, Applied Energy, 98: 448-457, 2012, doi: 10.1016/j.apenergy.2012.04.007.
- I.D. Bedoya, S. Saxena, S. Aceves, D. Flowers, F.J. Cadavid, and R.W. Dibble, A sequential chemical kinetics-CFD-chemical kinetics methodology to predict HCCI combustion and main emissions, SAE Paper 2012-01-1119, doi: 10.4271/2012-01-1119.
- I.D. Bedoya, S. Saxena, F.J. Cadavid, and R.W. Dibble, Exploring Strategies for Reducing High Inlet Temperature Requirements and Allowing Optimal Operating Conditions in a Biogas Fueled HCCI Engine for Power Generation, ASME Journal of Engineering for Gas Turbines and Power, 134(7): 072806, 2011, doi: 10.1115/1.4006075.
- I.D. Bedoya, S. Saxena, F.J. Cadavid, R.W. Dibble, M. Wissink, Experimental evaluation of strategies to increase the operation range of a biogas HCCI engine for power generation, Applied Energy, 97: 618-629, 2011, doi: 10.1016/j.apenergy.2012.01.008.
- S. Saxena, J-Y Chen, R.W. Dibble, Maximizing power output in an automotive scale multi-cylinder HCCI engine, SAE World Congress, SAE Paper 2011-01-0907, 2011, doi:10.4271/2011-01-0907.

Awards

NSERC PostGraduate Scholarship (Doctoral) **2009-2011**

- Award from the Natural Sciences and Engineering Research Council (NSERC) of Canada
- Nationally-competitive award for distinguished students based on research potential

Anselmo John Macchi Graduate Fellowship (Doctoral) **2011**

- Institutional-level award at UC Berkeley recognizing academic and research excellence

NSERC Canada Graduate Scholarship (Masters) **2007-2009**

- Nationally-competitive award for distinguished students based on academic excellence & research potential

Outstanding Graduate Student Instructor Award (UC Berkeley) **2008**

- Berkeley's highest teaching honor for graduate students, recognizing overall effectiveness as an instructor, ability to promote critical thinking, ability to motivate students, and command of the subject area

Ontario Graduate Scholarship – Declined acceptance of award **2007**

- Provincially-competitive award for distinguished students based on research potential

NSERC Industrial Undergraduate Student Research Award **2006**

- Nationally-competitive award for distinguished students to conduct advanced research with industrial sponsors. Conducted R&D on new technologies for internal combustion engine lubrication systems

Millennium Excellence Award Recipient **2005 - 2007**

- National award recognizing innovation, academic achievement, community involvement and leadership

Top 20 Under 20 Canada – Finalist **2004**

- National awards program recognizing youth who demonstrate significant level of achievement, innovation and leadership and are under the age of 20.

Research Interests

Vehicle powertrain analysis, engines, batteries, motors, vehicle-to-grid integration, control systems development, thermodynamics.

Corinne D. Scown, Ph.D.

Contact Information

1 Cyclotron Road, 90-2024M
Lawrence Berkeley National Lab
Berkeley, CA 94720 USA

Phone: (510) 486-4507
E-mail: cdscown@lbl.gov
Website: www.cscown.com

Research Interests

Life-cycle assessment, the environmental impacts of energy production, energy-water nexus, water scarcity impacts, economic input-output models, air quality, uncertainty quantification, interaction between science and policy/decision-making

Education

University of California, Berkeley, USA

Ph.D., Civil Engineering, December 2010

- Dissertation Title: "Life-Cycle Water Impacts of U.S. Transportation Fuels"
- Advisor: Arpad Horvath

M.S., Civil Engineering, May 2008

Carnegie Mellon University, Pittsburgh, Pennsylvania USA

B.S., Civil Engineering, December, 2006
double major in Engineering and Public Policy

Peer-Reviewed Publications

Corinne D. Scown, William W. Nazaroff, Umakant Mishra, Bret Strogen, Agnes B. Lobscheid, Eric Masanet, Nicholas J. Santero, Arpad Horvath, Thomas E. McKone (2012). "Lifecycle Greenhouse Gas Implications of US National Scenarios for Cellulosic Ethanol Production." *Environmental Research Letters*, 7 014011.

Corinne D. Scown, Arpad Horvath, Thomas E. McKone (2011). "Water Footprint of U.S. Transportation Fuels." *Environmental Science & Technology*, 45(7), 2541-2553. Also published in *Environmental Science & Technology* virtual issue entitled "Water-Energy Nexus" 1(1).

Thomas E. McKone, William W. Nazaroff, Peter Berck, Maximilian Auffhammer, Tim Lipman, Margaret S. Torn, Eric Masanet, Agnes Lobscheid, Nicholas Santero, Umakant Mishra, Audrey Barrett, Matthew Bomberg, Kevin Fingerman, Corinne Scown, Bret Strogen, Arpad Horvath (2011). "Grand Challenges for Life-Cycle Assessment of Biofuels." *Environmental Science & Technology*, 45(5), 1751-1756.

Iain S. Walker, Sara Al-Beaini, Samual Borgeson, Brian Coffey, David Gregory, Kyle Konis, Corinne Scown, Jelena Simjanovic, John Stanley, Bret Strogen (2009). *Feasibility of Achieving Net-Zero-Energy Net-Zero-Cost Homes.* Lawrence Berkeley National Laboratory, Berkeley, CA, LBNL 2067E.

Ping Chen, Corinne Scown, H. Scott Matthews, James H. Garrett, Jr., Chris Hendrickson (2009). "Managing Critical Infrastructure Interdependence through Economic Input-Output Methods." *ASCE Journal of Infrastructure Systems*, 15(3), 200-210.

Chung Yan Shih, Corinne D. Scown, Lucio Soibelman, H. Scott Matthews, James H. Garrett, Jr., Keith Dodrill, Sandra McSurdy (2009). "Data Management for Geospatial Vulnerability Assessment of Interdependencies in US Power Generation." *ASCE Journal of Infrastructure Systems*, 15(3), 179-189.

Selected Research Experience

Lawrence Berkeley National Lab, Berkeley, California USA

Principal Scientific Engineering Associate **2012-present**
Team: Emerging Technology Assessment Team, Carbon Cycle 2.0
PI: Jeffrey Greenblatt, Ph.D.
This is a long-term project that involves scenario and model development for energy efficient buildings, biomass for energy applications, photovoltaics, and carbon capture and sequestration. I am specifically focused on uncertainty quantification in scenario analysis of renewable energy technology scale-up.

Principal Scientific Engineering Associate **2012-present**
Project Title: Fuel Cell Total Cost of Ownership
PI: Professor Thomas McKone
Primary objective is to quantify the total monetary cost and externalities associated with purchasing and operating a fuel cell for stationary applications, such as commercial buildings. Primary output is an Analytica model that tracks material flows, heat and electricity consumption and use, greenhouse gas emissions, human health impacts, as well as parameter uncertainty throughout the model.

University of California, Berkeley, USA

Postdoctoral Scholar/Principal Scientific Engineering Associate **2011-present**
Project Title: Life-Cycle Environmental and Economic Decision-Making for Alternative Biofuels
Advisor: Professor Arpad Horvath
Primary objective is to develop an understanding of the broad environmental and economic impacts of producing biofuels with respect to other transportation fuel alternatives such as petroleum-based fuels and electricity. Deliverables include a carbon assessment tool and a series of national biofuel production scenarios.

Graduate Student Researcher **2008-2009**
Project Title: World Resources Institute Transportation Energy Tool
Advisor: Lee Schipper, Ph.D.
Tasks include developing an excel-based policy analysis tool for determining the greenhouse gas impacts of various transportation-related policies and writing a series of white papers to be published by the World Resources Institute in Washington, DC.

Carnegie Mellon University, Pittsburgh, Pennsylvania USA

Graduate Research Assistant **2007**
Project Title: Knowledge Management and Visualization in Support of Vulnerability Assessment of Electricity Production
Advisor: Professors H. Scott Matthews and Lucio Soibelman
Tasks include developing a prototype that integrates spatial and non-spatial data for vulnerability assessment of electricity supply based on coal mine production and rail transportation.

Undergraduate Research Assistant **2004-2006**
Project Title: Economic Input-Output Life-Cycle Assessment
Advisor: Professor H. Scott Matthews
Tasks include retrieval and aggregation of Occupational Safety and Health Administration data for integration into the Economic Input-Output Life-Cycle Assessment (EIO-LCA) tool.

Northeast Midwest Institute, Washington, DC USA

Undergraduate Research Fellow **2006**
Project Title: Electrical Grid Modernization
Advisor: Diane DeVaul, Ph.D. and Richard Munson
Tasks include collection of information on electrical grid modernization, distributed generation, and broadband over power lines for preparation of a white paper.

Michael Stadler

EDUCATION
Ph.D. (summa cum laude) in Energy Economics
Vienna University of Technology, Vienna, Austria, 2003
Thesis title: "The relevance of demand-side-measures and elastic demand curves to increase market performance in liberalized electricity markets: The case of Austria."
Field: Electrical Engineering and Energy Economics

M.S. (excellent completion) in Power Engineering and Electrical Drives
Vienna University of Technology, Vienna, Austria, 2001

RESEARCH EXPERIENCE
Lawrence Berkeley National Laboratory, Berkeley, CA
Environmental Energy Technologies Division,
Energy Analysis Department
Technology Evaluation, Modeling, & Assessment Group
October 2009 – present: Scientist
February 2008 – September 2009: Postdoctoral Fellow

Lawrence Berkeley National Laboratory, Berkeley, CA
Environmental Energy Technologies Division,
Energy Analysis Department
March 2006 – September 2006: Guest Researcher
September 2005 – February 2006: Postdoctoral Fellow

University of California at Berkeley, CA
Energy and Resources Group at University of California at Berkeley,
Pacific Region CHP Application Center
March 2006 – September 2006: Postdoctoral Fellow

Vienna University of Technology, Austria
Institute of Power Systems and Energy Economics,
Energy Economics Group
April 2004 – August 2005: Postgraduate Researcher & Senior Software Developer
December 2003 – August 2005: Postgraduate Researcher
March 2001 – November 2003: Junior Research Fellow
November 2000 – February 2001: Student Collaborator

MEMBERSHIP IN PROFESSIONAL SOCIETIES
- European Council for an Energy Efficient Economy (ECEEE)
- Institute of Electrical and Electronics Engineers (IEEE)

REVIEWER FOR
- American Society of Mechanical Engineers (ASME)
- ASHRAE
- Applied Energy, Elsevier
- European Council for an Energy Efficient Economy (ECEEE)
- European Transactions on Electrical Power
- International Journal of Electronic Business Management
- Institute of Electrical and Electronics Engineers (IEEE)

PUBLICATIONS
Summary

Number of Peer Reviewed Archival Journal Articles	**15**
Number of articles as first author	*6*
Refereed Conference Proceedings Publications	**49**
Number of publications as first author	*19*
Non-Refereed Journals, Books, and Proceedings Publications	**20**
Number of publications as first author	*12*
Seminars, Briefings and Interviews	**19**
Project Reports and Deliverables	**36**
Scientific Software Tools	**6**
Total	**145**

Most Recent Publications

Stadler Michael, Chris Marnay, Maximilian Kloess, Gonçalo Cardoso, Gonçalo Mendes, Afzal Siddiqui, Ratnesh Sharma, Olivier Mégel, Judy Lai: "Optimal Planning and Operation of Smart Grids with Electric Vehicle Interconnection," Journal of Energy Engineering, American Society of Civil Engineers (ASCE), Special Issue: Challenges and opportunities in the 21st century energy infrastructure, Volume 138, Issue 2, June 2012, ISSN 0733-9402 / e-ISSN - 1943-7897, http://dx.doi.org/10.1061/(ASCE)EY.1943-7897.0000070, LBNL-5251E.

Stadler Michael, Jonathan Donadee, Chris Marnay, Gonçalo Mendes, Jan von Appen, Olivier Mégel, Prajesh Bhattacharya, Judy Lai: "Application of the Software as a Service Model to the Control of Complex Building Systems," ECEEE 2011 Summer Study, 6–11 June 2011, Belambra Presqu'ile de Giens, France, ISBN 978-91-633-4455-8, LBNL-4860E.

"Storage Viability and Optimization Web Service." Michael Stadler, Chris Marnay, Judy Lai, Afzal Siddiqui, Tanachai Limpaitoon, Trucy Phan, Olivier Mégel, Jessica Chang, Nicholas DeForest, California Energy Commission, Public Interest Energy Research Program, CEC-500-02-004, LBNL-4014E, October 2010.

"The CO_2 Abatement Potential of California's Mid-Sized Commercial Buildings." Michael Stadler, Chris Marnay, Gonçalo Cardoso, Tim Lipman, Olivier Mégel, Srirupa Ganguly, Afzal Siddiqui, and Judy Lai, California Energy Commission, Public Interest Energy Research Program, CEC-500-07-043, 500-99-013, LBNL-3024E, December 2009.

SELECTION OF SCIENTIFIC SOFTWARE TOOLS

2010 – present: Web Optimization of Distributed Energy Resources (WebOpt). This tool aims to provide a fully accessible Web service that users can employ to evaluate potential Distributed Energy Resources (DER) options.

2009 – present: Industrial, Agricultural, and Water Storage Viability and Optimization Website Service (SVOW) financed by the California Energy Commission (CEC). This web based service aims to provide industrial, agricultural, and water (IAW) facilities with basic guidance on whether available storage technologies and photovoltaic of interest merit deeper analysis. This service is based on DER-CAM. http://der.lbl.gov/microgrids-lbnl/current-project-storage-viability-website.

2002 – present: The *Distributed Energy Resources Customer Adoption Model (DER-CAM)* is a mixed-integer linear program (MILP) written and executed in the General Algebraic Modeling System (GAMS). Its objective is to minimize the annual costs or CO_2 emissions for providing energy services to the modeled site, including utility electricity and natural gas purchases, amortized capital and maintenance costs for distributed generation (DG) investments. http://der.lbl.gov.

BUDGET DETAIL

The Regents of the University of California
c/o Sponsored Projects Office
2150 Shattuck Avenue, Suite 300
University of California, Berkeley, CA 94704-5940

ARB Pre-Proposal - Advanced Clean Cars

Period of Performance: April 1, 2013 through March 31, 2015

SALARIES					**2013**	**2013-14**	**2014-15**	
Personnel	Monthly Rate	# Months	Time Unit	% Time	4/01/2013 - 6/30/2013	7/01/2013 - 6/30/2014	7/01/2014 - 3/31/2015	Total
Tim Lipman, PhD, Assoc. Research Engineer (II-III)			Cal. Yr					
	$ 8,875	3		20%	$5,325.00			$5,325.00
	$ 9,141	12		20%		$21,939.00		$21,939.00
	$ 9,787	9		20%			$15,975.00	$15,975.00
Max Wei, LBL (MLA)			Cal. Yr					
	$ 7,400	3		20%	$4,440.00			$4,440.00
	$ 7,622	12		20%		$18,292.80		$18,292.80
	$ 7,851	9		20%			$13,320.00	$13,320.00
Corinne Scown, PhD, LBL (MLA)		0	Cal. Yr					
	$ 9,139	3		15%	$4,112.55			$4,112.55
	$ 9,413	12		15%		$16,943.71		$16,943.71
	$ 9,696	9		15%			$12,337.65	$12,337.65
Anand Gopal, PhD, Asst. Research Engineer		0	Cal. Yr					
	$ 8,100	3		15%	$3,645.00			$3,645.00
	$ 8,343	12		15%		$15,017.40		$15,017.40
	$ 8,593	9		15%			$10,935.00	$10,935.00
Post-Doctoral Researcher (TBN)			Cal. Yr					
	$ 3,695	3		70%	$7,759.50			$7,759.50
	$ 3,806	12		70%		$31,969.14		$31,969.14
	$ 3,920	9		70%			$24,696.16	$24,696.16
Madonna Camel, Research Analyst			Cal. Yr					
	$ 6,072	3		5%	$910.80			$910.80
	$ 6,254	12		5%		$3,752.50		$3,752.50
	$ 6,442	9		5%			$2,898.80	$2,898.80
Graduate Student Researcher III (TBN)								
	$ 3,426	2	Summer	100.00%		$6,852.00		$6,852.00
	$ 3,426	9	Academic Yr	49.50%		$15,262.83		$15,262.83
	$ 3,426	1	Summer	100.00%		$3,426.00		$3,426.00
TOTAL PERSONNEL SALARIES					**$26,192.85**	**$133,455.37**	**$80,162.61**	**$239,810.84**

BENEFITS	Benefit Rate			**2013**	**2013-14**	**2014-15**	
Personnel	Rate						Total
Tim Lipman, PhD, Assoc. Research Engineer (II-III)	15.90%	16.90%	17.90%	$846.68	$3,707.69	$2,859.53	$7,413.89
Max Wei, LBL (MLA)	36.70%	39.60%	42.90%	$1,629.48	$7,243.95	$5,714.28	$14,587.71
Corinne Scown, PhD, LBL (MLA)	36.70%	39.60%	42.90%	$1,509.31	$6,709.71	$5,292.85	$13,511.87
Anand Gopal, PhD, Asst. Research Engineer	15.90%	16.90%	17.90%	$579.56	$2,537.94	$1,957.37	$5,074.86
Post-Doctoral Researcher	15.90%	16.90%	17.90%	$1,233.76	$5,402.78	$4,420.61	$11,057.16
Madonna Camel, Research Analyst	38.00%	40.10%	42.30%	$346.10	$1,504.75	$1,226.19	$3,077.05
Graduate Student Researcher III	1.80%	1.90%	2.00%	$0.00	$485.28	$0.00	$485.28
Fee Remissions	$7,692.00	0	semesters				$0.00
	$8,241.00	2	semesters		$16,482.00		$16,482.00
TOTAL PERSONNEL BENEFITS				**$6,144.88**	**$44,074.10**	**$21,470.83**	**$71,689.81**
TOTAL PERSONNEL AND BENEFITS				**$32,337.73**	**$177,529.47**	**$101,633.44**	**$311,500.64**

OTHER DIRECT COSTS				
				Total
Subaward to LBL	$250,000.00			$250,000.00
AVL Cruise - software license ($5K) plus support for code improvements ($5K)	$5,000.00	$5,000.00		$10,000.00
Travel Expenses to project-related meetings and conference presentations		$2,000.00	$2,000.00	$4,000.00
Misc additional supplies, software, telephone, and materials	$500.00	$500.00	$361.00	$1,361.00
Rent on off-campus office space at 2150 Allston Way, Berkeley, CA	$1,050.00	$1,050.00	$1,050.00	$3,150.00
TOTAL EQUIPMENT, TRAVEL and OTHER COSTS				**$268,511.00**
TOTAL DIRECT COSTS				**$580,011.64**

INDIRECT COSTS		
Modified Total Direct Costs (MTDC)	$338,529.64	
off-campus rate	10%	
TOTAL INDIRECT COSTS		**$33,852.96**
TOTAL BUDGET		**$613,864.61**

* These rates include 7% for the employer paid contribution to the University of California Retirement Program (UCRP), effective July 1, 2011 and 10% for the employer paid contribution effective as of July 1, 2012. This charge applies to all eligible employees and is applicable to all university fund sources.