Title
Crazy Commuters: UC Davis Population Drives 300,000 miles a day.

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ESP 198

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Introduction

Collectively, people who drive to campus by themselves travel about 300,000 miles every day. UC Davis students, staff, and faculty drive to the moon and back every other day. While Davis is known for its large proportion of biking students and employees, approximately 46% of people who travel to campus do so by bike, about 22.9% of people travel to campus by driving alone. This is not only an expensive way to get to campus when accounting for costs like gasoline, insurance, and parking, but it also has impacts that are not immediately apparent such as carbon emissions, health impacts, and wear on public infrastructure.

Our task is to build a model that accounts for all these parameters and calculates the real cost of commuting to campus every day. In this model, we are including three main parameters: health costs (such as traffic injuries and fatalities), direct commuter costs (insurance, parking costs, vehicle maintenance, etc.), and the costs of emissions (in carbon dioxide equivalents). To build upon the calculated model, we are going to focus on possible climate solutions through possible alternatives to avoid construction cost of parking structures by finding ways to decrease vehicle miles traveled (VMT) per year. Additionally, if reducing VMT does not seem to be possible, because of the increases of car ownership in California, we will also form probable solutions to reduce emissions through social movements, governance, and technological advances. Hypothesizing that this alternatives will lead to benefits in health, commuter costs, and emissions for the entire planet.

The Real Cost of Commuting

The generated model is trying to assess the "true" cost of 300,000 miles/day being driven by UC Davis Students and Staff. The model will be calculating the impacts towards health costs, commuter costs, and emission costs with a reference period of 2015. Followed with a 15 year prediction of costs with one scenario focusing on business as usual, and one on a 10% decrease in VMT per day. It is important to note that not all possible scenarios were able to be calculated within the model, so the model is assessing the continuous use of gasoline powered vehicles and does not account for any hybrid, electric and hydrogen vehicles. That also includes other forms of transportation besides drive-alone commuters.

Health Costs

Prevention of injury, illness, and loss of life is a significant factor in many economic decisions, including job choices and consumer product purchases. Costs of accidents, comprising fatal and non-fatal damage costs, make up an important part of external cost of traffic that play a role in the economic market. The benefit of preventing a fatality is measured by what is conventionally called the Value of a Statistical Life (VSL), defined as the additional cost that individuals would be willing to bear for improvements in safety that reduce the expected number of fatalities by one (Blaeij et al, 2001). Valuation of a statistical life is concerned with valuation of changes in the level of risk exposure rather than the valuation of the life of a specific individual.

On the basis of the best available evidence, it was identified that $9.4 million was the value of a statistical life and is used by the Department of Transportation analysis assessing the benefits of preventing fatalities (National Highway Traffic Safety Administration, 2016). Using the VSL and the probability of getting in an accident within 100 million miles we can estimate the cost per 300,000 miles driven in California. Reported by the Insurance Institute for Highway Safety in California there is 0.95 fatal accidents for every 100 million miles driven (Federal Highway Administration, 2015).

$$\frac{0.95\ lives}{100\ Million\ Miles} * \frac{\$9.4\ Million}{1\ life} * 300{,}000\ Miles = \$26{,}790$$

The cost calculated ($26,790) is representing the risk price we put on driving 300,000 miles per day. This may not be a direct cost to anyone, but it is important to assess the probability of getting into a fatal accident and what the cost of those 300,000 miles can entail.

Other health implications assessed are the costs of lives being indirectly affected by the air pollutants of the vehicles. The accumulation of CO_2 in the atmosphere increases the amount of particulate matter people inhale, which leads to health problems. Amassed particulate matter in the lungs leads to a greater possibility of forming chronic bronchitis, cardiac arrhythmias, and may even cause premature deaths. A time series study concluded that an expansion of 10-$\mu g/m^3$ in particulate matter concentration has a relative risk for daily cardiovascular mortality of 0.4% to 1.0% within 24 hours, and long term exposure can contribute to approximately 800,000 premature deaths per year (Brook et al., 2010). Carbon dioxide, the longest lasting greenhouse gas, has elevated pollutants to alarming levels because its accumulation in the atmosphere. The accumulation intensifies the greenhouse effect on Earth causing for the plant to warm and have record breaking temperatures.

Beyond being harmful to the air, driving may also effect other systems in the environment like soils and water. These systems are effected by the oils, tire deterioration and trash that typically builds up on the side of major roads and highways. The product that is generated by driving can be released into the soils and water when it rains. Rains then wash all the toxins from the products into the soils, and that allow it to sink into ground water systems which may lead to rivers and streams. This can be a major problem because lots of agriculture land is located next to major roads and highways. Overall the product of driving gasoline powered vehicles cause negative health effects to humans and the environment, because of the toxins released into the air, water and soils.

Commuter Costs

The average annual monetary and temporal costs to individuals who commute to campus alone everyday can be calculated by adding up the costs of vehicle insurance, vehicle maintenance and repair, fuel, parking, and time spent commuting. Since we are focusing on the effects caused by driving 300,000 miles the commuter costs will be generated by a proportional population from the amount of miles driven daily (300,000) and the average mileage driven by a single drive-alone commuter at UC Davis, which is 27.2 miles (Handy, 2017). This proportional population representing 300,000 miles is equal to 11,029 drive-alone commuters, and all cost for commuters will be assessed from this proportional population.

The cost of vehicle insurance can vary based upon an individual's demographic characteristics, the type of vehicle they drive, their driving record, as well as the area that they live in. In determining the average annual cost of insurance for UC Davis commuters, we used the average annual cost of car insurance for a driver in California. This is estimated to be $1,962 by ValuePenguin. By using the annual cost of insurance and the proportional population we have estimated that the daily cost of insurance corresponding to 300,000 miles driven is $59,286.87.

The cost of vehicle maintenance and repair can vary based upon the type of vehicle driven, the amount and quality of care and maintenance undertaken by the commuter, as well as the area in which the vehicle is driven. In determining the average annual cost of vehicle maintenance, we used the average annual cost of maintenance for an American driver. This is estimated to be $1,186 by AAA and assumes that vehicle owners comply with maintenance recommendations by the manufacturer, and the daily cost to maintenance is estimated to be $35,838.03 for our population.

The cost of fuel varies upon many factors but we focused on California's vehicle standards, the average miles driven by the commuter, and the annual gas price. By using these

$$\frac{Ave.\, Mileage\ Driven\ (27.2)}{(1)\ Day} * \frac{(1) Gal.\ of\ Gas}{Ave.\, Mileage\ (27)} * \frac{\$3.22}{(1) Gal.\, of\ Gas} * Population\ (11{,}029)$$

components we calculated that the daily cost of fuel is $35,777.78. Just as a reminder this calculations are based on a reference year of 2015, which will be our baseline year for the future predictions.

The cost of parking on campus for commuters who drive to campus alone during the academic year is $46.50 per month based on the average cost of a C & A parking pass. Calculated through our population this leads to a cost of $17,095.59 per day.

The time spent commuting can vary based upon the distance of the commute, the behavior of the driver, predictable and unpredictable traffic events, and the route taken. Based upon the 2015-2016 Campus Travel Survey estimate that the average commuter travels 27.2 miles per day and information provided by Google Maps, we estimated that the average commute would take a driver 30 minutes to complete every day. By using the driving cost estimated to be $5.50 an hour by the Department of Transportation, we can calculate an estimated driving cost per day which is $30,330.88. The reason the driving cost turned out to be $5.50 was because the Department of Transportation values driving time at about half the hourly wage of an individual. Assuming that staff make more than students on campus we used $5.50 because it is about half the minimum wage, so we found it to be the best estimate that is both inclusive of students and staff that value their driving time.

Summing up all the commuter cost per day it is assumed that on a daily basis there is about $178,329.15 spent towards a proportional population representing 300,000 miles driven by the UC Davis students and staff.

Emissions Costs

The social cost of carbon is a measurement of the physical damage done by one metric ton of carbon in terms of dollars. This number includes estimates of damages to agricultural production, human health, damage to property and infrastructure due to extreme weather events, and changes in energy costs. There are many different estimates for the actual dollar value of the social cost of carbon, and if there should or should not be a discount rate applied to it (and what that should be). For our values we will be using the United States Environmental Protection Agencies predictions starting with the 2015 cost of $36 per ton of CO2 with a 3% discount rate, and increases for future years.

Students, staff, and faculty commute a total of 300,000 miles to and from campus every day, 22.9% of people who come to campus on an average day drive by themselves without anyone else in the car. The daily VMT by these people to campus is estimated to be about 27.2 miles, and by using California's vehicle standards along with the social cost of carbon we hope we can estimate the cost of carbon by 300,000 miles driven daily.

In order to calculate the physical impact of the emissions from this mode of transportation, we first must calculate how much carbon dioxide equivalent each commuter is emitting on a daily basis. A gallon of standard gasoline emits approximately $8.887 * 10^{-3}$ metric tons of carbon dioxide when combusted and the average vehicle gets about 27 miles per gallon:

$$\frac{(8.887 * 10^{3}) \mathit{Metric\ Tons\ of\ CO2}}{(1) \mathit{Gal.of\ Gas}} * \frac{(1) \mathit{Gal.of\ Gas}}{(27) \mathit{Miles}} = 0.000329\ \mathit{Metric\ Tons\ of\ CO2/Mile}$$

Each commuter drives approximately 27.2 miles per day:

$$\frac{(27.2) \mathit{Miles}}{(1) \mathit{Day}} * \frac{(0.000329) \mathit{Metric\ Ton\ of\ CO2}}{(1) \mathit{Mile}} = 0.008949\ \mathit{Metric\ Tons\ of\ CO2/Day}$$

From the 2015-2016 campus travel survey, we know that commuters who drive alone collectively travel about 300,000 miles every day:

$$\frac{(0.000329)Metric\ Tons\ of\ CO2}{(1)Mile} * \frac{(300{,}000)Miles}{(1)Day} = 98.7\ Metric\ Tons\ of\ CO2/Day$$

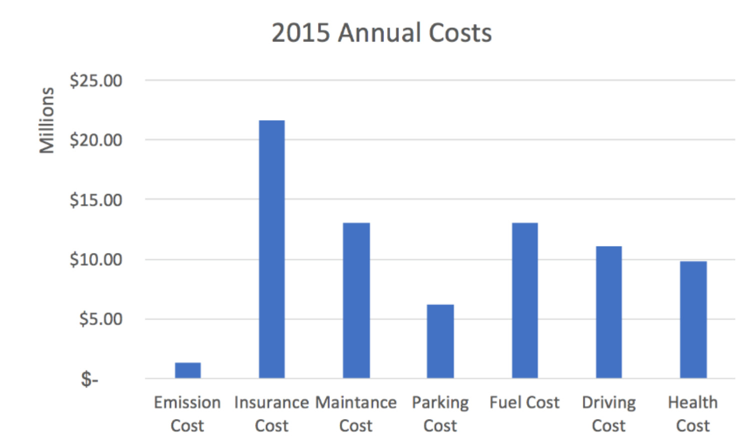
Carbon pricing numbers approximate the social cost of carbon at about $36 per metric tons of carbon dioxide:

$$\frac{(98.7)Metric\ Tons\ of\ CO2}{(1)Day} * \frac{\$36}{1\ Metric\ Ton\ of\ CO2} = \$3553.20/Day$$

People who drive alone to UC Davis are adding approximately 98.7 metric tons of carbon dioxide to the atmosphere daily that has an estimated cost of $3,553.20 per day.

Annual Costs and 15 year Prediction

The annual cost of 300,000 miles in 2015 was estimated to be around $76 million, and this is numbered was reached by using the daily health costs, commuter costs and emission cost multiplied by 365 days. These number represent a population that commutes an average of 300,000 miles every day, and is not meant to fully describe the cost of UC Davis staff and students. The model may not be fully representative of the actual UC Davis population, however, it allows four us to provide a great insight of the external values not included in the sticker price of a vehicle or even infrastructure that would increase driving. To our surprise the emission cost was the lowest cost, and yet it was very informative because it allows us to understand why people do not think about the environment while they are

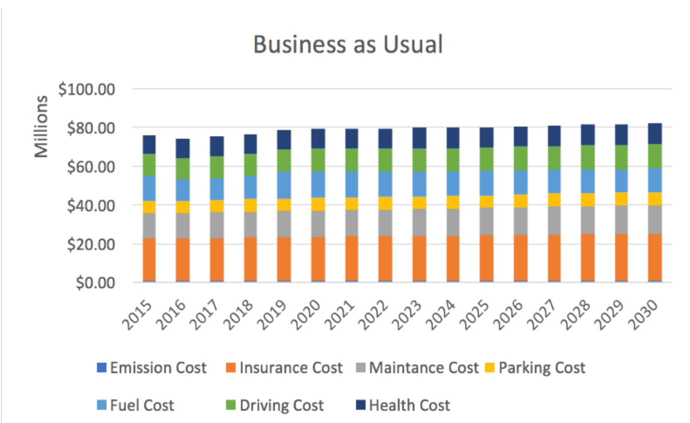


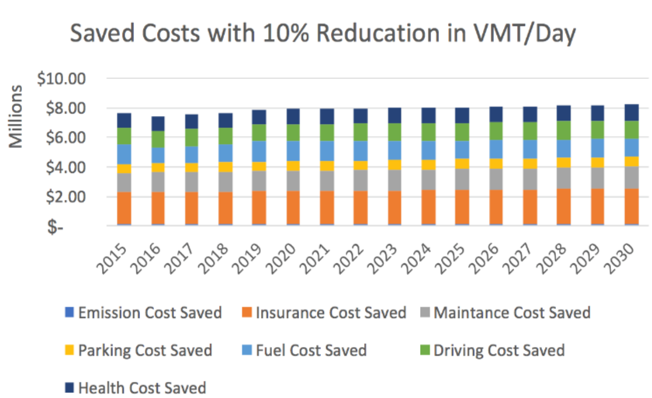
driving their vehicles. A big question that came to us was how would society react if the emission costs and insurance costs were switched?

15 Year Prediction and Reduction in VMT

The 15 year predictions were generated the same way as the annual value, but is also supported with regression's that calculate the predicted future costs for: the social cost of carbon; average miles/gallon based on California's vehicle standards; and gasoline prices in California over the 15 year time span. All regressions are generated by historical data and most accurate information available to us; also all other information is going to be assumed to be constant throughout the 15 year period. Also included is an estimated yearly increase of VMT of 1.01% of light-duty vehicles supported by a report that the Office of Highway Policy (2007).

With our 15 year prediction we generated two scenarios, one is business as usual and the second is a 10% reduction in vehicle miles traveled. Meaning that there would a daily value of 270,000 miles driven and not 300,000 miles. This may not seem like a large difference but it does show a large reduction in costs. For example, in 2015 if we reduced our daily mileage by 10% that would have resulted in an estimated annual savings of $7 million dollars. On a daily basis one person pays $19 that goes towards their commuter costs, health and emissions. This seems like a reasonable amount, but we must stop thinking short term because if





we wish to improve our environmental conditions a reduction in VMT is required. Long term predictions like the one generated allow us to see the direct savings and possible benefits from those reductions in VMT. If society does not see it possible to reduce their VMT then other options are available to us, but it is up to us to make a change.

Alternatives to Driving Alone

The University of California system wide plan for achieving carbon neutrality by 2025 consists of ten scalable solutions broken into six clusters. These solutions and their corresponding clusters encompass the ideas needed to achieve carbon neutrality for the ten UC campuses and to start bending the curve. These solutions can be scaled up for governments of almost any size to utilize. For the purpose of our project, we focused mainly on three clusters, societal transformations, governance solutions, and technological solutions, to reduce VMT by students and staff who commute alone to campus every day.

Our Solutions

Societal Transformations

We want to create a culture on campus that promotes healthy and cost effective ways to get around. With the data we collect from this project we hope to start a campus wide campaign to encourage people to carpool or take public transportation as an alternative to driving alone. The model we create can be adapted to be user friendly and will show students and staff their commute costs and how much they can save if they switched their mode of transportation. We propose partnering with the on campus organization GO Club, which gives students and faculty incentives to choose alternatives to driving alone to campus every day. These incentives include reduced Amtrak train fare, reserved parking for carpool participants, reduced cost of parking permits, and a payroll tax deduction for staff and faculty. The combination of the incentives program from the GO Club with our model and message will hopefully result in more people choosing public or other alternative transportation.

Governance Solutions

Many of the solutions we brainstormed require implementation and enforcement by the proper UC Davis authority. We propose increasing the number of charging stations for ZEVs and plug in hybrid vehicles on campus. There are currently about 100 AC level 2 charging stations on campus, most of which are near the Mondavi Center or in the backs of parking lots. These locations are often far from classes and not ideal for students or staff to use while they are on campus. We suggest increasing the number of AC level 2 charging stations by 150% over 10 years to accommodate increased demand by students and staff who chose to drive plug in hybrid or electric vehicles. We also suggest adding two DC fast charging stations for use by the on campus fleet of ZEVs. These additional charging stations should be located in well-traveled locations and be equitably dispersed across campus. This will allow students and staff with ZEVs or plug in hybrids to charge their vehicles on campus without having to search for a charging station and this may encourage other students or faculty to use a ZEV or plug in hybrid vehicle to reduce carbon emissions.

Other governance proposals include:

- Increasing the on campus fleet of ZEVs by 40% by 2020 and encouraging the use of ZEV and hybrid vehicles by students and staff.
- Forming an alliance with Amtrak and/or local bus services to negotiate discounted fare for UC Davis students and staff who may otherwise have seen those modes of transportation as cost prohibitive.

- Reducing the cost of on campus parking permits for students who drive lower emissions vehicles.
- Implementing an enhanced bike share program that is inexpensive for those who live in the city of Davis or close to campus.

Technological Solutions

We propose switching the Unitrans bus system from running on compressed natural gas to fuel cell technology as well as adding more buses to the fleet and adding additional routes so students from anywhere in Davis can get to campus by bus in 15 minutes. We also propose adding at least 2 hydrogen fuel stations on campus to support the new bus fleet as well as student and staff vehicles that run on hydrogen fuel cell technology. We also propose utilizing better electric car battery technology so an electric car can drive more miles without having to stop and recharge.

Solutions Pricing

Societal:

The cost of our societal transformation solution would most likely be similar to that of a student run club on campus. Approximately $500 a quarter will be enough to distribute media, organize volunteers, and produce a quality website.

Governance:

Increasing the current number of AC level 2 charging stations by 150% would add 150 charging stations on campus. The cost of charging units and installation varies greatly between types of units, types of mounts, and geographic location. A good estimate for a single AC level 2 unit is $2,700 but prices range from $400 to $6,500 (see table 1). The cost of installation for these units is also highly variable but in California, prices range from $4,000 to $4,400 due to labor costs (table 2). At $2,700 per AC level 2 unit and $4,200 for installation, an additional 150 units would cost approximately $1,035,000. DC fast charging units cost anywhere between $10,000 and $40,000, depending on the features, and installation averages $21,000. Adding two DC fast charging units would cost an additional $82,000, bringing the total cost for this project to $1,117,000.

The cost of increasing the number of ZEVs in the on campus fleet is difficult to calculate since some of these vehicles are small carts and some are larger cars and trucks. Determining the specific type and number of different vehicles is required to calculate potential costs for this aspect of the plan.

Discounted parking permits for students who drive lower emissions vehicles will save those students money on their commuter costs. The school can easily make up that money by raising the price of parking permits for all other vehicles by an amount equal to that lost by the discount. This may also encourage drivers of standard vehicles to consider taking public transportation or biking to campus as the cost of parking will be too high for them.

Technological:

The cost of purchasing and operating fuel cell buses is still very high. The Department of Transportation and the National Renewable Energy Laboratory estimates the cost of buying a single fuel cell bus to be approximately $1.356 million per bus, but the cost is expected to decrease with larger orders of buses. Maintenance costs are highly varied among current fleets but the current interim target is $0.70 per mile. The average fuel cell bus lifetime is 4.9 years or 131.963 miles. Total maintenance costs for an average fuel cell bus would be $92,374, bringing the total cost of a single bus (without fuel costs) to $1,448,374 (table 3). The cost of replacing all 48 buses currently used by Unitrans would be approximately $70 million. The cost of adding two hydrogen fueling stations to fuel this fleet is also quite expensive. The capital cost for a single station is estimated to be $2.8 million with a capacity of 450 kg/day, which is a cost of $6,222 per kg/day. Adding two stations would then result in a $5.6 million investment (table 4).

Total Costs:

The cost of all the analyzed solutions come to a total of $76.72 million, the majority of funding going to the hydrogen fuel cell bus fleet. This is a large sum of money, however, if we see these solutions as alternatives to building a new parking structure (with a construction cost of $156 million) the school would save approximately $79 million. These savings do not reflect the additional savings in commuter costs, health costs, and emissions costs that would also decrease with the implementation of this plan.

Solutions if VMT Continues to Grow

Although it would be ideal to reduce the number of people who commute to campus alone every day, there are still ways to reduce the real cost of commuting and building the proposed parking structure if the number of people who commute alone remains relatively stable. By encouraging societal transformations and implementing governance solutions and technological solutions, we can reduce both VMT and emissions which reduces some of the health, operation, and emissions costs.

Societal Transformations

Because carpooling reduces overall VMT and emissions by decreasing the number of vehicles on the road, starting a carpool campaign on campus would help influence an effective societal transformation. As previously discussed, educating students and faculty who commute to campus alone about the real costs of their commute and why carpooling is an easy and inexpensive alternative can increase the number of commuters who carpool and, in turn, decrease

VMT and emissions. This decrease in VMT and emissions reduces the real cost of commuting for both the individuals who begin carpooling and for society as a whole by reducing the health, operation, and emissions cost.

Governance Solutions

Campus policy can also reduce the real cost of commuting and building the parking structure by creating new incentives for commuters to travel to campus more sustainably. We propose that a new campus policy which reserves the lower levels of the proposed parking structure for low-emission vehicles, ZEVs, and vehicles used in carpooling be implemented. This creates an incentive for commuters to use these types of vehicles as the parking spaces on the lower levels are closer to the ground and, thus, easier to access. In addition, we propose that parking permit prices be reduced for ZEVs and low-emission vehicles, such as hybrids, just as permit prices for vehicles used in carpooling have. This serves as another incentive for commuters to use these types of vehicles by reducing the monthly cost of parking them on campus. These policies together, by encouraging use of these types of vehicles, could help reduce VMT and emissions and, thus, the health, operational, and emissions costs associated with commuting.

Technological Solutions

Some of the previously suggested solutions will only work when supplemented with technological solutions. We propose that the new parking structure feature a greater number of solar-powered electric vehicle chargers than in any other parking area on campus and that these chargers be located on the lower levels of the structure. This would make driving an electric vehicle to campus easier for commuters and assure that the vehicles are truly zero emissions as they would be charged using a renewable source. Furthermore, we recommend that the proposed

Green Transportation Hub project be pursued in order to better accommodate campus commuters who already use, and encourage others to use, vehicles fueled by hydrogen and even biofuels.

Conclusion

The “real cost” of current commuter behavior, assuming it remains the same and that the population grows according to current predictions, is projected to be a little over $1 billion from 2015 to 2030. This total cost can be reduced by nearly $150 million with a 10% reduction in VMT, which can then allow for additional funding for other resources such as health care, education, and environmental conservation. This 10% reduction, and perhaps an even greater reduction, in VMT and emissions can be achieved by implementing some or all of the solutions we have proposed. Although these solutions do have their own costs for implementation and maintenance/repair, these costs are far less than the “real cost” of commuting and the total cost of the proposed parking structure. In short, making these societal, governmental, and technological changes will lower the costs of commuting and mitigate the effects of commuting on the climate.

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Tables

Table 1.

Ballpark EVSE Unit and Installation Costs

EVSE Type	EVSE Unit* Cost Range (single port)	Average Installation Cost (per unit)	Installation Cost Range (per unit)
Level 1	$300-$1,500	not available	$0-$3,000** *Source: Industry Interviews*
Level 2	$400-$6,500	~$3,000 *EV Project (INL 2015b)*	$600-$12,700 *EV Project (INL 2015b)*
DCFC	$10,000-$40,000	~$21,000 *EV Project (INL 2015d)*	$4,000-$51,000 *EV Project (INL 2015d) and (OUC 2014)*

Table 4. Ballpark costs for EVSE units and installation.

**EVSE unit costs are based on units commercially available in 2015.*

***The $0 installation cost assumes the site host is offering an outlet for PEV users to plug in their Level 1 EVSE cordsets and that the outlet already has a dedicated circuit.*

Table 2.

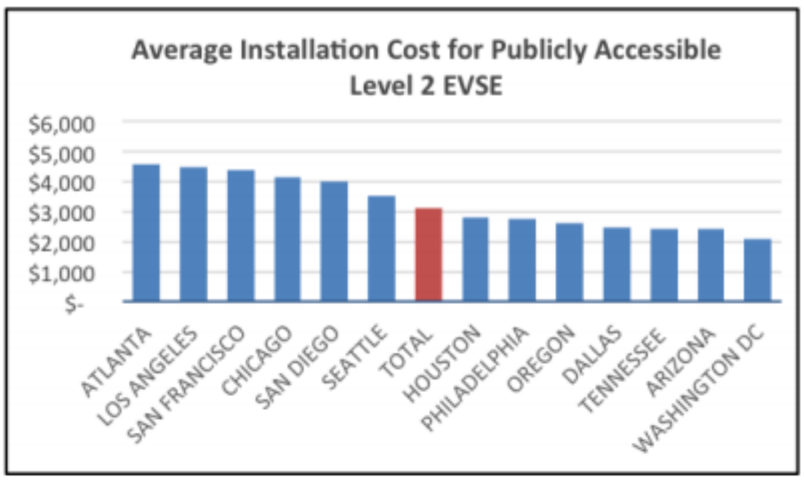

Figure 6. Average installation cost for publicly accessible Level 2 EVSE by EV Project market. *Graph from INL (INL 2015b).*

Table 3.

Table ES-1. Summary of FCEB Performance Compared to DOE/FTA Targets[1]

	Units	Current Status[a] (Range)	2016 Target[1]	Ultimate Target[1]
Bus lifetime	years/miles	0.7–7/ 16,900–189,000[b]	12/500,000	12/500,000
Power plant lifetime[c]	hours	600–25,000[b,d,e]	18,000	25,000
Bus availability	%	42–93	85	90
Fuel fills[f]	per day	1	1 (<10 min)	1 (<10 min)
Bus cost[g]	$	1,800,000– 2,400,000[h]	1,000,000	600,000
Roadcall frequency (bus/fuel cell system)	miles between roadcalls	1,100–8,700/ 7,600–23,700	3,500/ 15,000	4,000/ 20,000
Operation time	hours per day/ days per week	7–21/ 5–7	20/7	20/7
Scheduled and unscheduled maintenance cost[i]	$/mile	0.49–2.42	0.75	0.40
Range[j]	miles	277–357	300	300
Fuel economy	miles per diesel gallon equivalent	5.83–7.82	8	8

Table 4.

Table ES-1. Summary HSCC Results by Station Classification

Station Attribute	Units	Station Type			
		State-of-the-Art	Early Commercial	More Stations	Larger Stations
Introduction timeframe	years	2011-2012	2014-2016	after 2016	after 2016
Capacity	kg/day	160	450	600	1,500
Utilization	%	57%	74%	76%	80%
Average output	kg/day	91	333	456	1,200
Total Capital	$M	$2.65	$2.80	$3.09	$5.05
Capital Cost per capacity	$1000 per kg/d	$16.57	$6.22	$5.15	$3.37
reduction from SOTA	%	na	62%	69%	80%