List of STEPS Projects Proposed for 2018

Project Number	Project Title	PI	Team
1	Long Term Study on Environmentally Compatible Transportation Technologies: A California Case Study	Joan Ogden	Behdad Kiani, 1 GSR
2	STEPS Summary for Policymakers	Austin Brown	1 GSR
3	Comparing Impacts of Gasoline Prices and Government Policies on the New Car Market in Different Countries	Dan Sperling	Tongxin Xu (GSR) Alan Jenn, Erich Muehlegger
4	LCFS Status Review -- California and beyond	Julie Witcover	Lew Fulton
5	Engaging Consumers in Transportation Energy Transitions	Kenneth Kurani	1 GSR
6	Technologies and Fuels to Reduce GHGs in MD/HD trucks and buses	Andrew Burke	Marshall Miller, 1 GSR
7	Expansion of the Trucking Transition Scenarios Model to the US	Marshall Miller	Lew Fulton, 1 GSR
8	4 Revolutions in Urban Freight: On-Demand Economy, Automation, Electrification, and Sharing	Miguel Jaller	Lew Fulton, Marshall Miller, Giovanni Circella, GSR and Undergraduate Research Assistant
9	A multi-model approach to generate international electric vehicle future adoption scenarios	Alan Jenn	Lew Fulton, 1 GSR
10	Analysis of Hydrogen Infrastructure Requirements for Zero Emission Freight Applications in California	Joan Ogden	Marshall Miller, Research engineer, Guozhen Li (GSR)
11	Undertaking CCPM-2 CA Scenario Comparison Project	Lew Fulton	Austin Brown, 1 GSR
12	Peak Oil Demand	Lew Fulton	1 GSR
13	LCA of light duty Electric Vehicles – examining trends in vehicle efficiency, performance and battery capacity	Alissa Kendall	Lew Fulton, 1 GSR
14	21st Century Rail Propulsion: Case Study Analyses Examining Costs and Emissions across Motive Power Technology Options	Raphael Isaac	Lewis Fulton, Paul Erickson
15	Panel Study of Emerging Transportation Technologies and Trends in California (PHASE TWO)	Giovanni Circella	Lew Fulton, Susan Handy, Dan Sperling, 1 GSR
16	Modeling the Spatial distribution of the PEV Market: Exploring neighborhood effects, incentives and infrastructure on PEV market penetration in California.	Gil Tal	Jae Hyun Lee
17	Present and Future Costs of Shared Mobility and Automated Vehicle Services, and Consumer Response to Policy Incentive Systems	Lew fulton	Junia Compostella (GSR)

Projects organized by Track

1.	**INITIATING TRANSITIONS: 2015-2030**		
1	Long Term Study on Environmentally Compatible Transportation Technologies: A California Case Study (1,4)	Joan Ogden	Behdad Kiani, 1 GSR
5	Engaging Consumers in Transportation Energy Transitions (1)	Kenneth Kurani	1 GSR
10	Analysis of Hydrogen Infrastructure Requirements for Zero Emission Freight Applications in California (1,2)	Joan Ogden	Marshall Miller, Research engineer, Guozhen Li (GSR)
13	LCA of light duty Electric Vehicles – examining trends in vehicle efficiency, performance and battery capacity (1,4)	Alissa Kendall	Lew Fulton, 1 GSR
14	21st Century Rail Propulsion: Case Study Analyses Examining Costs and Emissions across Motive Power Technology Options (1,4)	Raphael Isaac	Lewis Fulton, Paul Erickson
2.	**THE FUTURE OF FUELS AND THE OIL AND GAS INDUSTRY**		
3	Comparing Impacts of Gasoline Prices and Government Policies on the New Car Market in Different Countries (2,3)	Dan Sperling	Tongxin Xu (GSR) Alan Jenn, Erich Muehlegger
2	STEPS Summary for Policymakers (1,2,3,4)	Austin Brown	1 GSR
4	LCFS Status Review -- California and beyond (1,2)	Julie Witcover	Lew Fulton
6	Technologies and Fuels to Reduce GHGs in MD/HD trucks and buses (1,2)	Andrew Burke	Marshall Miller, 1 GSR
12	Peak Oil Demand (2)	Lew Fulton	1 GSR
3.	**GUSTo; GLOBAL SUTATINABLE TRANSPORT**		
8	4 Revolutions in Urban Freight: On-Demand Economy, Automation, Electrification, and Sharing (3,4)	Miguel Jaller	Lew Fulton, Marshall Miller, Giovanni Circella, GSR and Undergraduate Research Assistant
9	A multi-model approach to generate international electric vehicle future adoption scenarios (1,3,4)	Alan Jenn	Lew Fulton, 1 GSR
15	Panel Study of Emerging Transportation Technologies and Trends in California (PHASE TWO) (1,3)	Giovanni Circella	Lew Fulton, Susan Handy, Dan Sperling, 1 GSR
17	Present and Future Costs of Shared Mobility and Automated Vehicle Services, and Consumer Response to Policy Incentive Systems (1,3)	Lew fulton	Junia Compostella (GSR)
4.	**MAVRIC: MODELING ANALYSIS VERIFICATION, REGULATORY AND INTERNATIONAL COMPARISONS**		
7	Expansion of the Trucking Transition Scenarios Model to the US (1, 4)	Marshall Miller	Lew Fulton, 1 GSR
11	Undertaking CCPM-2 CA Scenario Comparison Project (4)	Lew Fulton	Austin Brown, 1 GSR

16	Modeling the Spatial distribution of the PEV Market: Exploring neighborhood effects, incentives and infrastructure on PEV market penetration in California. (1,4)	Gil Tal	Jae Hyun Lee

1	Long Term Study on Environmentally Compatible Transportation Technologies: A California Case Study
Team	Joan Ogden, Ph.D. (PI); Behdad Kiani, Ph.D. (Assistant Project Scientist); Student Researchers: 1 master's student
Elevator Pitch	California's Renewable Portfolio Standard goals are expected to increase fractions of variable electricity on the grid (wind and solar), increasing the mismatch between supply and demand (the "duck curve" effect which is the result of deep midday drop in net load driven by lots of solar energy flooding into the grid and a steep ramp-up in the evening when solar fades out and peak demand increases), and resulting in more curtailment of variable renewable power. In this project, we propose an integrated and comprehensive techno-economic optimization to assess prospects for both EV and Hydrogen Fuel Cell transportation technologies. We will analyze their storage capability for an appropriate demand response and their ability to lower the intermittency and duck curve variability. For this purpose, MESSAGE (Model for Energy Supply Strategies and their General Environmental Impacts) would be utilized to model generation capacity expansion up to year 2050 as an integrated systems approach to find the optimal storage technology mix that enables us meet Renewable Portfolio Standard.
Project Description	<u>Introduction</u> Reaching California's Renewable Portfolio Standards goals brings up the challenge to utilize more storage technologies to avoid more renewable curtailments. Some previous STEPS research has been performed regarding Electric Vehicles and Hydrogen energy storage via electrolysis. In this project, we will be utilizing MESSAGE to develop a capacity expansion model that looks into the economic viability of utilizing environmentally compatible transportation systems such as EVs and Hydrogen vehicles which are capable of load shifting through a smart grid system. In long-term energy planning, it is essential to see how capacity expansion would be affected by Demand Side Management, load peak shifting, and optimal mix of end-use technologies, such as storage technologies. MESSAGE is a model capable of connecting demand side to supply side and optimizing the whole system as a mixed-integer mathematical programming and looking at capacity expansion of all technologies endogenously. Our proposed smart grid model will connect the supply and demand sides, such that electrical dispatch and end-use demand are matched for an optimal grid operation. At present, Independent System Operators are dealing with increased renewable energy curtailments due to increase in load profile changes between peak and off-peak hours. Although there are some storage technologies available, such as limited pumped hydro, the requirement for larger storage capacity is costly. In this study, by techno-economic mathematical analysis, we will be looking into EV and Hydrogen technologies compared with existing systems in such a way that: 1. As the model is demand driven, in long-term energy planning, by increasing demand in different sectors, capacity expansion of technologies will be calculated endogenously by suggesting optimal mix of technologies in the long run. 2. Based on society's demand for transportation and scenarios representing future penetration of electric vehicles into the transportation fleet, by optimally controlling the vehicle-to-grid (V2G) and grid-to-vehicle (G2V) time of day usage which is in accordance with people's daily use pattern, look into policies that make EVs economically viable 3. As the demand and supply are seen in one optimal smart grid model, electrical dispatch including renewables and other supply technologies will be economically optimized such that minimal societal costs as well are reached (both for IOUs and consumers).

	4. Mass penetration of hydrogen vehicles, which enhances the utilization of electrolysis technology for hydrogen production and storage, would also be considered as a storage technology to work as load shifting for our smart grid dispatch model. 5. Different policies will be looked into which enhance the implementation of environmentally compatible transportation technologies such as carbon tax policies, emission constraints and/or societal costs of pollutions. <u>Key Questions</u> • What is the optimal capacity expansion in long-term energy planning when optimal storage system mix is chosen by the model? • Under what policy and technical conditions would EVs and/or electrolysis technology become economically viable in California's energy system to enable optimized demand response? • How much is the net grid impact effect for these technologies to solve intermittent and duck curve issues in California? • What are the hourly operational behavior and demand response effects of these technologies in California grid network if to be implemented on a massive scale • What are the long-term effects of implementation of these systems and long-term policies for becoming economically viable in the future years up to 2050? <u>Methodology</u> To reach our goals in this project, we will be utilizing the enhanced MESSAGE (Model for Energy Supply Strategies and their General Environmentally compatibility) model. The model would be developed as a long-term integrated optimization model with the ability for capacity expansion. During first stage, it works as a dispatch model to optimize California's electrical energy system considering the supply and demand on hourly basis at the first stage. At this stage, the model would work as a smart grid model and optimizing the operation of the network by optimizing the EV and Hydrogen operations on a consumer market basis. Electricity shadow prices are key parameters for the model to choose the operation that would be economically viable. During the second stage, the model structure would look at long-term integrated energy planning for electric sector and end-use technologies, suggesting economically viable paths to large scale implementation of environmentally compatible transportation technologies which can be used as storage devices for the purpose of load shifting and enabling the whole electric system for larger integration of renewable energy, diminishing the curtailment and duck curve problems.
Geographic Scope	California
Anticipated Results and Relevance	This project will help identify system-level elements that contribute to the overall feasibility of implementing large-scale hydrogen energy storage as well as quantifying the costs and benefits of such a system. These benefits may include producing low-cost zero-carbon fuel for FCEVs, generation of zero-carbon industrial feedstock, providing flexible supply and energy storage for the grid, and providing a source of low-carbon gas. Also, PEVs can be utilized as storage devices for the grid and help in peak shifting when smart grid pricing triggers V2G or G2V o according to grid needs and owner's preferences to make the best out of price changes. A win-win situation for both utilities and PEV owners.
Relevance to STEPS Consortium Members	This research will be relevant to many of the STEPS corporate sponsors (electric vehicle and hydrogen vehicle developers, electric utilities, energy suppliers) and state and national government agencies involved with low carbon energy systems, who have the potential to benefit from further study of zero-carbon energy storage technologies.
Additional Research Plans	In the future, the project could be expanded beyond California to examine the potential for EV and Hydrogen vehicles used for peak shifting in other regions of the U.S. and internationally.

2	STEPS Summary for Policymakers
Team	Austin Brown (PI); 1 GSR
Elevator Pitch	Each of the 16 STEPS3 projects contains findings that are relevant to policy makers in different organizations. There are also likely to be findings from combined insights that might be missed in the individual projects. This project will ensure that the findings from each project are translated to forms useful for the policy community, and create a summary for policymakers of the STEPS program so far. The project would also include convening small workshops on the findings with the policy community to inform future STEPS projects. The summary for policymakers would be used as the introductory material for the STEPS3 book.
Project Description	<u>Background</u> STEPS3 is wrapping up, with 16 successful projects spanning four key thematic tracks (initiating transitions, future of fuels and the oil industry, global urban sustainable transport, and modeling analysis, verification, regulatory, and international comparisons). Each research project has associated publications and impacts, and many projects address policy-related topics – but often for different policy communities. There is a key opportunity to amplify the policy impact of these projects and of the STEPS program overall. <u>Key Research Questions</u> What are the findings for each paper that are most critical for policymakers to understand? Are these findings already communicated?; If not, how can they be translated and conveyed to the right people? What are the most significant findings across the research projects that would inform the policy process? For each theme, what are the key policy outcomes? Which specific policymakers need to understand which findings, and what recommendations emerge? How can the policy community best engage on planning for STEPS4? <u>Significance</u> If successful, this project will amplify the policy impacts of the STEPS program and increase the appeal and visibility of the program overall. Policy impact is at the core of the STEPS mission statement, and this aggregation, summary, and communications task will help achieve the most impact from the program. At the ITS Board of Advisors meeting, several members called for clear policy outcomes from STEPS. <u>Methodologies</u> *For the Summary for Policymakers:* 1. Identify key stakeholders overall for the STEPS projects, including sponsors and others in the policy and business communities. 2. Explore key findings from each project and develop into policy recommendations 3. Structure policy recommendations by customer, such as legislatures, state executive agencies, local governments, companies. 4. Draft a summary document with the top findings *Convening Activity:* 1. Identify key policy and business stakeholders, likely via the STEPS stakeholders 2. Hold a side workshop or session in the STEPS symposium with a focus on policy impact and summary outcomes 3. Brief attendees on draft findings and policy outcomes, 4. Identify key policy needs to inform STEPS4 *For Individual Projects:* 1. Work with PIs to identify top policy-relevant findings 2. Identify past policy uses and impact 3. Where appropriate, identify additional possible policy uses 4. Work with PIs to develop additional policy briefs or other policy-relevant materials where appropriate
Geographic Scope	Varies by project
Anticipated Results and Relevance	This project would increase the impacts of each of the STEPS3 projects, and the STEPS program overall. The project goal is to measurably increase policy uptake of STEPS3 findings and build excitement for STEPS4.
Relevance to STEPS Consortium Members	This project is relevant to consortium members because it will translate the work that they have funded into format and forms that are more useful for influencing policy.
Additional Research Plans	I anticipate this could become a replicable model for STEPS4 projects. We will document the impact of the activity to explore the value added from these sorts of outreach activities.

3	Comparing Impacts of Gasoline Prices and Government Policies on the New Car Market in Different Countries
Team	Tongxin Xu; Alan Jenn; Erich Muehlegger
Elevator Pitch	Low gasoline prices lead to higher sales for less efficient vehicles, which consumes more gasoline for a long run. We investigate how and why this effect varies from country to country. With the fuel price data, sales data and spec data collected, we are also able to test impacts of some policies that try to improve fuel efficiency of vehicles sold.
Project Description	<u>Introduction</u> Within the transportation field, the elasticity of vehicle sales with respect to gas price has always been a key issue. Even though emissions from vehicles could be affected by how much people drive, the fleet composition in terms of fuel economy might have bigger impacts on GHG emission and energy consumption in the longer run since it is in general difficult for people to reduce driving within several years. However, it is controversial whether consumers fully consider the fuel cost when buying cars (Greene 2010). If people fully incorporate the calculation of future fuel saving when making purchasing decision, then there is no need for any government intervention on the new car market, a fuel tax would be sufficient to incorporate the negative externality for automobiles and motivate people to make rational choices. If not so, then intervention over car purchasing like a feebate system or CAFE is needed. There is a large body of literature investigating how people value fuel economy when buying new cars (Helfand & Wolverton 2011). However, existing studies show different estimation of how people value fuel saving. Some show underestimation and some show overestimation or about correct estimation. Could it be that this is related with cultural differences across different regions and different demographic groups? A European study (Grigolon, Reynaert, and Verboven 2014) shows correct estimation while a U.S. study (Train & Winston 2007) shows underestimation might just be due to the fundamental difference in purchasing behavior of durable goods in the two countries. Besides, there have not been any vehicle demand analysis using revealed preference data for many developing countries yet. On the other hand, many countries have had policies aiming at using tools like tax and fees to improve fuel efficiency. However, some are not directly differentiating based on fuel efficiency, but instead target specifications like engine displacement. This is a controversial approach now since turbo-charging engines and Atkinson cycle engines are more common, and engine displacements are not that consistent with air intake, power output and fuel efficiency any longer. The policy might not be as effective as expected. This study for the first time will compare the responsiveness of automotive market to gasoline price shocks in different countries. The study then discusses possible causes of the international differences in sensitiveness to gasoline prices. While analyzing and comparing the purchasing behaviors in different countries, this study also helps to understand how automotive sales in different countries are affected by different factors. It also uses the gasoline price and sales data to identify the effect of certain policies on fuel efficiency of the new vehicle sold. <u>Key questions</u> • What are existing literature like in this field of studying relationship between automotive sales and fuel cost? Why do some studies show underestimation or even indifference of future fuel cost while some others show correct estimation? • How are different factors affecting car-purchasing choices differently in different countries, using revealed preference data? Are car buyers in different countries responsive to gasoline price shocks differently? • If different automotive markets have different levels of sensitiveness to gasoline prices, what are the possible causes of these differences? Do people in certain countries tend to under-evaluate future fuel savings more than in others? Are these differences on the supply side important? Is this also related to government policy? Or to how vehicles are sold? • What impacts did policies that intend to improve fuel efficiency have on the vehicle market? <u>Methodology</u> • Discrete choice model (multinomial logit) studying how different vehicle attributes and gasoline prices are valued by consumers • Hedonic regression of vehicle sales on gasoline prices based on panel data while other vehicle attributes are controlled • Regression sales-weighted average fuel efficiency of the entire country on gasoline prices, with socio-economic characteristics and auto policy and auto business differences controlled <u>Data</u> • IEA/IHS trim-level by country by year vehicle sales data matched to vehicle attributes; make & model level by country and by month data published by different countries.

Geographic Scope	Global (more details for China)
Anticipated Results and Relevance	• Lower gasoline price motivates people to buy more less efficient vehicles • Automobile consumers in different countries possibly have very different valuation of fuel costs • Many factors affect how an automotive market respond to gasoline price shocks • Some policies intended to improve fuel efficiency might not get the expected result, for instance the tax rate differentiation based on displacement-related tax
Relevance to STEPS Consortium Members	This study will help global automakers to better understand consumer behaviors in many countries that have not been studied with an advanced approach like the discrete choice model. It will also help governments to better understand how effective policies targeting fuel prices or fuel taxes could be, and what effects are like for other forms of taxes like engine displacement tax. This possibly will help with decision-making for regulation of the automobile industry in the future.

4	LCFS Status Review – California and Beyond
Team	Julie Witcover; Lew Fulton
Elevator Pitch	Carbon intensity standards like California's Low Carbon Fuel Standard are increasingly being turned to especially in North America to catalyze the decarbonization of transportation fuels through new technologies. What is the track record for jurisdictions that have instituted such policies and what is their outlook moving forward, given controversies and slow development of breakthrough low-carbon biofuels and excitement over electric vehicles?
Project Description	<u>Background</u> California adopted the Low Carbon Fuel Standard (LCFS) as a performance-based regulation requiring at least a 10% reduction in carbon intensity (CI) of the California transport fuel mix by 2020 from 2010 levels, as part of California's overall climate policy. The program has served as a model for similar programs in other jurisdictions, on the Pacific Coast of North America (Oregon and British Columbia) and under development elsewhere in Canada (nationwide policy, Ontario program). The policy works through a market mechanism to incentivize sufficient alternative supply to meet targets at lowest cost, and typically involves ambitious targets meant to drive technological innovation in the alternative fuel market. Policy design differs somewhat between jurisdictions, and the joint impact on fuel flows and development of multiple programs is not yet well understood. <u>Key research questions</u> What is the compliance status for California's LCFS and other similar programs, in terms of credits vs. deficits generated? What are the key characteristics (technology, carbon intensity) of the fuels appearing in the program? What are the trends in the incentive provided by the program via the LCFS credit market? What other factors (legal, other policies or conditions) affect LCFS compliance in important ways? What is the outlook as additional jurisdictions adopt similar programs? <u>Significance</u> The report to date has been used by a variety of stakeholders to track trends in California's LCFS, including state agency personnel involved in planning other state transportation incentive programs to meet climate goals. The project will look to perform similar functions in other LCFS jurisdictions, and in particular explore trends in biofuels. <u>Process/methodologies/models</u> Graphical representation of key program indicators. The data are synthesized from secondary sources; the analysis uses straightforward (spreadsheet-based) calculations. The value-added is improving data transparency through synthesis and analysis, and providing context from relevant regulations and outside conditions needed to interpret data trends. We will develop a common spreadsheet framework for jurisdiction compliance that encompasses some of the program design differences, for exploring scenarios. <u>Deliverables</u> 1 White Paper on Low Carbon Fuel Standards, in addition to 1 Status Review report (which may be a section of the white paper.
Geographic Scope	California, Oregon, British Columbia, potentially other Canadian provinces
Anticipated Results and Relevance	More tightness in low carbon fuel markets is expected as additional jurisdictions adopt programs and stringency increases. A weakening of the federal RFS could put additional upward pressure on credit prices. The unknown is how technology will respond at these incentive levels, especially given the other complementary measures that push particular low-carbon transport solutions.
Relevance to STEPS Consortium Members	Consortium members of all kinds have an interest in understanding the development of the low carbon fuels markets as input into decision-making (e.g., investment, policy)
Additional Research Plans	This project is likely to continue in some form beyond STEPS3, given the LCFS' growing importance as a low-carbon transportation fuel policy. The project complements technical support provided for Pacific Coast Collaborative jurisdictions and Canada on their climate policies, under separate funding.

5	Engaging Consumers in Transportation Energy Transitions
Team	Kenneth S. Kurani; GSR IV to be named
Elevator Pitch	Why are so few California households paying any attention to electric vehicles? Battery electric and plug-in hybrid electric vehicles have been for sale in California since late 2010; more makes and models are introduced every year. The number of places these vehicles can be charged has increased from tens to thousands. California leads the country in a transition to electric vehicles. It has spent over $440 million on rebates to vehicle buyers and $100s of millions more to support electric vehicle charging. But if so few households are paying attention in California, what are the prospects for other states? This study summarizes what has been learned about consumer engagement in the transition to electric transportation in California, extends that understanding to other states and to other possible transportation energy transitions.
Project Description	<u>Background</u> Electrifying light-duty transportation is a key strategy in reducing greenhouse gas and criteria pollutant emissions. California, many other states throughout the nation, automakers around the world, regional electric utilities, electric vehicle supply equipment suppliers, non-governmental organizations devoted to social and environmental causes, and many other stakeholders are actively facilitating this transition. California continues to incentivize purchases of vehicles that earn zero emission vehicle (ZEV) credits, i.e., plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs). It also continues to spend to incentivize growth of electric charging and hydrogen fueling networks. Other states—most notably those that have adopted California's ZEV standards and ZEV sales requirements—have more recently begun to spend public funds to incentivize ZEVs. ZEV offerings—primarily PHEVs and BEVs—from vehicle manufacturers continue to increase in variety of driving ranges and body styles; and prices continue to decline. Despite all this, there has been no increase in the proportion of the population of car-owning households that is engaged in this transition in any meaningful way. Surveys of car-owning households in California in June 2014 and June 2017 (as well as additional surveys in between) show no increase in the percent of respondents have already considered a vehicle that runs on electricity. Whatever else stakeholders are doing, they appear to be failing to grow the potential market for ZEVs. <u>Key Research Questions</u> Research to date indicates several causes and consequences of this failure to engage an increasing consumer base in a transition to electric transportation in California. This knowledge should be collected and summarized in a form accessible to decision makers across the spectrum of stakeholders. Further, because the strongest knowledge base is in California and because the transition to electric transportation can be viewed as regional, multi-state, national, and international phenomena, the basis for generalization of those learnings beyond California should be strengthened. This may be summarized as these key research questions: 1. What is known about consumer engagement in the transition to electric transportation in California? 2. How do other states in the U.S. compare? 3. How can stakeholders in in this transition use this information to recruit a larger base of consumers into this transition? <u>Significance</u> The State of California—and by extension all states with ZEV sales goals—are at risk of failing to meet ZEV sales goals. Governor Brown has called for 1.5 million ZEVs on-road in California by 2025. Compared to that goal, the PEV Collaborative estimates total sales of PEVs from the end of 2010 to 5 Oct. 2017, are 334,393 (http://www.pevcollaborative.org accessed 10 Oct. 2017). (PEVs dominate ZEV sales to date; 0nly 2,074 California Clean Vehicle Rebates have been paid for FCEVs in the same period. Also, it is notable the PEV Collaborative's estimate does not include vehicle retirements: over time, estimates of sales will increasingly overestimate the number of on-road vehicles.) The rising trajectory of ZEV sales in CA easily fits within the estimated 5% of all car-owning households (~550,000 households) who already own a PEV or seriously shopped for one. Achieving the Governor's goal—itself only a first milestone in a transition toward complete electrification of transportation—will require recruiting the whole population of car-owners. <u>Methodology</u> The study will deploy two primary methods: 1. Critical review and summary of prior work on consumer engagement with PEVs; and, 2. Interviews with buyers of ICEV/HEV/PEV variants of vehicles offered as both non-PEV and PEV in states outside California. a. Interviews will be conducted via the Internet using Skype, Zoom or other Voice over Internet Protocols (VoIP) that allow recording the interviews. The interview project design builds on the STEPs 2016 project: A Quasi-Experiment in Consumer Choice of Conventional and Alternative Fuel Vehicles. Sampling will match households on several measures, leaving the major difference between households the drivetrain variant of a recently purchased vehicle. Consumers in at least three states will be interviewed. Three vehicle-pairs will be selected; six households will be selected for

	each vehicle in the pair. Thus, the total number of interviews will be 3 states x 3 (vehicle-pairs) x 6 (households per vehicle-pair) = 54 interviews. Project personnel have developed the general interview methods as well as many of the specific elements of the intended interview design. Specifically, the interviews move from purely inductive storytelling to directed questioning regarding the existence and role of choice set formation: 1. History of all vehicles, major lifestyle and travel stages 2. Narrative of the most recent and other important vehicle purchases. 3. Prospect future purchases, i.e., how do households imagine they would conduct a future purchase? 4. (If necessary) Specific directed questioning about whether and how the household compared variants of the make-model they purchased. Two new topics will be added to the 2016 interview protocol based on questions from stakeholders (one policymaker, one automaker) asked at the 9 Oct. 2017 research briefing for the ITS-Davis Board of Advisors: 1) the visibility (or invisibility) of automotive OEM marketing of PEVs, and 2) households' response to the increasing number of bans of ICEVs instituted by cities and nations around the world and being discussed by California. Deliverables 1. Report on consumer engagement in states other than California. 2. White paper summarizing what has been learned since 2014 about consumer engagement in the transition to electricity and hydrogen (in the form of PHEVs, BEVs, and FCEVs), including the new results from other states in 2018.
Geographic Scope	California and other U.S. states in which plug-in electric and fuel cell electric vehicles are now for sale
Anticipated Results and Relevance	Anticipated research results are three-fold: 1. Placing the trajectory of PEV sales into context with the research conducted to date at ITS-Davis and by researchers around the world. These results explain who is buying PEVs and who is not—and more importantly how many people are not even asking themselves the question of whether to buy a PEV. 2. Extend the results of a project from STEPs 2016 on buyers of ICEV/HEV/PEV variants of vehicles from California to other states. Those findings documented the lack of engagement with PEVs of ICEV buyers: no recognition that the vehicle they bought was also available as a PEV, no knowledge of incentives or charging, incorrect perceptions of the capabilities of BEVs and no understanding of how PHEVs work. Will we find the same in other states (a year later)?
Relevance to STEPS Consortium Members	This research is directly relevant to most STEPs sponsors and at least indirectly relevant to the rest. It is directly relevant to all regional, state, and national environmental and energy agencies, all automakers, and electric utilities. It is at least indirectly relevant to all the energy companies as they navigate possible futures of increased electrification, including hydrogen to support FCEVs.

<table>
<tr><th>6</th><th>Technologies and Fuels to Reduce GHGs in MD/HD Trucks and Buses</th></tr>
<tr><td>Team</td><td>Andrew Burke; Marshall Miller</td></tr>
<tr><td>Elevator Pitch</td><td>In order to reduce both criteria pollutants and GHGs, ARB is proposing a ZEV mandate for trucks and buses. Details of a ZEV proposal depend critically on understanding various issues related to ZEVs, plug-in hybrids, and other relevant technologies. These issues include vehicle design, fuel economy, cost, commercial readiness, and fueling infrastructure. We would work closely with ARB (Tony Brasil’s group) to compare ZEVs and plug-in hybrids with other truck and bus technologies and to evaluate ARB’s work supporting the mandate.</td></tr>
<tr><td>Project Description</td><td><u>Introduction</u>
California is instituting regulations to greatly reduce greenhouse gas (GHG) emissions from all types of vehicles, including transit buses and medium/heavy-duty trucks. There are a number of advanced technologies that can be used in medium/heavy-duty vehicles to reduce their emissions by large factors. These technologies include battery electrics, hydrogen fuel cells, plug-in hybrid electrics, electrified roadways, and dual fuel/diesel/biogas engines. Each of these technologies has a significant effect on the capital and operating costs, the utility of the vehicle, and the cost and utility of the refueling infrastructure in comparison with the corresponding costs and utility of conventional diesel engine vehicles. During the past several years, we have studied in detail these various technologies and written reports and papers summarizing our findings. There are still a number of issues remaining to be evaluated in order to systematically compare the different advanced technologies in terms of their capital and operating costs, utility, and fuel and infrastructure costs. All of these issues will influence marketing of the various technologies in the truck and bus sector and what public policies are likely to result in their rapid commercialization. Special attention will be given to issues associated with establishing a ZEV Mandate for medium/heavy-duty trucks and buses.

It is convenient to divide the tasks to be undertaken in this project into five categories associated with the various advanced vehicle technologies. The categories are listed below along with specific tasks associated with each.
Fuel cells/hydrogen (both buses and medium/heavy-duty trucks)
1. Powertrain optimization (size fuel cell and battery)
2. Fuel cell performance and cost (present and future)
3. Trade-offs in the design of cryo-compressed hydrogen storage on-board the vehicles
4. Design and cost of hydrogen refueling for heavy-duty vehicles

Battery/electric (buses and medium-duty trucks)
1. Heavy-duty battery performance and cost (present and future)
2. Powertrain optimization (sizing the battery and electric motor)
3. Battery recharging options including along route charging
4. Plug-in hybrid designs using fuel cells for range extension

Hybrid- electric medium-duty and short-haul trucks
1. Heavy-duty power battery performance and cost (present and future)
2. Powertrain optimization (sizing the battery, electric motor, and engine)
3. Plug-in hybrid designs using fuel cells for range extension

Electrified roadways
1. Updated comparisons of vehicle dynamic electrification and catenaries
2. System costs and comparisons with alternatives

Dual-fuel diesel engine trucks using bio-diesel and bio-gas
1. Engine efficiency and emissions using bio-fuels (exhaust pollutants and CO_2)
2. Engine costs (present and future)

For each vehicle option, we will use the tasks described above to understand vehicle costs, fuel economies, and commercial readiness. We will then compare these advanced technology options with present commercial vehicles. A critical component of the research will be to understand whether ZEV and plug-in hybrid trucks and buses can be cost competitive and meet application requirements including fueling infrastructure in timeframes considered for a ZEV mandate. Further, we will evaluate which truck and bus applications are most suitable for ZEVs and plug-in hybrids, and what percentage of market penetration is appropriate. We will identify barriers to ZEV commercialization and try to understand solutions to overcome those barriers. We will also work with ARB to help validate their data and assumptions relative to a potential ZEV mandate.
<u>Key Questions</u></td></tr>
</table>

	1. What is the present status of these advanced vehicle and energy storage technologies as they apply to trucks and buses, and what improvements in the technologies are expected/needed in the future to better fit truck and bus applications? 2. What are the challenges in providing appropriate fueling infrastructure for trucks and buses especially for sustainable hydrogen? 3. What will be the performance and fuel consumption of advanced technology "supertrucks"? 4. What are the best technology choices for the energy storage component with fuel cells and what are their performance and cost characteristics? 5. What component costs are needed to make the economics of advanced technology trucks and buses comparable to diesel and natural gas fueled vehicles? 6. What can be learned from the experiences with fuel cells and batteries in buses in the U.S., China, and Europe that is applicable to heavy-duty freight vehicles? 7. How can a ZEV Mandate for MD/HD vehicles be structured and what sales fraction requirements for battery electric and fuel cell powered trucks in the various truck type categories make sense for 2020-2050?
Geographic Scope	California, U.S., China
Anticipated Results and Relevance	We anticipate that our research and the results attained will lead to detailed optimal paper designs of advanced technology vehicles for various applications. The research will inform regulatory agencies and OEMs about the potential for advanced technology vehicles to meet a ZEV mandate.
Relevance to STEPS Consortium Members	This project will be of great interest to a number of consortium members who are involved with MD/HD regulations and/or products as they consider the near- and far-term future of advanced technology trucks and buses. These members include ARB, Caltrans, CEC, DOE, EPA, Volvo, Cummins, Daimler, Westport, GM, Ford, etc.
Additional Research Plans	This research would be part of ongoing research at ITS on MD/HD advanced vehicles for freight and passenger travel. In addition, the use of hydrogen as a fuel and energy storage medium will become increasingly important in future years and our research will support those developments. We expect to become part of the ARB and CEC programs devoted to hydrogen fuel cell vehicles and truck and bus ZEV mandates.

7	Expansion of the Trucking Transition Scenarios Model to the U.S.
Team	Marshall Miller; Lew Fulton; GSR
Elevator Pitch	In the Transition Scenarios project, we created a transparent scenario-modeling tool and multiple transition scenarios in order to explore the future of transportation vehicles and fuels in California. This project will expand the focus from California to the entire U.S. and continue to incorporate much of the more detailed work that is being done across the STEPS program to help explore the potential implications of specific changes in technology, costs, and availability across resources, fuels and vehicles.
Project Description	<u>Introduction</u> This project will bring together inputs from a wide range of STEPS research activities to better understand the costs over time to transition from the current transportation system to a heavily decarbonized transportation sector. The 2017 project focused on developing the modeling framework and approach for alternative vehicle adoption and fuel infrastructure and applied it to the state of California. This project will continue that work and expand the geographic scope of the model to the entire United States for the trucking sector. These scenarios will include a reference (baseline) scenario as well as several decarbonization scenarios that take into account GHG reduction policy goals. The study results will show trucking fuel consumption, vehicle stock, emissions, and costs for each scenario, and the changes in fuel consumption, emissions and costs can be assessed across vehicles and fuels (via efficiency, advanced technologies, and fuel switching). The project will also track the development of fuel supply infrastructure via an infrastructure stock model. Results will also show the calculation of incremental costs for carbon mitigation. The project will span the 2015-2050 time horizon but will focus particular attention on the details of transitioning from 2015 to 2030 as part of our "critical transition dynamics" four-year program. The Transition Scenarios model is a stock-turnover spreadsheet modeled after the ARB VISION model which tracks vehicle stock, fuel consumption and emissions as a function of vehicle sales and technical characteristics. The model contains a fuels module that inputs fuel demand from the vehicle spreadsheet and calculates the number of fueling stations, number of fuel production facilities, and cost for advanced fuels. The model outputs total fuel consumption, GHG emissions, and costs for both vehicles and fuels for each scenario from the present through 2050. <u>Tasks</u> 1. Update model to incorporate data for the trucking sector in the U.S. DOT nine national regions. This task will utilize NEMS trucking sector data for the nine U.S. DOT regions. The current CA based spreadsheet will be expanded to the nine regions using the stock, VMT, and fuel economies from the NEMS data. Each region will have eight truck classes and a range of technologies including diesel, gasoline, natural gas, hybrid, battery electric, and fuel cell. 2. Update the fuels model for the U.S. DOT nine national regions. The current fuels module was developed for California. This module will be expanded to represent each of the nine U.S. DOT national regions. Researchers will investigate differences between the regions to understand how fuel production may vary. Fuel feedstocks and carbon intensities may vary significantly across the regions. 3. Create scenarios to explore potential market penetration of new technologies and fuels. A variety of market penetration scenarios will be developed. These scenarios will include at least a business as usual, one or more scenarios with significant ZEV (either battery electric or fuel cell) penetration, and a scenario with a high percentage of biofuels. Comparisons will be made between scenarios to understand the effect of market penetration of advanced technologies and fuels. We will analyze the cost of significant decarbonization in the trucking sector vehicles and fuels. Costs will be calculated year by year from the present out through 2050. These costs include vehicle capital costs, fuel costs, and infrastructure costs. <u>Key Research Questions</u> • Which technology/fuels scenarios produce the lowest overall cost and emissions reductions for transitions through 2050 in the US? • Does focusing on particular technologies in the near term provide better overall cost reductions in later years (2030-2050)?

	• How do different assumptions on technology cost reduction affect total costs and the desirability of different pathways? • How do these scenarios and results differ with different assumptions about uncertain parameters including technology costs or emissions? • How do U.S. regional differences in the trucking sector affect the various scenarios and paths to decarbonization? <u>Value of This Research</u> This research will expand the trucking sector portion of the Transition Scenarios model to the entire U.S. and help understand realistic scenarios for vehicle and fuel-related transitions that are needed to meet climate change goals. The results will estimate overall cost for these transitions. The change in technology adoption and fuel production capacity and the related increase in costs for these scenarios which meet 2050 GHG goals for the U.S. may be significant. Understanding the actual expected funding requirements can help governments prepare properly to provide necessary incentives to start and continue the transitions. Comparing scenarios on the basis of cost can help governments, NGOs, and the private sector decide which scenarios to initiate and focus on.
Geographic Scope	U.S.
Anticipated Results and Relevance	Results will include overall cost and fuel use for a variety of trucking technologies and fuels scenarios. These results will help understand potential differences in the nine regions, and how policies can appropriately target each region.
Relevance to STEPS Consortium Members	This work will be of wide interest to all consortium members interested in better understanding how advanced vehicle technologies and fuels can meet GHG reduction goals.
Additional Research Plans	This research combines STEPS efforts in many areas. STEPS researchers are currently working on almost all the vehicle sectors (LDVs, HDVs, Rail, Air) and all the vehicle technologies (Conventional, Hybrid, NG, BEV, FCEV) as well as scenario and system optimization tools (CA-TIMES, US-TIMES). This research would use inputs from all these research areas. As researchers update their knowledge in any or all of these areas, the results from this study may be updated to give the more current outputs.

<table>
<tr><th>8</th><th>Four Revolutions in Urban Freight: On-Demand Economy, Automation, Electrification, and Sharing</th></tr>
<tr><td>Team</td><td>PI: Miguel Jaller, Lew Fulton, and Marshall Miller; Other Personnel: Giovanni Circella; Students: GSR, TBD; Undergraduate Research Assistant</td></tr>
<tr><td>Elevator Pitch</td><td>The 3 Revolutions in light-duty vehicles and personal travel are a very popular concept. The excitement has extended to the heavy-duty sector, with the advent and news about zero emission heavy-duty trucks, buses, and other equipment. However, the implications for urban freight and logistics have been overlooked. This research wants to fill this gap by analyzing the 3Rs in urban freight and the fourth revolution that is reshaping how businesses operate, their logistics patterns, and how consumers are behaving: On-demand Economy.

The research will conduct a review and describe the current state of affairs for urban freight in the context of automation, electrification, and sharing, and develop a tool to quantify the impacts of the on-demand economy in shopping/consumer behavior, and logistics and supply chain patterns. Specifically, the tool will assess changes in passenger and freight travel, and identify opportunities and issues brought about by the on-demand economy.</td></tr>
<tr><td>Project Description</td><td><u>Introduction</u>

The growing interest in automation, shared mobility, and electrification (3Rs) has mostly focused on light-duty vehicles and passenger transportation. Additionally, major vehicle manufacturers have invested great resources in the development of heavy-duty trucks that adopt some of the characteristics considered in the 3Rs. On the contrary, the urban freight transportation system (UTFS) has been overlooked, and it constitutes the next frontier for the penetration and development of such technologies. The UTFS is very complex, and, in many cases, it is an inefficient system. However, companies have tackled into the technological and information advances to improve their operations driven by the on-demand economy or fourth revolution needs and requirements. This fourth revolution has pushed companies to find innovative ways to deal with issues such as availability of parking/staging areas; access to the curb side; access to the buildings/stores/houses; readiness of the receiver (customer); type and number of other logistics activities that have to be conducted during the transaction; presence of information and systems; availability of fueling/charging stations; safety/security requirements; type of commodity/ shipment size/weight; and delivery service/frequency, among others. Consequently, they have tried solutions involving the use of shared mobility services for the distribution of goods; maximizing asset utilization through load balancing and matching; the use of un-crewed (remotely controlled/guided or autonomous) vehicles (e.g., drones, pods); the implementation of alternative fuel technologies; improvements at logistics facilities; and new types of pricing and delivery services. However, there is a lack of a clear overview of their success and the system impacts of these efforts.

Moreover, the fourth revolution have also affected passenger travel and consumer behavior. Last year, e-commerce retail sales accounted for $394.9 billion or 8.1% of total retail sales, a 15% increase from 2015, and the projected growth is expected to reach 25 billion parcels annually over the next ten years. The impacts of online shopping fall on different spheres. On consumer activity and travel behavior, the impacts relate to potential decisions making changes in the short-, medium-, and long-term regarding location of residence, lifestyle, car ownership, modification, substitution or complementary effects of online and store shopping and travel, among others. Table 1 summarizes the findings from recent research about the net transportation impacts. The results are mixed, with some authors finding positive and others negative traffic, environmental, and energy effects.

Table 1: Substitution or complementary impacts of online shopping
<table>
<tr><th>Impact</th><th>Reference</th></tr>
<tr><td><u>Substitution</u>
E-commerce shopping time -> Reduces store travel time, trips and travel distances (-)</td><td>[6]</td></tr>
<tr><td>Complement
Store shopping -> Influences online shopping (+)
Online searching -> Make more short shopping trips (+)
Product choice has deferent shopping patterns</td><td>[7]</td></tr>
<tr><td>Substitution/Complement
City center attractiveness (+) -> Online shopping (-)</td><td>[8]</td></tr>
</table></td></tr>
</table>

Complement Online searching -> Increases online (+) and store shopping (++, 0.189) Online shopping -> Influences store shopping (+, 0.153)	[9]
Substitution/Complement Online shopping -> Encourages store shopping trips (+) Store shopping trips -> Reduces online shopping (-)	[10]
Substitution has positive impact Online shopping -> can reduce traffic congestion from store shopping but the latter has a better utility (immediate possession, customer service, etc.) (-)	[11]
Substitution has positive impact Online shopping -> has lower energy consumption compared to traditional store shopping supply chains (-)	[12]

Source: Adapted from [10]

On freight and logistics systems, online channels reduce, in general, transaction costs, which leads to an increase in the purchasing power of consumers and thus, their demand. More and more e-retailers are increasing the level of service to attract more customers and compete with other companies. This creates new configurations in the transportation and delivery systems that respond to higher frequencies, faster deliveries, adapting freight vehicles to enter residential areas, reverse logistics, induced freight traffic demand, location of distribution centers near customers, consolidation and cooperation with other stakeholders. Companies have implemented automated systems to increase the agility and efficiency of their warehousing activities, and developed sophisticated data analytics systems based on new artificial intelligence and machine learning to automate processes and optimize the flow of goods and information. Table provides a high-level comparison between traditional retailing and online retailing in terms of logistics impacts.

Table 2: Comparison between traditional retailing and online commerce

	Traditional retailing		Online retailing
	Retail stores (inbound) delivery	In-store consumer purchase	
Purchase frequency	Low/Medium	Low/High	High
Volume or quantity	Large quantities	Medium/Small q.	Smaller quantities
Goods flows	Product and goods are delivered to retail stores and customers buy them there		Delivered to the customer (home, work or other
Supply chain	Push demand	Push demand	Pull demand
ICT	B2B information to fulfill inventories (ERP)		B2C information and tracking of orders -> B2B
Delivery trucks/vehicles types	Larger trucks or trailers	Passenger vehicles	Medium/smaller trucks/vans, bicycles/walk
Maximization of space (FTL/LTL)	Full Truck Load (FTL) (homogeneous loads)	(heterogeneous loads)	Less than truck load (LTL) (hetero loads)
Location of delivery points	Urban and suburban	Urban and suburban	Residential, urban and highly dense areas
Tours	Few/One stops	Few/One stops	Many stops
Delivery failures	N/A	N/A	Many/Few

Source: Adapted from [4]

Overall, the fourth revolution has reshaped traditional retailing and consumer behavior, and the UTFS system have seen advances in the penetration of automation, electrification, and sharing mobility applications.

The objective of this research is two-fold: 1) conduct a review and inventory of the publicly proposed, implemented or pilot tested 3R applications to improve the UTFS at the private and public sector levels; and, 2) develop an approximate simulation tool to evaluate the impact of the fourth revolution through a combination of impact scenarios: consumer shopping and searching behaviors, traditional vs. online shopping, and induced demand. The team believes that a thorough understanding of the impacts of the on-demand economy will provide the basis for the evaluation of innovations in the 3R space.

Key Questions

	• What is the current state of innovation and practice to improve the UTFS in the context of the 3Rs? • What could be the benefits and/or unintended consequences of revolutionizing (4Rs) the UTFS? • What have we learned from implemented/pilot tested innovations? • What are the net impacts on vehicle miles traveled from the on-demand economy with respect to e-shopping? • What are the vehicle and fuel technologies most appropriate to mitigate potential negative impacts? • What are the transition scenarios to achieve a sustainable urban system considering the impacts on consumer travel behavior and urban freight under the 4Rs? <u>Methodology</u> For the analysis and inventory of the 3Rs applications in UTFS, the team will conduct a review of the research, proposed concepts, and pilot tests. The team will synthesize the findings and identify key lessons learned. The team will create a semi-structured database containing the publicly available information regarding the different 3R applications. Moreover, a web page will host a user-friendly version of the data for public access. This database will lay the ground of the current state of innovation and applications. Further research could explore them in more detail for specific industry sectors such as retail or food, to describe and identify the challenges and opportunities for efficient improvements. To develop the proposed model, the team will conduct research activities on two fronts. 1) Shopping and consumer behavior: the team expects to conduct a comprehensive literature review to identify the models in the literature that could help estimate the generation of freight and passenger shopping trips. The team will build on ongoing work that has summarized relevant research findings of the impact of e-commerce in terms of trip substitution and complementary effects. In addition, the team will use the 2016/17 National Household Travel Survey data to estimate econometric models for both regular and online shopping patterns based on socio-economic characteristics. 2) Supply chain structures, and last mile vocations: The team will build on previous research that analyzed the spatial location of warehouses and distribution centers, as well as the density of commercial activity in an urban area. The team will concentrate on the San Francisco Metropolitan Area for the analyses. Moreover, the team will use the shopping Origin-Destination matrices available in the MTC Activity Based Model as the base case, and modify the shopping travel demand, based on the online shopping estimated models. The team will design a number of scenarios to estimate changes in vehicle miles traveled, and environmental emissions impacts that result from the relationship between shopping trips and online shopping.
Geographic Scope	World with emphasis on California
Anticipated Results and Relevance	The work will 1) list and describe the innovations and application of the 4Rs in the UTFS; and 2) estimate travel impacts from a set of scenarios determined by changes in consumer behavior, supply chain structures and logistics services resulting from the on-demand economy.
Relevance to STEPS Consortium Members	The research is relevant to all consortium members. The simulation model developed will help evaluate different scenarios that involve trade-offs between passenger and freight traffic which constitutes a critical input for the assessment of both transportation services, vehicle type/specifications and markets. The results also have important policy and planning implications because they provide insights into the changing urban environment and how the freight system and passenger travel interact.
Additional Research Plans	This project will provide a much-needed simulation model for the evaluation of the impacts of different policies, or improvement scenarios for the urban freight system. It is a critical piece among the other freight-related projects and will provide a dynamic simulation/modeling framework.

9	A Multi-Model Approach to Generate International Electric Vehicle Future Adoption Scenarios
Team	Alan Jenn; Lew Fulton; 1 GSR
Elevator Pitch	In 2016/2017, the first phase of this study was undertaken, including a major data acquisition and analysis phase, and the development of three alternative model specifications which were then used to project EV sales to 2040. The modeling effort provided important insights into factors that impact the decision to buy EVs as well as how much various "drivers" of sales would have to change in the future, but it also had some shortcomings, such as data only through 2015. This second year effort will provide important improvements and a deeper set of insights into the development of international EV markets.
Project Description	The goal of this work is to understand the factors driving EV sales in countries around the world such as characteristics of the vehicles, their availability in different market segments, policy mechanisms, infrastructure requirements, and consumer behavior to see how scenarios of these variables can be leveraged to understand how electric vehicle sales may develop into the future. <u>Key Questions:</u> • What will EV adoption look like in 2030 and 2050? Is 100 million vehicle stocks possible by 2030 and under what conditions? • What factors appear to be most important in determining future sales? What does this mean for policy-making? • How do different models project the adoption of PEVs differently when provided the same inputs? <u>Methods:</u> Our research can be distinctly divided into two stages: 1. Developing and estimating econometric models of the current EV sales in the context of 35 country-level markets and 2. Using these model structures to project EV sales into the future using a scenario approach. In the previous phase of the study, using a large database with disaggregated sales for 35 countries through 2015, we were able to estimate three types of models (discrete choice, regression, and Bass diffusion curve), with a range of variables. This analysis provided important insights but did not include some important factors such as recharging infrastructure or any disaggregation of various cost and non-cost incentives. The three modeling approaches revealed a range of estimates and, when we conducted the second stages with future projections, these models resulted in very different projections using similar assumptions of future exogenous variables such as vehicle price and driving range. In the 2018 phase of the analysis, we will re-estimate these models, with a possible focus on the discrete choice model (depending on funding), using an updated database with sales through 2017. We will add in more variables, such as a proxy variable for the state of recharging infrastructure in each country. We will also explore doing "deep dives" for one or two countries (U.S. and China would be most likely) where we disaggregate the analysis into subregions to get more resolution on purchase choices with variation that does not exist on a national level. The most important such variable is recharging infrastructure but could also include things like existence and use of HOV lanes by EVs.
Geographic Scope	The project scope will continue to be very international, using the 35-country database, but may also include the deep dives for specific countries, likely including the US.
Anticipated Results and Relevance	We expect to provide important insights into the nature of EV demand over time and across geographic region and specific countries, and insights into the potential for EV growth into the future.
Relevance to STEPS Consortium Members	This research is highly relevant to consortium members since future EV market development will be critical to both car companies, and will affect energy demand. It also is heavily dependent on policy, as this analysis will explore.
Additional Research Plans	None at this time, project should be completed in 2018.

<table>
<tr><th>10</th><th>Analysis of Hydrogen Infrastructure Requirements for Zero Emission Freight Applications in California</th></tr>
<tr><td>Team</td><td>Prof. Joan Ogden (PI); Dr. Marshall Miller, Research Engineer; Guozhen Li, GSR 4</td></tr>
<tr><td>Elevator Pitch</td><td>The goal of this project is to illuminate hydrogen infrastructure strategies that may be critical to successfully implementing zero emission hydrogen fuel cells in freight applications in California.</td></tr>
<tr><td>Project Description</td><td>
<u>Introduction</u>
Recent state transportation plans highlight the need for sustainable freight technologies and fuels in California. Zero emission vehicles are seen as key technologies for reducing freight-related air pollutant and greenhouse gas emissions. California's 2016 Sustainable Freight Action Plan established a target of 100,000 zero emission freight vehicles in 2030, utilizing renewable fuels. Hydrogen fuel cell vehicles are a promising zero emission technology, especially for applications where batteries might be difficult to implement, such as heavy-duty trucks, rail, shipping and aviation. However, California's hydrogen infrastructure to date is sparse, with about 30 stations, primarily sited to serve fuel cell cars and buses. New infrastructure strategies will be critical for implementing hydrogen freight applications.
We propose to analyze infrastructure requirements for hydrogen in freight applications. We will develop scenarios to 2050, using California-specific transition models developed at UC Davis. Hydrogen vehicle adoption and fuel demand will be estimated for medium- and heavy-duty transportation sections such as trucks and buses. We will design infrastructure to meet demands, including hydrogen production, storage, delivery and refueling; estimating numbers and types of stations required, infrastructure capital and operating costs and delivered hydrogen costs. We will investigate the potential of business cases in the hydrogen infrastructure market. Finally, we assess potential infrastructure synergies, with hydrogen stations now under development and with natural gas infrastructure.
<u>Key Questions:</u>

What are possible scenarios for adoption of medium and heavy duty H2 FCVs in California to 2050?
How would a hydrogen supply network be designed to fuel these vehicles? (H2 demand, numbers of stations, locations, station capacity, station type?)
How much would H2 infrastructure cost?
When will there be a business case for developers of hydrogen stations? When will H2 FCVs compete with incumbent technologies? What kinds of policies might be needed to assure the mid-term success of a hydrogen transition?
Renewable hydrogen. Today most hydrogen is produced from natural gas, but to realize hydrogen's full climate benefits, hydrogen must be produced from low carbon sources such as renewables. What are viable scenarios for implementing low carbon hydrogen supply?

<u>Methodologies/Models:</u>
The proposed project builds on findings from ongoing STEPS research:

We conducted a literature review of available alternative fuel refueling network design and evaluation models.
We established a research framework that categorizes the medium- and heavy-duty hydrogen transportation market into two segments: the local market and the long-haul market. For each segment, we characterized refueling patterns, estimated hydrogen demand (magnitude and location), and collected data on MD/HD fleets, incorporating a variety of data sources.
In station siting analysis, we use R and Python for data analysis, ArcGIS and PostGIS for spatial analysis, Gurobi for mathematical programming, and various other tools for data visualization.

<u>Research Tasks:</u>
Develop H2 Infrastructure Cost Data Set for Transition.
From literature review and interviews with industry people, we will develop an EXCEL-based data set for near to mid-term (2015-2030) hydrogen infrastructure costs and performance during a transition. Focus is on a range of station sizes (100 kg/d, 180 kg/d, 350 kg/d, 500 kg/d; 1000 kg/d) and station types (compressed gas and liquid H2 truck delivery; onsite steam methane reformation; onsite electrolysis). Capital costs and operating costs will be estimated. Where possible, our estimates will be benchmarked against actual costs for recently constructed stations (data are available from the California AB 8 program via CEC and ARB, industrial gas
</td></tr>
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	companies, and station builders.) The data set will include projections for future technologies' cost and performance that take into account learning and scale economies over time. *Develop and analyze a range of transition scenarios for regional hydrogen rollouts for medium- and heavy-duty trucks.* We will develop a range of scenarios that vary rates of FCV adoption, mixes of station sizes and types, "green" hydrogen content, and cost assumptions. We will coordinate closely with ongoing hydrogen infrastructure development activities and roadmaps in California and nationally in the U.S., through ITS-Davis academic affiliated membership in both the California Fuel Cell Partnership and the U.S. DOE's public/private national partnership H2USA. *Techno Economic analysis of hydrogen rollout scenarios* Based on CARB surveys for future vehicle deployments, and longer-term goals for zero emission vehicles, we will estimate a growing, spatially resolved demand for hydrogen. Using the infrastructure models from Task 1, we will propose a specified mix of new stations each year to serve the growing hydrogen demand. This will allow us to estimate the capital and operating costs for the station network each year. We will conduct a "cash flow" analysis tracking station expenditures and hydrogen dispensed, and finding the levelized cost of hydrogen over time. We will also consider the economics from viewpoint of a single station operator, and the consumer. From this, we will estimate the conditions for hydrogen to achieve "breakeven" cost competitiveness with gasoline on a cent per mile basis and a lifetime cost basis. The effects of different policies on breakeven will be explored. We will estimate the number of stations and the investments required to reach breakeven under different assumptions. *Interface with STEPS Transition Scenario model (Project 1) and other STEPS projects.* Our transition calculations for hydrogen will be adapted for use in the STEPS Transition Scenario model under development (Project 1) and other STEPS projects.
Anticipated Results	• An open-source, reproducible, and transferrable modeling tool for analyzing the location, scale, and cost of hydrogen refueling infrastructure for freight applications. • EXCEL based station cost data appropriate for early transition conditions (2015-2030); • Set of realistic scenarios for hydrogen infrastructure rollout for freight applications in California that examine the conditions (numbers of stations, investments) for reaching a business case, and explore important sensitivities. • We will design this analysis so that it can be translated to other areas of the U.S. A final technical report will be produced by the end of 2018 and a journal paper will be submitted.
Relevance to STEPS Consortium Members	The proposed research is of high relevance to STEPS consortium members including OEMs developing advanced heavy and medium duty trucks (Cummins, Volvo, Daimler Trucks) and HD hydrogen fuel cell vehicles (Toyota); California agencies (CARB, CEC, SCAQMD) who have programs supporting hydrogen vehicles and infrastructure and are developing roadmaps for hydrogen MD/HD vehicles; federal agencies (U.S. DOE, U.S. DOT and U.S. EPA) which have programs in hydrogen; and energy companies including Shell, Sempra and PG&E involved in hydrogen energy projects.
Geographic Scope	California
Additional Research Plans	This year we will analyze scenarios for the regional rollout of hydrogen fuel cell MD/HD vehicles in California. In future, this work might be extended to other regions in the U.S. The proposed research will form part of Guozhen Li's TTP Ph.D. dissertation (expected 2018).

11	Undertaking CCPM-2 California Scenario Comparison Project
Team	Lew Fulton, Austin Brown, 1 GSR
Elevator Pitch	Following in the path of the original CCPM project, led by Sonia Yeh in 2014/2015, this project will revive this project and the modeling group to conduct a CCPM-2 comparison of scenarios focused on very ambitious CA targets. This process will feed into the planned Governor's Summit in September 2016 and provide a critical scientific foundation for targets considered at that summit. Initial discussions with ARB indicate strong interest.
Project Description	In 2014/2015, STEPS led the CA Climate Policy Modeling (CCPM) project, involving convening important energy system modelers from around the state to compare specific scenarios relevant to potential or actual CA targets and estimate optimal pathways and costs of achieving these targets. This forum was highly influential and was cited by the Governor's Office as a basis for various policy-making efforts underway at that time. Now in 2017, two new dynamics make it the right time to reconvene this forum: 1. The Governor and CA Legislature are considering important new targets that will be debated during 2018, such as a carbon neutrality goal and the possibility of a phase out of ICE vehicles, and 2. The Governor will convene a climate summit in September 2018 where such targets will be debated, and there will be a strong need for an underpinning of analysis to inform these discussions. This project proposes to undertake this process in 3 main steps: 1. An informal meeting with invited modelers to discuss the issues and consider which targets to analyze and how such analysis could be undertaken, resulting in an analysis plan over the following 6 months; 2. The analysis phase where UC Davis and other groups estimate and calibrate models as needed and run consistent scenarios, and 3. A formal, public workshop where the results are presented and discussion of the implications of these results is undertaken. 4. Results from this workshop will be shared with key officials at the Governor's office, in the legislature, and with ARB and other agencies, and will be fed into the planning for the CA Summit. In fact, key officials will be encouraged to be involved in the entire process. UC Davis will serve as both a central convener of the CCPM, and undertake modeling using the CA TIMES model to carry out our part in the comparative analysis. This will require having a person available to lead the planning effort and others to lead the analysis effort. This first effort will likely be undertaken in cooperation with NCST and both parts with the Policy Institute.
Geographic Scope	The project scope will continue to be CA-focused. Some models may include other regions that could be brought to bear on the analysis, but primarily this will be a CA-focused study.
Anticipated Results and Relevance	We expect to provide important insights into the nature of very ambitious and challenging targets and whether these targets can realistically be met, how they could be met, at what cost, and with what policies needed to achieve them.
Relevance to STEPS Consortium Members	This research is highly relevant to consortium members since very ambitious CO_2 reduction targets will require careful planning and robust policies by policy makers, and may heavily impact vehicle demand and energy demand in CA and beyond in the coming decades.
Additional Research Plans	None at this time, project should be complete by October 2018 except for preparation of reports, which should be complete by end of 2018

12	Peak Oil Demand
Team	Lew Fulton, GSR
Elevator Pitch	During 2016/2017, Amy Jaffe and various students developed a peak oil demand analysis that focused on a sensitivity analysis of future trends and factors affecting those trends, to see if combinations might trigger a peak in oil demand. In 2017, this moved into a phase of considering policies that might combine with other factors to trigger peak oil demand. In 2018, this project will complete the policy analysis, including considering the potential impacts of COP-related national CO2 reduction plans. It will also consider the potential impacts on oil prices from peak demand mainly via literature review. Finally, it will also develop a comprehensive report and output materials such as policy briefs.
Project Description	During 2016/2017, Amy Jaffe and various students developed a peak oil demand analysis that focused on a sensitivity analysis of future trends and factors affecting those trends, to see if combinations might trigger a peak in oil demand. This analysis indicated that even with a combination of a range of factors aligning on the "low oil demand" side of things, peak oil demand was not achieved, or at least not achieved in a permanent way (demand rises again after slowly falling for a decade or so). In 2017, this moved into a phase of considering policies that might combine with other factors to trigger peak oil demand. This included factors such as electric vehicle uptake, car bans in cities, and delivery truck uptake of electric vehicles. In 2018, this project will complete the policy analysis, including a wider range of policies such as those in aviation and shipping, as well as considering the potential impacts of COP-related national CO2 reduction plans. While these plans, known as "Nationally Determined Contributions" (NDC) plans, tend to be preliminary and only look out to 2025 or latest 2030, they will need to be updated by 2020 and probably strengthened in many cases. This analysis will consider how that process may evolve. As with the previous stages of the study, the IEA Mobility Model will be the main tool used to create the scenarios. The latest version of the model will be used to update the entire analysis. A better "control module" will be created to allow the scenarios to be saved and adjusted more easily, and that can be shared along with the report outputs. The project will also add a new discussion: the potential impacts of peak demand (and near-peak demand) on oil prices, oil markets, and the oil and energy industry in general. What might this mean for investments and the direction of the industry? What might be the impact of lower oil prices on travel and energy use (rebound effects)? This will include a review of the peak demand and oil markets/rebound literature. This is a rapidly evolving literature that should yield some important insights. Finally, we will also prepare a comprehensive report and other output materials such as policy briefs. A synthesis "white paper" will also be prepared – probably a condensed version of the full report.
Geographic Scope	The project scope will continue to be global and regional. More regional "breakout" results will be prepared in the 2018 analysis than were done previously.
Anticipated Results and Relevance	We expect to provide continued insights into the likelihood of peak oil occurring and the likely time frame of it occurring. We will also provide deeper insights into the potential role of policy in a climate constrained world, and the potential impacts on oil prices and the energy industry.
Relevance to STEPS Consortium Members	This research is highly relevant to consortium members since oil demand and oil prices underpin transportation and energy markets. Achieving a better understanding of potential future oil trends will assist consortium members in planning and policy makers in setting policies both around triggering peak oil and dealing with the impacts if it does occur.
Additional Research Plans	This may be the final project on this topic for STEPS, though this can be determined during 2018. If continued, it will need to fit into plans for STEPS4. In any case, the goal will be to have a report that stands as a final synthesis STEPS 3 report.

13	LCA of Light Duty Electric Vehicles – Examining Trends in Vehicle Efficiency, Performance and Battery Capacity.
Team	Alissa Kendall, Lew Fulton, GSR
Elevator Pitch	Though referred to as "zero emissions vehicles" because they do not have a tailpipe, electric vehicles (EVs) are responsible for significant "upstream" emissions including from electricity used to charge EV batteries and emissions from vehicle production. Though many studies have been published on life cycle emissions from EVs, few, if any, anticipated the trends we see in larger battery sizes and vehicle efficiency – which is highly variable across vehicles. In particular, high performance, long-range EVs like those produced by Tesla are not well represented by the body of work from the past, which focused on vehicles like the Nissan Leaf. This research proposes to update that LCA work to evaluate how these trends have affected environmental performance.
Project Description	This project proposes to develop a life cycle assessment (LCA) model of light-duty EVs with the goal of capturing the effects of current and near-term trends in EV design and technology evolution. While there is a significant body of literature on EV LCA, few if any of these studies have addressed current trends in EV design, including: • The effect of increased battery capacity on BEVs and PHEVs (for increased range), • Longer annual driving distances and the use of EVs in shared mobility situations where there could reach 100,000 miles per year and 500,000 miles over vehicle life • The effect of designing EVs for performance driving rather than efficiency. • Latest information on the trends and potential future evolution in battery chemistries and materials This research proposes to use secondary data to further develop an LCA model for estimating GHG emissions and other environmental impacts of interest for current and near-term vehicles that follow some of the current trends in EV design and sales.
Geographic Scope	We will focus on trends in U.S. EVs, but this is relevant for global markets as well. Global supply chains that provide parts to EVs will be included.
Anticipated Results and Relevance	New estimates of future LCA "scores" and sensitivities to assumptions will be made that should advance understanding in this very important area of research. For example, we expect to provide insights on the possibly countervailing trends of improved technology (e.g. battery improvements and efficiency gains) and increased performance and range. This will be important to policy, vehicle manufacturers, and consumers.
Relevance to STEPS Consortium Members	This research is relevant to OEMs who produce EVs, and potentially to EV policy makers and stakeholders as they consider how and if EVs should be promoted or supported through policy.
Additional Research Plans	We will seek co-funding and alternative sources of funding to provide long-term support of this work and to increase the scope.

14	21st Century Rail Propulsion: Case Study Analyses Examining Costs and Emissions across Motive Power Technology Options
Team	Raphael Isaac, under guidance of Dr. Lewis Fulton and Dr. Paul Erickson
Elevator Pitch	As cars shift over to cleaner fuels, how can trains do their part to help achieve sustainability/climate goals? How effective is a given fueling technology, for rail, in reducing life cycle (i.e. both fuel cycle and vehicle cycle) GHG and pollutant emissions? What is the technology's total cost of ownership to the equipment owners (i.e. firms or govt. agencies)? Are there any major logistical, rail-specific challenges that need to be addressed? The rail sector is somewhat slow to adopt new propulsion technologies. However, it is more centralized, so, once underway, a shift in technologies could proceed fairly swiftly (at least in terms of new sales). Other research related to innovative technologies is limited so far, both in terms of variety of technologies and geographic focus.
Project Description	<u>Summary</u> This project has been evaluating the environmental impacts and financial costs of alternative fuel and related technology pathways for use in domestic trains. Specifically, the study is evaluating the following powertrains: diesel-electric with after treatment, natural gas with after treatment, hydrogen fuel cell, electricity (via catenary), biofuel (i.e. Fischer-Tropsch derived), and hybridized diesel-electric and hydrogen (with batteries) powertrains. The primary focus will be a bit more on freight rail due to the disproportional impact of that sector on domestic rail energy consumption, but passenger rail (i.e. commuter and/or intercity passenger rail) is also being addressed. Using a 'single train simulator' tool developed in the UK, simulations of 5 different trains on four actual domestic routes (including a railyard 'switcher' route), along with the above-mentioned powertrain arrangements, are forming the basis for the evaluation. After the simulations determine energy consumption for a given trip and help to assess best fueling alternatives on selected routes and/or trip types, I will use a combination of existing models (e.g., the 'GREET,' model) and databases (e.g., GaBi, an LCA software), research literature, and my own refinements and additions where gaps exist, in order to determine a resulting life cycle-based inventory of GHG and other air pollutants resulting from these various alternatives, including the emissions from many of the equipment changes. A discussion of the potential costs of and barriers to developing these alternatives (especially between now and 2050) will follow, with a focus on how these might specifically impact the representative corridors that have been chosen (and others like them). In examining the costs and barriers to rail alternatives, this project relates strongly to one of STEPS3's topics of interest, i.e. understanding what is required for early alternative fuel/vehicle transitions to succeed. In its 2016 Annual Energy Outlook reference case, the U.S. Energy Information Administration suggests that freight rail in 2040 will rely on a combination of diesel fuel and natural gas (EIA, 2016), with passenger rail relying on the same, along with electricity via catenary, another incumbent technology within the sector. (EIA, 2016). The research proposed here may help to further encourage new ideas and policy, evidently important given that the current trajectory suggests a fairly conservative outlook for rail. <u>Introduction</u> The U.S. rail system (i.e. all rail except for transit), accounts for over 2% of the U.S. transportation energy consumption total, with over 90% of this impact from freight rail. Diesel fuel and its associated locomotive technologies currently provide the power source for approximately 87% of U.S. domestic rail service, while electricity and its associated infrastructure and locomotive technologies comprise the remaining 13%. Freight rail in the U.S. currently runs almost entirely on diesel operations (in which a diesel engine drives a generator, which powers motors 'at the wheels'). Class I railroads, which are the largest firms by annual revenue, were responsible for about 70% of domestic freight rail mileage in 2010. In 2015, the energy required by the Class I freight railroads, alone, translated into a consumption of over 3.5 billion gallons of diesel. Given the direct link between link between liquid fuels and GHG emissions, and the role of the transportation sector in domestic emissions, these numbers suggest that rail accounts for about ½ percent of all domestic GHG emissions. While these energy and emissions shares for rail are relatively small, evidence points to rail as a growing subsector, particularly beyond the shorter-term (freight rail has very recently experienced a slight, but temporary dip in traffic), both domestically as well as at the global level. This means that these impacts will continue to increase, both absolutely as well as relatively, given the shift in fuels that is progressing in the automotive sector. In addition, the operation of rail systems is highly centralized, with a limited number of operators, and, as such, a shift within the sector, once underway, is also likely to face fewer difficulties in coordination than a shift within the passenger automobile sector. Furthermore, freight firms are highly cost-sensitive when it comes to fuels (which, in 2013, accounted for 27.5% of operating costs, across Class I railroads), a characteristic that may

	become even more pertinent in the current operating environment, in which some of their previously reliable long-term business models (e.g. a major role for coal transport) are breaking down. With volumes decreasing in some traditionally strong areas, the sector needs to court business from new customer types, and offering low costs (vis-à-vis the alternative, trucking) is the primary way to achieve this. In order to lower the costs that they charge, the freight rail firms are continually on the lookout for fuel and/or powertrain alternatives that might provide cost savings. Passenger rail, meanwhile, is usually run at least in part by a government entity, and that can mean an openness to innovation, especially in order to meet public health and/or environmental goals (on top of regulations). My emissions analysis will employ a life cycle framework to assess greenhouse gases (i.e. CO_2, CH_3, and N_2O), four criteria pollutants, i.e. CO, PM, SOx, and NOx, and, finally, hydrocarbons (HC). (The latter four are the main pollutants that the EPA monitors and regulates for locomotives.) The scope of this analysis will include emissions from raw material acquisition (this may be already present in secondary data), engine and fuel technology/component production, and the use, or "operational," phases. The uncertainty present in the specifics of transportation/delivery and end-of-life and final disposal (especially given that some of these technologies have only recently begun to be used commercially, in large volume) suggests leaving these phases out of this initial analysis. Given that the goal is to determine the differences between technologies within the same mode, the analysis will only reflect those components which differ between operating a train on one technology vs. another. In most cases, the analysis will be built on a model of 'component swapping,' so to speak, in which some components are removed from the present locomotive design, while others are added.
Geographic Scope	National focus, but pertinent globally. Also, two of the routes are fully in CA, and one route (with two different train types) goes through CA.
Anticipated Results and Relevance	As we are beginning to see with automobile technologies, there may not in fact be one "winning" technology, in particular during the scope presented by this analysis (up to 2050). Instead, multiple primary technologies may end up being a likely solution, with no more than two predominating simultaneously, lest the variation begin to cut into freight rail's advantage of more centralized operations and relative uninterrupted travel routes. Hybridization is likely to play a key role in the findings, especially on routes with elevation changes and especially where there are frequent stops. Since stops are generally more frequent in passenger rail duty cycles than for freight cycles, passenger rail would almost certainly benefit from hybridization. (Early results demonstrate that the necessary equipment would fit into the confines of a standard passenger locomotive.) It is possible that a single prime mover (e.g. fuel cell using hydrogen) would become the most common propulsion method for freight locomotives, while it may thus make sense to use these same prime movers for passenger locomotives, but with the addition of batteries within the locomotive frame.
Relevance to STEPS Consortium Members	This research will be of interest to both state and national governments, as well as members of industry, e.g. Cummins (a heavy-duty engine maker), Chevron, and Siemens. The scale of diesel usage among rail explains the interest of oil companies. On the other hand, Cummins makes the engine that Siemens has been using in the Charger passenger locomotive (one of the locomotives being simulated), which will be running in at least five states in the next few years. Cummins has, in fact, contributed confidential data to the project already. Siemens, not currently a consortium member, has also contributed quite a bit of information; hopefully they will consider becoming a sponsor, either of this project only, or, ideally, of STEPS, overall.
Additional Research Plans	Again, this work will culminate in a dissertation, expected to be completed in the fall of 2018. Following my having graduated, there are follow-up studies that a new student could conduct that would benefit from this current project.

15	Panel Study of Emerging Transportation Technologies and Trends in California (PHASE TWO)
Team	PI: Dr. Giovanni Circella; Co-PI: Dr. Lew Fulton; Other Researchers: Dr. Susan Handy, Dr. Dan Sperling and GSR (TBD)
Elevator Pitch	In this Phase II of this study, we plan to launch the second round of data collection for the panel study of the adoption of new transportation technologies and emerging transportation trends in California. The dataset will be integrated with the first dataset collected in 2015 (California Millennials Dataset). The data collected in this longitudinal study with a rotating panel structure will allow us to harvest the full potential of this research, improving the understanding of 1) the adoption patterns of ridehailing services such as Uber/Lyft (and pooled services like UberPOOL and Lyft Line) among different socioeconomic groups; 2) how the adoption patterns of shared mobility services is changing over time; 3) the impacts that the adoption of new services has on other components of travel behavior and vehicle ownership (e.g., which could not be properly investigated with cross-sectional data); and 4) the propensity of users to share rides with others vs. own and use their own vehicles today and in a future dominated by driverless vehicles, among other topics.
Project Description	Panel data provide extremely rich information that allow investigating the relationships behind certain human decisions over time, and allow disentangling the complex interactions among multiple variables and better identify causal relationships, which could not properly measured with the analysis of cross-sectional data. However, the availability and use of panel data in transportation planning is not very common, mainly due to the high costs and needed resources for the data collection, and the need to plan the data collection well in advance and over longer temporal horizons. In this project, we build on the research efforts that led to the collection of 2015 California Millennials Dataset, and complement that dataset with a second wave of data collection, planned in Spring 2018, generating a longitudinal study of emerging transportation trends in California with a rotating panel structure. The use of longitudinal data will allow researchers to better analyze the evolution of transportation at a time of major technological disruptions and changes in lifestyles, disentangle the impacts of *lifecycle*, *periods* and *generational* factors on travel-related choices, and analyze the changes in travel behavior in response to the adoption of shared mobility services among different segments of the population, including changes in vehicle ownership over time. Key Questions 1. What are the relationships between the adoption of shared mobility and changes in vehicle ownership? 2. How does the adoption of ridehailing services like Uber and Lyft affect other components of travel behavior (e.g. the use of public transportation, active travel and/or private vehicles.) 3. How does the willingness to share rides in a driverless vehicle vs. own a private vehicle differ across groups of users? Methodology In the proposed Phase II of the project, we will build on the research efforts carried out with the collection of the 2015 California Millennials Dataset through launching the second wave of data collection of this panel study. We will use a combination of sampling strategies for this second wave of data collection, in order to maximize the benefits from the panel. In particular: SAMPLE A: We plan to recall respondents that completed the 2015 survey using the same online opinion panel (Sample A). SAMPLE B: We plan to expand the sample adding a group of participants recruited with the same strategy used for the original 2015 data collection and Sample A, and expanding the age cohorts by including younger members of Generation Z (currently between 18 and 21) and baby boomers who were not included in Sample A. SAMPLE C: We will create a paper version of the survey to be mailed to a random sample of respondents in the state, in order to expand the target population of the study and reach underrepresented segments of the population (e.g., elderly or people not familiar with technology).
Geographic Scope	California – a related statewide project focuses on Georgia and a pending proposal focuses on Nevada. These datasets will allow additional comparisons during the data analysis.
Anticipated Results and Relevance	The panel study will provide a unique opportunity to study the impacts of emerging technologies and transportation trends over time using a panel dataset. It will allow the researchers to build robust analyses of travel behavior at a time of major transportation disruptions, disentangle the role that shared mobility has in restructuring the relationship with private mobility over time, and evaluate other changes in travel behavior associated with the adoption of emerging technologies and modern lifestyles. It will provide information about expected changes in travel demand and vehicle ownership, and inform travel demand forecasting

	models and planning tools on the impacts of lifestyles, stage in life, adoption of shared mobility services and driverless vehicles among various socio- economic and demographic groups.
Relevance to STEPS Consortium Members	This research will be relevant to STEPS corporate sponsors (including state agencies and automakers) and provide important insights into the future evolution of transportation, and, among other topics, the impacts that modern transportation technologies such as the adoption of shared mobility have on vehicle ownership among various groups of users. STEPS members will find interest in the analysis of different groups of travelers, market segmentation, latent-class analysis and choice modeling, which will allow us to identify different behavioral patterns among various groups of individuals (e.g., different directions of causality in the relationship between the adoption of shared mobility and vehicle ownership over time).
Deliverables	All research insights will be made available through quarterly reports, presentations, and publications. We plan to present the results from the project through at least one presentation and/or one poster at each STEPS symposium. The project also helps creating synergies with the newly established 3 Revolutions Future Mobility Program at ITS Davis. Research results will be presented at top scientific conferences and published in relevant scientific studies. For example, six papers based on the results from the current Phase I project have been submitted to the 2018 TRB meeting and will be presented at the 2018 International Association of Travel Behavior Research Conference and are being published in leading journals including Travel Behavior and Society and the Journal of Choice Modeling.
Additional Research Plans	This is the fourth year of this panel study (NCST and Caltrans are the primary sources of funding for this project; STEPS provided funds to expand the data collection and increase the sample size for the administration of the first survey in 2015). The project has already generated tangible results in terms of scientific deliverables and findings of interest for the planning community. Building the longitudinal component of this study will allow exploring a number of research questions through many analyses which will span over the following years. Extensions of the project to other states and internationally are being considered: a related data collection is already under way in Georgia, and related data collection will be carried out in 2018 in four major U.S. metropolitan areas, allowing important future comparisons of results.

16	Modeling the Spatial distribution of the PEV Market: Exploring Neighborhood Effects, Incentives and Infrastructure on PEV Market Penetration in California.
Team	Gil Tal, Jae Hyun Lee,
Project Description	In this project, we expand this research by exhaustively examining the neighborhood effects in PEV market penetration with 7-8 years (2010-2017) in California. The first objective of this project is to understand the existence and boundaries of neighborhood effects in PEV market penetration in the largest PEV market in the U.S. By using different distances to define neighbors and testing their effects in PEV market penetration models, it is possible to find the boundary of neighborhood effects in PEV market penetration in California. The second objective is to examine year-to-year changes in neighborhood effects with both cross-sectional spatial models and longitudinal (panel) models. As electric vehicles become more prevalent, it is possible to observe stronger neighborhood effects. The last objective of this project is to explore spatial heterogeneity of neighborhood effects. The strength of neighborhood effects varies across the state of California: they can be negligible in areas with low level of PEV market penetration. Therefore, we will develop models to test neighborhood effects that take into account the spatial heterogeneity of PEV market penetration including the impact of incentives, HOV lanes, and public infrastructure. Data: Almost 200,000 Plug-in vehicles were sold in California between 2010 and 2016. About 180,000 applied for the state rebate and have their data included in our study. We use a subsample of 172,880 privately owned vehicles categorized by vehicle type and census tract location. Overall, we have 7,341 tracts with PEVs (out of a total of 8,057 in the state) or 91 percent of the tracts, representing a population of nearly 33.7 million. PEV sales data by 2016 based on the Clean Vehicle Rebate Program (CVRP) records was aggregated to census tract level and used to explore neighborhood effects in PEV market penetration. Socioeconomic data including median income and employment ratio of each census tract were derived from California household travel survey (CHTS) data (CalTrans, 2013). The weighted average commute distance of residents from each census tract and the ratio of the length of available HOV lanes on the shortest commute route over the total commute distance (HOV share) were calculated based on LODES data (U.S. Census Bureau, 2013). Methods: In order to examine neighborhood effects, we first computed Moran's I of PEV sales in each year. The Moran's I shows the similarity between each zone's value (PEV sales in each Census tract) and the mean of its neighbors' values, with the neighbors defined based on the distance between zones (Moran, 1950). Therefore, this Moran's I illustrates degrees of neighborhood effects (spatial dependency) on PEV sales based on proximity. Next, this effect also has to be examined with spatial models to test their impact on PEV market penetration with other important factors such as socio-demographic variables, travel patterns, incentives and infrastructure. We will use three different models to test the neighborhood effect with the above explanatory variables: 1) spatial lag models for each year's PEV sales; 2) latent class spatial lag model; and 3) spatial lag panel model (*Time-space recursive model*). The first model will show the year-to-year differences in neighborhood effects in PEV sales and the second model will show spatially heterogeneous neighborhood effects in California. The last model will show the existence of overall neighborhood effects in four recent years. Expected Results: This project will improve our ability to predict the impact of EVs prices, incentives, and infrastructure on the local market while considering the impact of the neighborhood effect over time. The results can be used to estimate the demand for home charging and will be used to update other forecasting tools.
Geographic Scope	California with strong implication to the U.S. and global market
Anticipated Results and Relevance	Overall, the preliminary results show significant neighborhood effects on PEV market penetration and spatially heterogeneous patterns of market penetration. These effects are missing in all other models in use today and have a significant impact on EV adoption. Early findings are encouraging and highlight the need to further investigate spatially and temporally heterogeneous neighborhood effects on PEV market penetration. This project aims to present a comprehensive set of models capturing spatial heterogeneity of the effects using Latent class regression models and the spatial panel models to understand overall neighborhood effects in in California. The results will be used to create forecasting tools for PEV sales by region and for estimating local energy demand.
Relevance to STEPS Consortium Members	OEMs can use this tool to estimate local and regional market demand. Utilities can use the results to estimate the demand for home charging and public infrastructure. For government organizations, the analysis will help in estimating the potential changes in impact of incentives over time by regions.
Additional Research Plans	This project will add to the PH&EV Research Center modeling work that will be presented at the STEPS symposium

17	Present and Future Costs of Shared Mobility and Automated Vehicle Services, and Consumer Response to Policy Incentive Systems
Team	Lew Fulton; GSR
Elevator Pitch	The emergence of "3 Revolutions" (automation, electrification and shared mobility) presents a range of questions regarding how consumers will travel in the future, and under what conditions there may be rapid adoption of various services. These include individual on-demand taxi-style services, shared mobility in pooled services, and use of public transit, all with or without drivers. There is now enough data and estimates on the costs of these service combinations, and in some cases ridership data, to consider how consumers are making choices and could do so in the future as things evolve. This project will a) review existing literature and data on consumer mode and vehicle choice, b) develop a new cost estimating system for various service/technology options now and in the future, such as 2030, and c) conduct an analysis of travel choice behavior, and policies that might influence this behavior, in the near and longer term. These policies could include simple VMT-based pricing, adjusted pricing such as taking into account vehicle occupancy, and non-market approaches such as road, urban area, or parking access restrictions.
Project Description	A range of new technologies and types of travel service are emerging, namely driverless, probably electric, vehicles and on-demand "Transportation as a Service" (TaaS) business models. These are still nascent trends but there is now a very important set of emerging questions regarding the conditions under which these may become important parts of the transportation ecosystem. Some studies (e.g., RethinkX, 2017) predict that both driverless cars and on-demand TaaS travel will become ubiquitous by 2030, based on a range of assumptions such as very low vehicle costs per mile and a willingness of individuals to give up private ownership of automobiles. This extreme scenario contrasts with more modest estimates of transitions and cost reductions related to driverless TaaS offerings such as Deloitte (2017). The recent STEPS report presenting 3 Revolutions Scenarios to 2050 (STEPS, 2017) provides a range of plausible futures and what these might portend for vehicle sales, stocks, energy use and CO_2 emissions, but does not attempt to model the choices and other factors that might be important in determining which scenarios win out. This project will focus on three areas: improving data on the relevant technologies and modes and using this to develop an improved cost model; taking a more behavior-based approach to projecting the potential market shares and transitions in question; and undertaking policy analysis of a range of options to speed transitions as needed or move them in more societally optimal directions. It will attempt to provide a clearer sense of the conditions that will be needed to achieve certain scenarios, and the design and intensity of policies that may be needed to achieve specific goals. It will build and expand on the analysis and scenarios in the STEPS report, ITS-Davis's "3 Revolutions" Policy Briefs, and other recent reports such as those by UC Berkeley, RMI, RethinkX, Deloitte, McKinsey, and others. This analysis will consist of three primary tasks, which also encompass the methodological approach: a literature review/data gathering effort; development of an economic model of consumer choice among a range of travel options now and in the future; and an analysis of those options using this model and applying various potential policy levers to estimate how these might affect choices and travel patterns now and in the future. More specifically: Task 1: We will review data and estimates of the costs of on-demand services, broken down by cost component and situational variability, and of automated vehicles and services provided with such vehicles (i.e. the two combined). We will try to improve on existing estimates as needed. For example, the estimated cost per mile (translated into retail price) of on-demand services with driverless vehicles has been estimated to be anywhere between \$0.10 and \$0.60 per vehicle mile, when such services become available. We will also investigate cost estimates associated with "hedonic" costs such as the perceived cost of sharing rides, travel time when driving and when riding in an automated vehicle, etc. These will be qualified and added to the "out of pocket" costs to get a more holistic set of estimates. Task 2: The project will involve developing economic models for automation and shared mobility, building on the data work from the review described above. This will include creating bottom-up cost models of automation and shared mobility per mile, and applying to these situations assumptions regarding consumer behavior and mode/technology choice under a range of situations and scenarios. The range of situations that we will consider will include switching trips from privately owned vehicles to on-demand commercial vehicles, with such vehicles as ICE, electric, and automated/electric vehicles. We will also consider elasticities with public transit services. Short run (e.g. trip choices while owning a private LDV) and longer run choices (including the decision to buy another car in the future or forego in favor of TaaS services) will be included in the analysis. Task 3: Once a basic cost and behavior model framework is developed, a set of baseline mode share/technology scenarios will be constructed going out to at least 2030. These will be linked to the STEPS

	3R scenarios but adjusted as appropriate to best test the choice modeling framework developed in Task 2. We may decide to use a single base scenario or multiple scenarios depending on what appears to allow for the most interesting, robust analysis. These baseline scenarios will then be tested for a range of policies to evaluate, given assumptions about choice behavior, under what conditions it seems likely that demand would shift in a major way (tipping points) to new and different modes of travel, most notably driven and driverless mobility services. Example policies and methodological approach for evaluation: • Pricing by impact: inclusion of an externality-based fee for all modes • Pricing of empty miles: inclusion of estimated costs for empty miles for all modes • Pooling incentives: reduction of cost for shared modes based on occupancy • Equity-based user-side incentives: reduction of cost for low-income users of shared services • Electrification incentives: reduction of cost of EV shared and personal modes
Geographic Scope	The project scope will be mainly U.S., since the particular cost estimates we will focus on will be for the U.S. As mentioned above we will also consider a second country as a case study.
Anticipated Results and Relevance	We expect to provide continued insights into the potential for 3 revolutions in transportation, with detailed comparisons of current and medium term costs of various transportation technologies and 3R "use cases" to 2030, including estimates of hedonic "non-market" costs. The analysis will also include some vehicle/mode choice modeling and estimations of how this might affect the market shares of different options in the near and medium terms, and the speeds of transitions.
Relevance to STEPS Consortium Members	This research is highly relevant to consortium members since the 3 revolutions are underway and are highly uncertain. We expect the results of this project to be applicable to the auto OEMs and others thinking about potential future directions in urban transport, and to provide cost estimates that may be of direct value as inputs into partners' own analyses.
Additional Research Plans	Once the basic choice model is developed, we may consider potential extensions to this model, such as connecting it to our scenario tool of travel/energy use in CA and the (to be developed) version for the U.S. That would occur in a later project.