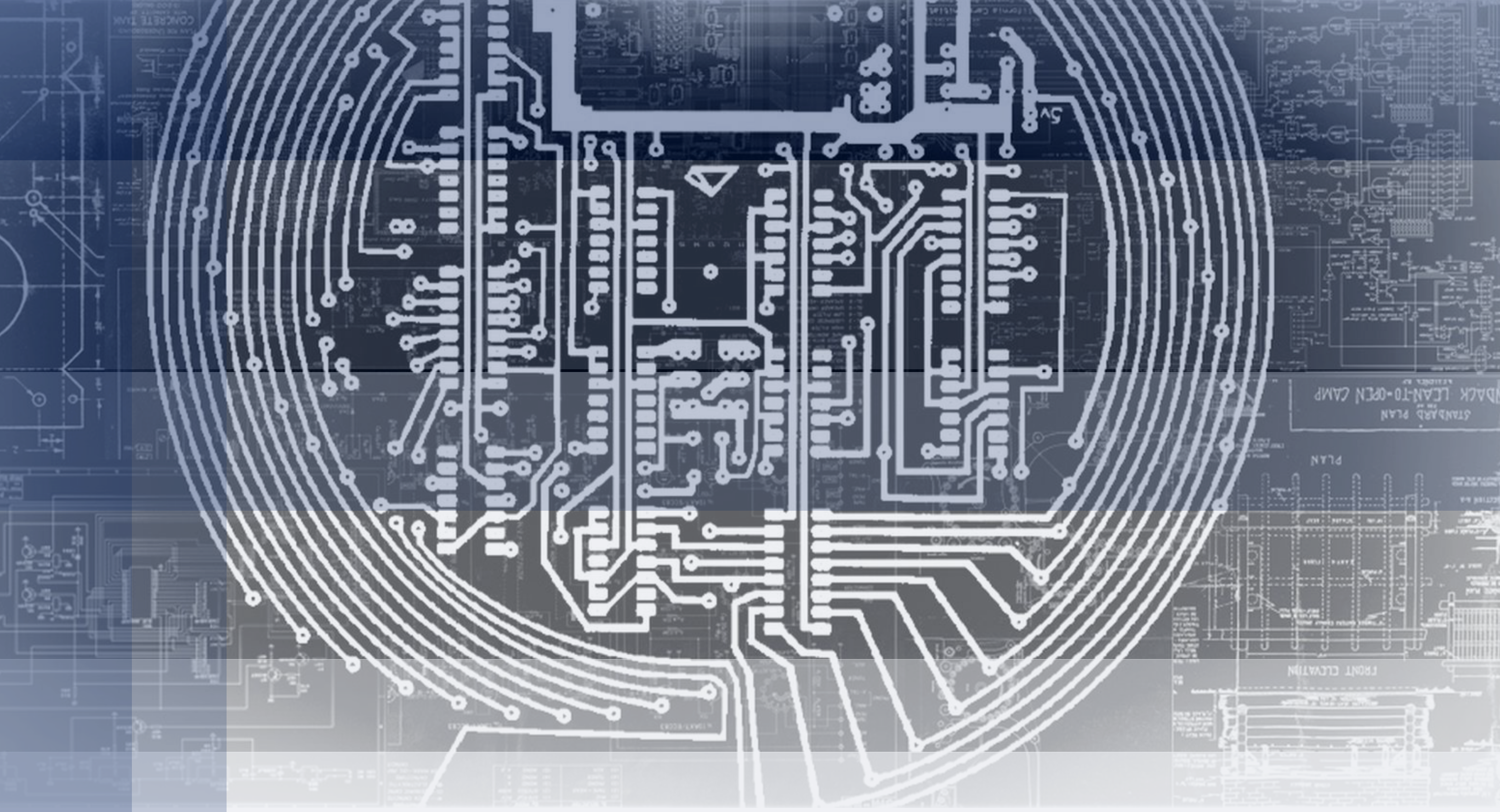

Transportation Technical Reference Manual:

Guide to Characterize the Savings, Benefits, and Costs of Transportation Efficiency Measures

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Table of Contents

List of Figures

List of Tables

Introduction

TRANSPORTATION ENERGY USE AND THE TECHNICAL REFERENCE MANUAL

While using standardized methodologies to measure the energy impacts and cost-effectiveness of efficiency programs is common practice in the electric and thermal energy sectors, this is not the case for transportation. As electric vehicles (EVs) spread nationwide, the electricity and transportation sectors have an increasing number of shared interests and an opportunity to learn from one another. One opportunity for knowledge transfer involves assessing the financial and environmental benefits of transportation measures, such as alternative fuel vehicles and fueling infrastructure, in the same way that energy utilities characterize efficiency measures and inform program development—namely, through a tool called the Technical Reference Manual (TRM). Inspired by this widely-used model, the National Association of State Energy Officials (NASEO) and the Vermont Energy Investment Corporation (VEIC) have developed the following Transportation TRM to characterize energy savings, environmental benefits, and financial costs of selected transportation efficiency measures and establish a framework for comprehensive and informed decision-making.

USERS OF A TRANSPORTATION TECHNICAL REFERENCE MANUAL

A Transportation TRM may be of interest to a variety of stakeholders, including those entities that already employ TRMs, such as utilities and Public Utilities Commissions (PUCs), as well as state energy and transportation planning agencies. The way that a Transportation TRM is refined and ultimately used will vary by end user and their objectives, whether for the design and implementation of efficiency programs or for policy and plan development.

Utilities

Electric, natural gas, and energy efficiency utilities may use a Transportation TRM to estimate the relative efficiency gains of measures such as conversions to electric and natural gas vehicles, as well as the installation of charging and fueling equipment. The development of a Transportation TRM enables the energy sector to view EVs as "mobile appliances" and thus assess their efficiency in much the same way that they do for appliances like washers and light bulbs in a conventional TRM. [1] A Transportation TRM could help to guide the optimal deployment of EVs, including through consideration of EV-specific rates and location and type of away-from-home charging stations (e.g., Level 2 240V charging vs. DC Fast charging). A proactive approach to EV deployment and infrastructure development, guided by a well-informed decision-making through a TRM, will ensure that grid impacts are minimized and environmental benefits fully realized. Strategies and approaches to efficiency vary among utilities, depending on whether they operate in a state that has undergone deregulation

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[1] Fuel switching away from conventional vehicles and fuels to regulated fuels is a different scope of efficiency measure than is often considered by electric and natural gas utility efficiency programs. There are two approaches to measuring alternative fuel vehicle (AFV) efficiency: comparing the environmental and financial benefits of an AFV to a similar AFV (e.g., electric vehicle to electric vehicle or natural gas vehicle to natural gas vehicle) and comparing an AFV to a conventional fuel vehicle. The former comparison generally results in smaller efficiency gains due to small variability in vehicle efficiency in AFVs available. The latter comparison generally yields substantial gains in overall energy use and emissions, but results in natural gas or electric load growth, rather than decreased demand: a stark difference from most utility efficiency programs. This challenge is discussed further on page 7 of this document in the *Cost-Effectiveness Screening* section.

or one that decouples usage from profits, thus requiring the customization and refinement of the TRM on a market-by-market basis.

State Energy Offices

Although TRMs have traditionally been used in the regulated realm, they can also inform energy policy as it applies to transportation energy. Most SEOs include transportation energy in their scope, often focusing on alternative fuels, but not on broader efficiency measures, or a systems-level approach to reducing energy use and ensuring accessibility for all users. A Transportation TRM can guide policy and program development to create financing, incentives and/or state and local fleet conversion efforts. Importantly, many SEOs are not limited in the same way that utilities and PUCs may be regarding fuel switching; rather, for SEOs, a switch to a more efficient fuel or mode may simply represent optimal management of a state's transportation energy portfolio.

Public Utility Commissions

Entities that oversee utility efficiency programs, such as Public Utility Commissions (PUCs) and some State Energy Offices (SEOS), can use a Transportation TRM as a framework for regulatory decision-making. To date, transportation energy has largely been left out of the scope of energy planning, thus limiting the transportation sector's engagement in energy efficiency and optimal least cost planning. As more of transportation is powered by regulated fuels, the opportunity to engage in such planning becomes a reality, facilitated by collaboration among state Departments of Transportations (DOTs), SEOs, and PUCs.

Transportation Planning Agencies

Transportation planning agencies, such as state DOTs and regional planning commissions, often lack a standardized means of conducting cost-benefit analysis or valuing externalities associated with transportation decisions. A TRM model would address this weakness and facilitate long-term planning that incorporates a full and accurate analysis of cost-effectiveness.

DEFINING ENERGY AND TRANSPORTATION EFFICIENCY

The term "energy" is often limited to energy used for electric power, a regulated sector. However, energy is used for heat, some of which is regulated (e.g., natural gas) and some of which is not (e.g., heating oil), and for transportation. The vast majority of energy used in the transportation sector– gasoline and diesel–is not regulated, beyond certain safety and environmental requirements. In regulated sectors such as electric power and natural gas, prices, profits, and often efficiency programs are negotiated between utility companies and PUCs, and guided by state energy policy as set by the governor, legislature, and SEO. In unregulated sectors, such negotiations do not occur and the regulatory power of the PUC is limited.

However, in some states, including Vermont and Washington, transportation is included in the state's statutory definition of energy. For instance, in the Vermont statutes that outline the power and duties of the Department of Public Service, energy is defined as:

> *"substances or processes used to produce heat, light, or motion, including but not limited to petroleum or other liquid fuels; natural or synthetic fuel gas; solid carbonaceous fuels ; solar radiation; geothermal sources; nuclear sources; biomass; organic waste products; wind; or flowing water. "*[2] *(Emphasis added)*

Thus, Vermont Department of Public Service (DPS) is empowered to oversee the implementation of efficiency programs, and energy policies as they apply to transportation, the same way that it does for regulated sources of energy. Similarly, in Washington statute, the policies and duties of the state energy office (under the Department of Commerce) contain a definition of energy that is inclusive of transportation.[3] However, no similar definition is present in the statutes that apply to the Public Utility commission, suggesting that although transportation energy must be accounted for in the state's energy policy, the PUC may not have regulatory power in this realm.

Definitions of energy vary in state statutes. Not uncommonly, transportation energy will be included in the scope of a state energy office but not within the regulatory power of a public utility commission, as in Washington. Vermont is an exception to this pattern- DPS also serves as the state energy office, providing the governor guidance on energy planning and policy issues.

Regardless of the mandate of its PUC, it is important for a state's definition of "energy" to include that which is used to produce motion or transportation, whether regulated or unregulated. Within transportation, "efficiency" is used most commonly in the context of fuel economy (miles per gallon), but it can also be used to measure the total amount of energy used to meet travel demand or access to services in a given area or by a given mode. Like estimates of vehicle fuel economy, which are estimates designed to capture a variety of real-world conditions, energy requirements of other modes of transport and other system-wide efficiency measures can be estimated. In this sense, long-term transportation efficiency is a systems-level approach to planning that aims to minimize the energy required to meet travel demand.

COST-EFFECTIVENESS SCREENING AND LEAST COST PLANNING

Cost-effective efficiency measures are those that reduce energy consumption and yield a positive net present value (NPV) over the average useful lifespan of a measure. Once potential efficiency measures have gone through a cost-benefit analysis or screening process, those that are deemed cost-effective and reduce energy consumption are included in a TRM. The TRM includes all algorithms, assumptions, and default values used to estimate the savings associated with each efficiency measure. The first TRM was compiled in 2001 and now includes hundreds of efficiency measures, all of which have been screened for cost effectiveness and energy savings.[4] Efficiency measures that are determined to be cost-effective and reduce energy consumption may be included in a utility's TRM and may also be eligible for financial incentives through utility energy efficiency programs.

The comprehensive approach to assessing efficiency and cost effectiveness provided by a screening tool and TRM would enable meaningful and consistent comparison among transportation efficiency measures, forming the basis of least-cost planning and informing potential incentive programs such that they maximize overall societal benefit. Least-cost planning is historically practiced in the electric sector and long-term integrated

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[2] Vermont Statutes Annotated, Title 30 Chapter 5, V.S.A. § 201.

[3] Revised Code of Washington, Chapter 43.21 F. 025.

[4] TRMs are in use across the country, including in Pennsylvania, Arkansas, Massachusetts, Illinois, Rhode Island, and Ohio.

resource plans are required of utilities in many states (Wilson and Biewald 2013). In some areas, efficiency utilities and programs have been designed and mandated to reduce consumption of specific regulated energy sources. Least-cost planning is contingent upon a comprehensive cost-benefit analysis to identify cost-effective measures and programs. A long-term approach to reducing financial and environmental costs of transportation energy use thus requires a methodology to assess the full cost and benefit of transportation efficiency measures (and the full cost and benefit of baseline, business-as-usual practices). An earlier effort to apply a utility cost-effectiveness screening test to transportation efficiency can be found in Sears et al. 2013.

Potential transportation efficiency measures may fall into three broad categories:

- Replacement of an existing vehicle with a more fuel efficient vehicle.
- Fuel switching (from gasoline or diesel to electric or natural gas, or other types of alternative fuel vehicles),
- Transportation mode switching (from single occupancy vehicle to car pool, transit, bicycle, or foot).

There are a number of challenges to applying least-cost planning methodologies to transportation efficiency measures, arising largely out of the fact that few of the costs associated with transportation energy use are included in the price of gasoline or diesel, and the costs and benefits of many transportation efficiency measures are not easily monetized. However, a screening and TRM process will help to standardize this analysis, maximizing overall societal benefit.

FUEL SWITCHING

Efficiency measures that entail fuel switching from gasoline or diesel to a regulated fuel may present a problem for some utilities. An example of a fuel switching efficiency measure is the replacement of conventional vehicles powered by gasoline or diesel with alternative fuel vehicles powered by electricity or natural gas. Although these measures may offer efficiency gains on a Btu/mile basis, energy cost savings, and reduced environmental impacts relative to conventional vehicles, they *increase* the use of the regulated energy. This resulting increased consumption of the regulated energy may conflict with the goals of most efficiency utilities and programs. While fuel switching may be an issue, particularly in states that have decoupled revenue from usage, it also provides utilities and PUCs an opportunity to reassess current revenue calculations. Further, fuel switching highlights the need for a broader view of efficiency, limited not just to a single fuel source but overall energy use and greenhouse gas (GHG) emissions.

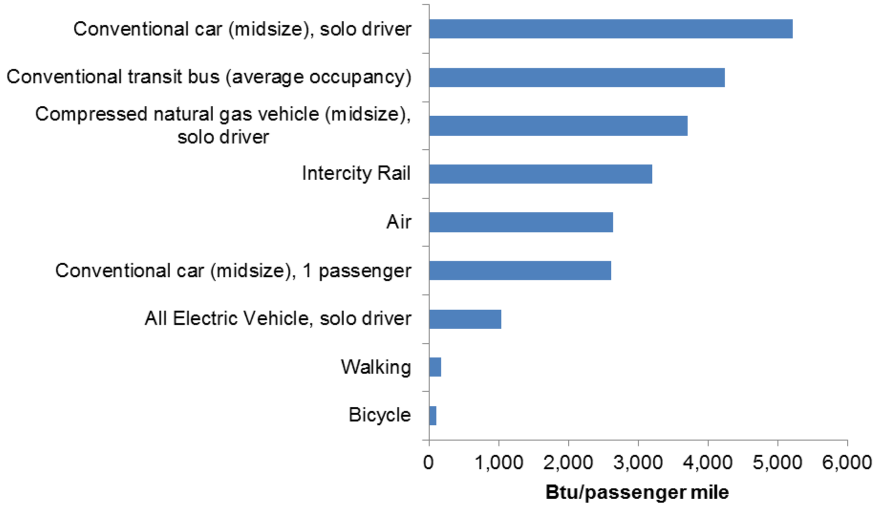
A transportation TRM can serve to ensure that load growth in regulated fuels is controlled and that efficiency and environmental gains from fuel switching are maximized. The TRM can be used to identify efficiency measures that will optimize the deployment of commercially available efficient electric or natural gas vehicles and efficient charging or fueling infrastructure. A more inclusive cost-benefit analysis that adequately values the variety of benefits of alternative fuel vehicles, such as reduced peak load, and reduced generation and transmission costs, will facilitate utility participation in their deployment. In addition, rate design can direct increased demand for regulated energy from alternative fuel vehicles to occur during off-peak hours, serving to flatten the overall load profile. If it proves too difficult in the short term to include measures that build load in utility efficiency programs, utilities may approach electric vehicles (EV) as large "mobile appliances", and apply similar tests and programs as those historically used for other appliances. Further, unlike most appliances, EVs offer flexibility in potential use of smart or managed charging measures, ancillary services, and potential vehicle-to-grid or vehicle-to-building capability.

MODE SWITCHING

Traditionally, transportation funding and planning have focused on infrastructure design and maintenance rather than on energy consumption. Planning protocols rely on travel demand models which generally use metrics associated with travel time, congestion, and safety. Further, transportation planning is often focused on optimizing infrastructure for automobiles. Planning for other modes of travel such as transit, bicycling, and walking may not figure as prominently. With no clear means to assess the long-term cost of projects, especially inclusion of externalities, it is difficult for the transportation sector to engage in least-cost planning.

The wide variation in energy efficiency (measured in Btus per passenger mile) across transport modes and fuels highlights the need for greater focus and consistency in measuring transportation efficiency (Figure 1). A primary means of travel in the United States is through one of the least efficient modes available-- conventional single occupancy vehicle--leaving much room for improvement in the overall operational efficiency of our transportation system. Travel demand models generally use metrics associated with travel time, congestion, and safety, but the boundaries used in modeling efforts can vary widely. Further, outputs of such models are often auto-centric, focusing on vehicle miles traveled (VMT) at the expense of non-auto-based measures (e.g., transit, bicycle, and pedestrian infrastructure). Additionally, behavioral aspects to travel and transportation energy use present both challenges and opportunities for improved transportation efficiency, including lifestyle choices and habits around walking and physical activity.

FIGURE 1. ENERGY USE BY TRANSPORTATION MODE (BTU/PASSENGER MILE)
(OAK RIDGE NATIONAL LAB 2013, EPA 2013A, HIRST 1974)



Approaches to Measuring Cost-Effectiveness

In the electric and thermal sectors, efficiency measures are assessed for cost-effectiveness using a cost-benefit analysis. There are a variety of tests available to assess cost-effectiveness, including: measuring the impact on rate-payers, quantifying the cost-effectiveness for utilities, and accounting for the total societal benefit by including externalities such as greenhouse gas (GHG) emissions and grid system reliability. Broadly, approaches to measuring the cost-effectiveness of energy efficiency measures include the following test methods:

1. The Total Resource Cost, which includes costs to society and the consumer,
2. The Societal Cost, which includes externalities not captured by market prices and non-energy benefits (e.g., avoided health costs, climate impacts, water usage).
3. The Program Administrator Cost, which calculates the cost of operating an efficiency program.
4. The Participant Cost, which estimates long term benefits to the consumer, accounting for lifetime costs, including maintenance and installation fees, and any available incentives.
5. The Rate-payer Impact, which examines lost revenue to the utility from reduced energy consumption achieved through greater efficiency (Energy Center of Wisconsin 2009). For efficiency measures that may alter patterns of use, any changes in the timing of demand must be considered (peak vs. off peak), in addition to overall energy use. For example, for EVs, there is some concern around the timing of charging and effects that widespread EV charging may have on peak load in areas with high EV penetration.

A particular cost-effectiveness test method is generally mandated through regulation and changes require PUC or Public Service Board approval. The sections below include a brief explanation of the major types of tests and our rationale in utilizing the Societal Cost test in this Transportation TRM.

TOTAL RESOURCE COST

The Total Resource Cost test is among the more common approaches to screening efficiency measures, though regulators may require a utility to perform more than one type of test (CPUC 2001). In recent years, these tests have received criticism for failing to value non-energy benefits properly. According to some critics, screening tools ignore or undervalue the benefits of efficiency measures while accounting for all of their costs, including incremental costs of installation and administrative program costs, which puts these measures at a disadvantage relative to business-as-usual scenarios (Neem and Kushler 2010). Despite this growing school of thought, capturing non-energy benefits remains challenging, as benefits are not easily quantified or may be highly variable. This challenge is especially pronounced in transportation cost-benefit analysis since many of the externalities and benefits associated with transportation efficiency measures are not energy-related, including health impacts of tailpipe emissions and active transportation, and quality of life impacts of bicycle and pedestrian infrastructure.

PROGRAM ADMINISTRATOR COST

Another test of cost-effectiveness test method is the Program Administrator Cost Test (PACT). A PACT considers only the costs and energy savings to the utility, and thus to the rate payers, and offers incentives based on these values. Although externalities can be included, non-energy benefits are not valued. A PACT leaves it to the consumer to judge the cost-effectiveness of a given measure. Incentives are available for a given measure and if consumers are willing to pay any additional amount required, they can. This type of test may be particularly relevant for the transportation sector, because many of the non-energy benefits of efficiency measures are difficult to quantify and highly localized or individualized. For instance, when screening electric vehicles, vehicles with a larger electric range may have a lower operating efficiency (kWh/mile) because the vehicle battery is heavier. However, the convenience afforded by this longer range may be what tips consumers' preference for an EV over a conventional vehicle.

Many screening tools currently in use, such as those employed by some energy efficiency utilities[5], do not capture the increased convenience of a product, only the decreased electrical usage. A PACT may resolve this discrepancy. While the PACT approach to valuing efficiency measures may eliminate the difficulty in valuing non-energy benefits, this approach would not facilitate a true least-cost approach to electricity or transportation planning since lifetime costs are not captured.

COMPARING AND CONTRASTING APPROACHES

The screening tools used to conduct cost-effectiveness tests usually generate two primary outputs: NPV of the proposed efficiency measure and net societal benefits accrued over the measure's lifetime.

- The NPV of the proposed efficiency measure presents savings in current dollars, accounting for inflation.
- The net societal benefit or benefit-to-cost ratio accrued over the measure's lifetime is the ratio between the total benefits derived from the measure and the total cost. A societal benefit of less than one indicates that the NPV of the proposed measure is negative and not cost effective (and thus would not be included in a TRM nor be eligible for incentive programs).

When evaluating the cost-effectiveness of a utility energy efficiency program, the NPV and benefit-to-cost ratio may vary based on the test used. In a 2008 report, the National Action Plan for Energy Efficiency estimates that the benefit-to-cost ratio of the Southern California Edison Residential Energy Efficiency Incentive Program ranges from 0.63 under the Ratepayer Impact Measure to 9.91 under the Program Administrator Cost Test (as demonstrated in Table 1).The Ratepayer Impact Measure shows that the value of energy savings for the utility is less than the amount of reduced revenue and cost to run the program. In contrast, the high values of the Participant Cost Test and Program Administration Cost Test indicate that energy savings are worth much more than any costs to customers or program costs to the utility. This range indicates that cost-effectiveness of a given measure varies widely, depending on the boundaries of the test. The key takeaway from this exercise is that it is not enough to conclude that a given product or program is cost-effective or cost-ineffective, but it must be specified for whom (society at large, the utility, the customer/participant, all ratepayers, etc.).

TABLE 1. SUMMARY OF COST-EFFECTIVENESS TEST RESULTS
(SOUTHERN CALIFORNIA EDISON RESIDENTIAL ENERGY EFFICIENCY INCENTIVE PROGRAM)

Test	Net Present Value	Benefit-Cost Ratio
PCT	$252 million	7.14
PACT	$168 million	9.91
RIM	-$109 million	0.63
TRC	$143 million	4.21
SCT[6]	$143 million	4.21

OUR APPROACH

In this TRM, we use the Societal Cost Test (SCT) to fully assess the costs and benefits of transportation efficiency measures to both consumers and society. The SCT may be the most accurate option for evaluating

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[5] For example, *Efficiency Smart*, which operates in Ohio and Pennsylvania, the *DC Sustainable Energy Utility*, which serves the District of Columbia, and *Efficiency Vermont*.

[6] In California, avoided costs of emissions are included in both the Total Resource Cost Test and the Societal Cost Test.

transportation efficiency measures because the externalities associated with baseline transportation measures are sizable. For instance, the climate and health impacts of tailpipe emissions are generally not included in gasoline and diesel prices or elsewhere in the market, and it is widely recognized that current transportation fuel taxes are insufficient to cover the cost of infrastructure maintenance.

This document provides assumptions, default values, and equations used to calculate the energy and cost savings of transportation efficiency measures. The measures included in this manual will not necessarily pass the screening process in all locations. The goal of this document is to provide a framework and some basic data for such screening. The computations utilize national averages (of fuel costs, GHG impacts, etc.). A more customized assessment of efficiency measures should replace these generic inputs and estimates of deemed savings with inputs specific to the state or location of interest.

ASSESSING TRANSPORTATION EFFICIENCY

The scope of costs associated with transportation efficiency measures considered are presented in Table 2. These measures may include switching to a more efficient gasoline or diesel-powered vehicle, a fuel switch from a conventional vehicle to natural gas or electric vehicle, an upgrade from a Level 1 to Level 2 electric vehicle supply equipment (EVSE), or a mode switch from single occupancy vehicle to carpool or transit. In our analysis we account for costs to the consumer, utility, and society, although the costs ultimately included in an analysis may vary by end-user. For instance, electric utilities may not be able to consider efficiency gains resulting from fuel switching (e.g., a switch away from a gasoline-powered vehicle to an electric vehicle), although they may be able to consider electric efficiency gains achieved through EVSE infrastructure.

TABLE 2. SCOPE OF CONSUMER, UTILITY, AND SOCIETAL COSTS CONSIDERED IN ASSESSMENT OF TRANSPORTATION EFFICIENCY MEASURES

Consumer costs	Utility Costs	Societal Costs
Purchase price of efficiency measure relative to non- efficient option	Impact on peak load	GHG emissions
Operation and maintenance, inc. energy costs (electricity, gasoline, natural gas, etc.)		Health impacts
		Congestion impacts (travel time and reliability; relevant for mode switching measures)

Major assumptions underlying this TRM's calculations are summarized in Table 2 and appear in greater detail in the accompanying spreadsheets. Generally, national averages are used to ensure applicability for a wide range of geographies, but these values can be substituted with local data where available. The assumptions used in our calculations include energy prices, vehicle operating costs, societal costs of externalities such as GHG emissions and emissions health impacts, and EV charging infrastructure, as explained in Table 3. This list is by no means exhaustive and should be expanded and refined as more transportation efficiency measures are assessed, including compressed natural gas vehicles and fueling infrastructure. Energy prices (gasoline, diesel, electricity, and natural gas) are reported as national averages and can be found in the accompanying spreadsheet (see 'EIA 2013 energy price forecasts.xlsx'). It is important to note that there is more uncertainty about future natural gas and petroleum prices, relative to electricity price. Assessments of transportation projects involving these fuel types may thus be more complex than those for electric energy efficiency projects.

Avoided electricity costs include the forecasted energy costs that would have occurred without the proposed or implemented efficiency measure and avoided capacity costs.

TABLE 3. MAJOR ASSUMPTIONS AND DATA SOURCES USED IN ASSESSING TRANSPORTATION EFFICIENCY MEASURES

Variable	Estimate	Source
Price of gasoline, 2014[1]	$26.37/MMBtu	Annual EIA Annual Energy Outlook, 2013
Price of diesel, 2014[1]	$24.22/MMBtu	EIA Annual Energy Outlook, 2013
Price of electricity, 2014[1]	$33.01 /MMBtu	EIA Annual Energy Outlook, 2013
Avoided electricity costs	$0.10/kWh	Wilson 2013
Gasoline CO_2 emissions	19 lbs/gallon	EPA 2013
Diesel CO_2 emissions	22 lbs/gallon	EPA 2013
Electricity GHG emissions, 2013[1,2]	0.65 tons/MWh	EPA 2013
Cost of GHG emissions	$100/ton CO_2 eq.	Synapse Energy Economics 2013
Health costs of vehicle emissions	$0.06/vehicle mile traveled	McCubbin and Delucchi (2011)
Health costs of electricity generation[1]	$0.07/kWh	Machol and Rizk 2013; see Table 3
Annual vehicle miles traveled[1]	10,650	FHWA 2012
Annual EV miles traveled[1]	9,000	EV Project 2013
Cost of Level 1 EVSE and installation	$500-$1,000	Vendor estimates
Cost of Level 2 EVSE and installation	$1,200-$1,800	Vendor estimates
Cost of Level 2 EVSE with ability to charge users a fee[3]	$7,000-$21,000	Vendor estimates
Cost of DC Fast Charging EVSE	$35,000-$125,000	Vendor estimates

[1] *National average*

[2] *Local value should be used due to high geographic variation*

[3] *For non-residential public charging*

Other factors considered in utility calculations of efficiency measures may include effects of spillover and free ridership. The former, spillover, refers to the adoption of efficiency measures not included in the program or incentive. The latter, free ridership, refers to savings that would have occurred even without the program. Often, these effects are assumed to be 1:1 and cancel one another out. Accurate measurement of these effects would require, at a minimum, surveying program participants. Due to lack of data, these factors are generally not accounted for in this document but they are a critical consideration for future analyses.

ACCOUNTING FOR EXTERNALITIES

The primary externalities included in this Transportation TRM are the societal costs of GHG emissions and health impacts of vehicle tailpipe emissions. Although there is no federal regulation of carbon at present, we suggest a cost of $100 perton of carbon dioxide equivalent (CO_2 eq.), the price estimated in the New England Avoided Energy Supply Cost Report (Synapse Energy Economics 2013). No federal compliance carbon market exists in the United States, so the proposed cost is meant to account for the externalities associated with global climate change (including increased extreme weather events, altered weather patterns, and rising sea levels) and is derived by estimating the cost of reducing emissions to "sustainability levels."[7] Measures achieving avoided GHG emissions are thus credited $100/ton CO_2 eq., while measures increasing such emissions are penalized.[8]

The health costs associated with vehicle emissions are assumed to be $0.06/mile, a mid-range of estimates reported by DeLucchi and McCubbin (2011) in their review of transportation externalities, adjusted for inflation.[9] These costs include health care costs of diseases and health problems aggravated and caused by local motor vehicle tailpipe emissions, including nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO), and particulate matter (PM). Future analysis could consider the geographic variation in exposure to tailpipe emissions.

The health impacts of electricity generation are estimated to be $0.07/kWh, on average for the nation in 2014, but more accurate estimates can be derived based on the particular mix of generation in a given location (available through the EPA database eGrid: www.epa.gov/egrid), and the values in Table 1. Estimates of the monetized costs of health impacts from electricity generation were only available for fossil fuels (coal and natural gas). Health costs to humans associated with hydropower and other renewable sources of electricity generation are generally thought to be minimal, although the noise impact from wind installations is still being evaluated.

TABLE 4. PROJECTED 2014 US ELECTRICITY GENERATION BY SOURCE AND ASSOCIATED HEALTH IMPACTS FROM EMISSIONS

Energy source	% Generation (EIA 2013)	Estimated cost of health impacts (Machol and Rizk 2013)[10]
Coal	39%	$0.19/kWh
Natural gas	27%	$0.015/kWh
Nuclear power	19%	unavailable
Renewables (wind, solar, biomass, hydropower)	13%	unavailable
	Weighted national average	**$.0.07/kWh**

FACTORS TO CONSIDER IN FUTURE ANALYSES

There are other costs and benefits that can be added as the screening and TRM processes are developed for transportation, including the health benefits of active forms of transportation, quality of life benefits associated with bicycle and pedestrian infrastructure, and benefits to property values gained through proximity to transit, bicycle, and pedestrian infrastructure. Future analysis may also consider the health care costs associated with

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[7] As a point of reference, the California cap and trade program's price per ton of CO_2 eq. has varied from about $23 to $11 between 2012 and 2013 (California Carbon Dashboard).

[8] We do not account for GHG emissions associated with methane release at hydroelectric dams, although there is growing evidence that these emissions from hydroelectric dam drawdowns can be sizable (see Hertwich 2013, Fearnside 2004, among others). As this research develops these emissions should be included in future analyses.

[9] DeLucchi and McCubbin report 8 estimates of health impacts (2006 dollars) per passenger mile traveled from a variety of peer reviewed studies. Average vehicle occupancy was assumed to be 1.6. We converted their mid-range estimate of $0.033 per passenger mile traveled to cost per vehicle mile traveled: $0.054. This value was then adjusted for inflation to 2013 dollars using the Bureau of Labor Statistics Consumer Price Index, to arrive at our estimate of $0.06 of health impacts per vehicle mile traveled. Future analyses should consider health impacts on a per kilogram basis, rather than per vehicle mile traveled, due to continuing improvements in engine design and fuel quality.

[10] Includes SO_2, NO_x, and PM emissions.

motor vehicle crashes, as a mode switch away from personal vehicles may achieve cost savings through avoided crash-induced health care costs.

In addition, research has shown sizable costs associated with noise generated from motor vehicle use. Noise damage costs arise from reduced home values in affected areas. However, it is a challenge to reliably characterize these costs nationally, or even much beyond the local level. Accurate estimates of noise damage are difficult due to local variation in ground cover and structures that may mitigate such damage. DeLucchi and Hsu (1998) estimate that noise costs of motor vehicles range from $40 million to $5 billion annually in 1991 dollars. They further provide estimates of noise damage by road type (major arterial, interstate, and local roads) that could guide future efforts to account for this externality.

In addition, there may be substantial financial and grid resiliency benefits resulting from EV vehicle-to-grid interoperability, including demand response and load balancing effects of EV night-time charging. With a large enough volume of EVs and provisions for aggregation, these vehicle batteries may have the capability to serve as energy storage units and perform frequency regulation for the electric grid or residences and other buildings.[11] The all-electric Nissan Leaf is already used for demonstration vehicle-to-home energy systems in Japan.

Widespread nighttime charging of EVs could serve to balance overall load. If base load is approximately even during the day and night, the operational efficiency of the generating system is improved. When generators drop load in the evening, there is an efficiency loss of "turn down". In order to be included in a cost-benefit analysis, a monetary value would need to be attached to these grid services. Research is currently underway by a variety of entities in this field, including the University of Delaware's Center for Carbon-free Power Integration and the National Renewable Energy Laboratory. With metering on EVSE units or directly from the vehicle to the utility meter through use of Advanced Meter Infrastructure (AMI), individual EVs could participate in demand response programs. The primary value of such programs is derived from avoided capacity costs, which will vary by utility area (CPUC 2010). Avoided capacity costs in New England are valued at $79.88/kW-year (Synapse 2013). However, at present, the use of EVs in demand response programs is only theoretical and there is some concern that using EVs in this manner could void the manufacturer's warranty.

Future transportation efficiency measures to consider include the bundling of transportation and electricity measures, such as electric vehicles and residential photovoltaic solar arrays. Bundling of this sort will facilitate a transition to renewably powered transportation and may increase the cost-effectiveness of both transportation and electric efficiency measures.

GEOGRAPHIC AND TEMPORAL VARIATION IN EXTERNALITIES

The associated energy, financial, and environmental benefits of efficiency measures will vary with location, most notably GHG emissions and health impacts associated with electricity generation. In this document we present national averages. The accompanying spreadsheet provides additional data sources that can be used to modify calculations for other locations. The Environmental Protection Agency compiles the database eGrid, which

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[11] See NASEO 2013 Review of Utility IRP Scans. Some utilities are projecting that up to 6% of demand will come from EV charging by 2030.

provides sub-region specific emissions estimates.[12] Alternatively, if the electricity mix is known, the associated emissions factor and health costs can be calculated using Table 3 and a $100/ton of CO_2 eq.

In addition, because the mix of sources used to generate electricity is expected to change over time, cost-benefit analysis can account for this change, which will affect both estimated health costs and GHG emissions. A forecast of the national generation fuel mix is available through the EIA and is included in the accompanying spreadsheet (EIA 2013).

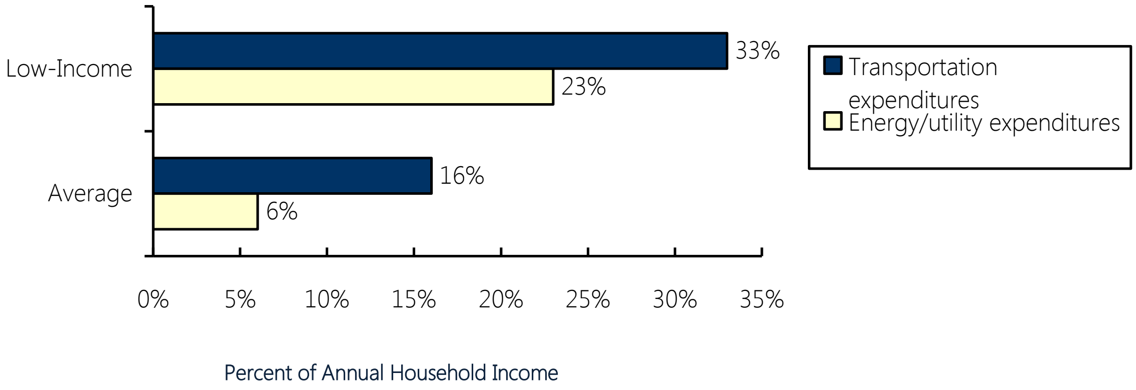
NON-ENERGY BENEFITS

Some utility screening tools also include a non-energy benefits adder, a deemed value that is added to the estimated benefits of the measure being screened. The adder is intended to capture benefits that may otherwise be excluded from the tool's characterization of savings and societal benefit. In buildings, non-energy benefits may include increased comfort resulting from weatherization efforts or increased convenience of using a programmable thermostat. In the screening of transportation efficiency measures, non-energy benefits may include some of the quality of life factors discussed above in the *"Factors to Consider in Future Analyses"* section.

ASSISTANCE FOR LOW INCOME HOUSEHOLDS

An additional adder can be included to encourage efficiency measures that benefit low income populations. In the case of transportation, a special effort should be made to target and implement such measures to ensure an equitable deployment and distribution of benefits. Transportation costs make up a significant portion of American household budgets, second only to housing costs, and similar to other energy-related costs, the cost burden grows as income declines (CHP and CNT 2012). In 2011, home energy and utility expenditures made up 6% of average household annual income and 23% of average low income household income. In contrast, transportation costs averaged 16% of overall household income and 33% of annual income in low income households (Figure 2). To alleviate this dynamic, it is common for utility efficiency programs to include low-income-targeted elements, although these programs may be less cost effective from a screening perspective than other efficiency measures.

FIGURE 2. ANNUAL HOUSEHOLD EXPENDITURES ON ENERGY AND TRANSPORTATION (BUREAU OF LABOR STATISTICS 2011)



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[12] See: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

Despite the disproportionately large burden that transportation costs present to low income households, there are few programs designed to defray these costs. Implementation of a standardized screening process in transportation planning could facilitate such programs and demonstrate their benefits. For instance, while public transit is often criticized for failing to meet costs through fares alone, it meets crucial mobility needs of those who either cannot afford their own vehicle or are unable or choose not to own one, including the elderly, young, and disabled.

In addition, although the upfront cost of EVs is generally higher than equivalent conventional vehicles, the overall lifecycle, fuel, and maintenance costs of these vehicles is considerably lower. As EVs enter the used car market and the price continues to drop with improved battery technology and increased production, they will become more affordable. The price of EVs continues to fall and available state and federal tax incentives help to make these vehicles more affordable. A crucial aspect of making EVs available to low income families will be outfitting multi-family residences with charging infrastructure. Although assigned parking spaces and individual apartment metering remain a challenge, programs and outreach to multi-family housing are needed.

The following sections outline three transportation efficiency measures within the scope of energy, environmental, and financial benefits described in Tables 2 and 3. These measures do not yet account for geographic variation, non-energy benefits, or impacts on low income populations, but these refinements can be incorporated as the Transportation TRM develops and is adapted for specific locales.

Glossary

Baseline: standard equipment or operating procedure, business as usual in absence of an efficiency program.

Coincidence Factor: the fraction of connected load expected to coincide with a particular system peak period, including summer, winter and spring/fall peak periods.

All-Electric Vehicle (AEV): a vehicle that is powered exclusively by electricity

Electric Vehicle Supply Equipment: the infrastructure used to charge the batteries of plug-in electric vehicles (AEVs and PHEVs)

Full Load Hours: the equivalent hours that equipment would need to operate at its peak capacity in order to consume its estimated annual kWh consumption (annual kWh/connected kW).

Free Ridership: the fraction of gross program savings that would have occurred despite the program.

Internal combustion engine (ICE): an engine in which fuel combustion of occurs in a chamber.

Lifetime: the number of years that new high efficiency equipment is expected to function; may be based on engineering lives or equipment warranties.

Line Loss Factor: the marginal electricity losses from the generator to the customer - expressed as a percent of meter-level savings. The energy line loss factors vary by period. The peak line loss factors reflect losses at the time of system peak, and are shown for three seasons of the year. Line loss factors are the same for all measures.

Load shape: estimated proportion of energy use, seasonally; includes percentage of energy use (for baseline or efficiency measure) for winter peak, winter off peak, summer peak, and summer off-peak

Operating Hours: the annual hours that equipment is expected to operate.

Persistence: the fraction of gross measure savings obtained over the measure life. Persistence factors may decline with measure life due to reduced operating efficiency of equipment and may be adjusted as needed.

Plug-in Hybrid Electric Vehicle: a vehicle that may be powered by both electricity drawn from the grid and a gasoline-powered motor.

Spillover: avings attributable to the program, but generated by customers not directly participating in the program.

Transportation Efficiency Measures

ALL-ELECTRIC VEHICLE

Definition of Efficient Equipment: A vehicle that is powered exclusively by electricity

Definition of Baseline: Gasoline-powered internal combustion engine vehicle

Description: The operating efficiency of all-electric vehicles (AEVs) is greater than 3 times that of conventional internal combustion vehicles and the tailpipe emissions are zero. On average AEVs achieve an operating efficiency of 901 Btu per mile while conventional vehicles achieve an operating efficiency of 4,696 Btu/mile.

Deemed Annual Energy Savings: 34.2 MMBtu per vehicle per year

Assumptions and supporting calculations

- Annual AEV miles traveled: 9,000[13] (slightly lower than the national average of 10,650 miles[14])
- Average fuel efficiency of new conventional vehicles sold, model year 2013: 24.7 miles per gallon (4,696 Btu per mile)[15]
- Average efficiency of AEVs available, model year 2013: 3.33 miles per kWh (901 Btu per mile)[16]
- Travel patterns are assumed to be the same for the conventional and all-electric vehicles.
- Energy savings = (Baseline energy use) – (Measure energy use)
- Baseline annual energy use (gallons gasoline consumed, conventional vehicle)
  (9,000) x (1 gallon gasoline/24.7 miles) x (0.116 MMBtu/gallon gasoline)= 42.3 MMBtu
- Measure annual energy use (electricity consumed, AEV)
  (9,000) x (1kWh/3.33 miles) x (0.003 MMBtu/kWh)= 8.1 MMBTU
- Energy savings = 42.3 MMBTU - 8.1 MMBTU = 34.2 MM BTU

Other Savings

GHG emissions: Use of an electric vehicle will displace 2,915 gallons of gasoline over the 8 year lifetime of the measure (see section *Measure Lifetime* below). Reductions in greenhouse gas emissions will vary widely by region with the source of electricity generation. National average reductions in CO_2 are estimated to be 14.32 tons (28,643 lbs) over the lifetime of the measure.[17]

- National average CO_2 emissions per MWh delivered electricity: 1,307 lbs CO_2[18]
- CO_2 emissions per gallon of gasoline: 19.52 lbs[19]

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[13] EV Project report

[14] FHWA 2012

[15] Sales-weighted average miles per gallon of model year 2013 vehicles, calculated in University of Michigan Transportation Research Institute Eco-driving Index, 2013: http://www.umich.edu/~umtriswt/EDI_sales-weighted-mpg.html. This average includes all light duty vehicles (cars, SUVs, pick-up trucks) and may include a small number of alternative fuel vehicles. This estimate was the best available of model year 2013 vehicle operating efficiency.

[16] Average operating efficiency of all-electric vehicles included on the US EPA site www.fueleconomy.gov as of January 2014.

[17] Per gallon estimates of non-CO_2 vehicle emissions are difficult to estimate. CO_2 accounts for 95-99% of vehicle emissions.

[18] US EPA, 2013, Clean Energy Calculations and References

[19] US EPA, 2011, Greenhouse Gas Emissions from a Typical Passenger Vehicle

- AEV lifetime energy use (MWh)=(9,000 miles) x (1 kWh/3.33 miles) x 8 years x (1 MWh/ 1,000 kWh) = 21.62 MWh
- CO_2 lifetime savings= (Gasoline vehicle emissions avoided) – (All-electric vehicle emissions):
- Lifetime gasoline vehicle use avoided: (9,000 miles) x (1 gallon/24.7 miles) x (8 years)=2,915 gallons (2,915 gallons gasoline) x (19.52 lbs CO_2/gallon)–(21.62 MWh) x (1,307 lbs CO2/MWh)=28,643 lbs CO_2

Health Impacts: Annual savings in health costs are estimated to be $351 per AEV. At a below average rate of use, a conventional vehicle results in $540 annually in associated health costs resulting from tailpipe emissions:

- (9,000 miles) x ($0.06) per mile= $540
- Health costs associated with AEV use (2014 national average generation fuel mix) are $189:
- (9,000 miles) x (1 kWh/3.3 miles x $0.07/kWh) = $189 annually

Measure Cost: The incremental cost of an AEV, exclusive of home charging equipment, is $8,639.

We estimate the average upfront cost of an equivalent conventional 2013 vehicle (fully loaded) to be $25,000, in accordance with the methods used in EPRI, 2013[20]. At this level, the mean incremental difference between a conventional and electric vehicle is $8,639 as of 2013, using the most price recent data available, excluding AEV incentives and residential EVSE costs (see http://www.afdc.energy.gov/vehicles/electric_availability.html for up to date information; further price details are included in Appendix A of this document).

This price differential will change as the number of available electric models increases. Lease deals and current federal and state incentives make EVs considerably more affordable for consumers and in some cases such deals are actually cheaper than the conventional ICE equivalent. However, because this analysis accounts for the full costs and benefits of AEV purchase and ownership, the full vehicle purchase price is used. The cost of a Level 1 (120 volt) residential EVSE is an additional cost of EV purchase and estimated to be $500 – $1,000 with installation.

Operation and Maintenance Costs: The deemed lifetime O&M cost of this measure is $2,173 (electricity) + $648 (maintenance) = $2,821. This is an overall lifetime savings in O&M costs over conventional vehicle baseline of $8,780 ($6,908 savings in fuel costs and $1,872 savings in annual maintenance costs).

Energy costs

The deemed energy costs average $271 annually, an average incremental savings of $864 annually.

Annual estimates of gasoline prices and kWh were obtained from the Energy Information Administration 2013 Annual Energy Outlook (EIA 2013).[21] Between 2014 and 2021, estimates of gasoline costs to power 9,000 vehicle miles range from $1,099 to $1,198 in 2011 dollars. These prices can be further modified for specific locations. Electricity prices range from $267 annually to $274, an average difference of $864 annually in energy costs for vehicle operation and a difference of $6,908 over the lifetime of the measure.

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[20] EPRI, 2013, Technical Report: Total Cost of Ownership Model for Current Plug-in Electric Vehicles

[21] See 'Calculating Vehicle Energy Cost' tab in in the accompanying spreadsheet 'EIA 2013 Energy Price Forecast.xlsx'

TABLE 5. ESTIMATED COST TO POWER 9,000 VEHICLE MILES OF TRAVEL

Year	Gasoline	Electricity
2014	$1,116	$267
2015	$1,099	$268
2016	$1,100	$272
2017	$1,110	$274
2018	$1,129	$274
2019	$1,151	$273
2020	$1,178	$272
2021	$1,198	$273
Total	$9,081	$2,173

Maintenance costs

Maintenance costs were considered for 8 years (warrantied battery lifetime) at 9,000 miles driven annually. Total maintenance costs for 72,000 vehicle miles are estimated to be $648 for an AEV and $2,520 for a conventional gasoline vehicle. Maintenance costs are calculated based on manufacturer suggested vehicle maintenance schedules. [22] Overall maintenance costs of AEVs are expected to be lower than conventional vehicles due to fewer moving and mechanical parts. AEVs experience slower wear of brake pads due to regenerative braking, do not require oil changes, and do not have exhaust systems or clutches.

Coincident Factor : 25%: Based on away-from home charging behavior and observation of charging behavior in areas with and without time of use (TOU) rates, it is assumed that in areas with time of use rates, 75% of charging will occur off-peak.[23, 24] In areas without TOU rates, it is assumed that 60% of charging will occur at home off peak. In the absence of TOU rates, there is a tendency for AEV drivers to begin charging in the early evening when they return home from work, resulting in a few hours of peak charging. Peak demand generally ends at 10 PM. It is assumed that charging patterns will not vary significantly seasonally, although this assumption can be modified as more data becomes available.

Persistence: Persistence refers to the fraction of gross measure savings obtained over the measure life. For electric vehicles, the persistence is assumed to be 1.00: There are no data available to suggest that energy savings achieved will decline as the battery ages.

Measure Lifetime: 8 years; most AEV batteries are under warranty for 8 years or 100,000 miles.[25] Although the vehicles may change ownership, the presumed lifetime of the measure is 8 years (efficiency benefits will be achieved regardless of who the individual owner is).

Spillover and Free ridership: Rates of spillover and free ridership can be updated as more data on electric vehicle adoption becomes available. Previous research on non-plug-in hybrid vehicles suggests that these

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[22] EPRI, 2013. Total Cost of Ownership Model for Current Plug-in Electric Vehicles. This document estimates maintenance costs for 100,000 vehicle miles. We discounted these costs by 28% to represent 72,000 miles of vehicle travel.

[23] The EV Project, 2013, PEV Driver Reponses to Time-of-Use (TOU) Rates While Charging EV Project Vehicles

[24] The EV Project Q2 2013 Report

[25] See vehicle manufacturer websites.

vehicles tend to occur in geographic clusters, indicating the potential of a spillover effect.[26] Most likely, the rate of free ridership will depend on the level of incentive provided.

Referenced Documents

- University of Michigan Transportation Research Institute Eco-Driving Index, October 2013: http://www.umich.edu/~umtriswt/EDI_sales-weighted-mpg.html
- Federal Highway Administration, 2012, Highway Statistics 2010: http://www.fhwa.dot.gov/policyinformation/statistics/2010/vm1.cfm
- US EPA. 2013: www.fueleconomy.gov
- US EPA. 2013: Clean Energy Calculations and References.
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[26] See Aultman-Hall et al. Transportation Research Record. 2012, and Zhu and Liu Transportation Research Board Annual Meeting, 2013.

COMMERCIAL/PUBLIC LEVEL 2 ELECTRIC VEHICLE SUPPLY EQUIPMENT

Definition of Efficient Equipment: Level 2 240 volt Electric Vehicle Supply Equipment at a public or commercial location

Definition of Baseline: Level 1 Electric Vehicle Supply Equipment

Description: Electric Vehicle Supply Equipment (EVSE) is the infrastructure that is used to charge electric vehicle batteries. At non-residential locations EVSE may simply be a designated outlet in a parking lot or garage, or may include embedded intelligence that allows a fee to be charged for use of the EVSE and communications with a charging network such as ChargePoint. Additional functionality (the ability to charge a fee or communicate with a network) adds substantially to the cost of EVSE installation and often includes a monthly subscription fee. A field study was conducted to examine the relative efficiency of Level 1 and Level 2 EV charging. Details of study methodology are presented in Appendix B. Field observations show that Level 2 240 volt EVSE offers efficiency gains of approximately 5.6% over 120 Volt Level 1 EVSE (see Appendix A). Efficiency gains achieved per unit will be greatest at those EVSE locations that are heavily used, such as downtown areas and retail locations. Data further show that efficiency gains are greatest (approximately 13%) for low energy charge events (those less than 4 kWh). As more data on charging behavior and efficiency becomes available, multiple savings profiles may be created. There is potential to make this measure semi-custom, accounting for variations in efficiency that come with charge duration. Categories by EVSE location (parking lot, grocery store, mall, Park and Ride) can be created with savings estimates based on average length of charge.

Deemed Annual Energy Savings: 403 kWh per unit (Savings will vary depending on the amount of charging done at a particular EVSE and with charge durations.) Mean efficiency gains of Level 1 over Level 2 are 5.6% on average, and 13% for charge events when less than 4 kWh is taken up by the vehicle battery. Charging efficiency is defined as:

- *(total energy taken up by the vehicle battery) ÷ (total energy drawn from the grid) x 100*

Heavily used public EVSE currently report 600 kWh of monthly use (7,200 kWh annually), although this value is expected to grow with adoption of electric vehicles. Although charge events less than 4kWh (approximately one hour of charging at Level 2) presumably are not uncommon at public EVSE, until more data is available, deemed savings are based on the overall efficiency gain. Future calculations may use a weighted average to determine savings.

- *(7,200 kWh) x (0.056) = 403 kWh*

Operating Hours: The number of hours each unit is in operation will vary with location and vehicle charging capacity. On average, 600 kWh of energy used at a given EVSE will equate to approximately 120 hours of use. The rate at which vehicles can charge is limited by the vehicle's internal charger, which generally range from 3.3 to 6.6 kW capacity (Newer models of all-electric Vehicles tend to have a 6.6 kW charger while Plug-in Hybrid Electric Vehicles often have a 3.3 kW charger). Assuming an average charger capacity of 5 kW, operating hours can be estimated by:

- *(600 kWh used at EVSE per month) ÷ (5 kW average vehicle internal charger capacity)= 120 operating hours at EVSE*

Other Savings: Like energy savings GHG emission reductions will vary with the amount of EVSE usage but an overall reduction of 5.6% is expected. Over the lifetime of the measure, avoiding 432 kWh annually in electricity would amount to 5,646 lbs CO_2 avoided (2.8 tons) and $302 in health impacts avoided.

- National average CO_2 emissions per MWh delivered electricity: 1,307 lbs CO_2[27]
- Lifetime avoided emissions through improved efficiency = *(403 kWh annual energy savings per unit) x (1 MWh/1,000 kWh) x 1,307 lbs* CO_2 *x 10 years= 5,267 lbs* CO_2 *(2.6 tons)*
- Health impacts of avoided electricity *=(403kWh annual energy savings per unit) x ($0.07/kWh) x 10 years = $282*

Measure Cost: The incremental measure cost of a Level 2 EVSE will vary with site characteristics and system functionality (i.e., capability to charge users a fee, to interact with advanced metering infrastructure, participate in demand response programs). These costs are changing quickly and should be tailored to the geography of interest. Estimated total cost of baseline equipment (commercial/public Level 1 EVSE) and installation ranges from $230 to $1,350, although depending on the requirements of the site and trenching and signage needs, the cost could be more. In locations where wiring already exists, the cost could be close to zero. Measure costs (commercial/public Level 2 EVSE), including installation, are estimated to be $2,600-$21,000, although again, this cost will vary by site and with system functionality.

Maintenance Costs: Maintenance costs are not expected to differ between Level 1 and Level 2 EVSE.

Coincident Factor: 75%: Most use of commercial EVSE occurs during business hours 9-5, and will thus add to peak load (although definitions of 'peak' can vary by utility territory). Region specific data of charging behavior at public EVSE may be available through The EV Project (www.theevproject.com).

Persistence: 1.00: There is no data to suggest that efficiency gains will decline over the lifetime of the measure.

Measure Lifetime: 10 years (length of unit warranty; see individual EVSE manufacturer websites)

Spillover and Free Ridership: N/A

Referenced Documents

- Appendix B
- Efficiency Vermont, 2012, An Assessment of Level 1 and Level 2 Electric Vehicle Charging Efficiency: http://www.veic.org/resource-library/an-assessment-of-level-1-and-level-2-electric-vehicle-charging-efficiency
- The EV Project. 2013. PEV Driver Reponses to Time-of-Use (TOU) Rates While Charging EV Project Vehicles.
- The EV Project. 2013. Q2 2013 Report.

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[27] US EPA, 2013, Clean Energy Calculations and References

RESIDENTIAL LEVEL 2 ELECTRIC VEHICLE SUPPLY EQUIPMENT

Definition of Efficient Equipment: Residential Level 2 240 Electric Vehicle Supply Equipment

Definition of Baseline: Residential Level 1 Electric Vehicle Supply Equipment

Description: Electric Vehicle Supply Equipment (EVSE) is the infrastructure used to charge electric vehicle batteries. Residential EVSE is nearly always either Level 1 (120 volt) or Level 2 (240 volt EVSE) and may be as simple as an outlet in a driveway or garage with a dedicated electric line. Access to EV charging in multi-family residences can be a challenge. In order for EV ownership to be practical for residents in multifamily dwellings, dedicated grounded outlets in parking or garage space must be available to EV-owning tenants. A field study was conducted to examine the relative efficiency of Level 1 and Level 2 EV charging. Details of study methodology are presented in Appendix B. Field observations show that Level 2 240 volt EVSE offers efficiency gains of approximately 5.6% over 120 volt Level 1 EVSE. Savings will vary with use and thus type of EV. Savings will be greatest for all-electric vehicles (AEVs), which have larger batteries and longer ranges than plug-in hybrid electric vehicles (PHEVs). PHEVs use less electric energy than all-electric vehicles so fewer savings will be achieved through a switch from residential Level 1 to Level 2 EVSE.

Deemed Annual Energy Savings

- AEV: 113 kWh per unit
- PHEV- 12: 33 kWh per unit
- PHEV-21: 78 kWh per unit
- PHEV-35: 93 kWh per unit
- (Savings will vary depending on the amount of charging done at a particular EVSE and with charge durations.)

Assumptions and Supporting Calculations

- Annual electric vehicle miles traveled: 9,000[28] (slightly lower than the national average of 10,650 miles[29])
- Average efficiency of AEVs available, model year 2013: 3.33 miles per kWh[30]

TABLE 6. PHEV ELECTRIC RANGE AND OPERATING EFFICIENCY

Electric Range	Miles per kWh (avg.)[31]	% of miles in electric mode
12	3.4	30 (estimate, no data available)
21	2.9	60[32]
38	2.6	64[33]

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[28] EV Project report
[29] FHWA 2012
[30] US EPA, www.fueleconomy.gov
[31] US EPA, www.fueleconomy.gov
[32] Estimate from Ford Motor Company based on Fusion and C-Max owners
[33] Estimate from Chevrolet based on Volt owners

Deemed Annual Savings by Vehicle Type

Annual energy savings were calculated as (annual miles driven) x (% miles powered by electricity) x (% performed at home)/ (vehicle operating efficiency) x(efficiency gain of Level 2 EVSE over Level 1 EVSE)

Mean efficiency gains of Level 1 over Level 2 are 5.6% on average. Charging efficiency is defined as: (total energy taken up by the vehicle battery) ÷ (total energy drawn from the grid) x 100

Supporting Calculations

- AEV: (9,000 miles) x (100% miles powered by electricity) x (75% at home charging) / (3.33 miles per kWh) x (5.6% efficiency gain) = 113 kWh
- PHEV- 12: (9,000 miles) x (30% miles powered by electricity) x (75% at home charging) / (3.4 miles per kWh) x (5.6% efficiency gain) = 33 kWh
- PHEV- 21: (9,000 miles) x (60% miles powered by electricity) x (75% at home charging) / (2.9 miles per kWh) x (5.6% efficiency gain) = 78 kWh
- PHEV-35: (9,000 miles) x (64% miles powered by electricity) x (75% at home charging) / (2.6 miles per kWh) x (5.6% efficiency gain) = 93 kWh

Other Savings: Like energy savings GHG emission reductions will vary with the level of EVSE use but an overall reduction of 5.6% is expected. Over the lifetime of the measure, avoiding between 33 kWh and 113 kWh annually would amount to between 431and 1,477 lbs CO_2 avoided.

National average CO_2 emissions per MWh delivered electricity: 1,307 lbs CO_2[34]

Lifetime avoided emissions through improved efficiency =

- EV: (113 kWh) x (1 MWh/1,000 kWh) x 1,307 lbs CO_2 x 10 years= 1,477 lbs CO_2 (0.7 tons)
- PHEV-12: (33 kWh) x (1 MWh/1,000 kWh) x 1,307 lbs CO_2 x 10 years= 431 lbs CO_2 (0.2 tons)
- PHEV-21: (78kWh) x (1 MWh/1,000 kWh) x 1,307 lbs CO_2 x 10 years= 1,019 lbs CO_2 (0.5 tons)
- PHEV-35: (93kWh) x (1 MWh/1,000 kWh) x 1,307 lbs CO_2 x 10 years= 1,215 lbs CO_2 (0.6 tons)

Health impacts of avoided electricity over the measure lifetime are nominal (< $100).

Measure Cost: The incremental measure cost of a base unit Level 2 EVSE is $900. A base Level 2 EVSE is estimated to cost $1,500 to $1,800, including installation. Installation costs will vary, depending on site characteristics. Baseline equipment costs, including installation are estimated to be $500-$1,000.

Maintenance Costs: Maintenance costs are not expected to differ between Level 1 and Level 2 EVSE.

Coincident Factor: 25%: Based on away-from home charging behavior and observation of charging behavior in areas with and without TOU rates, it is assumed that in areas with time of use rates, 75% of charging will occur off peak.[35, 36] In areas without TOU rates, it is assumed that 60% of charging will occur at home off peak. In the absence of TOU rates, there is a tendency for EV drivers to begin charging in the early evening when they

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[34] US EPA, 2013, Clean Energy Calculations and References

[35] The EV Project, 2013, PEV Driver Reponses to Time-of-Use (TOU) Rates While Charging EV Project Vehicles

[36] The EV Project Q2 2013 Report

return home from work, resulting in a few hours of peak charging (peak demand generally ends at 10 PM). It is assumed that charging patterns will not vary significantly seasonally, although this assumption can be modified as more data becomes available.

Persistence: 1.00: There is no data to suggest that efficiency gains will decline over the lifetime of the measure.

Measure Lifetime: 10 years (length of unit warranty; see manufacturer websites)

Spillover and Free ridership: N/A

Referenced Documents

- Appendix B
- Efficiency Vermont, 2012, An Assessment of Level 1 and Level 2 Electric Vehicle Charging Efficiency: http://www.veic.org/resource-library/an-assessment-of-level-1-and-level-2-electric-vehicle-charging-efficiency
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Conclusion

This document presents the general values and calculations needed to assess three transportation efficiency measures. Many of the values presented in this document are national averages that should be tailored to specific locations as needed (individual states, utility service areas, metropolitan areas, counties, etc.). In addition, the methodology presented can easily be extended to assess the energy and non-energy benefits of other transportation efficiency measures, including bicycling and walking infrastructure, ultra efficient conventional vehicles, and natural gas vehicles. Transportation efficiency and a comprehensive means of measuring such efficiency have relevance for all stakeholders involved in energy and transportation planning.

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Appendix A

PRICES OF 2013 AND 2014 ALL-ELECTRIC VEHICLES

Prices of available 2013 and 2014 all-electric vehicles as of December 2013. The base model AEV price is used in this analysis. As noted in EPRI (2013), base model AEVs tend to come with standard features not available in their base model conventional equivalent. In the EPRI report, base model AEVs and plug-in hybrid electric vehicles are compared to fully loaded conventional vehicles. For updated price information, see manufacturer websites or http://www.afdc.energy.gov/vehicles/electric_availability.html .

TABLE 7. PRICES OF 2013 AND 2014 ALL-ELECTRIC VEHICLES

Electric Model	MSRP
2014 Ford Focus Electric	$35,995
2013 Nissan Leaf	$28,800
2014 Chevrolet Spark Electric	$34,185
2014 Honda Fit EV	$37,415
2013 Fiat 500e	$31,800
Average	$33,639

Appendix B

ESTIMATING EFFICIENCY OF LEVEL 1 AND 2 ELECTRIC VEHICLE SUPPLY EQUIPMENT

A field study was conducted to estimate the relative efficiencies of Level 1 and Level 2 Electric Vehicle Supply Equipment (EVSE). This study built upon previous research of the Chevrolet Volt which found Level 2 EV charging to be 2.7% more efficient than Level 1 charging, on average, and as much as 12.8% more efficient for shorter charge events (those that draw less than 2kWh from the grid; Sears et al. 2014).

METHODOLOGY

Logging devices were installed in 2 Chevrolet Volts and 2 Nissan Leafs to measure charging efficiency of each vehicle charging event. Although our sample size was very limited, the study is intended to provide preliminary data and results on this topic. All vehicles were located and charged in Vermont and data was collected between June and November 2013. The Volts were outfitted with the F-5 logging device from the company FleetCarma, which plugged into the vehicle dash and collected data on the amount of energy received from the EVSE and the amount taken up by the vehicle battery.

There was no similar device available for the Nissan Leaf (one that directly measures energy uptake by both the vehicle charger and the vehicle battery) but we wanted to ensure that at least two EV models were included in our study. To estimate charging efficiency of the Nissan Leaf, a vehicle logging device was used in combination with a meter on the EVSE unit. One device, the WattsLeft™ monitor was plugged into the vehicle and measured the amount of energy taken up by the battery at each charging event. Another device, the Watts Up meter, was attached to the EVSE unit and measured the amount of energy that was taken from the grid during each charging event.

For both logging devices, the efficiency of each charge event was calculated as:

(total energy taken up by the vehicle battery) ÷ (total energy drawn from the grid) x 100

Usable data was collected from a total of 115 charge events, 64 Level 1 and 51 Level 2. Of these 115 charge events, 75 were Chevrolet Volts and 39 were Nissan Leafs. We found mean charge efficiency for all charge events to be 85.7% ± 0.09 SD.

Because previous research (Sears et al. 2014) indicated that charging efficiency of the Chevrolet Volt was affected by ambient temperature and charge duration, we also examined the effects of these factors on charging efficiency. Hourly temperature data for each charge event was obtained from the Cornell Northeast Regional Climate Center. We observed that the efficiency of low energy charge events (those in which the battery took up less than 4 kWh), was generally lower, especially for Level 1 charging. Level 1 'low charge events' exhibited an average charge efficiency of 74.2% and Level 2 low charge events exhibited a mean efficiency of 87.2%. In addition, we observed that high ambient temperatures (> 70°F) reduced charging efficiency of Level 1 charges to 81.4%, but there was no similar effect observed for cold temperatures (< 50° F). Ambient temperature did not appear to affect the efficiency of Level 2 charge events within the temperature ranges examined. There may be effects on charging efficiency at lower temperatures (e.g., < 40°F or < 30°F) but we did not have enough observations for both Level 1 and Level 2 charging events at these temperatures to assess these effects. The table below summarizes the study results.

TABLE 8. ESTIMATING EFFICIENCY OF LEVEL 1 AND 2 ELECTRIC VEHICLE SUPPLY EQUIPMENT

	N	Mean charge efficiency (%) ± SD
All charge events	114	85.7 ± 0.09
Level 1	63	83.8 ± 0.08
Level 2	51	89.4 ± 0.05
Level 1 charge events < 4kWh	11	74.2 ± 0.12
Level 2 charge events < 4kWh	13	87.2 ± 0.06
Level 1 charge events < 50°F	32	83.0 ± 0.09
Level 1 charge events > 70°F	9	81.4 ±0.09
Level 2 charge events < 50°F	23	90.6 ± 0.04
Level 2 charge events > 70°F	10	89.9 ± 0.04

The previous research cited above reported that temperatures below 53°F and above 70°F reduced charging efficiency for charge events that drew less than 2kWh from the grid. Due to limited sample size, we were not able to examine combined effects of temperature and charge duration. Further data collection can clarify the effects of ambient temperature on Level 1 and 2 EV charging efficiency. Energy savings may vary seasonally and may be greater in hot or cold climates.