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Clean Transportation Program

FINAL PROJECT REPORT

Emerging Technologies

Research from the National Center for Sustainable Transportation to support the transition to low-carbon fuel technologies

Prepared for: California Energy Commission

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Gavin Newsom, Governor

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and non-road vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued PON-13-604 to leverage Clean Transportation Program funds to bring federal cost-sharing projects to California that will improve air quality. In response to PON-13-604, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards February 26, 2014 and the agreement was executed as ARV-13-020 on April 22, 2014.

ABSTRACT

Vehicle and fuel technology improvements have led to significant progress in reducing air pollution and greenhouse gas emissions, and have potential to reduce the demand for petroleum for transportation. The adoption of these technologies still faces barriers to maximizing their potential. These include scientific, technical, market adoption, institutional, environmental, and financial barriers. This project sought to address these remaining barriers through continued research. The first research task focused on identifying and addressing the specific barriers related to natural gas, electricity, and biofuels in discussion with relevant stakeholders. The second research task focused on understanding the potential market adoption barriers, particularly for light-duty electric vehicles, and the changes in the market potential over time. The third research task focused on the technology and institutional changes related to implementing intelligent transportation systems. Finally, the last task was to share these research results with the institutions in California that would need to be involved in their successful implementation.

Keywords: emerging technologies, alternative fuels, vehicles, intelligent transportation systems, consumers

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EXECUTIVE SUMMARY

This project allowed for the National Center for Sustainable Transportation at University of California, Davis to assist the CEC in understanding the impacts of emerging transportation technologies. These technology changes ranged from emerging fuels such as electrification, biofuels and natural gas to system-level technological changes such as intelligent transportation systems for freight vehicles.

Assessment of Critical Barriers to Alternative and Renewable Fuel and Vehicle Deployment

The workshops and information gathered to understand the key barriers to alternative and renewable fuel adoption in California provided a thorough examination of the opportunities and challenges, bolstered by the input of over 100 workshop attendees. The workshops focused on the adoption of biofuels as a transportation fuel, the barriers and opportunities to improve fuel economy and reduce emissions in medium-and heavy-duty truck technologies primarily through hybridization and electrification, and the barriers and opportunities related to providing infrastructure for all classes of plug-in electric vehicles in California.

Accelerating Commercialization of Alternative and Renewable Fuels and Vehicles

This task included two surveys of car-owning households in California to gauge awareness and consideration of zero-emission vehicles. The surveys were conducted online, approximately five months apart in 2017, with each survey eliciting approximately 1,700 responses. The survey asked respondents about their awareness of electric, hybrid and fuel cell vehicle technologies, current incentives, and knowledge about the technologies, and assessed their name recognition of current vehicle models. Approximately 80% of car-owning households in California had no or nearly no consideration of purchasing a zero-emission vehicle, and only 10% had either actively shopped for or actually owned a zero-emission vehicle. Unfortunately, when compared, the surveys did not show any significant change over time in the awareness or consideration of zero-emission vehicles by respondents. These surveys pointed again to the need for ongoing and targeted education and outreach campaigns to accelerate the adoption of new vehicles by households.

Eco-Friendly Intelligent Transportation System Technology for Freight Vehicles

Heavy-duty freight travel contributes a disproportionate amount of emissions relative to the number of vehicles and miles traveled. California, in particular, carries a large burden of travel associated with freight coming into and leaving through its major ports. One potential strategy to reduce emissions associated with freight travel is the use of Intelligent Transportation Systems, an approach studied to improve arterial roadway performance and freight vehicle emissions. The use of connected vehicle technology allows for more information to be used in intelligent transportation strategies, such as adaptive traffic signal control. Research from University of California, Riverside and University of Southern California indicated that enhanced vehicle connectivity integrated into existing intelligent transportation systems can improve the performance of those systems.

CHAPTER 1: Assessment of Critical Barriers to Alternative and Renewable Fuel and Vehicle Deployment

The agreement contained a series of tasks that the contractor needed to fulfill as ascribed throughout this document

Task 2.1: Assessment of Critical Barriers to Alternative and Renewable Fuel and Vehicle Deployment

The objective of this subtask was to identify environmentally and economically promising alternative fuel and vehicle emerging technologies, to identify and evaluate the critical business and policy barriers blocking their widespread adoption in the state, and to identify actionable solutions to overcome those barriers. Through this subtask, the project team analyzed the broad range of commercial barriers and identified strategies to increase the adoption and accelerate the scale-up of emerging technologies, fuels and fueling infrastructure that will help the state achieve its AB118 targets and goals for air quality and greenhouse gas emissions. To accomplish this task, University of California, Davis (UC Davis) convened three workshops on the topics identified below. Each of these workshops included over 100 stakeholders engaged in the commercialization of emerging technologies for the light-, medium-, and heavy-duty transportation sectors.

"Assessment of Critical Barriers and Opportunities to Accelerate Biofuels and Biomethane as Transportation Fuels in California"

September 17, 2015

"Assessment of Critical Barriers and Opportunities to Commercialize Medium- and Heavy-Duty Truck Technologies in California"

December 3, 2015

"Critical Barriers and Opportunities for PEV Commercialization in California: Infrastructure for Light-Duty Vehicles, Freight, and People Movement"

April 26, 2016

Following the workshops, the Emerging Technology Workshop reports were prepared, detailing the findings and discussions from each workshop. These are briefly summarized below.

Biofuels Commercialization, Technology, Emerging Markets, and Government Policies

Workshop Purpose and Objectives

California and the rest of the U.S. have committed to the goal of reducing energy-related greenhouse gases by 80% from 1990 levels by 2050. In order to reach desired and stable atmospheric concentrations of greenhouse gases, the use of biofuels and low-carbon fuel mixtures in addition to more accessible fuel sources is necessary. In 2015, the UC Davis Institute of Transportation Studies and the CEC held workshops on September 17-18 to discuss emerging technologies, current markets, and related government policies for California biofuels. Primarily, the topic of interest was the maximization and acceleration of biofuel commercialization, especially in public transportation sectors.

Summaries of General Workshop Findings

Session I, Status (2015) of Biofuel Markets:

Ethanol, biodiesel, renewable diesel, drop-in gasoline, biomethane, and converted feedstock were the biofuels discussed in the workshops. As of fall 2015, for California and the U.S., summaries for the aforementioned biofuel markets are found in Table 1.

Table 1: Workshop Summaries of Various Biofuel Markets (Fall 2015)

Biofuel	Annual Usage/Production	Benefits	Challenges
Ethanol	15 billion gallons produced (2014); California usage: 1.6 billion gallons	Produced from corn kernels; Gasoline blends	Low production in California (2014): 1.6 billion gallons used and 0.22 billion gallons produced
Biodiesel Fatty acid methyl ester	1.8 billion gallons produced (2014); California (2014) produced 65 million gallons	Produced from soybeans and waste oil; B20 usage without engine modifications	Only blends with conventional fuel; vehicle performance and emissions degraded
Renewable Diesel	0.12 - 0.2 billion gallons per year (imports)	Blending of renewable and conventional fuel not required; RD100 usage unrestricted	California produces small volumes
Drop-in Gasoline	No commercial production	Produced from wood	Low focus and production
Biomethane	420 billion standard cubic feet possible (2012); California can produce 93 billion standard cubic feet (2013)	Produced from landfills	Small energy content; high price compared to natural gas
Feedstock to Produce Biofuels	30 million metric tons available (2014)	Large supply of feedstock (many millions of dry metric tons)	Feedstock constrained (small fraction of total supply used to create biofuel)

Source: Burke, et al. University of California, Davis.

Session II, Critical Barriers for Commercialization of Biofuels:

The major barriers for commercialization of biofuels in the U.S. are funding, uncertainty in government policy and regulations, uncertainty in the feedstock market, relatively slow development of drop-in liquid fuel technologies, and competition with fossil natural gas.

Capital and Research and Development Funding:
The uncertainty that future technologies will efficiently and sustainably produce biofuels is an issue for funding agencies and investors. The development and application of these processes can span many years. Investors are concluding that, compared to conventional energy resource investments, biofuels investments are currently too expensive and risky.

Government Policy and Regulations:
The number one barrier to biofuel investing discussed at the September 17 workshop is uncertainty in how long policies remain in effect. Three policies mentioned were the United States Environmental Protection Agency (U.S. EPA) Renewable Fuel Standard, Low Carbon Fuel Standard post 2020, and Cap-and-trade eligibility. From investing and industry perspectives, policy uncertainties have directly affected profitability of biofuel projects by reducing revenue predictability.

Uncertainty in Feedstock Availability, Source, and Cost:
Workshop attendees mentioned that biofuel production faces uncertainties in supply and cost of feedstock. Attendees also suggested the establishment of more "BCAP" (Biomass Crop Assistance Program) type programs to financially assist land owners and operators wishing to enter the biofuel market. Also, compared to larger gasoline refineries, existing biomass facilities are small-scale and sparsely distributed.

Barriers for Development of Drop-in Liquid Fuels:
For the current fleet, the fastest way to reduce greenhouse gases is replacing gasoline with drop-in biomass fuel. The development of biomass production is slow because of the high cost and risk associated with scaling-up from pilot and demonstration to commercialization. Attendees concluded that the development of facilities to produce biomass will continue to be slow in the future. Another barrier mentioned is the 10% "blend wall" upheld by the auto industry and other stakeholders.

Barriers for Renewable Natural Gas:
The primary barrier for the commercialization of renewable natural gas is the low cost of fossil natural gas. A large contributor to this cost gap is the variability of tipping fees for solid waste disposal and the cost of removing impurities from biogas. The key barrier is rules recommended by major California utilities, which have limited sale only to nearby consumers.

Session III, Ideas and Solution to Overcome Commercialization Barriers:
Workshop attendees shared ideas and solutions for biofuel government regulation continuity, incentive and policy structure, profitability barriers for commercialization, long-term feedstock availability, production and transport technologies, and customer demand.

Ways to maintain continuity of government regulations, incentives, and Research and Development funding:
At the Federal level, incentives and price supports should target biofuel development facilities most critical to meeting greenhouse gas reduction goals. All tax credits for these facilities should be designed to remain in effect for 10 to 20 years. It is recommended that government research and development funding be allocated to projects with potential to attract private funding for demonstration and commercial phases. New fuel usage and greenhouse gas targets should be set systematically and over extended periods to prevent regulation changes during development periods.

Ways to structure incentives and government policies to accelerate improvement in technology, scale-up projects, and feedstock availability and flexibility:
Incentives that were discussed by workshop attendees were CEC grant funding, RINS and Low Carbon Fuel Standard credits, CalRecycle loans and grant funding (Recycling Market Development Zone program), tax incentives for electricity instead of transportation fuels, the Clean Transportation Program, and state and federal funding the existing transportation fuel industry, and U.S. EPA requirements. Regulatory and funding programs should focus on consistency to allow for private investor confidence and the ability to remain compliant to regulations. Government policies that were discussed were compliance policies, building codes, program rules, reporting requirements, infrastructure development in relation to.

Ways to improve the business climate for biofuel commercialization by increasing private investment, oil industry involvement, and general economic profitability:
California state agencies and obligated parties under the Low Carbon Fuel Standard program would be required to enter long-term renewable natural gas agreements. Loan guarantees and greater state support would also benefit state biofuel production. Financial incentives for the sale of biofuels and financial support geared towards feedstock would help as well.

Ways to reduce the carbon intensity and increase the long-term availability of affordable feedstocks for low carbon fuels:
The determination of biofuel and feedstock carbon intensity should be rational and transparent. Carbon intensity estimates and feedstock availability must be reliable for the development of cleaner processes can be achieved. In biofuel production, inefficiencies must be reduced or eliminated in each conversion step because conversion yields normalize carbon intensity estimations.

Ways to accelerate the development of technology for biofuels, especially drop-in biogasoline and diesel, from cellulosic feedstocks:
In order to establish large-scale production of biogasoline and diesel from cellulosic feedstocks, cost-effective technologies must be developed. Large research and development and capital investments must be guaranteed over long periods. There must be a national commitment to replace fossil-based fuels with biofuels using regulations and incentives lasting for at least 10 years. Large oil companies are likely to respond to a national commitment by getting re-involved in biofuel production and marketing.

Ways to increase customer demand for biofuels to enhance investments in infrastructure and vehicles that can use biofuels:
The two solution to increasing customer demand for biofuels is through regulation of fossil-based fuels and competitive pricing of biofuels. Consumers are aware of the per-gallon energy content of these two types of products, so this must be kept in mind with competitive pricing. Also, consumers must be assured that available biofuels will not damage their vehicle’s engine or void any warranties. Workshop attendees were highly in favor of electric vehicles (EVs) and fuel cell vehicles over the biofuel alternative.

Emerging Medium- and Heavy-Duty Vehicle Technologies: Market Barriers and Solutions

Both the United States and California have made commitments to achieve an 80% reduction in energy-related greenhouse gases from 1990 levels by 2050 to help stabilize atmospheric concentrations of greenhouse gases. In 2011, The U.S. EPA and National Highway Traffic Safety Administration began setting fuel efficiency and carbon dioxide (CO_2) emission standards for engines and medium- and heavy-duty vehicles through an increasingly stringent two-phase approach. Phase 1 (2014-2017) and Phase 2 (2018-2027) of this approach are viewed as primary drivers for the development and adoption of reduced emission vehicles. To discuss the current status and areas of progress, the Sustainable Transportation Energy Pathway team at the UC Davis Institute of Transportation Studies and the CEC held two workshops with over 100 stakeholders from industry, academia, and government. The workshops were held on December 2 and 3, 2015, and were meant to “identify environmentally economically promising alternative fuel and vehicle emerging technologies, and to identify and evaluate the critical business and policy barriers blocking their widespread adoption in the state and actionable solutions to overcome those barriers”. The report produced after these workshops summarizes the results of the two meetings with respect to the present status of alternative vehicles, market drivers for the adoption of alternative trucks, barriers to market development, and proposed solutions to promote market success.

Alternative medium and heavy-duty trucks are entering a variety of different markets. Although alternative trucks are being commercialized in a few markets, such as medium-duty delivery trucks and transit and school buses, most alternative technology is currently being developed by small companies and demonstrated within niche markets. Markets being commercialized or demonstrated in include the following: Heavy duty drayage (ports), heavy-duty long-haul, heavy-duty day cab, heavy-duty refuse, work-site utility, medium-duty delivery, and transit and school buses. Table 2 displays battery electric vehicles (BEVs) in the field being produced and their commercialization status.

Table 2: Summary of BEV Deployment and Technology Readiness

Vehicle Type	**Technology Readiness**	**Number in Service**	**Notes**
Transit Bus	Commercially Available	~40 in California >2,5000 Worldwide	3 models are commercially available in US
School Bus	Limited Commercial Availability	4 in California	3 new buses ordered in SCAQMD
Medium-Duty (8,501-14,000 lbs Gross Vehicle Weight Rating)	Limited Commercial Availability	300+	Focused on delivery service
Heavy-Duty (> 14,000 lbs Gross Vehicle Weight Rating)	Demonstration Phase	2 Drayage 1 Refuse	13 Class-8 Trucks under Construct

Source: Burke, et al. University of California, Davis.

In addition to electrification, alternative fuel sources such as fuel cells, hydrogen, and dimethyl ether fuel are being pursued. A variety of different powertrain configurations are also being tested. Among them, the most technological advancement has been seen in battery-electric powertrains and hybrid-electric powertrains. Thanks to the massive investment of the Clean

Transportation Program, over 250 alternative medium and heavy-duty vehicles have been deployed in California.

In addition to investment in renewable technology, new standards and incentives are driving alternative vehicles into the market. The U.S. EPA/ National Highway Traffic Safety Administration are setting fuel efficiency and CO_2 engine and efficiency standards in their Phases 1 and 2. The standards are divided into three general groups of trucks; Commercial pickups and vans, vocational trucks, and long-haul tractor-trailers and buses. Different standards are being set for each group of vehicles and are described in length by the U.S. EPA/ National Highway Traffic Safety Administration in the following 2 reports, titled *Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles*, Phase 1, Final rules and *Proposed Rulemaking for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-duty Engines and Vehicles-Phase 2*. In total, the combined reductions in fuel consumption and CO_2 emissions from Phase 1 and 2 are expected to total 28-38%, depending on the vehicle type, by 2027. California and the Federal government also set limits on pollution standards related to air quality. Among other standards, the most significant standard set is on the emission of nitrogen oxides (NOx). There are a variety of methods of achieving these standards for different types of vehicles, and California is implementing optional lower NOx emission standards for heavy-duty engines with the incentive of state funding.

The National Highway Traffic Safety Administration and United States Department of Energy claim that Phase 1 and 2 standards can be met with improved conventional technology with a payback period of less than 3 years. Both California and the federal government are offering incentives for purchases of advanced technologies rather than improved conventional technology because they offer much higher emission reductions but are significantly more expensive. For example, California established the hybrid and zero-emission truck and bus voucher incentive project (HVIP) to offer incentives to purchase electric trucks and buses and natural gas fueled MD/HD trucks.

There are a variety of barriers that are withholding the market development. First, the battery electric and fuel cell truck markets are dominated by new, small-scale companies that usually do not produce the truck chassis. Instead, they must partner with larger original equipment manufacturers to integrate their technology. As a result, these smaller companies are often heavily reliant on public funding. They can, however, produce and demonstrate new technology at a much faster rate than large original equipment manufacturers. Second, the low purchase volume of alternative vehicles makes them expensive and not yet cost-competitive with diesel vehicles. It is also important to note that highly reduced maintenance costs for battery electric and fuel cell trucks play a considerable role in accounting for a realistic payback period, and that further research is being done on the exact savings that can be expected due to maintenance. In the case of hydrogen alternatives, hydrogen storage tanks for medium and heavy-duty trucks are currently bulky, heavy, and expensive. The refueling infrastructure is also very limited and expensive. The high potential risk of investing in newer technology is also viewed as a major barrier to entry.

To promote market success despite these barriers, a variety of solutions are being implemented. First, government policies like the U.S. EPA/ National Highway Traffic Safety Administration's Phase 1 and 2 place increasingly stringent fuel efficiency and emission standards on vehicles. Additional standards like California's regulation on NOx emissions will further strain the market for standards diesel engines. Combined with incentives to reduce the cost of investment, the government hopes to equalize the market between standard and alternative vehicles. Finally, California is discussing the mitigation of high cost fueling infrastructure for medium and heavy-duty vehicles. This would drastically help reduce the payback period for advanced technologies.

Infrastructure for Light Duty Vehicles, Freight Movement, and Transit Buses and Port Vehicles

Workshop Purpose and Objectives

The Sustainable Transportation Energy Pathways team at the UC Davis Institute of Transportation Studies and the CEC conducted joint workshops on April 25 and 26, 2016 to seek and discuss insights on the growth and potential of plug-in electric vehicle (PEV) infrastructure deployments in California, including progress achieved to date, critical barriers, and strategies and policies needed to boost commercialization. The workshops were held at the CEC on April 25, 2016 and at UC Davis on April 26, 2016.

The third workshop in this series focused on commercialization and deployment of plug-in electric vehicle infrastructure in California for light duty vehicles, freight, and transit. This coincided with an April 25th merit review public workshop conducted at the CEC on the same topic.

Summaries of General Workshop Findings

Part I: Infrastructure for light-study electric vehicles:

As of April 2016, there are about 200,000 PEVs on the road in California and about 20,000 non-residential charging stations available to provide battery charging for them. The California Zero Emission Vehicle Action Plan (2015) from the Governor's Office has set goals of 1 million PEVs by 2020 and 1.5 million PEVs by 2025. This will require about 200,000 non-residential charging stations by 2020 and about 300,000 stations by 2025. These charging stations must be placed so that PEV owners who do not live in single-family dwellings have convenient access to them. In addition, about 10,000 fast charging points must be built along the major highways in California so that PEVs can be used for inter-city travel. Below, Table 3 shows the charging levels for light, medium, and heavy duty electric vehicles and their primary applications.

Table 3: Charging Levels and Primary Uses

	Current type	Amperage	Voltage	Kilowatts (kW)	Primary Use
Level 1	AC	Up to 15A	120	Up to 1.8 kW	Light Duty Residential
Level 2	AC	Up to 80 A	240	Up to 19.2 kW	Light Duty Residential and Public; Short Range Medium Duty
Level 3 (Under Development)	AC	Up to 200A	Up to 600	Unknown	Light Duty Public Charging; Medium Duty and Heavy Duty Fleet charging
Direct Current Fast Charging	DC	Up to 200A	480	Up to 240 kW	Light Duty Public Charging; Medium Duty and Heavy Duty Fleet Charging

Source: Adapted from the California Air Resources Board Draft Technology Assessment: Medium-and Heavy-Duty Battery Electric Trucks and Buses (2015)

To date many of the charging stations have been built with funding from the CEC and California Air Resources Board, but in the future the major funding for the large expansion of charging stations needed will likely come from the investor-owned electric utilities who have shown a serious interest in providing infrastructure for electrification of transportation. It is critical that the California Public Utilities Commission formulate in the near future an acceptable approach for the involvement of the utilities in large infrastructure projects. Auto manufacturers could become involved in building infrastructure like Tesla, but that seems unlikely.

Both the PEV and battery charger technologies that meet the car buying public's needs are available at decreasing costs as sales volumes increase. Hence a major factor in maintaining increasing sales of PEVs will likely be the timely building of the battery charging infrastructure needed by the new PEV owners. The cost of the infrastructure seems manageable being in the range of $100-$200 million per year between now and 2025. At the present time, the business case for installing and operating charging stations is difficult, but it will significantly improve as the numbers of electric cars on the road continues to increase.

Part II: Infrastructure for medium-and heavy-duty electric vehicles:

At the present time there are far fewer medium- and heavy-duty electric vehicles on the road in California compared to light-duty vehicles and the charging infrastructures for those vehicles have been designed and built specifically for them. Medium-duty electric delivery trucks and vans represent the largest number of medium and heavy duty electric vehicles on the road and charging of their batteries can be done using available Level 2 chargers. Electric transit buses in relatively small numbers are in commercial service, but these numbers are expected to increase rapidly in future years, and are already expanding rapidly in worldwide markets.

The challenge to electrification of medium- and heavy-duty vehicles in most cases is that the electrified powertrains are more expensive than the internal combustion engine and transmission components they replace, and the energy storage for batteries (or fuel cells) is heavier or requires more volume than the case of liquid fuels for engines. Current demonstration projects will provide valuable information concerning both the durability and cost of electrified powertrains in large freight vehicles. While the potential market for medium- and heavy-duty vehicles is unknown, it will be affected by technology improvements, demonstration results, and the willingness of fleet operators to invest in new technologies.

Infrastructure for charging transit buses and other heavy-duty vehicles is very different from light-duty vehicles, requiring special equipment due to the energy storage capacity (kilowatt-hours) and high voltage of their battery packs, and the fact that they are housed and charged in commercial fleets with centralized charging and scheduling needs. The battery size, measured in kilowatt-hours, in these vehicles varies considerably. This results in corresponding large variations in charging requirements.

As shown in Table 4, most medium- and heavy-duty electric vehicles require higher than Level 2 power charging in order to be able to charge in a reasonable overnight timeframe of 6-8 hours. Direct current fast charging, typically with 50-120 kW charging power, are currently available and would be suitable for charging most heavy-duty vehicles. Charging of heavy-duty vehicles and transit buses with long electric ranges are the most challenging, especially if those vehicles need to be charged between routes in timeframes closer to one hour than six hours. This would require charging outputs of 100-200 kW, which are under development but not yet common, and will continue to pose a significant challenge in terms of investment costs.

Table 4: Range, Battery. Motor and Charging KW of Each Vehicle Type

Vehicle type	Range (miles)	Battery (kilowatt-hours)	Motor (kW)	Charging kW required to complete charge in 6 hours
Transit bus	150-200	300-350	200-250	60
School Bus	50-75	80-100	150	20
Deliver Truck	50-100	40-80	120	15
Port drayage truck	50-75	270	300	50
Refuse truck	60-80	220	230	40

Source: Burke, et al. University of California, Davis.

Alternative Charging Solutions for Medium- and Heavy-Duty EVs

The conventional conductive technology for charging batteries in medium- and heavy-duty EVs appears to be well-developed and commercially available in the United States, Europe, and Japan. At the present time, high voltage, high power charging stations are expensive primarily because the products have not been standardized both because sales volumes are low and standards for both connectors/docking units and interface protocols have not yet been established. Meetings are currently underway worldwide to establish the needed standards.

Two alternative charging options are under investigation, in particular for transit bus applications. Both would allow for charging along their route, either through overhead connections, or through wireless charging. In the case of overhead high power units, these would dock with the bus at a stop and provide direct current fast charge to the batteries while stopped. Development of high power wireless charging technology is presently underway for heavy-duty electric vehicles. Deployment/demonstration of the wireless technology has only begun. In most cases, the charging facilities for medium- and heavy-duty electric vehicles will be provided by the vehicle operators in collaboration with the local electric utilities. The challenge for both en-route charging options is the cost; however, the business case for the charging stations should be reasonably attractive because they can be optimally sized for the fleet to be charged, and may allow for smaller batteries on-board the buses. For transit buses, funding for charging facilities is available as part of Federal Transit Administration grants for zero-emissions vehicles. For demonstration projects, funding for small fleets and/or single vehicles is available in California with HVIP and CEC grants.

While the cost of infrastructure remains the largest challenge especially for faster charging options, in the long term, the business case for fast chargers should become more attractive as more vehicles are able to charge per day, allowing for higher utilization of the infrastructure. The current electricity tariff rates, with peak pricing and demand charges, will be an important consideration for fleets, as will the ability to add smart charging to control and balance the charging demand, and therefore reduce costs, when there is operational flexibility.

Full Report:

1. Burke, A., Jaffe, A. M, Fulton, L., Dominguez-Faus, R., Miller, M., Zhao, H., et al. (2016). Assessment of Critical Barriers to Alternative and Renewable Fuel and Vehicle Deployment – Workshop Series. *UC Davis: National Center for Sustainable Transportation*. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/9z62g376)

CHAPTER 2: Accelerating Commercialization of Alternative and Renewable Fuels and Vehicles

Task 2.2: Accelerating commercialization of alternative and renewable fuels and vehicles

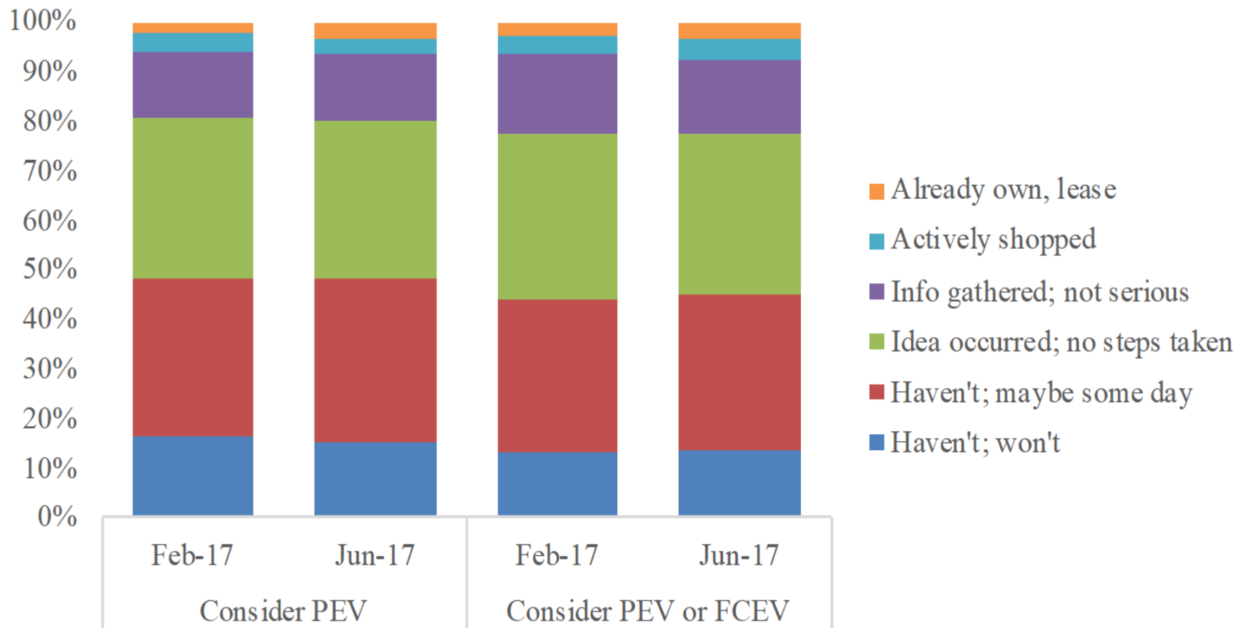
The objective of this subtask was to implement a market research project with a recurring survey to advise California state agencies and alternative-fuel vehicle /PEV stakeholders on the most effective ways to expand the market for alternative and renewable fuels and vehicles in California and the US.

Project Findings

The analysis is based on two on-line surveys of car-owning households in California. The first was conducted in February (n = 1,681) and June 2017 (n = 1,706). The goal of these two studies was to build an on-going record to monitor charge in the market and consumer awareness by repeating a survey using the same methods of recruitment, questioning, analysis in order to provide a consistent view over time. Analysis of the February 2017 data is presented in the companion State of the Market Report II. Nothing in the results for the June data contradicts the general findings from February.

The primary measure of interest is the extent to which respondents have already considered a zero-emission vehicle for their household. Figure 1 shows 4-of-5 car-owning households in California had given either no or nearly no consideration to zero-emission vehicles. Combined, less than 10 percent had given the highest two levels of consideration; active shopping or ownership. Other measures of awareness, name recognition, incentive knowledge, and driving experience were commensurately low.

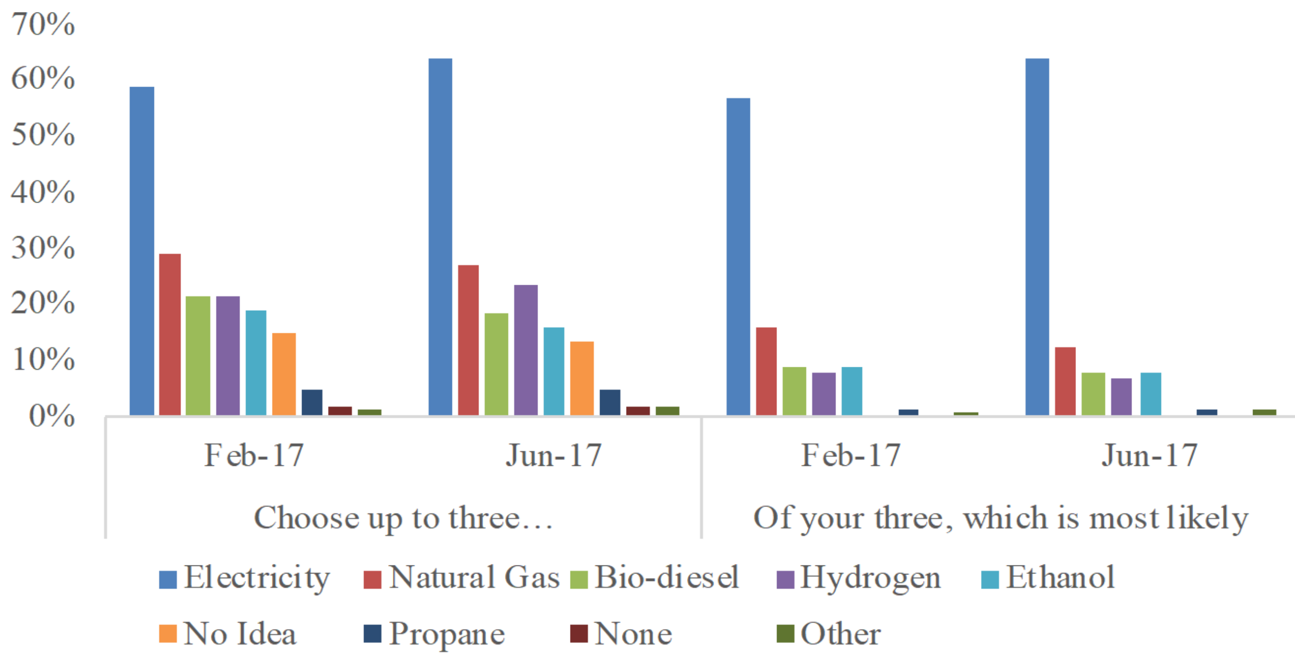
Figure 1: Consideration of Electric Vehicle Types; February 2017



Source: Kurani, Kenneth. University of California, Davis. State of the Market Report 2

The survey also asked about replacing gasoline or diesel with alternative fuels, and in this case, electricity is viewed as the most likely replacement, as shown in Figure 2.

Figure 2: Consideration of replacement alternative fuels 2017



Source: Kurani, Kenneth. University of California, Davis.

Despite electricity being viewed by respondents as the most likely replacement fuel for gasoline or diesel, it was not a vehicle technology that respondents felt familiar with, likely meaning that they don't have a sense of urgency at the need to replace traditional fossil fuels with alternatives, and have therefore not invested much in learning about or considering purchase of alternative fueled vehicles.

Additional analysis of the role of biological sex/social gender is based on a recommendation in the first State of the market report. The lower likeliness that female respondents have considered zero-emission vehicles is solely for fuel cell electric vehicles. There appear to be some slight differences in how some explanatory variables are correlated to consideration between males and females: for females, it matters more that they live in a household that has flexible vehicle assignments; for males, it matters more whether they claim familiarity with internal combustion engine vehicles and experience with zero-emission vehicles. Still, these differences are marginal and do not contravene the overall finding that across all respondents—female and male—few have paid much attention to any kind of zero-emission vehicle.

Full Reports:

1. Kurani, K. S. (2018). State of the Plug-In Electric Vehicle Market: Report I. UC Davis: National Center for Sustainable Transportation. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/4gn9x59z)
2. Kurani, K. S. (2018). University of California, Davis. 2018 *State of the PEV Market: Report II*. California Energy Commission. Publication Number: CEC-600-2018-XXX. *UC Davis: National Center for Sustainable Transportation*. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/8rp9h6fb)

CHAPTER 3: Eco-Friendly Intelligent Transportation System Technology for Freight Vehicles

Task 2.3: Develop Models on Eco-Friendly Intelligent Transportation System

Technology for Freight Vehicles

The objective of this subtask was to develop new eco-friendly intelligent transportation system technologies that can be applied to freight vehicles (e.g., heavy-duty trucks) associated with goods movement to improve energy efficiency and reduce emissions. These technologies could then be evaluated in a number of different operating scenarios using state-of-the-art simulation modeling tools. The results and recommendations can inform the adoption of policies and practices to promote improved efficiency and reduced emissions in the freight sector.

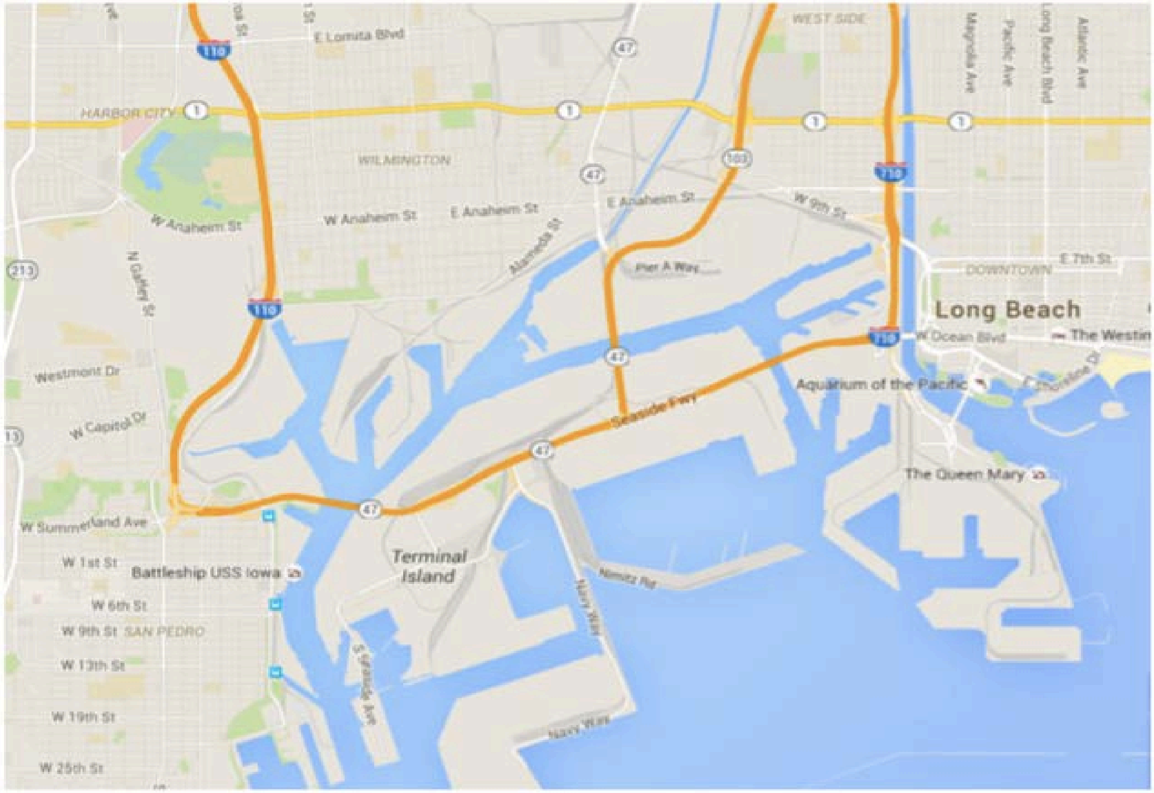
This task was divided between two teams working in collaboration at the University of Southern California, and at the University of California, Riverside (UC Riverside). Results from the University of Southern California are presented first, followed by the project results from University of California, Riverside.

University of Southern California

Overview

Ioannou et al. report on the effects of various techniques to control traffic in a simulation of a segment of freeway on I-710. The simulation involves a network of some highways and important (arterial) streets in Long Beach, California, shown in Figure 3.

Figure 3: Selected Freeway Network Area



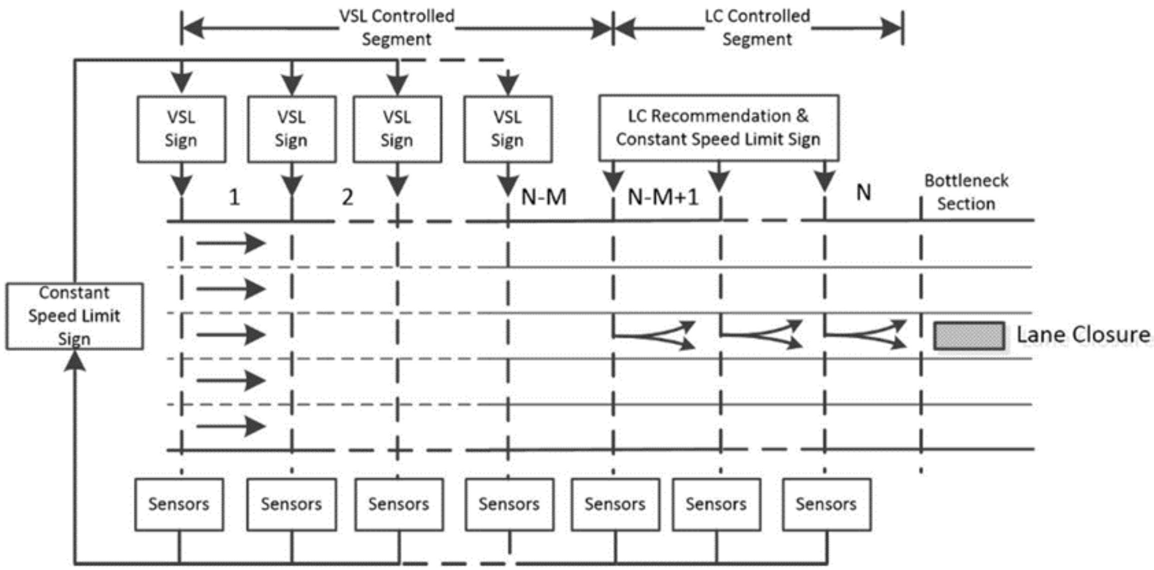
Source: Ionnou et al. University of Southern California. Traffic Flow Models and Impact of Combined Lane Change and Speed Limit Control on Environment in Case of High Truck Traffic Volumes.

This simulation specifically analyzes an area of high truck volume. Due to their size and slow speed, trucks negatively affect traffic, increasing travel time, accident rates, and air pollutant rates.

Method

The study performed by Loannou et al. uses Lane Changing (LC) control and Variable Speed Limit (VSL) control as methods to control traffic. LC control provide suggestions to drivers to change lanes or not based upon if the lane is closed farther down the road. VSL control provide a speed limit to drivers so they slow down based upon the flow of traffic farther down the road. In the study, Loannou et al. executed a simulation using differing scenarios of lanes closed and use of no controls, LC, VSL, or both. Figure 4 is an example of how LC and VSL control would be used.

Figure 4: Configuration of LC &VSL Controller



Source: Ionnou et al. University of Southern California. Traffic Flow Models and Impact of Combined Lane Change and Speed Limit Control on Environment in Case of High Truck Traffic Volumes.

Results

The study analyzes LC and VSL control individually and collectively. Loannou et al. find that LC control by itself decreases Total Travel Time and number of stops but increases the amount of lane changing. VSL control by itself homogenizes the density and speed of cars, which causes drivers to change lanes less. Combined LC and VSL control improves the flow rate of traffic at the bottleneck and homogenizes traffic, consequently increasing safety, traffic mobility, and lowering the level of emissions. LC and VSL control also have the following positive effects on traffic:

- Reduced travel time by 25-36%
- Reduced number of stops by 90%
- Fuel savings of about 20%
- Reduced Carbon Dioxide and Nitrogen Oxides emissions by 16-20%

The study concludes that the above changes are feasible with today's technology and will be beneficial if enacted.

Full Report:

1. Ioannou, P., Zhang, Y., & Zhao, Y. (2016). Traffic Flow Models and Impact of Combined Lane Change and Speed Limit Control on Environment in Case of High Truck Traffic Volumes. University of Southern California: National Center for Sustainable Transportation. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/0d33t3j6)

University of California, Riverside

Introduction and Goals

In 2012, heavy-duty freight vehicles contributed 21.9% of overall transportation sector greenhouse gas emissions, despite constituting only 9.2% of vehicle miles traveled. As such, it is especially important to address these higher-polluting vehicles to reduce greenhouse gas emissions. System modification is necessary to minimize the amount of emissions heavy-duty freight vehicles release, primarily by minimizing the time they spend active on the road. New technologies, such as Intelligent Transportation Systems, have provided promising potential to do just this.

One major application of Intelligent Transportation Systems is in adaptive traffic signal control (ATSC) for signalized intersections. With ATSC, existing signalized intersections could be modified to become significantly more reactive and dynamic to changing traffic flows. Moreover, such systems could be optimized for certain parameters (queue length, vehicle energy consumption, vehicle emissions, etc.). Such optimization can be fine-tuned to minimize contributions from heavy-duty vehicles, thus addressing the freight sector. In this report, researchers evaluated these possibilities using simulations of such systems, and compared them to conventional signalized intersection strategies (fixed timing, Webster calculations, etc.). The report also considered this comparison for both isolated intersections and consecutive intersections on an arterial traffic corridor.

Method and Results

The core technology involved with ATSC is connected vehicle (CV) technology. CV technology enables vehicles to wirelessly and automatically communicate with one another, sharing information such as speed, direction, and distance from objects. Existing CV applications involve small-scale situations such as maintaining steady flow on a highway. For the system considered here, the researchers expanded this technology to optimize traffic flows at intersections. The system can be explained as follows: When approaching an intersection, CVs communicate relevant information (speed, position, direction) to the intersection. Computer software associated with the intersection (its “management agent”) takes in this information, and then follows a structured process to determine the best setup for the intersection in that moment. This “setup” entails having a certain phase or set of phases (green lights) active, or the changing of phases (yellow lights, all red) to introduce a new phase or set of phases. Essentially, the intersection intelligently controls the traffic lights based on whatever traffic is present. Of course, such a concept has been applied before, with features such as inductive loop detectors that vehicles drive over. However, these existing systems have a very limited source of information. Using ATSC provides a much greater amount of information, and thus allows for far more informed decision making by the intersection.

To test this system, advanced computer simulations were used to compare the performance of ATSC (optimized for minimum queue length) with that of two conventional signal planning strategies. The comparison considered both an isolated intersection and a corridor (of 3 consecutive intersections). The simulation was tested with gradually increasing traffic levels. The two conventional strategies, fixed phase signal timing and Webster signal timing, require known existing average traffic flows, and are blind to the current traffic. As such, they have no ability to react and change based on the variable traffic. ATSC is very reactive and dynamic, and this flexibility proved effective.

When compared to both fixed and Webster (isolated) intersections, ATSC reduced average travel time across almost all traffic levels. Low traffic levels saw the greatest reductions with ATSC, with around 30% for fixed and 10% for Webster. High traffic levels saw the two systems performing about the same, though ATSC did perform worse at the very highest levels, but only by margins of a few percent. Vehicle energy consumption and emissions followed a similar trend as queue length, with ATSC providing reductions across almost all traffic levels (though with decreasing margins as traffic increased, just like with queue length. For the corridor, ATSC also proved beneficial (with a similar trend), though mainly for "uncoordinated phase vehicles" (vehicles not able to make consecutive green lights).

For coordinated phase vehicles, ATSC performed worse across almost all traffic levels. It is important to note though that for the ATSC run, the 3 intersections could not communicate with one another, and thus were all running independently. If the communication within ATSC were to be expanded to include contact between intersections, it is likely that ATSC would have performed a lot better in the corridor than it did here.

Conclusion

As the simulations reveal, ATSC has great potential to increase efficiency for signalized intersections. Specifically, CV-based ATSC can greatly improve intersections during low to medium traffic flow. It can provide such improvements for multiple measures of efficiency, such as queue length, vehicle energy consumption, and vehicle emissions. It is here where ATSC can reduce emissions for heavy-duty freight vehicles. Optimizing by queue length was found to be the most beneficial choice for improving traffic flow. However, for highly-polluting freight vehicles, the system can be modified to increase the "importance" of said vehicles at an intersection. Such "important" vehicles would be more favored by the intersection to let through. Therefore, intersections can be optimized in a way most beneficial for traffic flow, while also decreasing idle time for freight vehicles. This combination shows great potential for improving both traffic flow and vehicle emissions. More research is needed for further expansions of this concept, like intersections communicating with one another on the scale of city grids. The potential for improved flow is great, and greater emissions reduction is bound to follow.

Full Report:

1. Kari, D., Wu, G., & Barth, M. (2017). Eco-Friendly Intelligent Transportation System Technology for Freight Vehicles. UC Riverside: National Center for Sustainable Transportation. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/8858n2wn)

CHAPTER 4: Outreach and Technology Transfer

Task 3: Outreach and Technology Transfer

Workshop March 14, 2017: Growing the PEV Market in a Variety of Policy Scenarios

The goal of this full-day workshop was to explore potential policy scenarios for the US and California, and their possible impacts on continuing to grow the PEV market as it moves into the second generation of vehicles and buyers in a changing political and economic climate. The project team discussed prior expectations for the early PEV market development and what has changed – such as longer range EVs, and auto manufacturers reaching the 200,000 vehicle sales limit for the federal tax credit, and the potential for changing federal guidelines. Researchers from the Plug-in Hybrid & Electric Vehicle Center (which performed research Task 2.2) presented current research results and explored potential policy changes in order to maximize the impact of the project team's current work as well as what was needed to keep research policy relevant in the future. The afternoon included a breakout into focused discussion groups on the following topics:

1. Consumer Education,
2. Infrastructure,
3. City, State, and National Policy Levers, and
4. Revolutions: How do automation and shared vehicles impact electrification?

Legislative Workshop November 30, 2017: Accelerating the Adoption of Electric Vehicles in California: What we Know, What we Don't, and Future Directions

The National Center for Sustainable Transportation with the Plug-in Hybrid & Electric Vehicle Research Center held a half-day workshop on Nov. 30th to share the results of the Task 2.2 project around consumer awareness, as well as other electric-vehicle related research findings with staff and analysts from the California State Senate and House. The focus for the workshop was on understanding consumers, infrastructure needs and utilization, and the role of incentives, and left time for discussion on other areas of interest to the legislative staff attending the workshop. This workshop was attended by approximately 13 legislative staffers from budget, transportation, energy and other related committees.

Webinar May 30, 2018: Consumer Awareness of Electric Vehicles: Challenges and Opportunities

The Plug-In Hybrid & Electric Vehicle Research Center held a one-hour webinar on May 30th, 2018, to present the project findings from Task 2.2. The Plug-in Hybrid & Electric Vehicle Center at UC Davis has been studying consumer adoption of clean vehicles for many years. The startling results of the project team's 2017 surveys show that compared to 2014 survey results, consumers are no more aware of electric vehicles than they were 3 years prior. While automakers and governments are working toward increasing adoption of electric vehicles, consumers are trailing behind. This webinar presented comparative survey results, electric vehicle market information, and potential opportunities for increasing consumer awareness and knowledge of electrified vehicles.

Pre-registration for the webinar was at 34 people, and the webinar was attended by about 15 people live. The Webinar was recorded, and will be available for viewing on the Plug-in Hybrid & Electric Vehicle Research Center website.

Additional Outreach Efforts

Dr. Kurani presented the comparative analysis from his Task 2.2 work (first survey results, in comparison to previous 2014 survey results) at the UC Davis hosted STEPs Symposium in December 2017. The Sustainable Transportation Energy Pathways symposium was attended by over 150 stakeholders from automotive and energy companies, state and federal agencies, and other non-governmental research organizations, universities, and foundations.

On Jan 18, 2018, Institute of Transportation Studies published a blog which included some research findings from Task 2.2. Link to Blog post: UC Davis Institute of Transportation Studies (https://its.ucdavis.edu/blog-post/automakers-policymakers-on-path-to-electric-vehicles-consumers-are-not/)

After this blog post, Dr. Kurani presented at the VELOZ meeting on March 14th, 2018 his comparative analysis looking at awareness and engagement of consumers in the EV market (Task 2.2). Veloz attendees included automakers and utilities, as well as representatives from city and state agencies focused on increasing the awareness and adoption of electric vehicles in California. Energy Commission Commissioner Janea Scott is the Chair of the Public Policy Board for Veloz, which also includes Mary Nichols from the Air Resources Board, and Carla Peterman from the California Public Utilities Commission. The Public Policy Board advising Veloz also includes representatives from the Bay Area Air Quality Management District and the California Independent System Operator. The agenda for the event as well as Dr. Kurani's presentation can be found at the following link: http://www.veloz.org/event/veloz-symposium-accelerating-the-electric-car-movement-together/

Publications

This series of projects has resulted in several research reports and publications by the associated researchers:

Research Task 2.1

1. Burke, A., Jaffe, A. M, Fulton, L., Dominguez-Faus, R., Miller, M., Zhao, H., et al. (2016). Assessment of Critical Barriers to Alternative and Renewable Fuel and Vehicle Deployment – Workshop Series. UC Davis: National Center for Sustainable Transportation. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/9z62g376)

Research Task 2.2

1 Kurani, K. S. (2018). State of the Plug-In Electric Vehicle Market: Report I. UC Davis: National Center for Sustainable Transportation. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/4gn9x59z)

2 Kurani, K. S. (2018). University of California, Davis. 2018 *State of the PEV Market: Report II*. California Energy Commission. Publication Number: CEC-600-2018-XXX. *UC Davis: National Center for Sustainable Transportation*. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/8rp9h6fb)

Research Task 2.3

1. Ioannou, P., Zhang, Y., & Zhao, Y. (2016). Traffic Flow Models and Impact of Combined Lane Change and Speed Limit Control on Environment in Case of High Truck Traffic Volumes. UC Davis: Institute of Transportation Studies (UCD). Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/0d33t3j6)

2. Y. Zhang and P. Ioannou 'Highway Traffic Flow Control with High Volume of trucks' submitted to the National Urban Freight Conference, Oct. 2015

3. Y. Zhang and P. Ioannou, 'Combined Variable Speed Limit and Lane Change Control for Highway Traffic' IEEE, Control Conference on Decision and Control, Dec. 2015

4. Kari, D., Wu, G., & Barth, M. (2017). Eco-Friendly Intelligent Transportation System Technology for Freight Vehicles. UC Davis: National Center for Sustainable Transportation. Retrieved from UC Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/8858n2wn)

GLOSSARY

ADAPTIVE TRAFFIC SIGNAL CONTROL (ATSC) —Uses real-time traffic information from road sensors to determine when a traffic light should be red or green. When effective, adaptive traffic signal controls can reduce congestion and thus improve traffic flow.[1]

BATTERY ELECTRIC VEHICLE (BEV)—Also known as an “All-electric” vehicle (AEV), BEVs utilize energy that is stored in rechargeable battery packs. BEVs sustain their power through the batteries and therefore must be plugged into an external electricity source in order to recharge.

CALIFORNIA ENERGY COMMISSION (CEC) — The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The CEC's five major areas of responsibilities are:

1. Forecasting future statewide energy needs.
2. Licensing power plants sufficient to meet those needs.
3. Promoting energy conservation and efficiency measures.
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels.
5. Planning for and directing state response to energy emergencies.

Funding for the CEC's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account, and other sources.

CARBON DIOXIDE (CO2) — A colorless, odorless, nonpoisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent).

CONNECTED VEHICLE TECHNOLOGY (CV) — Technology that will enable cars, buses, trucks, trains, roads and other infrastructure, and our smartphones and other devices to “talk” to one another.[2]

ELECTRIC VEHICLE (EV) — A broad category that includes all vehicles that are fully powered by electricity or an electric motor.

MEDIUM/HEAVY DUTY (M/HD) – Medium/heavy duty, refers to vehicles 14,001 – 26,000 lbs GVWR (medium duty) or 26,001 and greater lbs GVWR (heavy duty)

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1 University of California, Berkeley: Institute of Transportation Studies (https://path.berkeley.edu/research/traffic-operations/adaptive-traffic-signal-control)

2 United States Department of Transportation (https://www.its.dot.gov/cv_basics/cv_basics_what.htm)

HYBRID AND ZERO-EMISSION TRUCK AND BUS VOUCHER INCENTIVE PROJECT (HVIP) — A project launched in 2009 by the ARB in partnership with CALSTART to accelerate the purchase of cleaner, more efficient trucks and buses in California.

KILOWATT (kW) — One thousand watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon, a typical home—with central air conditioning and other equipment in use—might have a demand of 4 kW each hour.

LANE CHANGE CONTROL (LC) — Provides lane change recommendations to upstream vehicles, which spreads lane changes along a long distance and hence mitigates the capacity drop at bottlenecks. [3]

NITROGEN OXIDES (OXIDES OF NITROGEN, NOx) — A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation and acid deposition. NO2 is a criteria air pollutant and may result in numerous adverse health effects.

PLUG-IN ELECTRIC VEHICLE (PEV) — A general term for any car that runs at least partially on battery power and is recharged from the electricity grid. There are two different types of PEVs to choose from—pure battery electric and plug-in hybrid vehicles.

VARIABLE SPEED LIMIT (VSL) — Is an important highway control strategy which has long been studied and reported to be able to smooth traffic flows and dampen shockwaves. VSLs are speed limits that change based on road, traffic, and weather conditions. [3]

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA) — A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards setting, and enforcement activities.

UNIVERSITY OF CALIFORNIA, DAVIS (UC Davis) — A public research university located in Davis, California. It is one of the 10 campuses in the University of California (UC) system.

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3 University of California, Davis: National Center for Sustainable Transportation (https://escholarship.org/uc/item/0d33t3j6)