California High-Speed Rail Authority and California Air Resources Board

Greenhouse Gas Quantification Methodology for the California High-Speed Rail Program

Greenhouse Gas Reduction Fund
Fiscal Year 2016-17

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Section A. Introduction

The goal of California Climate Investments (CCI) is to reduce greenhouse gas (GHG) emissions and further the purposes of the Global Warming Solutions Act of 2006, known as Assembly Bill (AB) 32 (Núñez, Chapter 488, Statutes of 2006). The California Air Resources Board (ARB) is responsible for providing the quantification methodology to estimate the net GHG emission reductions and other benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). ARB develops these methodologies based on the project types eligible for funding by each administering agency as reflected in the program Expenditure Records available at: https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/expenditurerecords.htm. ARB staff periodically review each quantification methodology to evaluate its effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified.

The California High-Speed Rail Authority (Authority) is responsible for planning, designing, building, and operating California's high-speed rail (HSR) system, initially connecting San Francisco and Los Angeles. Provision 10 of Item 2665-306-6043 of Senate Bill (SB) 1029 (Committee on Budget, Chapter 152, Statutes of 2012) directs the Authority to analyze the GHG impacts of the HSR system. This methodology is used for GGRF quantification. Additionally, the Authority is required by Public Utilities Code Sec. 185033 to prepare, publish, adopt, and submit a business plan to the California Legislature every two years. The Authority's business plan is an overarching policy document used to inform the Legislature, the public, and stakeholders of the project's implementation and assist the Legislature in making policy decisions regarding the project.

The Authority estimates a net GHG emission reduction of 58.7 million metric tons (MMT) of carbon dioxide equivalents (CO_2e)—resulting from the difference of GHG emission reductions in mode shift from automobiles and air flights to HSR, and GHG emissions from renewable energy produced required to operate the HSR system. ARB staff reviewed the Authority's GHG emission reduction quantification methodology and determined it is consistent with current ARB quantification approaches, and that the GHG-emission-reduction-estimate of 58.7 MMT CO_2e is a reasonable estimate for GGRF funding of the HSR system. Note that GHG emissions from site preparation, upstream[1] GHG emissions from materials, and GHG emission mitigation activities (e.g., sequestration from tree planting) are not included in Authority's net GHG emission reduction estimate, nor were they evaluated by ARB staff for purposes of this quantification methodology.

[1] "Upstream" is used in the context of life cycle assessment, and pertains to feedstock materials and energy associated with the production, processing, and delivery of infrastructure materials.

California High-Speed Rail Program

The goal of the HSR program is to connect San Francisco and the Los Angeles Basin and eventually extend to Sacramento and San Diego, totaling 800 miles with up to 24 stations. The HSR program reduces GHG emissions by:

- Shifting travel from cars and planes to HSR;
- Operating HSR on 100 percent renewable energy;
- Implementing a multi-faceted tree planting program; and
- Mitigating emissions from the construction phase through strict, binding requirements on construction contractors.

The project is separated into two main phases:

1. **Initial Operating Segments (IOS): Silicon Valley to Central Valley (V2V)** – San Jose to a station north of Bakersfield opening in 2025:
    a. Silicon Valley to Central Valley Extension – San Francisco to Bakersfield opening in 2025
2. **Phase 1: San Francisco and Merced to Los Angeles and Anaheim** opening in 2029

GHG Emissions Forecast and Inventory Report

In July 2013, the Authority published a GHG emissions forecast and inventory report: *Contribution of the High-Speed Rail Program to Reducing California's Greenhouse Gas Emission Levels* (2013 GHG Report).[i] For the 2013 GHG Report, the Authority followed methods in reporting GHG emissions based on the Climate Registry General Reporting Protocol.[ii] Additionally, the Authority referenced the U.S. Council on Environmental Quality (CEQ) and the American Public Transportation Association (APTA) guidance on project-level benefits for rail projects.

The 2013 GHG Report describes the methods used to estimate net GHG emission reductions associated with the operation of the HSR system, GHG emissions associated with construction, and qualitative descriptions of potential upstream GHG emissions associated with the production of infrastructure materials. The report also discusses the Authority's approach to estimating the direct GHG emissions sequestered through specific offset projects (such as tree planting), and sequestered or offset GHG emissions through required mitigation activities during construction (such as engine efficiency requirements).

The GHG quantification methodology can be accessed here: http://www.hsr.ca.gov/docs/programs/green_practices/HSR_Reducing_CA_GHG_Emissions_2013.pdf.

Business Plan

The Authority's 2016 Business Plan[iii] (adopted by the Authority Board on April 28, 2016) summarizes the progress made over the past two years, including updates to available funding and financing, ridership forecasts, and risk management information. The updated ridership forecasts were produced using the Business Plan Model – Version 3 (BPM-V3). The ridership forecasts reported in the 2016 Business Plan have increased approximately 25 percent over the forecasts in the 2014 Business Plan,[iv] which is primarily responsible for the increase in the reported net GHG emission reduction estimate. The increase in projected ridership was due to updates to Version 2 of the Business Plan Model (BPM-V2), which was used for ridership forecasts for the 2014 Business Plan, and improved service to Anaheim in Phase 1 forecasts.

Ridership modeling for the 2016 Business Plan was refined per suggestions from the Ridership Technical Advisory Panel (RTAP) and comments from the Authority's Peer Review Group (PRG). The ridership model forecasts have also been reviewed by the United States (U.S.) Government Accountability Office (GAO) and an independent financial advisory firm specializing in infrastructure projects.[v,vi]

In addition to updated ridership forecasts, the 2016 ridership model also updated passenger auto vehicle miles travelled (VMT) and air trip reduction forecasts. The Authority also used updated emission factors for the analysis in order to maintain consistency with Federal and California policy and regulation. The quantification methodology to estimate GHG emission reductions from the operation of the HSR system remained consistent with the 2013 GHG Report.

As a result of the updated ridership forecasts, the Authority updated the net GHG emission reductions for the 2016 Business Plan. The estimated net GHG emission reductions from HSR increased from the 44.0 MMT CO_2e estimated in the 2014 Business Plan to 58.7 MMT CO_2e. The net GHG emission reduction estimates from the 2014 and 2016 Business Plans are shown in Table 1.

Table 1. Net GHG Emission Reduction Estimates

Business Plan	First Year of Operation	Out Year	Net GHG Emission Reduction Estimate (MMT CO_2e)
2014	2022	2072	44.0
2016	2025	2075	58.7

ARB staff have evaluated the quantification methodology utilized by the Authority to estimate the 58.7 MMT CO_2e net GHG emission reductions and have determined it to be reasonable for estimating GHG emission reductions achieved by GGRF funding of the HSR system.

Methodology Development

The Authority developed the GHG quantification methodology for use in estimating proposed project GHG emission reductions for HSR operations. With HSR operations scheduled to begin in 2025, the net GHG emission reductions are estimated over a 50-year period, from 2025 to 2075. The quantification methodology estimates the impacts associated with transportation mode shifts to the lower-GHG-emitting HSR system and other impacts, including:

- Mode shift from low-occupancy auto VMT to HSR;
- Mode shift from air travel to HSR; and
- 100 percent shift from higher emitting energy sources and petroleum-based fuels to cleaner renewable energy sources for rail operations.

Tools

The Authority's quantification methodology relies on project-specific outputs from the BPM-V3 and ARB Mobile Source Emission Factor Model (EMFAC2014).[vii]

Ridership and revenue forecasts for different HSR service options were produced using BPM-V3, a travel demand model developed by Cambridge Systematics, Inc. (CS). The BPM-V3 incorporates HSR and all other long-distance travel mode network assumptions, socioeconomic data, and travel behavior and preference data, among other inputs, to project ridership and revenue for each forecast year (i.e., 2025, 2029, and 2040). The BPM-V3 is a travel demand model that has been enhanced and developed over the past 15 years and incorporates the latest industry best practices, data, surveys, and methodologies. It has been reviewed and approved by several independent parties, including the International Union of Railways (UIC). A more detailed overview of the BPM-V3 is located in Appendix A of this document; the full model documentation can be found on the Authority website at: http://hsr.ca.gov/About/ridership_and_revenue.html.

The Authority used EMFAC2014 to develop vehicle emission factors for calculating GHG emission reduction estimates. The tool is used statewide, subject to regular updates to incorporate new information, and available free of charge to anyone with internet access. The tool can be accessed at: https://www.arb.ca.gov/emfac/2014/

Major Updates

Updates to the Authority's GHG quantification methodology for estimates presented in the 2014 Business Plan include updates to the methods, models, and reports on HSR. The major changes include:

- Updates to the Business Plan Model;
- Geographic changes to the initial operating segment;

- Changes to the first year of operation;
- Use of EMFAC2014 for auto VMT emissions factors;
- Use of ARB 2016 Edition California's 2000-2014 Greenhouse Gas Emission Inventory Technical Support Document[viii] for air trip emissions factors;
- Updates to account for smaller planes for short-trip distances displaced; and
- Updates to renewable energy portfolio percentages to operate HSR.

The BPM-V3 was updated from the BPM-V2 of the model to incorporate more recent input data, new variables that better reflect travel behavior, and adjustments to transit access network and station locations. Major updates to the model include:

- Full integration of the 2013-14 revealed preference/stated-preference survey data;[ix]
- Incorporation of revisions to socioeconomic growth assumptions consistent with the California Statewide Transportation Demand Model, customized for the years for which forecasts were needed;[x]
- Addition of variables that make trips with long access and/or egress times, coupled with relatively short trips on HSR less desirable;
- Incorporation of new variables in mode choice utility functions;
- Adjustments to average passenger auto occupancy and costs; and
- Updates to inputs for transit access networks and HSR system characteristics (e.g., station locations and planned phasing of system).

Additional details on the BPM-V3 ridership model updates and methods used to produce ridership forecasts are documented in Appendix A of this document and the full model documentation can be found on the Authority website at: http://www.hsr.ca.gov/About/ridership_and_revenue.html.

Scope of Review

ARB staff reviewed the Authority's GHG emission reduction quantification methodology for estimating GHG emission reductions achieved with GGRF funding of the HSR system. This review included the ridership forecasts in the 2016 Business Plan and emission factors utilized in the GHG emission reduction estimates.

ARB staff did not evaluate the GHG emissions analysis for site preparation, upstream GHG emissions from materials, or any other mitigation activities (e.g., sequestration). In accordance with the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA), the Authority prepared an Environmental Impact Report/Environmental Impact Statement.[xi] ARB staff considered the Authority's compliance with CEQA and NEPA as an appropriate mechanism for evaluation of other environmental aspects of HSR not evaluated in this quantification methodology.

Program Assistance

Stakeholders should use the following resources for additional questions and comments:

- Questions on this document should be sent to GGRFProgram@arb.ca.gov.
- For more information on ARB's efforts to support implementation of GGRF investments, see: https://www.arb.ca.gov/auctionproceeds.
- Questions pertaining to HSR should be sent to info@hsr.ca.gov.

Section B. GHG Reduction Methodology for Awarded Funds

Overview

The quantification methodology in this section describes how the Authority estimated the net GHG emission reductions, as reported in the 2016 Business Plan. The net GHG emission reduction estimates account for GHG emission reductions from VMT and air trip reductions estimated by BPM-V3, as well as GHG emissions generated from energy production to operate and maintain the HSR system. In general, the net GHG emission reduction estimates are calculated using the following approaches:

Table 2. General Approach to GHG Quantification

Total GHG Emission Reductions
$Total\ GHG\ Emission\ Reductions = GHG\ Emission\ Reductions_{Auto\ VMT} + GHG\ Emission\ Reductions_{Airplane\ Flight}$
Net GHG Emission Reductions
$Net\ GHG\ Emission\ Reductions = Total\ GHG\ Emission\ Reductions\ -\ GHG\ Emissions_{Energy\ Use}$

ARB staff reviewed the Authority's GHG emission reduction quantification methodology in order to determine if the methodology was reasonable for estimating GHG emission reductions achieved with GGRF funding of the HSR system. This included a review of the ridership forecasts in the 2016 Business Plan and emission factors utilized in the GHG emission reduction estimates.

The ARB staff review included an evaluation of the quantification methodology used to estimate the GHG emission reductions associated with:

- Ridership and Revenue Model, BPM-V3;
- Mode shift from low-occupancy auto VMT to HSR;
- Mode shift from air travel to HSR; and
- 100 percent shift from higher emitting energy sources and petroleum-based fuels to cleaner renewable energy sources for rail operations.

Ridership and Revenue Model (BPM-V3)

The BPM-V3 has been reviewed by various experts, including the Authority's RTAP, the GAOand an independent financial advisory firm specializing in infrastructure projects. The BPM-V3 has been updated to include the most recently available data inputs, as documented in Appendix A. The inputs and methods used in the model are detailed in

the Authority's 2016 Business Plan and its supporting documents. ARB staff concluded that the ridership values produced by the BPM-V3 are reasonable for GGRF GHG emission reduction quantification purposes.

GHG Emission Reductions from Auto Mode Shift

The Authority estimated the GHG emission reductions that result from the mode shift of low-occupancy autos to HSR using the reduction in statewide auto VMT from the BPM-V3 and auto emission factors from EMFAC2014. The GHG emission reductions from auto VMT reductions are calculated using Equation 1.

Equation 1: GHG Emission Reductions from Auto Mode Shift

$$GHG_{AutoVMT} = \sum_{i=2025}^{2075} \left[\frac{Annual\ VMT_{BPMV3}\ x\ EF_{Auto}}{1{,}000{,}000} \right]_i$$

Where,

			Units
$GHG_{AutoVMT}$	=	Total GHG emission reductions from auto VMT displaced	MT CO_2
i	=	The operation year (from 2025 to 2075)	year
$Annual\ VMT_{BPMV3}$	=	Annual auto VMT displaced from the BPM-V3	miles
EF_{Auto}	=	Emission factor developed for autos; see equation 2	gCO2/mile
1,000,000	=	Factor to convert grams to metric ton	g/MT

The BPM-V3 forecasts statewide long-distance travel behavior, including long-distance travel by low-occupancy vehicles, in build and no-build scenarios expressed annually from 2025 to 2075. Annual VMT reductions are calculated by subtracting total VMT in the HSR-build scenario from total VMT in the no-build scenario. Total VMT reductions account for over 65 percent of the total emissions reductions for HSR, even though the statewide auto VMT reductions from the mode shift to HSR is only estimated to be about 1 percent of the total statewide auto VMT.

EMFAC2014 provides emission factors in two modes: stabilized running mode (RUNEX) and start mode (STREX). For carbon dioxide (CO_2), RUNEX provides tailpipe emission rates for the vehicle after it has reached optimal running temperature, while STREX provides emission rates for the vehicle during the first 100 seconds of operation after the engine has been started, when engine and/or catalyst may not have achieved their optimal operating temperature range. Additionally, EMFAC2014 categorizes passenger vehicles as light-duty autos (LDA), light-duty trucks (LDT1 and LDT2), and medium-duty vehicles (MDV).

The Authority developed annual statewide emission factors using RUNEX CO_2 emission rates for LDA, LDT1 and LDT2. The Authority excluded STREX emission rates and the MDV category from the analysis. The exclusion of the STREX emission rates and the MDV category results in an underestimate of the emission factor for autos. EMFAC2014 currently does not project emission rates beyond 2050; therefore, the developed emission factors used in the analysis remain constant at the 2050 emission rate for years beyond 2050.

The Authority developed the annual auto emission factors using a weighted average by VMT of the RUNEX for gasoline and diesel fuel types calculated using Equation 2.

Equation 2: Annual Auto Emission Factor

$$EF_{Auto} = \sum_{i=2025}^{2050} \left[\frac{(VMT * CO2_{RUNEX})_{LDA} + (VMT * CO2_{RUNEX})_{LDT1} + (VMT * CO2_{RUNEX})_{LDT2}}{Total\ VMT} \right]_i$$

Where,			Units
EF_{Auto}	=	Annual auto emission factor	gCO_2/mile
i	=	The operation year (from 2025 to 2050)	Year
VMT	=	Vehicle miles traveled by speed, vehicle and fuel type	Miles
$CO2_{RUNEX}$	=	Emission rate by speed, vehicle and fuel type	gCO_2/mile

The Authority applied a correction factor[2] to the RUNEX emission rates to account for the projected future saturation of zero-emissions vehicles in the California vehicle fleet. Lastly, the emission factors were converted from GHG emissions to carbon dioxide equivalents (CO_2e) by dividing by a factor of 0.98.

The statewide emission factors developed by the Authority and used for estimating auto VMT reductions for the HSR project were based on the RUNEX CO_2 emission rates for LDA, LDT1, and LDT2 and exclude the RUNEX MDV and STREX emission rates. By excluding the RUNEX MDV and STREX emission rates, the emission factors developed by the Authority are conservative, as leaving out these emission rates results in a lower GHG emission baseline. Additionally, the Authority accounted for the projected future saturation of zero-emissions vehicles in the California vehicle fleet, which further reduces the projected GHG emission baseline. ARB staff concluded that the Authority's method for estimating GHG emission reductions from auto VMT reductions is reasonable for GGRF GHG emission reduction quantification purposes.

GHG Emission Reductions from Airplane Flight Mode Shift

The Authority estimated GHG emission reductions that result from the mode shift of air trips to HSR based on the reduction in statewide air travel from the BPM-V3 and emission factors from ARB's Inventory for California Air Planes.[viii] The GHG emission reductions from airplane flight reductions are calculated using Equation 3.

[2] The factor was developed using percentage of electric VMT divided by total VMT using EMFAC2014.

Equation 3: GHG Emission Reductions from Airplane Mode Shift

$$GHG_{AirplaneFlights} = \sum_{i=2025}^{2075} \left[\frac{(Annual\ Air\ Trips_{BPMV3}/Passengers)\ x\ EF_{Plane}}{1{,}000{,}000} \right]_i$$

Where,			Units
$GHG_{PlaneFlights}$	=	Total GHG emission reductions from plane flight reduced	MT CO_2
i	=	The operation year (from 2025 to 2075)	Year
$Annual\ Air\ Trips_{BPMV3}$	=	Annual air-passengers diverted to HSR from BPM-V3	passengers
$Passengers$	=	50 passengers (for i=2025 through i=2029) 101.25 passengers (for i=2030 through i=2075)	passengers/flight
EF_{Plane}	=	Emission factor for air plane trips	gCO2 /flight
1,000,000	=	Factor to convert grams to metric ton	g/MT

Similar to auto VMT reductions, air trip reductions are estimate from BPM-V3 forecasts of long-distance air trips in build and no-build scenarios expressed annually from 2025 to 2075. The HSR system captures a significant portion of the air market (30% of the market in 2040), but those emissions results are still less than 35% of the cumulative GHG emission reductions for HSR.

Air-passenger trip reductions are the number of passengers that shift from travel by air to travel by HSR. Air-passenger trips are used to estimate the number of plane flights reduced which results in airline fuel use reductions. During the Valley to Valley (V2V) phase, from 2025 to 2028, the Authority estimated airplane flights reduced by assuming one flight would be removed for every 50 passengers diverted from air to rail (representing planes used for shorter distance flights, given the shorter HSR initial system). For Phase 1, from 2029 to 2075, the Authority estimated plane flights reduced by assuming one flight would be removed for every 101.25 passengers diverted from air to rail. In both instances, the GHG emission reductions associated with flights removed are based on a full plane cycle, including taxi/idle, take-off, climbing, cruise, decent, and landing. Emission factors are provided by plane type and for each component of the full plane cycle.

The Authority accounted for the passengers per flight using different values for the V2V and Phase 1. The assumed, average air trip length replaced by HSR is shorter for the V2V than for Phase 1 and accordingly, a smaller plane is assumed for the V2V and a larger plane is assumed for Phase 1. Additionally, the emission factors for air plane trips are from ARB's inventory for California Air Planes. ARB staff concluded that by accounting for the passengers per plane in the V2V and Phase 1 separately and by using air plane emission factors developed by ARB, the Authority's method for estimating GHG emission reductions from reduced plane flights is reasonable for GGRF quantification purposes.

GHG Emissions from Energy Usage

GHG emissions from the operation and maintenance of the HSR system are estimated using the amount of energy needed annually to operate and maintain the HSR system, and the emission factors for the production of renewable energy used to operate the HSR system. The GHG emissions associated with the operation of the HSR system are calculated using Equation 4.

Equation 4: GHG Emissions from Energy Usage

$$GHG_{Energy} = \sum_{i=2025}^{2075} \left[\frac{Annual\ Energy_{BPMV3}\ x\ EF_{Renewable}}{1{,}000{,}000} \right]_i$$

Where,			Units
GHG_{Energy}	=	Total GHG emissions from energy to operate the HSR system	MT CO_2
i	=	The operation year (from 2025 to 2075)	Year
$Annual\ Energy_{BPMV3}$	=	Annual energy required to operate the HSR system from BPM-V3	GWh
$EF_{Renewable}$	=	Emission factor for renewable energy	gCO2/GWh
1,000,000	=	Factor to convert grams to metric ton	g/MT

The estimated energy needed annually to operate and maintain the system includes energy for maintenance facilities, station facilities, revenue train-miles, and non-revenue train-miles. The Authority has committed to operating the system on 100 percent renewable energy. While there are several different methods that can be used to determine net-zero operations, the Authority's basic concept is that it will procure and produce enough new renewable energy to supply to the electric grid to compensate for any non-renewable energy loads used to operate the HSR system. The net use of energy from the grid will equal the net supply of renewable energy supplied to the grid.

To estimate GHG emissions associated with the production of renewable energy to operate the HSR system, the Authority assumed a mix of 20 percent solar, 34 percent wind, 45 percent geothermal, and 1 percent biogas (i.e., methane capture), as reported in the Authority's 2013 GHG Report.[i] To maintain consistency with past forecasts, an emission factor was applied to the renewable energy. The GHG emission factors were taken from the 2013 Climate Registry Default Emissions Factors[xii] and the Geothermal Energy Association 2012 Report, Geothermal Energy and Greenhouse Gas Emissions.[xiii]

The Authority accounted for biogenic emissions that occur from the production of renewable energy, which have not been included in the estimates for other GGRF programs. ARB staff concluded that the inclusion of GHG emissions associated with the production of renewable energy results in a conservative estimate of the net GHG emission reductions; therefore, the approach is reasonable for GGRF quantification purposes, even though this approach differs from other GGRF programs.

ARB staff did not evaluate the estimated energy needed to operate the HSR system nor the feasability of producing or procuring the amount of renewable energy the Authority will need to operate the HSR system. Once the HSR sytem is operational and the final energy mix is determined, ARB staff recommend further evaluation of the impact on the grid due to the increase in demand.

Net GHG Emission Reductions

The net program GHG emission reductions, which is equal to the sum of each of the GHG emission reductions minus the sum of GHG emissions (calculated from Equations 1 to 4), is calculated using Equation 5.

Equation 5: Net Program GHG Emission Reductions

$$Net\ Program\ GHG\ Emission\ Reductions\ in\ MTCO_2e = \sum GHG_{Auto\ VMT} + \sum GHG_{\ Airplane\ Flights} - \sum GHG_{\ Energy}$$

The Autority's 2016 Business Plan utilized the BPM-V3 and the methods described in this section to estimate the net GHG emsission reductions from the HSR system. The 2016 Sustainability Report[xiv] reports a Net GHG Emission Reduction of 58.7 MMT CO_2e. ARB staff reviewed the BPM-V3 model and the methods described in this section; ARB staff concluded that the model and methods, as well as the resulting net GHG emission reduction estimate, were reasonable.

Section C. Reporting after Funding Award

Accountability and transparency are essential elements for all GGRF CCI projects. As described in Volume 3 of ARB's Funding Guidelines,[xv] each administering agency is required to track and report on the benefits of the CCI funded under their program(s). Each project funded by the GGRF is expected to provide quantifiable GHG emission reductions.

The previous sections of this document provide a summary and review of the methods and tools used to estimate the net GHG emission reductions of the HSR system based on project characteristics and assumptions of expected conditions and activity levels. This section explains the minimum reporting requirements for administering agencies and funding recipients during project implementation, termed Phase 1, and after a project is completed, termed Phase 2. Table 2 below shows the project phases and when reporting is required.

Table 2. Quantification and Reporting By Project Phase

	Timeframe & Reporting Frequency	Quantification Methods
Phase 1	Period from project award date through project completion date. The Authority reports to ARB on an annual basis.	The Authority will use the methods in Section B to estimate the GHG emission reductions of the project.
Phase 2	Starts after the initial operating segment is complete and HSR becomes operational.	GHG emission reductions achieved are quantified and reported.

It is the responsibility of the Authority to collect and compile project data, including GHG emission reductions and information on benefits to disadvantaged communities.

Phase 1 reporting is required for all funded projects. The Authority will collect and submit data to ARB to satisfy Phase 1 reporting requirements. The Authority must report any changes that impact GHG emission reduction estimates (i.e., assumptions or quantities) to ARB prior to project completion.

Phase 2 reporting requirements and methods of data collection are still under development. Once the Phase 2 quantification method and data needs are determined, ARB will develop and post the final ARB approved Phase 2 methodology for use in Phase 2 reporting.

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[i] California High Speed Rail Authority. Contribution of the High-Speed Rail Program to Reducing California's Greenhouse Gas Emission Levels. June 2013 http://www.hsr.ca.gov/docs/programs/green_practices/HSR_Reducing_CA_GHG_Emissions_2013.pdf

[ii] Climate Registry: General Reporting Protocol, Version 2.0. March 2013.

[iii] California High Speed Rail Authority. Connecting and Transforming California 2016 Business Plan. May, 1 2016. http://hsr.ca.gov/About/Business_Plans/2016_Business_Plan.html

[iv] California High Speed Rail Authority. Connecting California 2014 Business Plan. April 30, 2014. http://www.hsr.ca.gov/docs/about/business_plans/BPlan_2014_Business_Plan_Final.pdf

[v] California High-Speed Rail Authority. Ridership and Revenue Forecasting 2016 Business Plan: Technical Supporting Document. April 8, 2016. http://www.hsr.ca.gov/docs/about/business_plans/2016_Business_Plan_Ridersihp_Revenue_Forecast.pdf

[vi] Project Finance Advisory Limited. HSR14-65 Draft Memo on Ridership and Revenue for Valley to Valley Line of the California High-Speed Rail System. December 5, 2016 http://www.hsr.ca.gov/docs/brdmeetings/2016/brdmtg_121316_item2_ATTACHMENT_Ind_Con_Draft_Memo_Ridership_Revenue_for_Valley_to_Valley_Line.pdf

[vii] California Air Resources Board. EMFAC2014 Web Database V1.0.7. http://www.arb.ca.gov/emfac/2014/

[viii] California Air Resources Board. California 2000-2014 GHG Emission Inventory: Technical Support Document. 2016 Edition. September 2016 https://www.arb.ca.gov/cc/inventory/doc/methods_00-14/ghg_inventory_00-14_technical_support_document.pdf

[ix] Cambridge Systematics, Inc. California High Speed Rail 2013-14 Traveler Survey. http://hsr.ca.gov/docs/about/ridership/2013_2014_RPSP_Survey_Documentation.pdf.

[x] California Department of Transportation. California Statewide Transportation Demand Model Version 2.0. http://www.dot.ca.gov/hq/tpp/offices/omsp/statewide_modeling/cstdm.html.

[xi] California High Speed Rail Authority. Addendum/Errata to Final Program EIR/EIS for the Bay Area to Ventral Valley Portion of the California HST System. June 2008. http://www.hsr.ca.gov/docs/programs/bay_area_eir/BayCValley2008_EIR_fin_adn3errata.pdf.

[xii] The Climate Registry. 2013 Default Emission Factors. April 2, 2013. www.theclimateregistry.org

[xiii] Geothermal Energy Association. Geothermal Energy and Greenhouse Gas Emissions. November 2012. http://geo-energy.org/reports/GeothermalGreenhouseEmissionsNov2012GEA_web.pdf

[xiv] California High Speed Rail Authority. Sustainability Report. December 2016. http://www.hsr.ca.gov/docs/programs/green_practices/sustainability/Sustainability_Report_Dec_2016.pdf

[xv] California Air Resources Board. Funding Guidelines for Agencies Administering California Climate Investments. December 21, 2015. www.arb.ca.gov/ccifundingguidelines

Appendix A. BPM-V3 Ridership and Revenue Model

The Authority has been developing and enhancing their travel demand forecast tools for over 15 years. The 2016 Business Plan uses the BPM-V3 for all travel demand forecasting. The BPM-V3 incorporates HSR and all other long-distance travel mode network assumptions, socioeconomic data, and travel behavior and preference data, among other inputs, to project ridership and revenue for each forecast year (i.e., 2025, 2029, and 2040).

The Authority consulted with the RTAP and the U.S. GAO to identify improvements needed for the BPM-V2. The RTAP is a panel of international experts in travel demand forecasting that provided external review and feedback throughout the development of ridership and revenue forecasting. The GAO is the audit institution for the U.S. federal government, and provides independent and nonpartisan audit, evaluation, and investigative services. The ridership model forecasts have also been reviewed by an independent financial advisory firm specializing in infrastructure projects.
The BPM-V3 includes a variety of updates to refine the BPM-V2, which was used to generate forecasts for the 2014 Business Plan. Further refinements to the model were carried out to estimate ridership and revenue forecasts for the 2016 Business Plan and the environmental analyses for the Phase 1 system.

The BPM-V3 was updated from the BPM-V2 of the model to incorporate more recent input data, new variables that better reflect travel behavior, and adjustments to transit access network and station locations. Major updates to the model include:

- Full integration of the 2013-14 revealed preference/stated-preference survey data;
- Incorporation of revisions to socioeconomic growth assumptions consistent with the California Statewide Transportation Demand Model, customized for the years for which forecasts were needed;
- Addition of variables that make trips with long access and/or egress times, coupled with relatively short trips on HSR less desirable;
- Incorporation of new variables in mode choice utility functions;
- Adjustments to average passenger auto occupancy and costs; and
- Updates to inputs for transit access networks and HSR system characteristics (e.g., station locations and planned phasing of system).

Model Overview

The BPM-V3 forecasts statewide long-distance travel in a given year. Long-distance trips are defined as more than 50 miles from the traveler's origin to their destination; only travel within California is captured. Distances are estimated using Geographic

Information System (GIS) to calculate the straight-line distance between geocoded origin and destination locations. The following travel is not included in BPM-V3:

- Non-home-based travel occurring more than 50 miles from home;
- Trips by visitors to California;
- Trips with one end outside of California; and
- Short-distance trips (defined as trips less than 50 miles in length).

The long-distance model estimates trip frequency, destination choice, access/egress, and main mode choice stratified by trip purpose. Trip purposes include:

- **Business** – Includes all business travel to locations other than a traveler's normal place of work.
- **Commute** – Includes all travel to a person's regular place of work. Note that a person might work from home three or more days per week, but travel to an assigned office more than 50 miles from their home one or two days per week; such travel is included in the commute category.
- **Recreation** – Includes all trips made for recreation, vacations, leisure, or entertainment.
- **Other** – Includes all trips made for other purposes, such as school, visiting friends or relatives, medical, personal business, weddings, and funerals.

The long-distance trip frequency estimates account for induced travel resulting from improved accessibility due to the HSR system. Likewise, the destination choice estimates account for induced HSR corridor travel resulting from diversion from other corridors.

Model Scenarios

CS developed forecasts for two main phases of the project as specified by the Authority:

1. **V2V: Silicon Valley to Central Valley** – San Jose to a station north of Bakersfield opening in 2025:
    a. V2V Extended: Silicon Valley to Central Valley Extension – San Francisco to Bakersfield opening in 2025
2. **Phase 1: San Francisco and Merced to Los Angeles and Anaheim** opening in 2029

Ridership and revenue forecasts were prepared for the opening year for V2V and Phase 1 as well as a Phase 1 out year. The 2040 forecast would reflect ridership on a mature system that would have more than 10 years of operating history.

Risk Analysis

As part of the 2016 Business Plan travel demand forecasting, the Authority developed a list of potential risks that could impact ridership and revenue. The Authority then identified risk variables that could be adjusted within the BPM-V3 to reflect upside and downside of the individual risks listed. Sensitivity analysis on each risk variable was performed to select the risk variables with the greatest potential impact on ridership and revenue forecasts. These risk variables included:

- Business, commute, recreation, and other HSR mode constants;
- Business, commute, recreation, and other trip frequency constants;
- Auto operating costs;
- HSR fares;
- HSR frequency of service;
- Coefficient on transit access/egress time/auto distance variable;
- Availability and frequency of service of conventional rail and HSR feeder buses;
- Airfares;
- Number and distribution of households throughout the State; and
- Auto travel time.

For each of the risk variables, a range (i.e., minimum, most likely, and maximum) and probability distribution was assigned to describe the associated uncertainty. Range and distribution values for each risk variable were developed from available research and analysis, as documented in the 2016 Ridership and Revenue Risk Analysis Technical Report.[i] For example, auto operating costs may be as low as $0.15 per mile, but as high as $0.31 per mile in 2025. Based on these ranges for each risk variable, Monte Carlo simulations[1] were used to project a range of ridership and revenue forecasts with a

[1] Monte Carlo simulations involve an analytical model to quantify the level of confidence that a certain event might occur, where multiple simulations are run to identify the probability of a potential outcome.

probability of each forecast occurring. The risk variables included varied based on the forecast year being analyzed. For example, the number and distribution of households across the state could have greater potential influence on ridership in 2040 than in 2025.

Model Runs

The BPM-V3 was fully run 59 times for each operating plan and forecast year. Data points from these runs were used in linear regression models to approximate relationships between the BPM-V3 revenue and ridership, and model inputs and variables. Monte Carlo simulations provided distributions of a range of HSR ridership and revenue forecasts, and the relative impact of each risk factor. Overall, these distributions showed the projected high, medium, and low ridership forecasts, as presented in the 2016 Business Plan.

Technical memos, findings, and recommendations from the RTAP, as well as information on ridership and revenue estimates, the BPM-V3, and model documentation, are available on the Authority's Ridership and Revenue Forecasting webpage at: http://hsr.ca.gov/About/ridership_and_revenue.html.

[i] Cambridge Systematics, Inc. 2016 California High-Speed Rail Business Plan Ridership and Revenue Risk Analysis Technical Report. April 8, 2016. http://hsr.ca.gov/docs/about/ridership/DR1_2016_CAHSRA_Business_Plan_Risk_Analysis_Documentation.pdf