MEMORANDUM

To: Josh Shaw, CTA

From: Frank Gallivan and Eliot Rose, ICF International

Date: October 24, 2014

Re: Task 2: Document Justification for and Revisions Needed to APTA's 2009 Methodology

1. Background

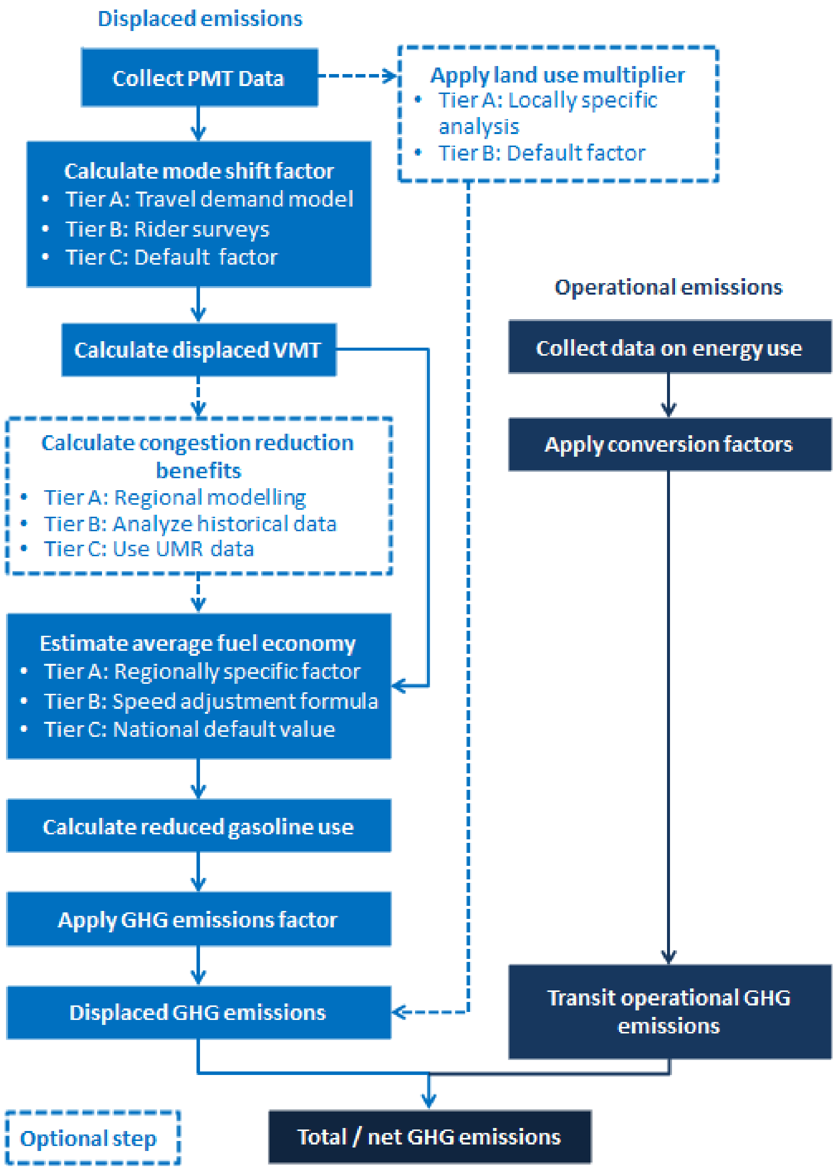
The California Transit Association has engaged ICF International to develop a recommended GHG-reduction evaluation methodology for the State to use in scoring transit agency applications for Cap & Trade funds. This memo is the second of four memos to detail transit project characteristics and greenhouse gas (GHG) quantification methodologies as applicable to the funding programs outlined under Senate Bills 852 and 862. The first memo provided a catalog of transit projects that reduce GHG emissions and an analysis of quantification methodologies that can be used to analyze the benefits of potential projects.

This memo reviews the American Public Transportation Association's *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit* ('the APTA Protocol') as a basis for estimating the emission reductions from transit projects and makes recommendations for its use. To support this exercise, the quantification techniques for individual project types are specified in more detail, and the level of effort necessary to quantify GHG emission reductions are classified in qualitative categories. Likely co-benefits from different types of transit projects are also discussed, according to categories of co-benefits mentioned in Assembly Bill 32 (AB 32).

2. Overview of APTA Protocol

The American Public Transportation Association's *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit* serves as the guiding document for quantifying GHG emissions from transit systems. The APTA Protocol discusses both emissions displaced due to transit and emissions from transit operations, outlining a series of steps to convert inputs such as passenger miles traveled and transit fuel use to GHG emissions. For many of these steps, the Protocol outlines different quantification methods, or tiers, which allows agencies to select the most appropriate method based on available data and resources. Figure 1 summarizes the most important components of the APTA process, and the following sections describe each step in more detail.

Figure 1: Summary of APTA Protocol Process for Quantifying GHG Emissions



2.1. Displaced Emissions

Transit displaces GHG emissions when riders switch from driving to transit. The APTA Protocol measures displaced emissions from mode shift to transit, congestion reduction, and compact land uses near transit stations. The primary input for measuring displaced emissions is PMT, and the APTA Protocol outlines a series of steps to convert PMT to GHG reductions.

2.1.1. Mode shift

Many of the transit projects discussed in these memos reduce GHG emissions by shifting trips from private automobile to transit, which reduces GHG emissions. In order to calculate the GHG reductions due to mode shift, the APTA Protocol recommends the following steps:

1. **Collect data on PMT** from the National Transit Database.
2. **Calculate the mode shift factor**, which is the ratio of transit passenger miles to displaced vehicle miles traveled, and is used to estimate how much increases in transit ridership result in reductions in driving. The APTA Protocol describes three different tiers for estimating the mode shift factor:
    a. Using a **regional travel demand model** to assess the increase in driving under an alternative scenario without transit.
    b. **Surveying riders** about what mode they would use if transit were unavailable.
    c. Applying a **default mode shift factor** based on data from the Transit Performance Monitoring System (TPMS).[1] The APTA Protocol recommends this approach only as a last resort for agencies without the resources for the other two tiers.
3. **Calculate displaced vehicle miles traveled (VMT)** by multiplying PMT by the mode shift factor.
4. **Estimate average fuel economy** for displaced VMT in order to convert displaced VMT to reductions in gasoline usage. The APTA Protocol describes three different tiers for estimating average fuel economy:
    a. Use a **regionally specific factor** published by the region's MPO that accounts for fleet composition and vehicle speeds in the area.
    b. Apply the **speed adjustment formula** from the Texas Transportation Institute's *Urban Mobility Report*, which assesses congestion in U.S. metropolitan areas, to adjust fuel economy based on average vehicle speeds in the region. The *Urban Mobility Report* only includes data on vehicle speeds for large urban areas.
    c. Use the **national default value** for fleet fuel economy from the EPA.
5. Calculate **reduced gasoline use** by multiplying displaced VMT by average fuel economy

[1] American Public Transportation Association's *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit* p.38

6. Apply a **GHG emissions factor** to convert gasoline savings to reductions in GHG emissions. The APTA Protocol contains default emissions factors from the Climate Registry, but notes that state- or region-specific factors can be used if available.

2.1.2. Congestion reduction

Transit projects that result in mode shift can have additional impacts on GHG emissions if they reduce congestion, because vehicles operate less efficiently under congestion. The APTA Protocol allows agencies the option of calculating additional GHG impacts due to congestion reduction. The Protocol then outlines three tiers for calculating congestion reduction.

1. Use a **regional travel demand model** to assess the change in vehicle speeds and the resulting impacts on GHG emissions under an alternative scenario without transit.
2. Analyze **historical data** from the *Urban Mobility Report* on the relationship between traffic density and excess fuel consumed due to congestion, and then apply results to displaced VMT (calculated using steps 1-3 in the previous section) in order to calculate additional fuel savings and GHG reductions due to congestion reduction. Historical data is only available for large U.S. urban areas.
3. Multiply the mode shift factor (calculated under step 2 of the previous section) to ***Urban Mobility Report* data** on excess fuel consumed in congestion to calculate the additional congestion-related fuel reductions due to transit. The *Urban Mobility Report* only publishes data for large U.S. urban areas; agencies in other areas can use published averages by population size.

2.1.3. Land-use multiplier

In addition to reducing GHG emissions through mode shift, transit reduces emissions indirectly by fostering compact development that reduces trip lengths, facilitates bicycle and pedestrian travel, and reduces vehicle ownership. The land-use multiplier is the ratio of indirect VMT emissions reductions to PMT. The APTA Protocol includes two tiers for quantifying and applying the land-use multiplier:

1. Conduct a **locally specific analysis** using a combination of a four step model, statistical evaluation, and GIS modeling.
2. Apply a **default factor using national data** and convert additional displaced VMT to GHG reductions. The Protocol recommends this approach as a last resort for agencies without the resources to conduct a locally specific analysis.

2.2. Emissions from Transit

Some of the GHG reduction strategies discussed in this memo reduce GHG emissions due to transit operations by deploying more efficient vehicles or shifting to less GHG-intensive sources of energy. The APTA Protocol contains guidance on estimating GHG emissions due to transit operations that can be applied to quantify the impact of these strategies. Operational emissions from transit can also be subtracted from displaced GHG emissions in order to calculate net GHG reductions. The Protocol covers five main types of operational emissions: direct emissions from stationary combustion, direct emissions from mobile combustion, indirect emissions from electricity use, other indirect emissions, and fugitive emissions. In most cases the approach for quantifying these emissions involves collecting data on energy consumption (e.g., fuel use, electric bills) and applying the appropriate GHG conversion factor.

3. The APTA Protocol as a Basis for Project Quantification

The APTA Protocol outlines a process for quantifying GHG reductions due to the entire transit system, but it is not designed to analyze individual transit projects. Estimating GHG reductions due to individual projects is much more complicated than analyzing system-wide reductions because it involves predicting the impact of strategies with diverse natures and scales.

This does not mean that the APTA Protocol needs revision. It is beyond the scope of the Protocol to outline in depth all the options for quantifying different strategies that transit agencies can use to reduce GHG emissions. However, any guidance on estimating GHG reductions for transit projects applying for cap and trade funding should acknowledge and address the limitations of the APTA Protocol. Transit agencies will need to apply those parts of the Protocol that are relevant, and funding agencies will need to provide further guidance and allow for some flexibility where the Protocol is limited. Below we discuss key findings with respect to using the APTA Protocol to estimate the benefits of projects.

3.1. Greenhouse Gases Covered

The APTA Protocol covers the six GHGs included in The Climate Registry Protocol:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)

Carbon dioxide is by far the most common GHG from transportation sources, accounting for roughly 95% of emissions from transportation (on a CO_2 equivalent basis). To limit the burden of quantification, it would be reasonable to include only CO_2 in quantification of project-level impacts.

Black carbon, a type of particulate matter, is another potential source of global warming impact from transportation that is not typically incorporated in GHG inventories. Because the State of California has not incorporated black carbon in its GHG inventory, we do not recommend quantifying emissions of black carbon from transit projects.

3.2. Emissions Factors for Passenger Vehicles

The process outlined in Section 6.4 of the APTA protocol for converting displaced VMT to gasoline use and then to GHG emissions is appropriate for quantifying GHG reductions due to transit, but more California-specific emissions factors for private autos are available. The California Air Pollution Control Officers' Association *Quantifying Greenhouse Gas Mitigation Measures* Handbook[2] (CAPCOA Handbook), a comprehensive resource for estimating project-level GHG reductions, recommends using a county-specific factor from ARB's EMFAC model[3] based on the county fleet mix.[4] This is a commonly used best practice for converting VMT reductions to GHG reductions in California, and is consistent with the approach outlined in the APTA Protocol. EMFAC is released by CARB and is the required emissions model for CEQA analyses of transportation-related GHG emissions.

The guidance in Section 5.2.9 of the APTA protocol should still be used for quantifying emissions due to transit vehicles.

3.3. Emissions Due to Displaced VMT

In general, the process outlined in the APTA protocol can be adapted to quantify project-level GHG reductions for strategies that displace VMT due to mode shift. However, it is not appropriate to factor in additional GHG reductions due to congestion reduction or the land-use effect, as described in the APTA Protocol, in project-level analyses. The regional, highly-aggregate approach outlined in the APTA protocol will not be applicable to individual projects that take place on corridors with very different travel environments and land use characteristics; and estimating the system wide impacts of a given project on congestion or land use development will typically be prohibitively complex. Furthermore, land use projects in areas well-served by transit are eligible for separate funding under the Affordable Housing and Sustainable Communities (AHSC) program, so it would be double-counting GHG reductions if transit agencies were to take credit for indirect effects of transit on land use. The only case in which it is appropriate for transit projects to take credit for additional GHG reductions due to congestion relief are for projects that are analyzed using a regional travel demand model, which is an appropriate tool to capture impacts on congestion.

3.4. Lifecycle Emissions from Transit

The APTA Protocol discusses some issues related to lifecycle emissions from transit, but does not provide a comprehensive discussion of the topic. In this memo we define 'lifecycle' emissions as all of the reasonably foreseeable emissions that occur upstream or downstream from operation of transit service. These are in contrast to 'operational emissions', which are the focus of the APTA Protocol's

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[2] http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf.
[3] http://www.arb.ca.gov/emfac/
[4] CAPCOA Handbook, p. B-19.

discussion of emissions from transit. 'Operational emissions' consist largely of tailpipe emissions from vehicles and emissions associated with generation of electricity used by vehicles and facilities.

The APTA Protocol provides the following guidance about various components of lifecycle emissions that are relevant to transit projects:

- Construction materials (steel, cement, asphalt): Quantify emissions of materials used each year. Emission factors per ton of material are provided.
- Vehicle manufacture (buses and light rail vehicles): Quantify emissions of new vehicles purchased each year. Emission factors by vehicle type are provided.
- Production and transportation of fuels: Can be quantified using the GREET model (for example) but are not a standard component of the inventory.
- Other lifecycle emission sources (tires, mobile source emissions from construction equipment, emissions from construction-induced traffic congestion, construction waste transportation and disposal): Do not quantify.

In general, we only recommend quantifying lifecycle emissions in the context of projects that reduce GHG emissions due to the use of alternative fuels. Other state policies focused on GHG reductions due to displaced VMT, such as SB 375, do not account for lifecycle impacts. However, lifecycle analysis is the only way to get an accurate estimate of the scale of GHG reductions from projects that change the fuel sources used by transit agencies.

Recommendations for treatment of specific lifecycle emission components are provided below.

3.4.1. Construction and Vehicle Manufacture Emissions

Including emissions from these sources in project-level estimates is an emerging but controversial practice. Emissions associated with construction of transit capital projects and manufacture of vehicles are often significant. The 'payback period' for a transit capital project to offset the emissions from these sources via VMT reductions can be decades long. This means that including construction and vehicle manufacture emissions can cause some large capital projects to be evaluated as causing a net increase in GHG emissions, depending on the underlying assumptions. New tools, such as FHWA's recently released Infrastructure Carbon Estimator[5], provide more direction on quantifying construction emissions and may support more comprehensive methodology for accounting for construction emissions in the future. For now, we do not recommend calculating emissions due to construction and vehicle manufacture.

3.4.2. Fuel Production and Distribution

While the APTA Protocol is largely silent on the topic of these emissions, it is important to consider fuel production and distribution as emission sources when quantifying the impacts of projects that change

[5] https://www.fhwa.dot.gov/environment/climate_change/mitigation/publications_and_tools/carbon_estimator/

the fuel sources used by transit agencies. Because the ratio of these upstream emissions to tailpipe emissions can be dramatically different between different fuels, accurately evaluating these strategies requires estimation of upstream emissions. For example:

- Replacement of diesel with biodiesel only shows significant GHG reduction benefits when upstream emissions are considered
- Switching from methane to biomethane only shows significant GHG reduction benefits when upstream emissions are considered
- Replacing diesel buses with battery electric buses must consider the additional emissions associated with electricity used to charge buses

The CA-GREET model[6] is the preferred source for emission factors for fuel production and distribution. For electricity used in new vehicles, emission factors from utilities or from EPA's eGRID can be used in place of factors from CA-GREET.

3.4.3. Transportation & Distribution Losses

Inclusion of emissions associated with transportation & distribution (T&D) losses for electricity use has become commonplace in Climate Action Plans and CEQA documents in California. T&D losses should be incorporated in quantification of projects that reduce agency electricity use, such as renewable energy facilities and building efficiency improvements. Factors can be obtained from individual utilities or an average factor for EPA's eGRID can be used.

3.5. Other Challenges with Applying the APTA Protocol in the Context of Cap and Trade Funding

The APTA Protocol does not describe how to forecast the impact of projects on ridership or energy use.

Since the Protocol is focused on quantifying current GHG emissions, it assumes that users will collect data on the primary inputs needed to estimate emissions—either PMT, from the NTD, or energy use, from agency fuel purchases and utility bills. In order to forecast future GHG reductions due to projects, agencies must first estimate how these projects increase ridership or affect other underlying variables such as VMT or fuel consumption, then convert these variables into GHG reductions. The APTA Protocol can be used for the latter step, but transit agencies need more guidance on how to project the impacts of transit projects on travel behavior and fuel consumption.

The APTA Protocol does not fully capture many of the GHG reduction strategies available to transit agencies.

The Protocol focuses on analyzing GHG reductions due to more efficient operations and to riders taking transit instead of driving. However, there are many other ways for transit agencies to reduce emissions. Projects that improve bicycle and pedestrian access to stations may increase ridership, but they will also

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[6] http://www.arb.ca.gov/fuels/lcfs/greet1.7ca_v98.xls

reduce GHG emissions associated with trips to and from stations. Transit-oriented development projects also can boost ridership, but often have a greater effect on GHG emissions because compact development shortens car trips and enables bicycling and walking instead of driving. Some of these indirect impacts are captured in the land use multiplier described in the APTA Protocol. However, estimating land use changes based on ridership data is a roundabout approach given that agencies are likely to have data on land use changes for specific projects and that extensive research quantifies GHG reductions due to land use changes. Funding agencies will need to allow for alternative approaches to quantifying indirect GHG reductions not included in the Protocol in order to capture the full array of GHG reduction strategies.

The APTA Protocol does not discuss many of the resources that agencies can use to assess project-level GHG reductions.

Since the Protocol is meant to analyze system-wide impacts, it focuses on resources that are well-suited for examining impacts at the regional scale, such as travel demand models and the *Urban Mobility Report*. However, these are not always the best tools for project-level analysis. Travel demand models are designed to assess major capital projects, such as route expansions, and may not capture other types of GHG reduction strategies. Even in cases where regional-scale tools can provide factors that help estimate GHG reductions, agencies may be able to more accurately estimate reductions by applying locally-specific information. Transit agencies will need to draw on a broader variety of resources to capture GHG reductions from a variety of strategies.

The APTA Protocol offers a confusing array of options for converting inputs to GHG reductions.

The various tiers and methods outlined in the Protocol are meant to provide flexibility, but that flexibility comes at the expense of clarity. Given that California's state agencies provide or influence many of the different tools that support quantification of GHG emissions, there are opportunities for the State to provide clearer guidance on estimating GHG reductions due to transit. For example, the California Transportation Commission could work with MPOs to create mode shift factors that can be used to quantify GHG reductions, or the Air Resources Board could specify GHG emissions factors from its Emissions Factors (EMFAC) model to apply to particular vehicles and transit technologies.

4. Quantification of Transit Strategies to Reduce GHG Emissions

The following sections of this memo examine resources and methods to quantify GHG reductions due to transit and address the limitations of the APTA Protocol discussed above. For each category of transit GHG reduction strategies, we identify the project impacts (such as increased ridership, reduced VMT, or reduced fuel consumption) that agencies will need to analyze in order to estimate reductions, but are not explicitly covered by the APTA protocol, and assess the resources and methods that are available to support this analysis. We organize this assessment around three general types of resources:

1. **General research** that provides factors that can be easily applied to project data in order to estimate the impact of projects.

2. **Agency-specific data and tools**, such as station access surveys and alternative energy models that transit agencies can apply to estimate the impact of projects. Not all transit agencies will have the resources to collect data or apply tools, but those that do may be better able to capture the impacts of certain strategies.

3. **Travel demand models**, which are important tools both in the APTA protocol and under the GHG analysis framework created by SB 375, and are well-suited to assess the impacts of many strategies on travel behavior.

These resources are listed in order of the level of effort it takes to apply them. Generally speaking, it is more labor-intensive to collect data and use complex analytical tools than to apply existing research findings, and still more challenging to collaborate with MPOs in order to conduct specialized travel model runs. However, there may be exceptions where transit agencies have already collected data, developed analytical tools, or established a collaborative process with their MPO. In some cases, we break project categories into individual project types to capture differences in the types of resources that are available to quantify impacts. We also list the relevant sections of the APTA protocol that agencies should apply to convert these impacts into GHG reductions.

Based on this assessment, we identify a recommended approach for quantifying each category of GHG reduction strategies. If strategies can be quantified using research, tools, and other generally-available information, we outline a recommended quantification method, including calculation steps and key resources. In some cases, we also outline alternative methods that will better capture certain strategies or apply in certain cases. We also identify which strategies are best quantified using agency-specific data and travel demand models, but due to the wide variation in resources, data, and modeling practices we do not outline specific methodologies for these. If there are not sufficient resources to support quantification of a project category, we discuss qualitative criteria that can be used to demonstrate GHG reductions.

4.1. Expanding or Improving Transit Capacity

Strategies that expand or improve transit capacity reduce GHG emissions increasing transit use, but also produce more GHG emissions if they increase transit energy consumption. Both aspects need to be quantitatively analyzed to determine the net impact of the projects on GHG emissions. While the APTA Protocol does not specifically address how to forecast increases in energy consumption due to transit expansion (see Section 3.5), this can generally be accomplished through a combination of assumptions drawn from current energy use patterns and methods discussed in Section 4.4. Table 1 below provides more detail on methods to quantify displaced emissions due to changes in ridership.

Table 1: Expanding or Improving Transit Capacity: Quantification Options

Project category	How the project reduces GHG emissions	Could it be quantified using… General research	Local / agency-specific data	A regional travel demand model	Relevant sections of APTA protocol
Increase capacity of existing service	Increases transit ridership	No	Yes	Sometimes, if models control for transit capacity constraints, and capacity change is regionally significant	Mode shift factor (section 6.5) Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)
Increase service frequency	Increases transit ridership	Yes, if change in service frequency is quantified	Yes	Sometimes, if change in service frequency is quantified and regionally significant	Mode shift factor (section 6.5) Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)
Enhance travel speeds and reliability	Increases transit ridership	Yes, if change in average travel speeds is quantified	Yes	Sometimes, if change in average travel speeds is quantified and regionally significant	Mode shift factor (section 6.5) Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)
Extend operating hours	Increases transit ridership	No	Yes	Sometimes, if project is regionally significant	Mode shift factor (section 6.5) Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)
Route expansion	Increases transit ridership	No	Yes	Sometimes, if project is regionally significant	Mode shift factor (section 6.5) Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)

4.1.1. Increase capacity of existing service

Recommended quantification method

Research does not specify a general methodology for estimating the impact of projects that increase capacity of existing service on ridership or GHG emissions, and the effect of these projects depends greatly on existing capacity and demand. GHG reductions from small projects, such as increasing the size of buses in service or providing feeder shuttles for high capacity transit stations, should be demonstrated qualitatively using the following criteria:

- Project serves high-growth areas identified in an SCS
- The service is currently at capacity or projected to be at capacity in the next five years (this is consistent with the criteria for allocating Core Capacity grants under MAP-21)[7]
- Project uses low emissions vehicles or other strategies to improve the efficiency of transit use to offset increased GHG emissions due to transit operations (see Section 4.4 for more information on these strategies)

Transit agencies or MPOs are likely to have analyzed the ridership impacts of major capacity-increasing projects that also include changes to transit levels of service. Such projects include upgrading an existing bus line to BRT or rail, or reconfiguring rail systems to allow for both more passengers per vehicle and more vehicles per hour. These projects may have quantifiable GHG reductions due to increased service frequency (see Section 4.1.2) or enhanced travel speeds (Section 4.1.3) alone. However, if agencies wish to account for the cross-cutting impacts of both capacity increases and service changes, major projects should be quantified using agency-specific methods or travel models.

When quantifying GHG reductions due to increased capacity, it is important for agencies to account for any additional emissions from transit operations following the methodology in Section 5.2.9 of the APTA Protocol, but using data for the specific line in question rather than agency-wide data.

4.1.2. Increase service frequency

Recommended quantification method

Strategies that increase service frequency (e.g., reduce headways or wait times) can be quantified using general research. GHG reductions due to these strategies can be quantified using the following formula:

GHG reductions = (percent change in headways * frequency elasticity * current ridership * mode shift factor * emissions factor for running emissions) – additional GHG emissions due to increased transit operations

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[7] http://www.hdrinc.com/sites/all/files/content/presentations/presentation-files/5090-map-21-new-starts-core-capacity-and-small-starts.pdf

For projects that affect frequency for service with different baseline headways (e.g., increasing frequencies on two different lines that currently have different headways, or on a single line during both peak and off-peak service), these calculations should be repeated for each service period or line affected. These calculations involve the following steps.

Step 1: Calculate the percent change in headways.

Step 2: Identify the relevant headway elasticity. The headway elasticity is the percent change in transit ridership with respect to the percent change in headways. The Transit Cooperative Research Program (TCRP) has compiled research on headway elasticities, which vary depending on the baseline headway (increasing frequency has a greater ridership impact on lines with less frequent service) and mode.[8] Table 2 summarizes these elasticities.

Table 2: TCRP Headway Elasticities[9]

Mode	Baseline headway	Headway elasticity
Bus	<10 min.	-0.22
Bus	10-50 min.	-0.46
Bus	>50 min.	-0.58
Commuter Rail	10-50 min.	-0.41
Commuter Rail	>50 min.	-0.76

No research is available on headway elasticities for light rail or other modes; agencies should take a conservative approach and apply the bus elasticities for these modes.

Step 3: Estimate the percent increase in transit ridership. Multiply the percent change in headways (Step 1) by the relevant headway elasticity (Step 2).

Step 4: Calculate total increase in PMT. Multiply the result of Step 3 by PMT for the service in question. PMT should be collected from agency data; if PMT is not available agencies can multiply total passenger trips for the service in question by average trip length.

Step 5: Calculate the mode shift factor as directed in Section 6.5 of the APTA protocol.

Step 6: Calculate displaced VMT. Multiply total increase in PMT (Step 4) by the mode shift factor (Step 5).

Step 7: Convert displaced VMT to GHG reductions. Multiply displaced VMT (Step 7) by the appropriate county-specific GHG emissions factor from ARB's EMFAC model.

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[8] TCRP Report 95, Traveler Response to Transportation System Changes Handbook, Third Edition: Chapter 9, Transit Scheduling and Frequency, http://www.trb.org/Publications/Blurbs/154748.aspx.

[9] Summarized from TCRP Report 95, Tables 9-2 and 9-5.

Step 8: Estimate additional GHG emissions due to increased transit operations. These emissions can be calculated following the methodology in Section 5.2.9 of the APTA Protocol, but using data for the specific vehicles or route in question rather than agency-wide data.

Step 9: Calculate net GHG reductions. Subtract additional GHG emissions due to increased transit operations (Step 8) from GHG reductions due to displaced VMT (Step 7).

4.1.3. Enhance travel speeds and reliability

Recommended quantification method

Strategies that reduce travel times can be quantified using general research. GHG reductions due to these strategies can be quantified using the following formula:

GHG reductions = (Percent change in travel times * travel time elasticity * current ridership * mode shift factor * emissions factor for running emissions) – additional GHG emissions due to increased transit operations

These calculations involve the following steps.

Step 1: Calculate the percent change in average travel times due to the project.

- For projects that increase speeds, calculate the percent change as follows:

  Percent change in travel time = -1 * percent change in average speed

- For projects that enhance reliability, agencies will need to estimate the resulting change in average travel times using microsimulation or data from similar projects.

Step 2: Identify the relevant travel time elasticity. Travel time elasticity varies depending on the service period:

- Peak: -0.129
- Off-peak: -0.074[10]

Step 3: Estimate the percent increase in transit ridership. Multiply the percent change in travel times (Step 1) by the relevant travel time elasticity (Step 2).

Step 4: Calculate total increase in annual PMT. Multiply the result of Step 3 by annual PMT for the service in question. PMT should be collected from agency data; if PMT is not available agencies can multiply total passenger trips on the service by average trip length.

Step 5: Calculate the mode shift factor as directed in Section 6.5 of the APTA protocol.

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[10] Based on research summarized in Table 31 of Litman (2013), Understanding Transport Demands and Elasticities, http://www.vtpi.org/elasticities.pdf.

Step 6: Calculate displaced VMT. Multiply total increase in PMT (Step 4) by the mode shift factor (Step 5).

Step 7: Convert displaced VMT to GHG reductions. Multiply displaced VMT (Step 7) by the appropriate county-specific GHG emissions factor from ARB's EMFAC model.

Step 8: Estimate additional GHG emissions due to increased transit operations. These emissions can be calculated following the methodology in Section 5.2.9 of the APTA Protocol, but using data for the specific vehicles or route in question rather than agency-wide data.

Step 9: Calculate net GHG reductions. Subtract additional GHG emissions due to increased transit operations (Step 8) from GHG reductions due to displaced VMT (Step 7).

4.1.4. Extend operating hours

Recommended quantification method

GHG reductions from small projects that extend operating hours should be demonstrated qualitatively using the following criteria:

- Project serves high-growth areas identified in an SCS
- Project uses low emissions vehicles or other strategies to improve the efficiency of transit use to offset increased GHG emissions due to transit operations (see Section 4.4 for more information on these strategies)

4.1.5. Route expansion

Recommended quantification method

Transit agencies or MPOs are likely to have analyzed the ridership impacts of projects that extend transit routes. Since the impacts of these projects depends greatly on the level of existing transit service and the land use characteristics of the areas served, GHG emissions from these projects should be quantified using agency-specific methods or travel models.

4.2. Transit Rider Outreach and Incentives

Transit rider outreach and incentives are designed to reduce GHG emissions by increasing transit use, but can be challenging to quantify. Table 3 summarizes quantification options.

Table 3: Transit Rider Outreach and Incentives: Quantification Options

Project category	How the project reduces GHG emissions	Could it be quantified using… General research	Local / agency-specific data	A regional travel demand model?	Relevant sections of APTA protocol
Transportation demand management programs	Increases transit ridership	Sometimes	No	Sometimes	Mode shift factor (section 6.5) Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)
E.g.: Discounted transit passes		Yes; using research on the price elasticity of transit	No	Only for system-wide fare discounts	
E.g.: Transit vouchers		Yes; using research on the price elasticity of transit	No	No	
E.g.: Bike to transit incentives		Sometimes; using research on existing programs	No	No	
E.g.: Vanpool subsidies		Yes; using research on the price elasticity of transit	No	Rarely	
E.g.: Transit encouragement programs		Sometimes; using research on existing programs	No	No	
Improvements to transit customer experience	Increases transit ridership	No	No	No	Mode shift factor (section 6.5) Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)
Network/fare integration	Increases transit ridership	No	No	No	Mode shift factor (section 6.5) Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)

4.2.1. Transportation demand management programs

Recommended quantification method

There is sufficient research to quantify increased ridership and GHG reductions for incentives that offer discounted fares or vouchers to certain users. For other transportation demand management programs, see the alternative quantification method below. GHG reductions due to strategies that reduce fares can be quantified using the following formula:

GHG reductions = percent change in fares * fare elasticity * percent of the population eligible for incentives * total system PMT * mode shift factor * emissions factor for running emissions

These calculations involve the following steps:

Step 1: Calculate the percent change in fares due to incentives or vouchers.

Step 2: Identify the relevant fare elasticity. The fare elasticity is the percentage change in transit use with respect to a percentage change in the cost of transit.

- For buses – Fare elasticities vary depend on service period (i.e., peak or off-peak hours) and population size of the city in which the agency is located. Table 4 summarizes bus fare elasticities published by APTA.

Table 4: Bus Fare Elasticities[11]

Project category	Large cities (>1m Population)	Smaller cities (<1m population)
Average for All Hours	-0.36	-0.43
Peak Hour	-0.18	-0.27
Off-Peak	-0.39	-0.46
Off-peak Average	-0.42	
Peak Hour Average	-0.23	

- For other modes – A conservative approach would be to apply the bus fare elasticities in Table 4. However, other researchers have updated this research by examining elasticities for different modes or in different contexts;[12] agencies may wish to review this research to identify elasticities that are more relevant to their predominant mode or the context in which they operate.

Step 3: Calculate the percent increase in transit ridership. Multiply the percent change in fares (Step 1) by the relevant fare elasticity (Step 2).

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[11] http://www.apta.com/resources/reportsandpublications/Documents/Pham_Linsalata_Fare_Elasticity_1991.pdf; summarized in http://www.vtpi.org/tranelas.pdf.

[12] For a summary of this research, see http://www.vtpi.org/tranelas.pdf.

- For incentives targeted toward specific groups, such as low-income riders, people who bike to transit, or people living in priority development areas – Adjust the change in ridership by the percent of riders or trips eligible for incentives.

Step 4: Calculate total increase in PMT. Multiply the result of Step 3 by total system PMT. Data on total system PMT is typically collected by agencies and reported to the National Transit Database.[13]

Step 5: Calculate the mode shift factor as directed in Section 6.5 of the APTA protocol.

Step 6: Calculate displaced VMT. Multiply total increase in PMT (Step 4) by the mode shift factor (Step 5).

Step 7: Convert displaced VMT to GHG reductions. Multiply displaced VMT (Step 7) by the appropriate county-specific GHG emissions factor from ARB's EMFAC model.

Alternative quantification methods

GHG reductions from programs that encourage transit use without affecting fares should be demonstrated qualitatively using one of the following criteria:

- Project is specifically targeted toward high-growth areas identified in an SCS
- Project is implemented in conjunction with capacity-increasing projects that serve high-growth areas identified in an SCS

These are aligned with the project selection criteria in the AHSC. There is insufficient research to quantify GHG reductions due to outreach programs that do not involve financial incentives. Agencies that have implemented transit encouragement programs in the past and collected data on the ridership impacts of these programs may be able to use this data to demonstrate the benefit of similar programs.

4.2.2. Improvements to transit customer experience

Recommended quantification method

GHG reductions from improvements to the transit customer experience should be demonstrated qualitatively using one of the following criteria:

- Project is specifically targeted toward high-growth areas identified in an SCS
- Project is implemented in conjunction with capacity-increasing projects that serve high-growth areas identified in an SCS

These are aligned with the project selection criteria in the AHSC. There is insufficient research to quantify GHG reductions due to the wide variety of possible improvements to the transit customer experience, and the limited research that does exist typically shows limited impacts on ridership.

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[13] See Tables 19 and 20 at http://www.ntdprogram.gov/ntdprogram/pubs/dt/2012/excel/DataTables.htm.

Agencies that have collected data on the ridership impacts of these projects in the past may be able to use this data to estimate the benefit of similar programs.

4.2.3. Network/fare integration

Recommended quantification method

GHG reductions from network or fare integration should be demonstrated qualitatively using one of the following criteria:

- Project is specifically targeted toward high-growth areas identified in an SCS
- Project is implemented in conjunction with capacity-increasing projects that serve high-growth areas identified in an SCS

These are aligned with the project selection criteria in the AHSC. There is insufficient research to quantify GHG reductions due to fare integration. Agencies that have collected data on the ridership impacts of these projects in the past may be able to use this data to estimate the benefit of similar programs.

4.3. Active Transportation and Land Use Strategies

Active transportation and land use strategies can result in both direct GHG reductions due to increased transit use and indirect GHG reductions due to more efficient travel, even for trips where transit does not substitute for driving. There are many different approaches to quantifying these strategies; Table 5 below summarizes potential quantification options.

Table 5: Active Transportation and Land Use: Quantification Options

		Could it be quantified using…			
Project category	How the project reduces GHG emissions	General research	Local / agency-specific data	A regional travel demand model?	Relevant sections of APTA protocol
Bicycle and pedestrian connections to transit	Reduces VMT due to access to transit, and in some cases increases ridership	Potentially	Sometimes	Rarely	Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)
E.g.: Bike/ped paths		Sometimes; BART has created a bicycle assessment tool[14]	Yes; if agencies have conducted surveys on station area access	Sometimes; only in the case of regionally significant facilities	
E.g.: Bike share at transit stations		Potentially; new research looks at increases in ridership due to bike share in certain cities[15]	Sometimes; if agencies have detailed bike share ridership forecasts and station area access surveys	No	
E.g.: Bicycle parking at stations		Potentially; BART has created a bicycle assessment tool[16]	Yes; if agencies have conducted surveys on station area access	No	
E.g.: Bike racks on buses/trains		No	No	No	

[14] http://www.bart.gov/guide/bikes/investment
[15] http://www.sciencedirect.com/science/article/pii/S0966692314001409
[16] http://www.bart.gov/guide/bikes/investment

		Could it be quantified using…			
Project category	**How the project reduces GHG emissions**	**General research**	**Local / agency-specific data**	**A regional travel demand model?**	**Relevant sections of APTA protocol**
Transit oriented development	Reduces VMT due to both increased transit use and reduced driving for non-transit trips	Yes; using research on the relationship between the Ds of land use and VMT	Yes; by comparing transportation analyses of similar local developments to business as usual	Sometimes; only for very large developments	Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)
Carshare at transit stations	Reduces VMT due to increased transit use	No	Rarely, if agencies have conducted surveys to evaluate similar projects	No	Fuel economy factors (section 6.4.4) CO2 conversion factors (section 6.4.5)

4.3.1. Active Transportation Projects

Recommended quantification method

Active transportation projects primarily reduce GHG emissions due to vehicle travel to and from stations, and in some cases these projects can also increase ridership. The impacts of these projects on GHG emissions are typically small, and are not well-captured by existing research, Therefore, GHG emissions due to active transportation projects are best demonstrated qualitatively using the following criteria:

- Project is located at a station area where service will be improved (The CAPCOA Handbook considers bicycle parking a "grouped strategy" that can augment GHG reductions due to increased frequency/speed or route expansion[17])
- Project is located in an area with high levels of biking and/or walking (as demonstrated by commute data from the American Community Survey or MPO travel surveys)
- Project provides active transportation connections between transit and new development called for in the SCS (this criterion is applied in the Draft AHSC Guidelines)

Alternative quantification methods

In certain cases, agencies may have enough information through a combination of research and station access surveys that ask transit riders about their travel to transit to quantify the impact of certain GHG reduction strategies. In general, the research in this field is based on ridership data from large metropolitan area with extensive transit systems and relatively high bike ridership, and should only be applied in similar contexts. This, in combination that relatively few transit agencies conduct in-depth station access surveys, will limit the applicability of this method. However, there may be opportunities for the state to build on existing research to provide more broadly applicable quantification guidance.

Bicycle facilities at transit stations in major metropolitan areas

There is an emerging body of research that can potentially be used to quantify the impacts of bicycle facilities at or connecting to stations. Transit agencies that have conducted station access surveys can apply this research using the following formula:

GHG reductions = increase in bicycle station access mode share * bicycle mode shift factor * average length of a bicycle station access trip * emissions factor for running emissions

This calculation involves the following steps:

Step 1: Calculate increase in bicycle station access mode share (percentage of riders accessing stations by bicycle). This can be calculated by dividing results from the BART Bicycle Investment Tool, which estimates the impact of new station area bicycle facilities on the number of riders who bike to stations, by the total number of riders boarding at the station, from agency data.[18]

[17] CAPCOA Handbook, p. 285.
[18] http://www.bart.gov/guide/bikes/investment

Step 2: Estimate bicycle mode shift factor (percentage of bicycle trips that substitute for driving trips). This can be calculated based on station access surveys that ask bicyclists how they would get to transit if they did not ride their bicycles. See Section 6.5 of the APTA protocol for more guidance on how to derive a mode shift factor from surveys.

Step 3: Estimate displaced vehicle trips. Multiply the increase in bicycle station access mode share (Step 1) by the bicycle mode shift factor (Step 2).

Step 4: Calculate displaced VMT. Multiply displaced vehicle trips by the average length (in miles) of bicycle station access trip = the length (in miles) that an average cyclist travels to reach the station. This can be derived from station access surveys.

Step 5: Convert displaced VMT to GHG reductions. Multiply displaced VMT (Step 7) by the appropriate county-specific GHG emissions factor from ARB's EMFAC model.

Bike share facilities at transit stations

Researchers have quantified the impact of bike share systems on both access to and use of the transit system in two cities, which varies by station based on location within the transit system.[19] This research stops short of recommending a methodology for estimating increases in ridership due to bike share. However, it may serve as a basis for doing so in the future.

Agencies that have conducted station access surveys

Agencies that have conducted in-depth station access surveys may also be able to use these surveys to quantify the GHG reduction benefits of a broader set of active transportation facilities. Doing so would involve comparing the share of people who access transit via active transportation at stations served by different bicycle and pedestrian facilities, as BART did in order to create the Bicycle Investment Tool discussed above. The process for doing so will depend on the information that agencies collect through their station access surveys. There may be an opportunity for state agencies or CTA to work with BART to share best practices in using surveys to estimate the travel and GHG impacts of different transportation facilities.

Recommended GHG quantification methodology

<u>In general, the GHG reductions due to TOD projects can be quantified using existing research.</u>

GHG reductions due to TOD can be quantified using the following formula:

Reduced VMT due to TOD project * emissions factor for running emissions

There is an extensive body of research describing the relationship between the "D variables" of land use (density, design, diversity of land uses, destination accessibility, distance to transit) and VMT. This research is encapsulated in in the CAPCOA Handbook and the associated Transportation Demand

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[19] http://www.sciencedirect.com/science/article/pii/S0966692314001409; for a summary see http://www.citylab.com/commute/2014/07/the-most-persuasive-evidence-yet-that-bike-share-serves-as-public-transit/375142/

Management (TDM) spreadsheet tool[20] created by the Bay Area Air Quality Management District (BAAQMD). These resources should generally be used to quantify GHG emissions due to TOD projects.

Quantifying GHG reductions due to TOD involves the following steps:

Step 1: Estimate reduced VMT due to the TOD project.

- For most projects – Agencies should use the CAPCOA Handbook and BAAQMD TDM tool to estimate VMT reductions. Agencies will need to supply data on at least one of the following D variables for the proposed project (the associated strategy in the CAPCOA Handbook is listed in parentheses; see the Handbook for details on variables and calculations):
    - Density (in housing units per acre) (Strategy LUT-1)
    - Diversity (area devoted to each of the following land uses: single family residential, multifamily residential, commercial, industrial, institutional, park) (Strategy LUT-3)
    - Destination accessibility (distance to downtown or major job center) (Strategy LUT-4)
    - Distance to the nearest transit station (Strategy LUT-5)

  The Handbook takes a conservative approach to applying research, capping both the potential VMT reductions of individual strategies at 20 to 65 percent and the total VMT reductions due to a combination of strategies at five to 65 percent based on empirical evidence from California developments[21] These caps are built into the BAAQMD tool, and the tool also automates the calculation of VMT reductions based on simplified land use information provided by the user. However, since the tool is designed for the Bay Area, users may need to modify assumptions in order to tailor the tool to their region. Appendix A of the Transportation Demand Management tool User's Guide provides more information on how to modify assumptions.[22]

- For projects in highly urbanized areas – The CAPCOA Handbook cites instances where VMT reductions exceed the 65 percent VMT reduction cap for urban TOD projects in highly compact and walkable areas with excellent transit service.[23] Agencies can still use the CAPCOA approach to estimate VMT reductions due to these projects, but it may be more accurate compare trip generation forecasts between comparable projects and projects that represent conventional development in the region.

- For projects in rural areas – The CAPCOA Handbook does not allow for any reductions due to TOD in rural areas because of a lack of supporting research. Agencies can also estimate VMT reductions by comparing trip generation forecasts between comparable projects and projects that represent

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[20] http://www.baaqmd.gov/Divisions/Planning-and-Research/Smart-Growth.aspx. The default version of the tool is calibrated for local use with data from Bay Area projects, but the assumptions could be modified to ensure that the tool is generally applicable to projects across California.

[21] CAPCOA Handbook, p. 61.

[22] http://www.baaqmd.gov/~/media/Files/Planning%20and%20Research/Smart%20Growth/BAAQMD%20TDM%20Tool%20Users%20Guide.ashx?la=en

[23] CAPCOA Handbook, 59.

conventional development in the region, or show that the project is consistent with the growth pattern in the SCS in order to qualitatively demonstrate VMT reductions.

- For regionally significant projects – The travel impacts of regionally significant projects that involve major land use changes across several stations, such as a plan to develop several parcels of agency-owned land along a new rail line or a large site that is several square miles in area, are best captured by a travel model. Even though travel models are labor-intensive to run and this approach requires coordination with the MPO, it may streamline analysis since the CAPCOA Handbook recommends treating larger sites as several different half-mile-radius sites when quantifying VMT reductions, requiring separate quantification of VMT reductions for each of these smaller sites.

Step 2: Convert displaced VMT to GHG reductions. Multiply displaced VMT (Step 7) by the appropriate county-specific GHG emissions factor from ARB's EMFAC model.

4.3.2. Carshare at Transit Stations

Recommended quantification method

<u>We recommend evaluating carshare pods qualitatively. Any carshare pod at a high-quality transit station is likely to contribute to reducing GHG emissions.</u>

While carshare pods at transit stations are an existing strategy to promote transit use through better first mile/last mile connections to transit, we are not aware of any published studies that quantify the impact of carshare pods on transit ridership. It may be possible to quantify the emissions impact of this strategy by conducting surveys at stations with carshare facilities in order to determine the impact on station access or transit use, using an approach similar to the alternative approach for quantifying the impact of active transportation facilities discussed in Section 4.3.1. However, the level of effort required to do so coupled with relatively limited deployment of carshare at transit stations

4.4. Improving the Efficiency of Transit Energy Use

Unlike the other strategies addressed in this memo, projects in this category reduce GHG emissions from transit vehicles and infrastructure rather than displacing emissions due to use of the transportation system. Although projects that reduce energy and emission impacts through vehicle and facility improvements can vary widely, they all approach GHG emission reductions in two ways: (1) by increasing their energy efficiency; and (2) by switching to fuel and energy sources with lower carbon intensities. Since travel demand models will not be useful for analyzing strategies in this category, we use slightly different categories when assessing the resources that are available to quantify GHG reductions than we use for the other categories in this memo:

1. **General resources** that estimate the impacts of projects on energy consumption or on the carbon intensity of energy sources, such as research, quantification tools, and manufacturer specifications.
2. **Agency-specific data** on the energy and GHG impacts of similar projects.
3. **Significant modeling/analysis**, which involves applying complex tools and methods to project the impacts of a particular technology, and typically requires contracting with a consulting firm with specialized expertise.

In general, transit agencies will be able to estimate the impacts of these strategies more accurately than for other strategies, will have more diverse options for selecting specific GHG-reduction technologies and approaches, and will be able to draw on more in-depth data from their own operations and from published information. Table 6 summarizes quantification options for strategies to improve the efficiency of transit energy use.

Table 6: Improving the Efficiency of Transit Energy Use: Quantification Options

		Could it be quantified using…			
Project category	How the project reduces GHG emissions	General research	Local / agency-specific data	A regional travel demand model?	Relevant sections of APTA protocol
Bus and railcar retrofits or replacement to improve fuel efficiency	Improves vehicle fuel economy	Sometimes; for projects not significantly affected by agency operational practices, e.g. LED lighting retrofits.	Sometimes; if the agency has conducted a pilot test of the retrofit.	Yes; recommended for complex or cutting-edge projects, such as regenerative braking on railcars.	Direct emissions from mobile combustion (5.2.9)
Rail electrification	Improves vehicle fuel economy and shifts to lower carbon energy source	No; emissions factors for different energy sources are available but little is available to quantify energy demand.	Sometimes; if the agency has implemented similar projects.	Yes; recommended for these projects.	Direct emissions from mobile combustion (5.2.9) Indirect emissions from electricity use (5.2.10)
Non-transit vehicle improvements	Improves vehicle fuel economy and/or shifts to lower carbon energy source	Sometimes; for widely-used vehicle types covered by emissions models.	Sometimes; if the agency has conducted a pilot test of the improvement.	Yes; recommended for vehicles not included in emissions models.	Direct emissions from mobile combustion (5.2.9) Indirect emissions from electricity use (5.2.10) Fugitive emissions (5.2.12)

		Could it be quantified using…			
Project category	**How the project reduces GHG emissions**	**General research**	**Local / agency-specific data**	**A regional travel demand model?**	**Relevant sections of APTA protocol**
Deploy hybrid, alternative fuel, or more efficient transit vehicles	Improves vehicle fuel economy and/or shifts to lower carbon energy source	Sometimes; for widely-used vehicle types covered by emissions models.	Sometimes; if the agency has conducted a pilot test of the vehicle deployment.	Yes; recommended for vehicles not included in emissions models.	Direct emissions from mobile combustion (5.2.9) Indirect emissions from electricity use (5.2.10) Fugitive emissions (5.2.12)
Renewable energy projects	Shifts to lower carbon energy source	Sometimes; tools and manufacturer specifications can estimate energy generation.	Yes; if agency has installed similar projects in similar settings.	Yes; recommended for projects in unconventional settings, e.g., wind energy in subway tunnels.	Indirect emissions from electricity use (5.2.10) Other indirect emissions (5.2.11)
Facility energy efficiency improvements	Reduces energy consumed by facilities	Sometimes; for projects focused on lighting, HVAC, or other common equipment upgrades.	Sometimes; if the agency has implemented similar projects.	Yes; recommended for significant facility upgrades or projects that upgrade multiple different systems at once.	Direct emissions from stationary combustion (5.2.8) Indirect emissions from electricity use (5.2.10) Other indirect emissions (5.2.11) Reporting Scope 3 emissions (5.3)

Below we describe recommended quantification methodologies for strategies to increase the efficiency of transit use. We group together project categories that have similar quantification methods.

4.4.1. Vehicle projects: for projects that improve vehicle fuel efficiency only, without changing fuel type

Recommended quantification method

This quantification methodology applies to the following project categories:

- Bus and railcar retrofits or replacement to improve fuel efficiency
- Non-transit vehicle improvements (except projects that change fuel type)
- Deploy hybrid, alternative fuel, or more efficient transit vehicles (except projects that change fuel type)

These projects can be quantified using information that is readily available to transit agencies through agency data, manufacturer specifications, and research. GHG reductions can be quantified using the following formula:

GHG reductions = annual VMT for target vehicles * (new fuel economy – baseline fuel economy) * emissions factor

These calculations involve the following steps:

Step 1: Determine annual VMT for target vehicles. VMT figures should be drawn from transit agencies' internal records for the vehicles that will be subject to the project.

Step 2: Determine baseline fuel economy for target vehicles (in miles per gallon or equivalent). Fuel economy for the vehicles in question should be estimated using the transit agencies' internal records, dividing annual VMT for the target vehicles by annual fuel consumption for the target vehicles.

Step 3: Determine new fuel economy for target vehicles (in miles per gallon or equivalent).

- For vehicle retrofit projects – There is no single methodology that can be established to estimate fuel economy improvements for retrofits. Generally a vehicle expert within or outside the transit agency should be consulted on appropriate methods. The following resources could apply:
    - Manufacturer specifications for retrofit equipment
    - Observed fuel economy improvements from similar projects or pilot tests[24]
    - Energy modeling by a qualified consultant
- For new vehicles – Manufacturer specifications should be consulted for expected average fuel economy of the particular vehicle make and model. However, fuel economy performance in the field

[24] FTA's TIGGER program has funded a number of pilot projects to reduce energy consumption of transit vehicles. Quantified results from these efforts should be available in the near future.

can vary based on operating conditions. Observed fuel economy performance from agency field tests is a preferred source of data, if available.

Step 4: Calculate annual fuel savings (in gallons or equivalent). Multiply annual VMT for target vehicles (Step 1) by the difference between new fuel economy (Step 3) and baseline fuel economy (Step 2)

Step 5: Convert fuel savings to GHG reductions. Apply fuel-specific emission factors from Section 5.2.9 of the APTA Protocol and Chapter 13 of The Climate Registry General Reporting Protocol. If electricity is the applicable fuel type, emission factors should be scaled up to incorporate T&D losses, using factors available from EPA's eGRID or directly from utilities.

4.4.2. Vehicle projects: for projects that change vehicle fuel type

Recommended quantification method

This quantification method applies to the following project categories:

- Rail electrification
- Non-transit vehicle improvements (projects that change fuel type)
- Deploy hybrid, alternative fuel, or more efficient transit vehicles (projects that change fuel type)

<u>These projects can be quantified using information that is readily available to transit agencies through agency data, manufacturer specifications, and research</u>. GHG reductions can be quantified using the following formula:

GHG reductions = (baseline fuel consumption * baseline fuel emissions factor) - (annual VMT * new fuel economy * new fuel emissions factor)

These calculations involve the following steps:

Step 1: Determine annual VMT for target vehicles. VMT figures should be drawn from transit agencies' internal records for the vehicles that will be subject to the project.

Step 2: Determine baseline annual fuel consumption (in gallons or equivalent). Baseline fuel consumption can generally be sourced from transit agency fuel records.

Step 3: Convert baseline fuel consumption to baseline well-to-wheels (WTW) GHG emissions. Multiply baseline fuel consumption by the appropriate emissions factor:

- *Step 3a*: Apply fuel-specific emission factors from Section 5.2.9 of the APTA Protocol and Chapter 13 of The Climate Registry General Reporting Protocol – These correspond to tank-to-wheels (TTW) emission factors.
- *Step 3b*: Scale up emission factors from Step 3a to include well-to-tank emissions – WTW = WTT + TTW. A ratio of TTW to WTW should be calculated for the fuel type in question using the CA-GREET model.

If electricity is the applicable fuel type, emission factors should be scaled up to incorporate T&D losses, using factors available from EPA's eGRID or directly from utilities.

Step 4: Determine annual fuel consumption of new or modified vehicles (in gallons or equivalent).

- For on-road vehicles - Manufacturer specifications should be consulted for expected average fuel economy of the particular vehicle make and model. However, fuel economy performance in the field can vary based on operating conditions. Observed fuel economy performance from agency field tests is a preferred source of data, if available.[25]
- For rail vehicles – There is no single source that can be established for rail vehicle fuel economy. Generally a rail expert within or outside the transit agency should be consulted on appropriate methods. The following resources could apply:
    - Manufacturer specifications for new trains
    - Observed fuel economy of trains in similar contexts
    - Energy modeling by a qualified consultant

Step 5: Calculate fuel consumption of new or modified vehicles (in gallons or equivalent). Multiply annual VMT (Step 1) by fuel economy of new or modified vehicles (Step 4).

Step 6: Convert fuel consumption of new or modified vehicles to well-to-wheels (WTW) GHG emissions

- Step 6a: Apply fuel-specific emission factors from Section 5.2.9 of the APTA Protocol and Chapter 13 of The Climate Registry General Reporting Protocol – These correspond to tank-to-wheels (TTW) emission factors.
- Step 6b: Scale up emission factors from Step 3a to include well-to-tank emissions – WTW = WTT + TTW. A ratio of TTW to WTW should be calculated for the fuel type in question using the CA-GREET model.

If electricity is the applicable fuel type, emission factors should be scaled up to incorporate T&D losses, using factors available from EPA's eGRID or directly from utilities.

Step 7: Calculate GHG emission reductions

Subtract annual GHG emissions from new or modified vehicles (Step 6 from baseline GHG emissions (Step 3).

4.4.3. Renewable energy projects

Recommended quantification method

<u>These projects can be quantified using information that is readily available to transit agencies through manufacturer specifications and research.</u> GHG reductions can be quantified using the following formula:

GHG reductions = annual energy generation of renewable energy facilities * electricity emissions factor

[25] EMFAC and Fueleconomy.gov can also provide fuel economy estimates for some vehicle types, if other data is not available.

This methodology assumes renewable energy projects are carbon neutral, e.g. solar photovoltaics or wind power. If this is not the case, agencies will have to subtract additional GHG emissions from new projects from the results above.

These calculations involve the following steps:

Step 1: Estimate energy generation potential in annual MWh. Preliminary estimates of solar generation potential can be estimated using the National Renewable Energy Laboratory's PVWatts Calculator.[26] For more accurate estimates or for other types of projects, transit agencies should engage a qualified consultant to estimate energy generation potential.

Step 2: Convert energy generation potential to GHG reductions. Apply GHG emission factors for electricity sourced from eGRID or from the specific utilities. Emission factors should be scaled up to incorporate T&D losses, using factors available from EPA's eGRID or directly from utilities.

4.4.4. Facility energy efficiency improvements

Recommended quantification method

In most cases, these projects can be quantified using information that is readily available to transit agencies through manufacturer specifications and research. GHG reductions can be quantified using the following formula:

GHG reductions = annual energy savings due to facility improvements * electricity emissions factor

These calculations involve the following steps:

Step 1: Estimate annual energy savings due to facility improvements.

- For lighting retrofits:
    - Step 1a: Calculate energy consumption of current light fixtures (in kWh)= Number of bulbs x wattage per current bulb (including ballast if applicable)[27] x annual hours of usage
    - Step 1b: Calculate energy consumption of new light fixtures (in kWh)= Number of bulbs x wattage per new bulb (including ballast if applicable)[28] x annual hours of usage
    - Step 1c: Calculate annual energy savings = energy consumption of current light fixtures – energy consumption of new light fixtures
- There is no single methodology that can be established for other types of improvements. In general, other improvements will reduce GHG emissions either by:
    - Reducing the amount of time that equipment is used (e.g. by putting lights on timers or motion sensors),

[26] Available online at: http://www.nrel.gov/rredc/pvwatts/.

[27] Available from manufacturer specifications

[28] Available from manufacturer specifications

- Improving the energy efficiency of appliances (e.g. switching to Energy Star rated appliances), or
- Both (e.g. installing an HVAC system that is both more energy efficient and is controlled by an automated system to reduce use based on building occupancy and/or time of day.)

Custom methods must be developed to evaluate projects by estimating reductions in hours of use and/or energy use per hour. The following resources could apply:

- Data on current electricity consumption and hours of use of equipment
- Manufacturer specifications for current vs. new equipment
- Observed energy savings from similar projects
- Energy modeling by a qualified consultant

Step 2: Convert energy savings potential to GHG reductions. Apply GHG emission factors for electricity sourced from eGRID or from the specific utilities. For other energy types, apply GHG emission factors from Section 5.2.8 of the APTA Protocol and Chapter 13 of The Climate Registry General Reporting Protocol. If electricity is the applicable energy type, emission factors should be scaled up to incorporate T&D losses, using factors available from EPA's eGRID or directly from utilities.

5. Co-benefits of Transit Projects

Though AB 32 focuses on GHG emissions, it also identifies five co-benefits often associated with GHG reduction projects:

- Environmental justice
- Reductions in other air pollutants
- Diversification of energy sources
- Economic benefits
- Public health benefits

Table 7 contains a qualitative assessment of the co-benefits of each category of transit GHG reduction strategies discussed in this memo. The following text summarizes what type of strategies are likely to be associated with each co-benefit.

Table 7: Summary of Transit Strategy Co-Benefits

Strategy Category	Co-benefits: Environmental justice	Reduced air pollution	Diversification of energy sources	Economic benefits	Public health benefits
Expanding or Improving Transit Capacity					
Increase capacity of existing service	Sometimes; for routes serving disadvantaged communities	Yes; via mode shift to transit	Sometimes; if transit vehicles use alternative fuels	Yes; supports higher levels of development and improves job accessibility	Yes; transit riders are more physically active than drivers, reduces pollution
Increase service frequency	Sometimes; for routes serving disadvantaged communities	Yes; via mode shift to transit	Sometimes; if transit vehicles use alternative fuels	Yes; supports higher levels of development, improves job accessibility	Yes; transit riders are more physically active than drivers, reduces pollution
Enhance travel speeds and reliability	Sometimes; for routes serving disadvantaged communities	Yes; via mode shift to transit	Sometimes; if transit vehicles use alternative fuels	Yes; supports higher levels of development and improves job accessibility	Yes; transit riders are more physically active than drivers, reduces pollution
Extend operating hours	Sometimes; for routes serving disadvantaged communities	Yes; via mode shift to transit	Sometimes; if transit vehicles use alternative fuels	Yes; longer operating hours improves job accessibility, especially for low-income workers who are more likely to work outside of typical working hours.	Yes; transit riders are more physically active than drivers, reduces pollution
Route expansion	Sometimes; for routes serving disadvantaged communities	Yes; via mode shift to transit	Sometimes; if transit vehicles use alternative fuels	Yes; supports higher levels of development and improves job accessibility	Yes; transit riders are more physically active than drivers, reduces pollution
Transit Rider Outreach and Incentives					
Transportation demand management	Sometimes; for incentives targeted at low-income riders	Yes; for projects that reduce fares	Sometimes; if transit vehicles use alternative fuels	No	Sometimes; for reduced fares or incentives that promote biking/walking
Improvements to transit customer experience	No	No	No	No	No

	Co-benefits				
Strategy Category	**Environmental justice**	**Reduced air pollution**	**Diversification of energy sources**	**Economic benefits**	**Public health benefits**
Network/fare integration	No	No	No	No	No
Active Transportation and Land Use					
Transit oriented development	Sometimes; for projects that contain affordable housing or community-serving amenities	Yes; reduces indirect emissions	No	Yes; fosters new development, which improves access to jobs and creates new jobs	Yes; compact development near transit promotes walking and bicycling
Bike/ped connections to transit	Sometimes; for projects serving disadvantaged communities	Yes; though impacts can be small and hard to quantify	No	No	Yes; promotes active transportation
Improving the Efficiency of Transit Energy Use					
Bus and railcar retrofits	Sometimes; for routes serving disadvantaged communities	In most cases; increasing efficiency reduces pollution, most alternative fuels reduce pollution	No	No	Yes; via reduced air pollution
Rail electrification	Sometimes; for routes serving disadvantaged communities	Yes; electricity generally produced fewer pollutants than conventional fuels	Yes	Yes; new infrastructure creates construction jobs	Yes; via reduced air pollution
Non-transit vehicle improvements	No	Yes; increasing vehicle efficiency reduces pollution	Sometimes; for alternative fuel vehicles	No	Yes; via reduced air pollution
Deploy hybrid, alternative fuel, or more efficient transit vehicles	Sometimes; for routes serving disadvantaged communities	In most cases; increasing efficiency reduces pollution, most alternative fuels reduce pollution	Yes	No	Yes; via reduced air pollution
Renewable energy projects	No	Yes	Yes	Yes; projects create construction jobs	Sometimes; depending upon location of electricity sources relative to population centers

	Co-benefits				
Strategy Category	**Environmental justice**	**Reduced air pollution**	**Diversification of energy sources**	**Economic benefits**	**Public health benefits**
Facility energy efficiency improvements	No	Yes	No	Yes; projects create construction jobs	Sometimes; depending upon location of electricity sources relative to population centers

Environmental justice: The location of a project is much more important than the type of project in demonstrating environmental justice co-benefits. Generally, any project that reduces air pollution in a disadvantaged community[29] will have demonstrable environmental justice co-benefits. This includes projects that add new transit capacity that connects disadvantages communities to destinations, fare discounts for low-income riders, active transportation projects in disadvantaged communities, and efficiency improvements for vehicles that operate on routes running through disadvantaged communities. In most cases, system-wide outreach or incentive programs and efficiency improvements that reduce off-site emissions associated with electricity consumption will not have environmental justice co-benefits.

Reduced air pollution: Since combustion of fossil fuels is a leading source of air pollution, and most transit strategies to reduce GHG emissions do so by reducing fuel consumption in vehicles, most projects that produce demonstrable GHG reductions will also reduce air pollution. The only exceptions are in the case of some alternative vehicle fuels, such as biodiesel, which have higher emissions of some air pollutants than conventional fuels.

Diversification of energy sources: Strategies will only be able to demonstrate this co-benefit if they involve using renewable energy in facilities or alternative fuels in vehicles, or if they can demonstrate an increase in transit service and ridership on lines that use alternative fuels.

Economic benefits: The economic benefits of transit include:

- Improving accessibility to jobs, which strengthens the regional economy by broadening the pool of skilled workers for employers to draw from.
- Supporting compact development near stations, which broadens local tax bases and reduces infrastructure costs over the long term.
- Creating new job opportunities associated with construction and operation of the transit system.

Most capacity-increasing projects and transit-oriented development projects involve all three of these benefits, and vehicle or facility efficiency projects that involve substantial construction can also create jobs.

Public health benefits: transit projects improve public health by either increasing the use of active transportation or by reducing negative health impacts associated with air pollution. Though active transportation is typically defined as bicycle and pedestrian travel, transit itself can be considered an active transportation mode, since studies have shown that transit riders walk significantly more than

[29] Technically, the communities of concern that are the focus of environmental justice analyses are defined differently than the disadvantaged communities that are given consideration in the allocation of cap and trade funding, and include communities with significant low-income or minority populations. However, the similarities between the two, coupled with the importance of disadvantaged communities in allocating cap and trade funding, makes it likely that disadvantaged communities will serve as the basis for demonstrating environmental justice benefits.

drivers.[30] Capacity-increasing projects, transit-oriented development, and active transportation projects generally both promote active transportation and reduce health impacts associated with pollution. Projects that improve the efficiency of transit energy use also often reduce health impacts associated with pollution, though this may be more challenging to demonstrate in the case of projects that reduce off-site pollution associated with electricity use.

6. Conclusions and Next Steps

The APTA Protocol provides an important starting point for quantification of GHG benefits of transit projects by highlighting the main sources of emissions produced and displaced by transit. However, the bulk of the effort needed to quantify emissions impacts of transit projects is not described in the APTA Protocol. In addition, the Protocol does not provide guidance on estimating lifecycle emissions, which is an essential component of evaluating alternative fuel projects. Evaluation guidance for transit project eligible for Cap and Trade funding should use the APTA Protocol as a starting point, but will need to provide much more detail about specific project types.

The level of effort necessary to quantify emissions impacts of projects is largely determined by whether the project quantifiable and whether it is appropriate for evaluation by one of three methods, ranked from lowest level of effort to highest:

1. General research
2. Transit agency-specific data and tools
3. Travel demand models or other significant modeling/analysis (conducted outside the transit agency)

Proposed evaluation methods also have implications for which entities are best positioned to carry out project quantification. A subsequent memo will discuss several possible divisions of responsibilities among state and local agencies with respect to project quantification.

[30] For examples, see Edwards, Ryan D. (2007), Public Transit, Obesity, and Medical Costs: Assessing the Magnitudes, Preventive Medicine (46), http://health-equity.pitt.edu/910/1/06pm.pdf; and MacDonald, John M., et al. (2010), The Effect of Light Rail Transit on Body Mass Index and Physical Activity, American Journal of Preventative Medicine 39(2), 105–112, http://www.portlandoregon.gov/transportation/article/377155.